Western Lake Ontario: Compendium of Coastal Resilience Issues and Typology of Nature-based and Hybrid Solutions

Prepared for the Land to Lake Initiative
by Toronto and Region Conservation Authority

2026

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About the Land to Lake Initiative

Established in 2022, the Land to Lake Initiative (L2L) is a partnership network that aims to foster stronger, more coordinated collaborations to enhance capacity for actions that improve water quality and ecosystem health in Western Lake Ontario, stretching between the Niagara River and Cobourg.

Land acknowledgement

This region is covered by the Upper Canada and Williams Treaties, and include the Traditional Territories of the Mississaugas of the Credit, Six Nations of the Grand River, and the Williams Treaties First Nations. It is also the Traditional Territories of the Huron-Wendat, the Haudenosaunee, and the Anishinaabe, and are now home to many diverse First Nations, Inuit, and Métis peoples.

Reviewers and contributors

Special thanks go to members of the L2L Advisory Committee, members of Aquatic Habitat Toronto, and the following individuals who helped to inform the development of the typology, visual guide, and StoryMap:

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CONTENTS

SUMMARY OF KEY MESSAGES

Across Western Lake Ontario, the climate is getting warmer and wetter, with rising surface water temperatures, declining ice cover, and more extreme high and low lake levels. Long-term datasets available for Canada and the Great Lakes provide a comprehensive picture of these recent changes (Figure 1), which have already led to diverse impacts on people and communities across Western Lake Ontario.

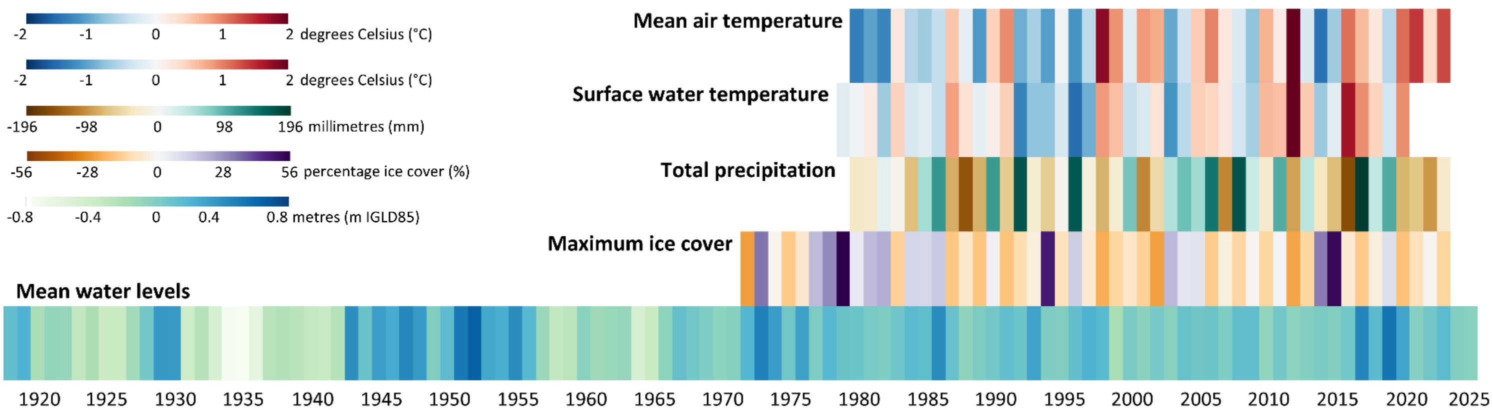

Figure 1. Climate stripes showing differences in annual a) mean air temperature (1980-2023) compared to 1981-2010, b) surface water temperature (1979-2000) compared to 1981-2010, c) total precipitation (1980-2023) compared to 1981-2010, d) maximum ice cover (1973-2023) compared to 1973-2023, and e) mean water levels (1918-2025) compared to 1918-2025

Stories shared by community members across Western Lake Ontario illustrate these impacts such as extensive flooding and erosion from record high lake levels in 2017 and 2019, increases in algal blooms and invasive species, less winter ice cover, and more extreme heat and poor air quality days due to wildfire smoke. Many of these impacts have become more noticeable in recent years, affecting regional waterfront destinations, people's use and enjoyment of the coast, water quality, fish and other wildlife, and local economies.

As the pace and impacts of climate change accelerate, there is a need for actions that provide multiple co-benefits. Nature-based approaches use natural features and processes like vegetation, beaches, dunes, and wetlands to protect the shoreline. Unlike conventional grey infrastructure (e.g., concrete seawalls), which is often designed for a single purpose, nature-based solutions can perform a variety of functions and provide multiple benefits at the same time (e.g., reduce stormwater runoff and soil erosion, and provide natural cooling, recreational spaces, and habitat for wildlife). In some cases, a hybrid (or combination) of natural and hard features may be used.

To help advance the implementation of more nature-based approaches for enhanced coastal resilience, 27 types of nature-based and hybrid solutions have been identified that may be relevant for Western Lake Ontario. This typology showcases how nature-based and hybrid solutions can help address the impacts of climate-related hazards across Western Lake Ontario, which are amplifying existing pressures such as urbanization, land conversion, and legacy contamination. A collection of 30 case studies help demonstrate the effectiveness of these techniques where they have been implemented across the region.

INTRODUCTION

Stretching between the Niagara River in the south to Cobourg in the east, Western Lake Ontario is home to nearly a quarter of Canada's population[1] and a major economic engine (Figure 2). Beginning with Indigenous peoples who have lived and met here for thousands of years, many people have converged along these shorelines over time, relying on the lake for drinking water, food, electricity, navigation, recreation, and spiritual connection. Climate change poses a growing threat to communities and ecosystems along Western Lake Ontario, intensifying the costs and impacts of coastal hazards such as flooding and erosion. From changes in temperature and precipitation, to more extreme lake levels, intense heat events, and extreme storms, climate change is putting people, ecosystems, economies, and regional waterfront destinations at increasing risk.

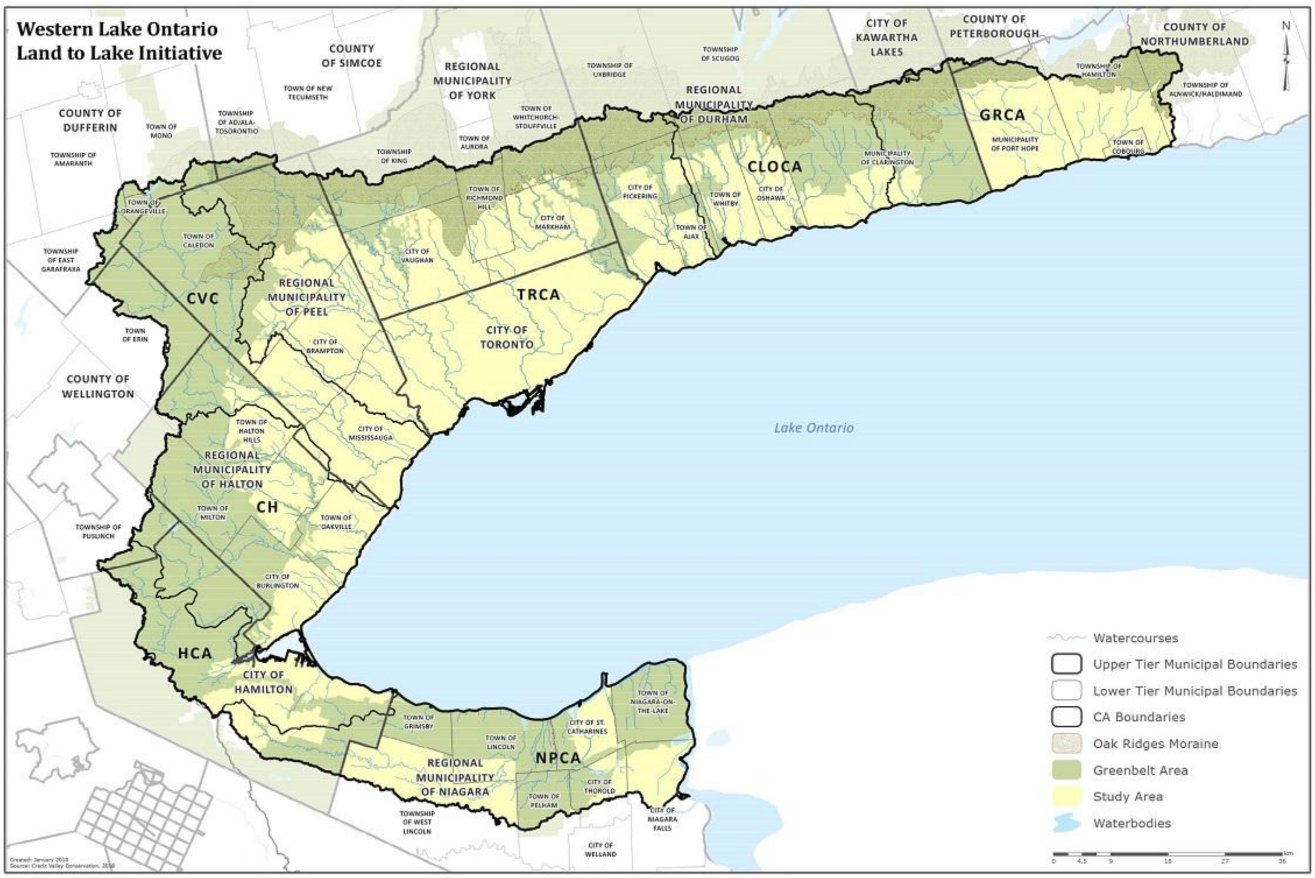

Figure 2. Map of the watersheds and municipalities along Western Lake Ontario (Toronto and Region Conservation Authority and Credit Valley Conservation, 2018)

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[1] Based on 2021 Canadian census data

As the fastest growing region in the Great Lakes Basin (Environment and Climate Change Canada and the U.S. Environmental Protection Agency, 2018), the need to enhance coastal resilience also presents a major opportunity to revitalize hardened, unwelcoming shorelines and protect and restore the land and water that have become degraded following hundreds of years of colonization, industrialization, and intensive development. By directing investments towards more nature-based approaches, actions that enhance resilience can also provide multiple environmental, social, and economic co-benefits.

The term, **nature-based solutions (NbS)**, has emerged to describe actions that respect and work with nature, rather than against it, to address societal challenges such as climate change, biodiversity loss, and food insecurity (International Union for Conservation of Nature, 2016). While the term is relatively new, efforts to protect, restore, and care for the land and water are not new and have been ongoing for many decades to millennia, including efforts by Indigenous peoples and communities and their relationships to the land and water.

Across Western Lake Ontario, many NbS have also been implemented by conservation authorities, municipalities, non-profit organizations, local community groups, and property owners – from wetland restoration and creation to the planting of native trees and shrubs. However, much of the shoreline along Western Lake Ontario remains hardened or modified, with limited and isolated habitats for wildlife (Coastal area at a glance). The amount of paved areas in the surrounding watersheds is also increasing, amplifying flooding and erosion risk and water quality issues along the coast. As the pace of climate change continues to accelerate, there is an urgent need to scale up the adoption of nature-based approaches – from individual sites to networks of interconnected projects.

This study aims to help advance the implementation of more nature-based approaches across Western Lake Ontario for enhanced coastal resilience by: 1) broadening understanding of coastal resilience issues affecting this region, and 2) identifying different types of NbS and hybrid (or “green-grey”) solutions that can help address these challenges. It supports the objectives of the Land to Lake (L2L) Initiative, which aims to foster stronger, more coordinated collaborations to enhance capacity for actions that improve water quality and ecosystem health in Western Lake Ontario.

Established in 2022, this partnership initiative is currently comprised of 9 municipalities, 7 conservation authorities and Conservation Ontario, and provincial and federal governments (as of April 2026). Spanning over 8,000 km^2 and stretching across more than 500 km of Lake Ontario shoreline, this region offers an excellent study area for the identification of broad types of NbS and hybrid options for enhancing coastal resilience, while recognizing the importance of land to lake connections.

Together with a visual guide and online StoryMap, this report aims to support members of the L2L Initiative and other interested parties in advancing the implementation of more nature-based approaches for enhanced coastal resilience across Western Lake Ontario.

Coastal area at a glance

The following presents an overview of the coastal margin of Western Lake Ontario where the land meets the lake. Data is presented based on an approximately 2-km buffer of the shoreline, unless otherwise specified. Explore this data and more through our online Data Explorer!

Coastal population

1.2 million in 2021

1.18 million in 2016

↑ 6%

More than half of this population resides in the city of Toronto and surrounding regions.

(Based on Canadian census data)

Coastal pervious and impervious surfaces

49% pervious

51% impervious (as of 2015)

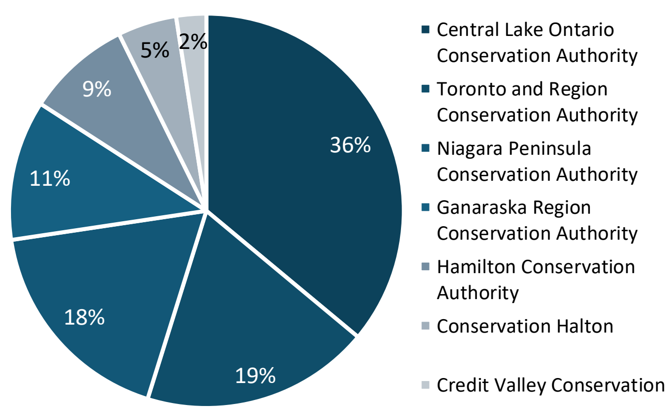
In and around Toronto, some areas are covered by more than 70% of impervious surfaces.

(Based on Southern Ontario Land Resource Information System [SOLRIS], version 3.0)

Ecological communities along the shore

Community class	Area (hectares)	% of total area
Constructed	35,208	63.4%
Agriculture	8,471	15.3%
Treed	4,796	8.6%
Meadow	2,830	5.1%
Marsh	1,338	2.4%
Swamp	892	1.6%
Open water	753	1.4%
Shrubland	341	0.6%
Actively managed	319	0.6%
Shoreline	201	0.4%
Bluff	178	0.3%
Unvegetated ephemeral	86	0.2%
Shrub swamp	70	0.1%
Dune	14	0.0%
Cliff and talus	10	0.0%
Rockland	3	0.0%
Prairie	1	0.0%

Marshes by conservation authority:



(Based on the Great Lakes Shoreline Ecosystem [GLSE] inventory, version 3.0)

Watercourses within the coastal margin

621 km
of streams

48 km
of potentially obstructed flow

The watercourses found near the shores of Niagara and Ganaraska regions make up more than 40% of the total stream length found in the 2-km coastal margin of Western Lake Ontario.

(Based on the Ontario Hydro Network [OHN], accessed in November 2025)

Shoreline types across Western Lake Ontario

126 km
of natural shorelines

419 km
of human-made or potentially modified shorelines (not classified)

Toronto and region consist of nearly a third (or 30%) of all human-made and unclassified shorelines found in Western Lake Ontario.

Shoreline classification	Length (km)	% of total length
Human-made permeable	213	39.1%
Not classified	206	37.8%
Pebble/cobble beach or bank	94	17.3%
Sediment cliff	17	3.2%
Marsh	12	2.3%
Bedrock platform	2	0.4%

(Based on ECCC's Ontario Shoreline Classification)

Surficial sediments along the shore

Single primary material	Area (km^2)	% of total area
Sand	267	47%
Diamicton	141	25%
Silt	91	16%
Paleozoic Bedrock	42	7%
Gravel	13	2%
Clay	6	1%
Organic deposits	5	1%
Fill	3	1%

(Based on Surficial Geology of Southern Ontario)

Nearshore health

9 out of 10
Regional nearshore units received a moderate overall cumulative stress rating

(Based on the Great Lakes Nearshore Waters Assessment)

Hamilton Harbour received a high overall cumulative stress rating

PART 1: CHANGING CLIMATE CONDITIONS IN WESTERN LAKE ONTARIO

Historical data analysis

Multiple datasets were used to characterize recent changes in the climate, surface water temperature, ice cover, and lake levels across Western Lake Ontario and the broader lake basin (Table 1). Together, these datasets provide a comprehensive picture of the changing context for life in this region, including what plants and animals can grow and thrive, the quality and safety of our waterways, and the operating conditions for our buildings and infrastructure.

Table 1. Historical datasets used to characterize changing climate conditions in Western Lake Ontario

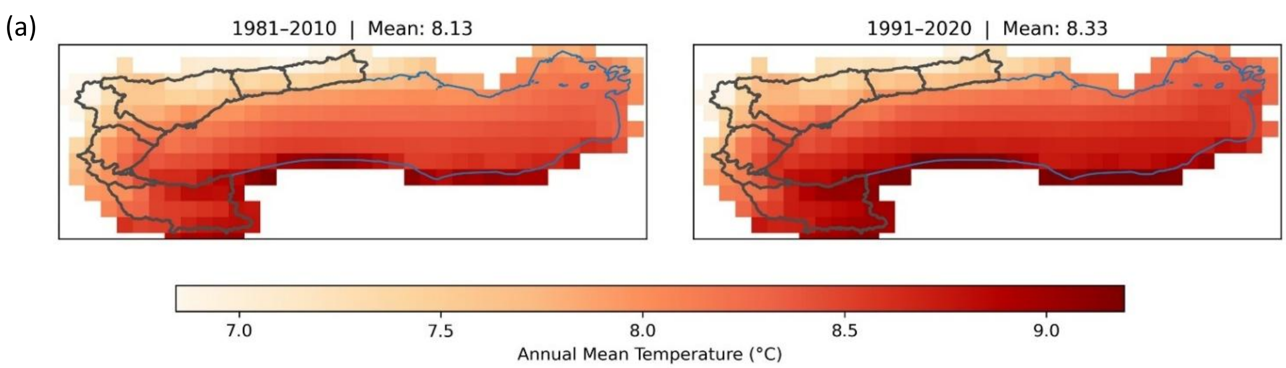
Data	Description
Climate	The Canadian Surface Reanalysis (CaSR, version 3.2) was used for the historical climate analysis. This dataset was initially developed by Environment and Climate Change Canada with funding from the International Joint Commission to enhance understanding of Canada-U.S. transboundary waters. Since then, it has often been used in runoff models across the Great Lakes, air quality analyses, and river flood modelling, among others. It provides high-resolution continuous estimates of atmospheric and surface variables at a 10-km resolution, spanning approximately 43 years (1980-2023). Example variables include daily and 1-hour total precipitation, air temperature, relative humidity, meteorological wind direction, snow depth, and water equivalent of snow depth. In this study, the daily dataset was extracted to calculate changes between **1981-2010 and 1991-2020** for **15 annual and 16 seasonal climate variables**, reflecting changes in temperature, precipitation, snow depth, and wind.
Lake surface temperature	A reconstructed daily dataset of lake surface temperature developed by Kayastha and others (2023) was used to analyze changes in surface water temperature. A deep learning model was used to derive lake surface temperature from reanalysis and satellite data. Daily gridded data for Lake Ontario covering the 1979-2020 period at a 1-km resolution was obtained from their open-source online repository. In this study, **annual and seasonal changes** in lake surface temperature were analyzed between **1981-2010 and 1991-2020**.
Ice cover	Historical ice cover data for Lake Ontario was obtained from the NOAA Great Lakes Environmental Research Laboratory (NOAA-GLERL). This dataset provides a long-term record of ice concentration (1973-present) derived from a combination of satellite observations and in-situ measurements. This data was resampled using the method and R script developed by Yang and others (2020) to derive a more consistent and higher resolution set of ice cover data. The “Ice Grid Resampling tool” uses a specialized unstructured grid-to-grid approach to interpolate disparate historical ice records into a standardized, high-resolution format. In this study, the resampled ice data was used to analyze changes in **annual winter ice cover** for Lake Ontario between **1973-2001 and 1994-2023**.

Data	Description
Water levels	Water level data was compiled from two primary sources to ensure both regional consistency and localized precision: 1. Lakewide average datasets (1918-2025) were obtained from the Great Lakes Coordinating Committee, which provides standardized, basin-wide monthly and annual water level records. 2. Historical hydrometric station data maintained by Water Survey of Canada was obtained for four stations within Western Lake Ontario including: Port Weller (1956-2024), Burlington (1971-2024), Toronto (1911-2024), and Cobourg (1957-2024). Together, these datasets support the assessment of **annual and monthly variability** and extreme water level events at the regional (lakewide) and local scales.

The following presents the results of our data analysis, summarizing recent changes in the climate, surface water temperature, ice conditions, and water levels across Lake Ontario and the watersheds along its western shores.

Warming air temperature

Across this region, **annual average temperature** used to be around 8.1°C in the 1990s (Figure 3). In the 2010s, annual average temperature increased to 8.3°C (or +0.2°C). Unsurprisingly, areas on the southern shores of Lake Ontario, including Niagara region, tend to be warmer. Notably, Toronto and surrounding areas have seen increased warming over this period, which may in part be due to the urban heat island effect. For a more detailed breakdown of recent changes in the climate over the land compared to the lake, see Appendix A.



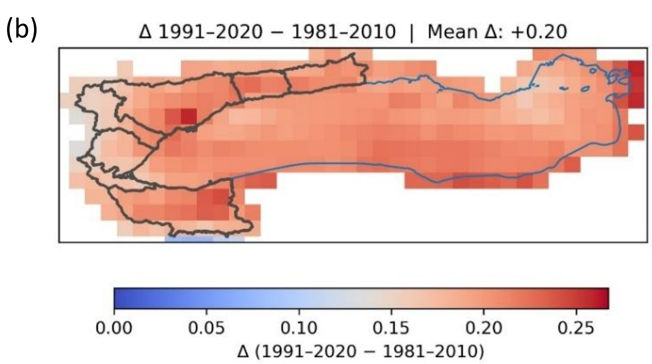


Figure 3. Change in annual mean air temperature (°C) across the watersheds along Western Lake Ontario and the lake basin between the 1990s (1981-2010) and 2010s (1991-2020) based on the Canadian Surface Reanalysis (version 3.2)

(a) Annual mean air temperature (°C) between 1981-2010 (left) and 1991-2020 (right)

(b) Difference in annual mean air temperature (°C) between 1991-2020 and 1981-2010

Across **seasons**, mean air temperature in the fall has increased the most (+0.3°C), followed by winter and summer which have increased by +0.26°C (Figure 4). Spring mean air temperature has remained relatively unchanged (-0.01°C).

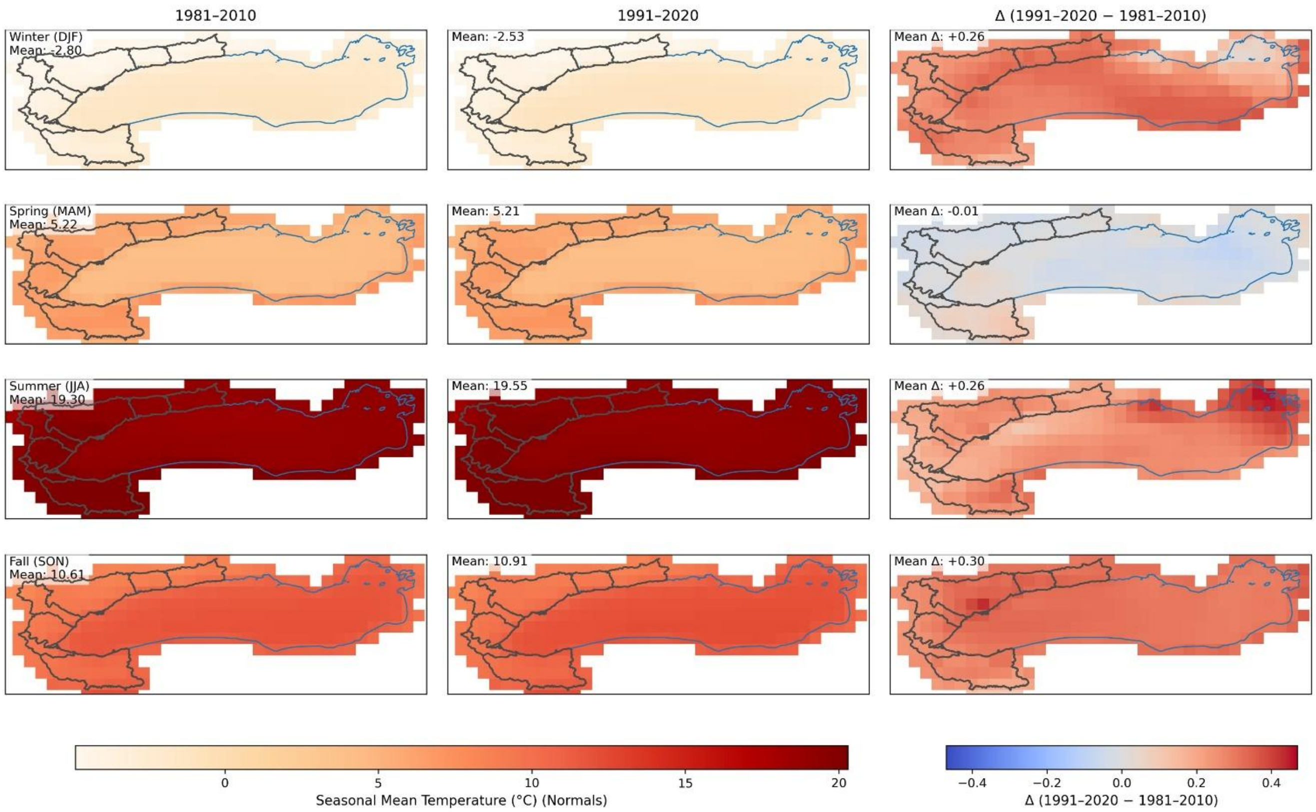


Figure 4. Change in seasonal mean air temperature (°C) across the watersheds along Western Lake Ontario and the lake basin between the 1990s (1981-2010) and 2010s (1991-2020) based on the Canadian Surface Reanalysis (version 3.2)

Daily highs (or **annual maximum air temperature**) have also increased over this period, increasing from 11.6°C in the 1990s to 11.8°C in the 2010s (or +0.17°C). Meanwhile, **annual minimum air temperature**, which typically represents nighttime lows, has increased even more, from 5.2°C in the 1990s to 5.5°C in the 2010s (or +0.22°C).

With warming temperatures, the **diurnal temperature range** – or difference between the daily maximum and daily minimum temperature – has decreased slightly, from 6.4°C in the 1990s to 6.3°C in the 2010s (decreasing by -0.05°C). Across the Western Lake Ontario region, the greatest decreases have occurred in and around Toronto. Meanwhile, some parts of Niagara region to the south have seen slight increases in diurnal temperature variation as daily highs in this area have increased.

More frequent and intense hot days

In the 1990s, there used to be an average of 3.3 days in a year with **daily maximum temperature above 30°C**. In the 2010s, the number of hot days above 30°C increased to 3.6 days (or +0.35 days). Across the Western Lake Ontario region, the greatest increases have occurred in and around Niagara region to the south.

Extreme heat is also becoming more intense. The **temperature on the hottest day in a year** used to be around 29°C in the 1990s (Figure 5). In the 2010s, this increased to 29.3°C (or +0.24°C). Increases have occurred across most of the Western Lake Ontario region, with some decreases in and around Hamilton.

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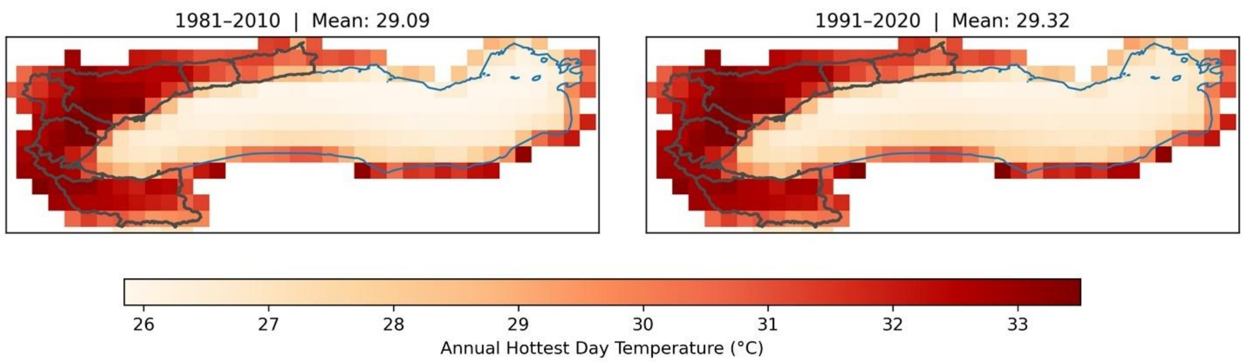

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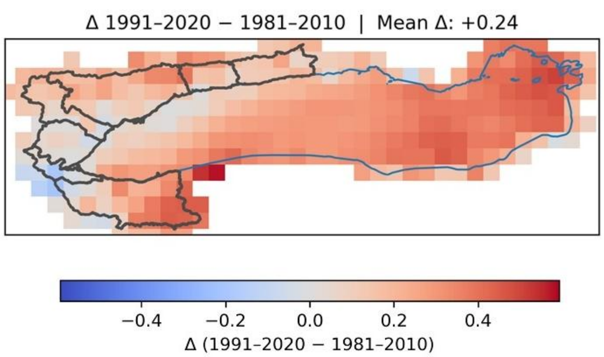


Figure 5. Change in temperature on the hottest days (°C) across the watersheds along Western Lake Ontario and the lake basin between the 1990s (1981-2010) and 2010s (1991-2020) based on the Canadian Surface Reanalysis (version 3.2)

(a) Annual average of the highest maximum daily air temperature (or hottest day temperature; °C) between 1981-2010 (left) and 1991-2020 (right)

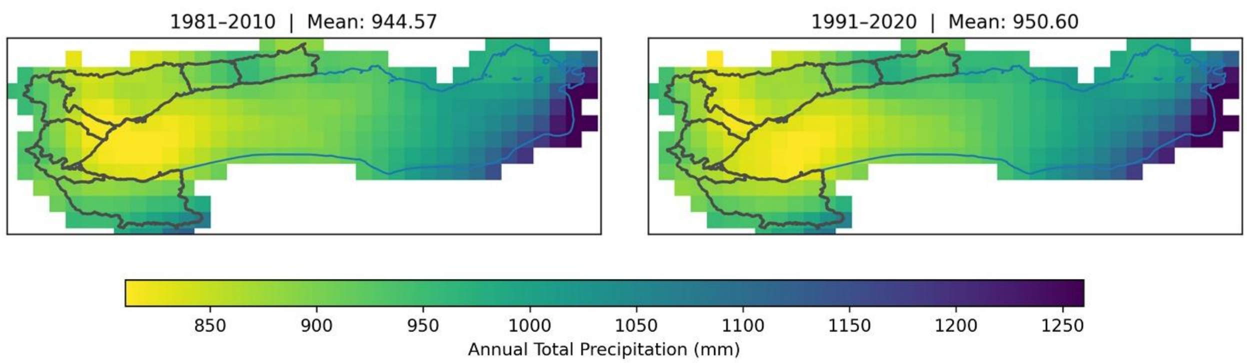
(b) Difference in hottest day temperature (°C) between 1991-2020 and 1981-2010

Changing precipitation patterns

Precipitation varies across the lake and the watersheds along its western shores. Between the 1990s and 2010s, some areas have seen increases in **annual total precipitation**, while others have seen decreases (Figure 6).

Across this region, annual total precipitation used to be around 944.6 mm in the 1990s. In the 2010s, annual total precipitation increased to 950.6 mm (or +6 mm), on average. Much of this increase appears to have occurred on the northern shores of Lake Ontario, especially in the central region. Meanwhile, decreases in annual total precipitation have occurred along the southwestern shores of Lake Ontario.

(a)



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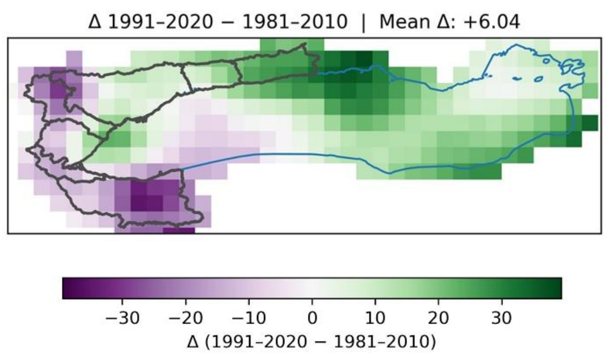

Figure 6. Change in annual total precipitation (mm) across the watersheds along Western Lake Ontario and the lake basin between the 1990s (1981-2010) and 2010s (1991-2020) based on the Canadian Surface Reanalysis (version 3.2)

(a) Annual total precipitation (mm) between 1981-2010 (left) and 1991-2020 (right)

(b) Difference in annual total precipitation (mm) between 1991-2020 and 1981-2010

Precipitation patterns also vary by **season** (Figure 7). Between the 1990s and 2010s, total precipitation increased during the winter and spring (+9.3 and +8.7 mm, respectively). Meanwhile, total precipitation decreased during the fall and summer (-9.1 and -0.5 mm, respectively), with notable decreases in and around Niagara region.

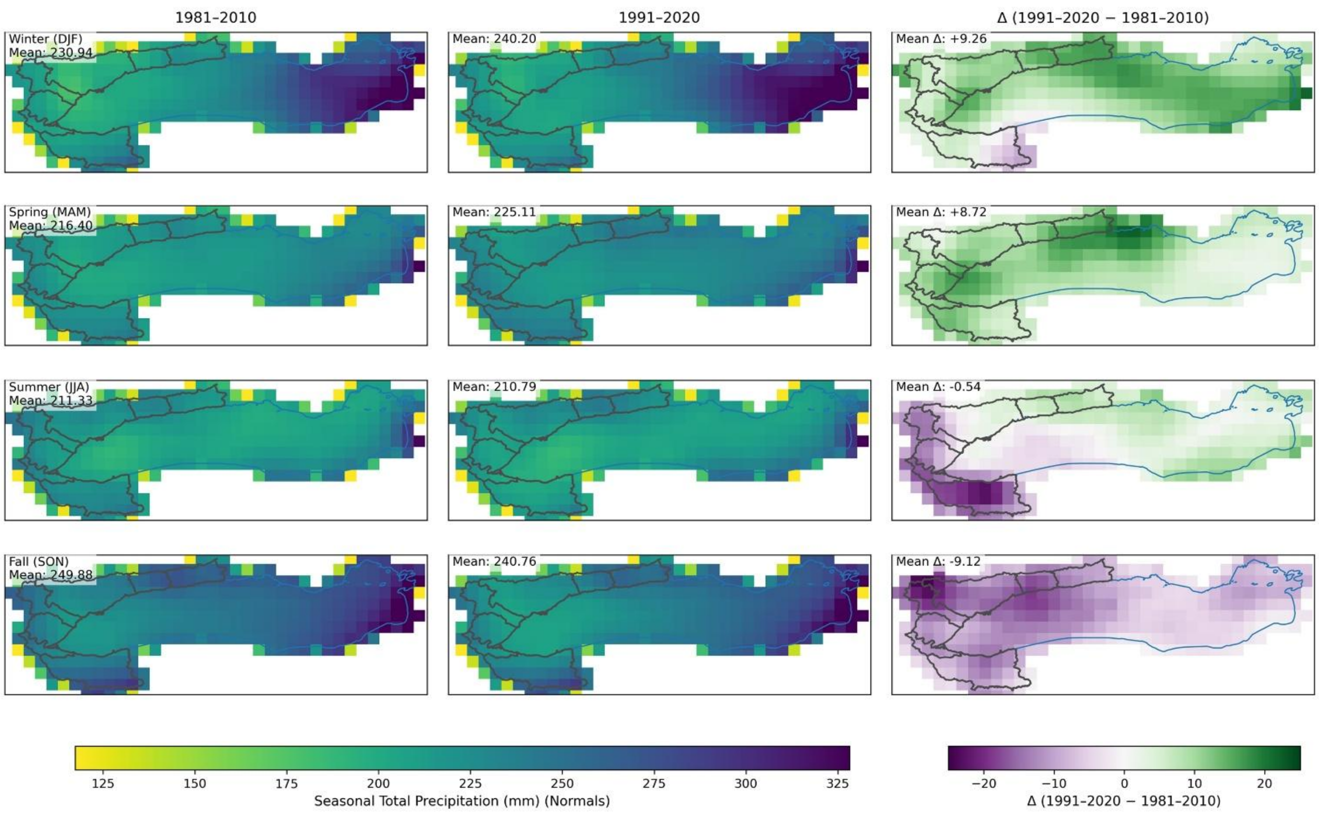

Figure 7. Change in seasonal total precipitation (mm) across the watersheds along Western Lake Ontario and the lake basin between the 1990s (1981-2010) and 2010s (1991-2020) based on the Canadian Surface Reanalysis (version 3.2)

Across this region, most areas have seen slight increases in **daily precipitation intensity** (mm/day) between the 1990s and 2010s (Figure 8). The average daily precipitation intensity in a year used to be around 7.3 mm/day in the 1990s. In the 2010s, this increased to 7.4 mm/day (or +0.07 mm/day).

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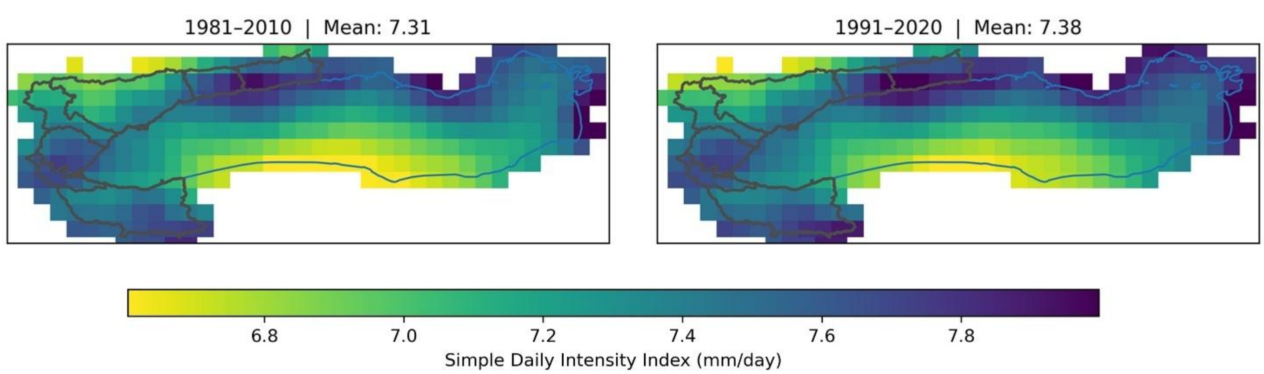

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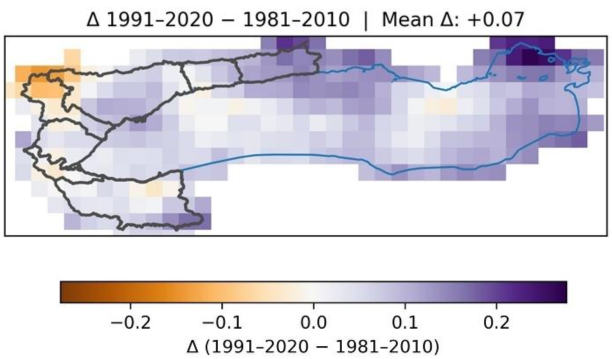


Figure 8. Change in annual average daily precipitation intensity (mm/day) across the watersheds along Western Lake Ontario and the lake basin between the 1990s (1981-2010) and 2010s (1991-2020) based on the Canadian Surface Reanalysis (version 3.2)

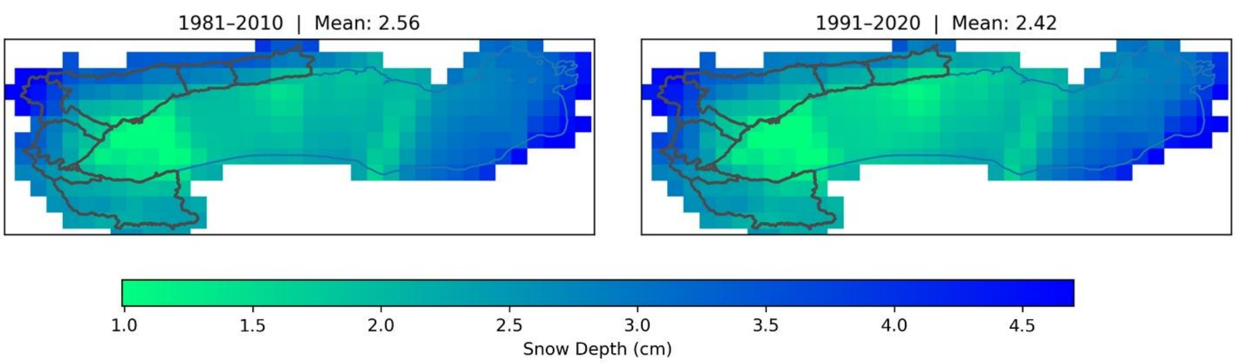
(a) Annual average daily precipitation intensity (mm/day) between 1981-2010 (left) and 1991-2020 (right)

(b) Difference in average daily precipitation intensity (mm/day) between 1991-2020 and 1981-2010

Changing snow depths

In the 1990s, **annual average snow depth** used to be around 2.6 cm (Figure 9). In the 2010s, this decreased to 2.4 cm (or -0.14 cm). Decreases in annual average snow depth have occurred across most of the Western Lake Ontario region, with some notable increases in and around Hamilton Harbour.

(a)



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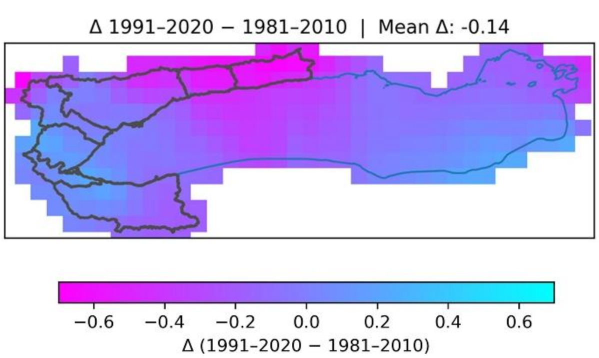

Figure 9. Change in annual average snow depth (cm) across the watersheds along Western Lake Ontario and the lake basin between the 1990s (1981-2010) and 2010s (1991-2020) based on the Canadian Surface Reanalysis (version 3.2)

(a) Annual average snow depth (cm) between 1981-2010 (left) and 1991-2020 (right)

(b) Difference in annual average snow depth (cm) between 1991-2020 and 1981-2010

Over this period, **annual maximum snow depth** has decreased even more compared to average snow depth, decreasing from 29.5 cm to 28.2 cm (or -1.2 cm).

Fewer cold days

With warming temperatures, the number of cold days has decreased across Western Lake Ontario. In the 1990s, there used to be an average of 114.1 days in a year with **minimum temperatures below freezing (or 0°C**; Figure 10). In the 2010s, the number of frost days decreased to 112.9 days (or -1.2 days), resulting in more frequent frost-free days.

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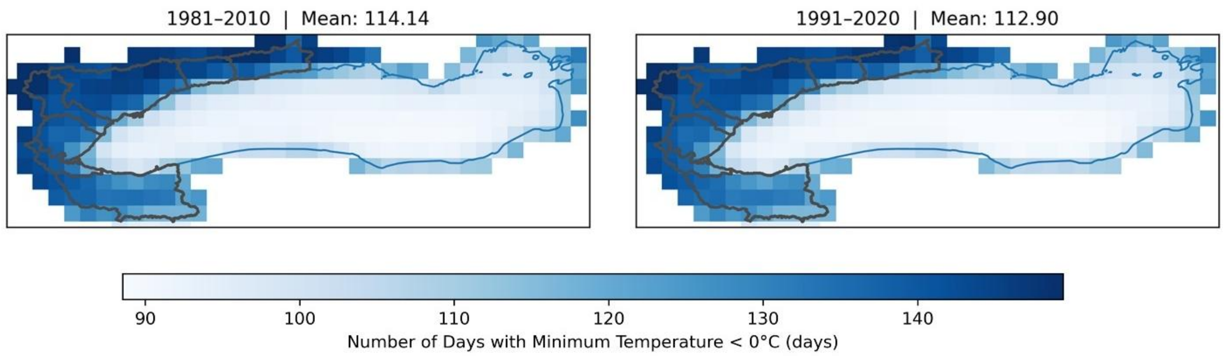

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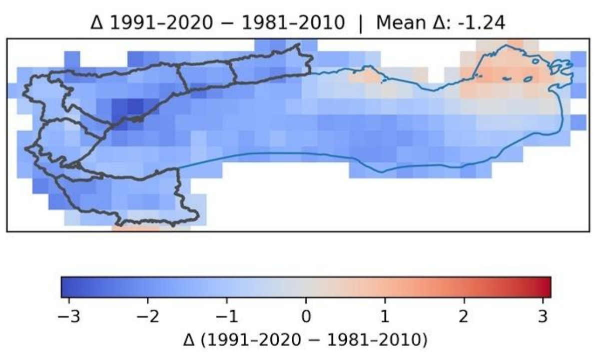


Figure 10. Change in the annual average number of frost days with minimum temperature below 0°C across the watersheds along Western Lake Ontario and the lake basin between the 1990s (1981-2010) and 2010s (1991-2020) based on the Canadian Surface Reanalysis (version 3.2)

(a) Annual average number of frost days below 0°C between 1981-2010 (left) and 1991-2020 (right)

(b) Difference in the annual average number of frost days below 0°C between 1991-2020 and 1981-2010

The number of very cold days has also decreased over this period. In the 1990s, there used to be an average of 8.5 days in a year with **minimum temperatures below -15°C**. In the 2010s, this decreased to 8.2 days (or -0.3 days).

Stronger winds

Maximum near-surface wind speed (10 m above ground) varies across the lake and the watersheds along its western shores, with higher wind speeds typically occurring over the lake compared to the land (Figure 11; see Appendix A for details). Across this region, **annual maximum near-surface wind speed** used to be around 61.6 km/h in the 1990s. In the 2010s, this increased to 62.5 km/h (or +0.9 km/h). Most of the coastal areas along Western Lake Ontario have seen increases in maximum wind speeds over this period, while some decreases have occurred in some inland areas to the northwest.

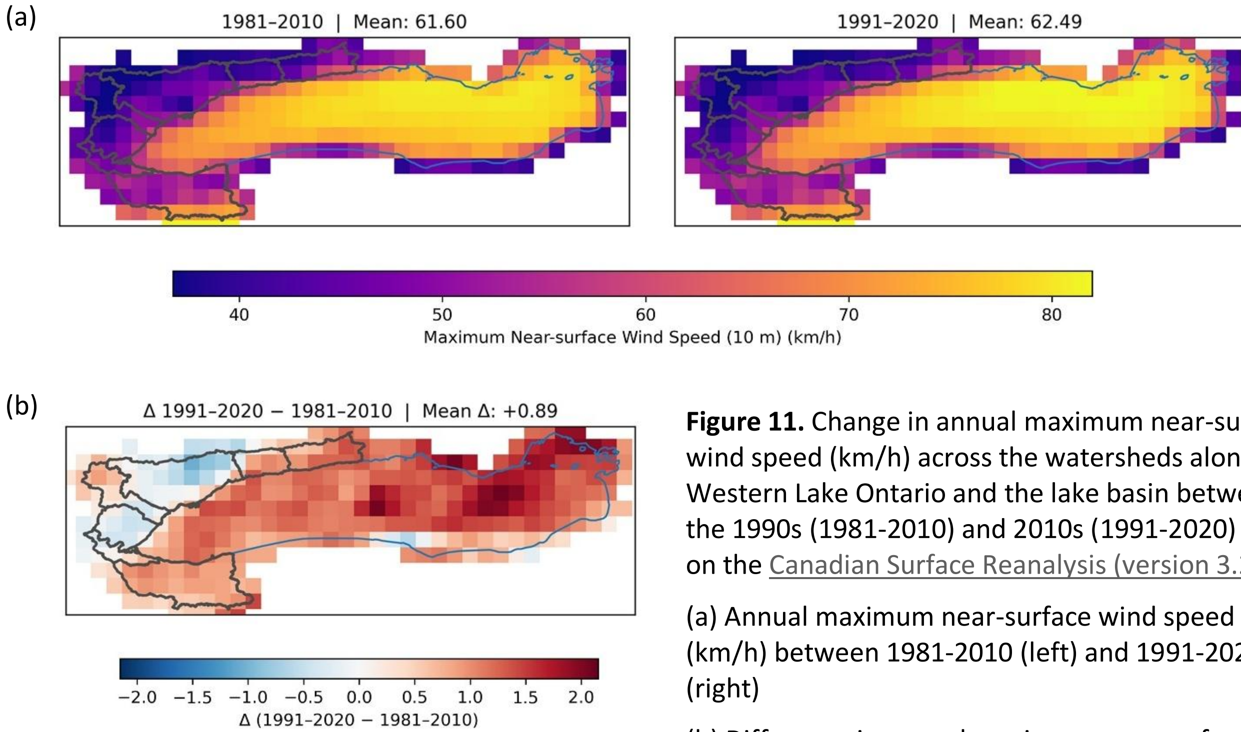


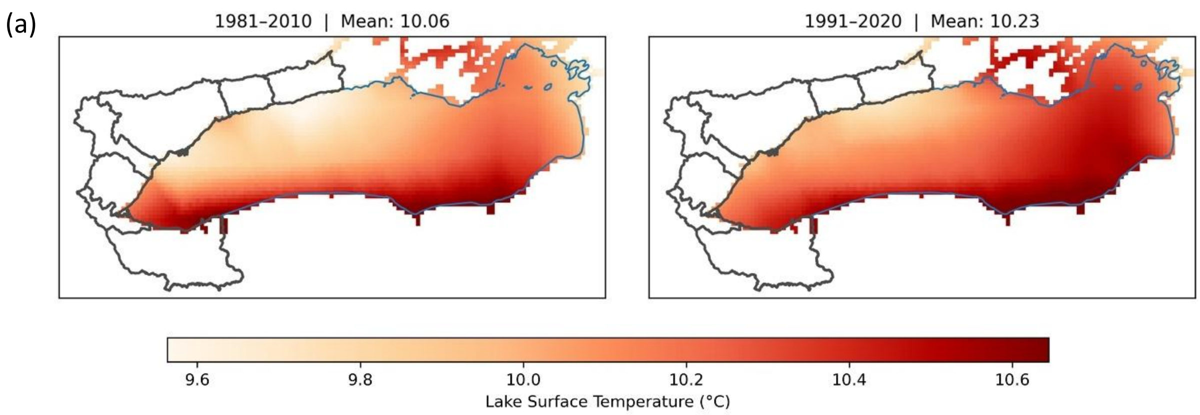
Figure 11. Change in annual maximum near-surface wind speed (km/h) across the watersheds along Western Lake Ontario and the lake basin between the 1990s (1981-2010) and 2010s (1991-2020) based on the Canadian Surface Reanalysis (version 3.2)

(a) Annual maximum near-surface wind speed (km/h) between 1981-2010 (left) and 1991-2020 (right)

(b) Difference in annual maximum near-surface wind speed (km/h) below 0°C between 1991-2020 and 1981-2010

Warming lake surface temperature

Lake surface temperature (largely derived from satellite imagery) is often used to help understand changes in water temperature and ice cover in the Great Lakes (NOAA CoastWatch Great Lakes Regional Node, n.d.). Between the 1990s and 2010s, much of Lake Ontario experienced some degree of warming, particularly around the Toronto and region waterfront (Figure 12). Meanwhile, some areas in the western part of Western Lake Ontario have seen slight decreases or minimal changes in lake surface temperature over this period.



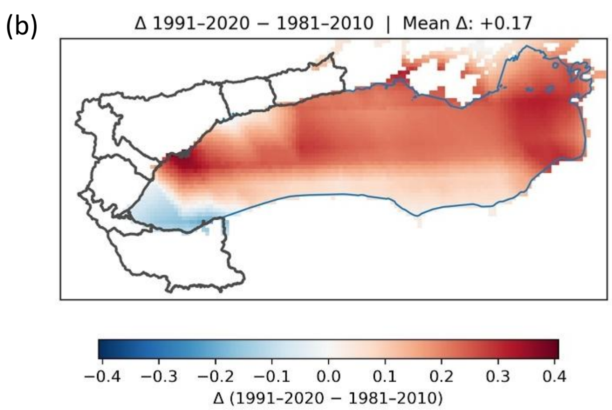


Figure 12. Change in annual average lake surface temperature (°C) across Lake Ontario between the 1990s (1981-2010) and 2010s (1991-2020) based on Kayastha et al. (2023)

(a) Annual average lake surface temperature (°C) between 1981-2010 (left) and 1991-2020 (right)

(b) Difference in annual average lake surface temperature (°C) below 0°C between 1991-2020 and 1981-2010

Across **seasons**, lake surface temperature has increased the most during the fall (+0.4°C), followed by winter and summer (+0.3 and +0.1°C, respectively; Figure 13). Meanwhile, spring lake surface temperature decreased by -0.1°C over this period. Warmer lake surface temperature during winter aligns with the decrease in ice cover that has been observed in recent decades (next section).

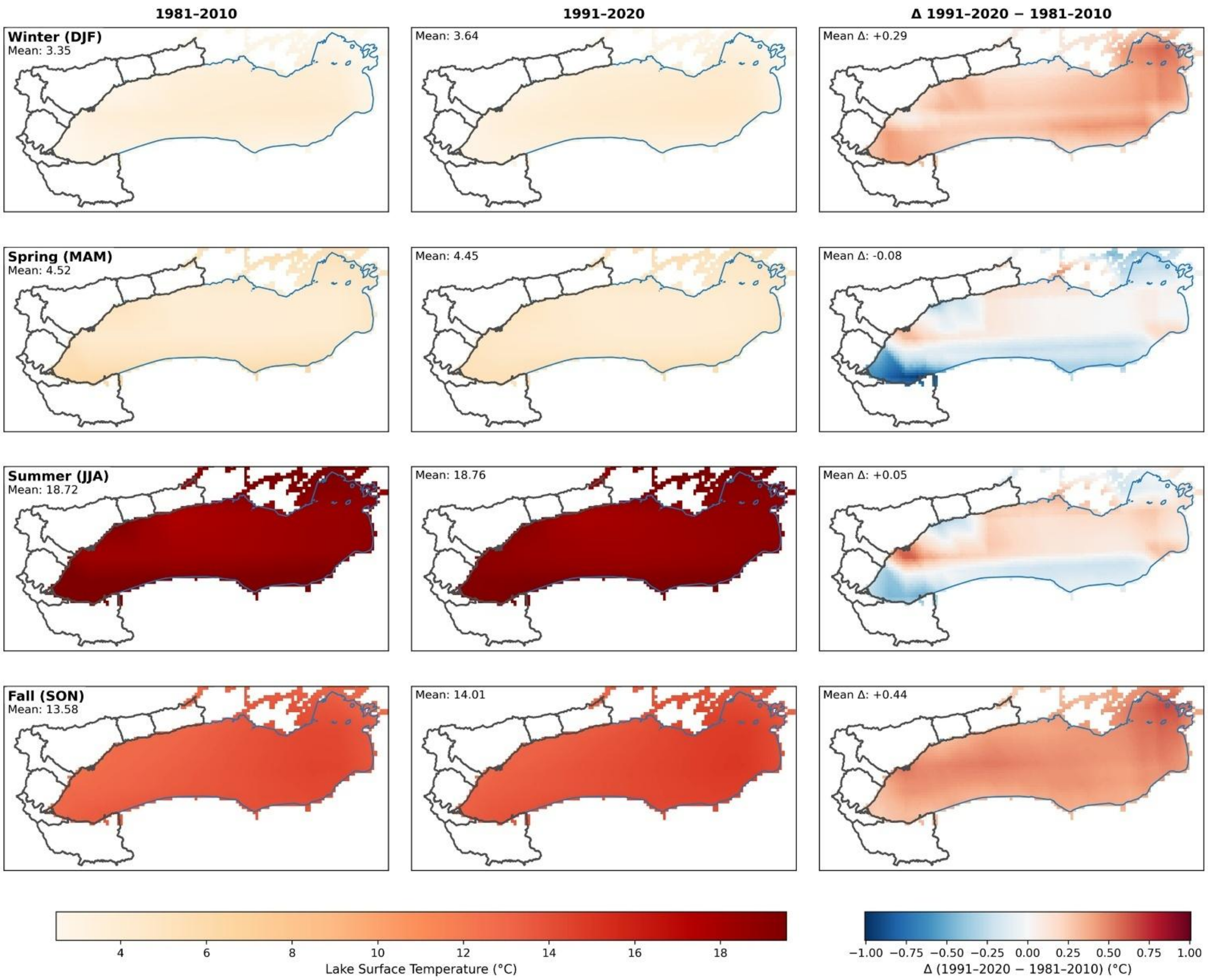


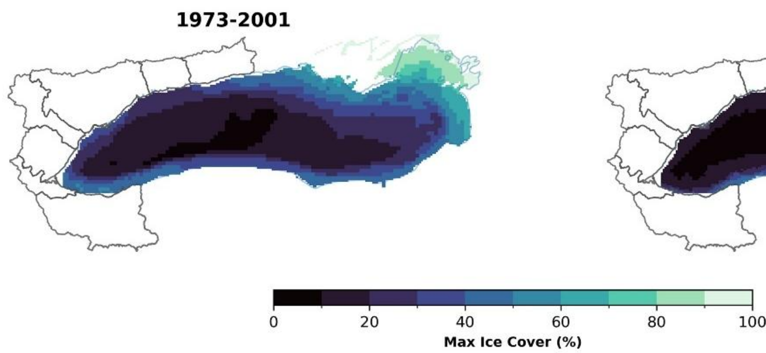
Figure 13. Change in seasonal average lake surface temperature (°C) across Lake Ontario between the 1990s (1981-2010) and 2010s (1991-2020) based on Kayastha et al. (2023)

Declining ice cover

While the amount of ice cover that forms on the Great Lakes varies from year to year, ice cover has been declining across the lakes by approximately 5 percent per decade since records began in 1973 (NASA Earth Observatory, 2024). Declining ice cover increases the risk of shoreline flooding and erosion, reduces shelter and protection for spawning habitat, increases the risk of lake-effect snow, and impacts people and communities who rely on or enjoy ice fishing and other ice-related activities, among other impacts (NOAA Research, 2024; Lam and Dokoska, 2022).

On Lake Ontario, **annual maximum ice cover** used to be an average of 32.3% between 1973-2001. Between 1994-2023, this value dropped to 26.6%, representing a decline of approximately 6%, with more ice-free years since 2002. Across Western Lake Ontario, annual maximum ice cover has declined, especially in the nearshore areas along the Canadian south shore (Figure 14).

(a)



(b)

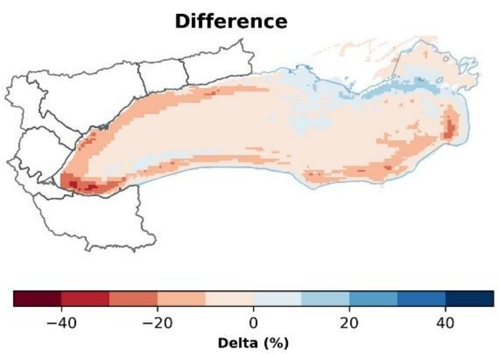


Figure 14. Change in annual maximum ice cover (%) across Lake Ontario between 1973-2001 and 1994-2023 based on NOAA - Great Lakes Environmental Research Laboratory and resampled based on Yang et al. (2020)

(a) Annual maximum ice cover (%) between 1973-2001 (left) and 1994-2023 (right)

(b) Difference in annual maximum ice cover (%) between 1973-2001 and 1994-2023

More extreme high and low water levels

Lake Ontario water levels fluctuate naturally, with some high periods and some low periods (Ministry of Natural Resources, 2026a; Government of Canada, 2022). As the easternmost lake, Lake Ontario is the receiving waters of the other Great Lakes before flowing into the St. Lawrence River (International Joint Commission, 2026). While outflows from Lake Superior and Lake Ontario are overseen by binational regulatory boards and are regulated through dams and control structures, there are no controls for outflows from the other lakes. Despite outflow regulations for Lake Superior and Lake Ontario, there is limited ability to alter lake levels, which are dominated by changes in water supplies that are driven by weather.

Prior to the completion of the Moses-Saunders Power Dam in 1958, there was greater variability in **annual average Lake Ontario water levels** (Figure 15). While regulation of Lake Ontario outflows has reduced the overall variability of Lake Ontario water levels, periods of high and low water levels remain unpredictable. Notably, high water levels in 2017 and 2019 set new **monthly maximum** records since coordinated records of Great Lakes water levels began in 1918 (Figure 16). These record high water levels caused extensive flooding and erosion damage along many coastal areas in Lake Ontario (Stories of past climate and weather-related impacts).

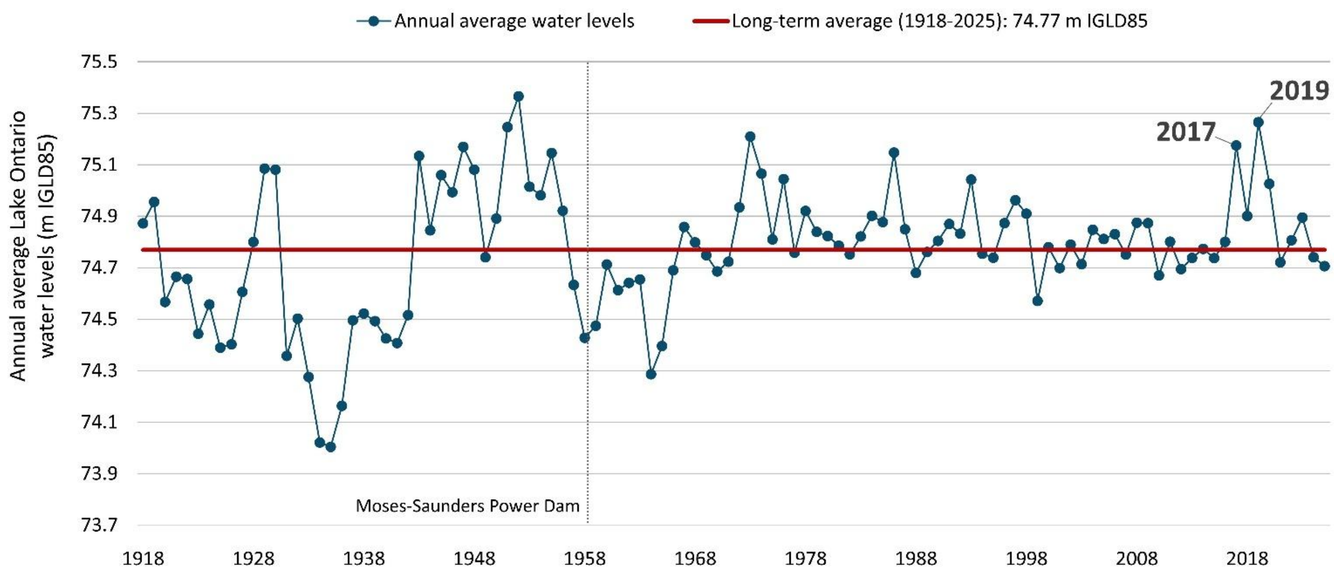


Figure 15. Annual average Lake Ontario water levels between 1918-2025 (m IGLD85) based on data from the Great Lakes Coordinating Committee

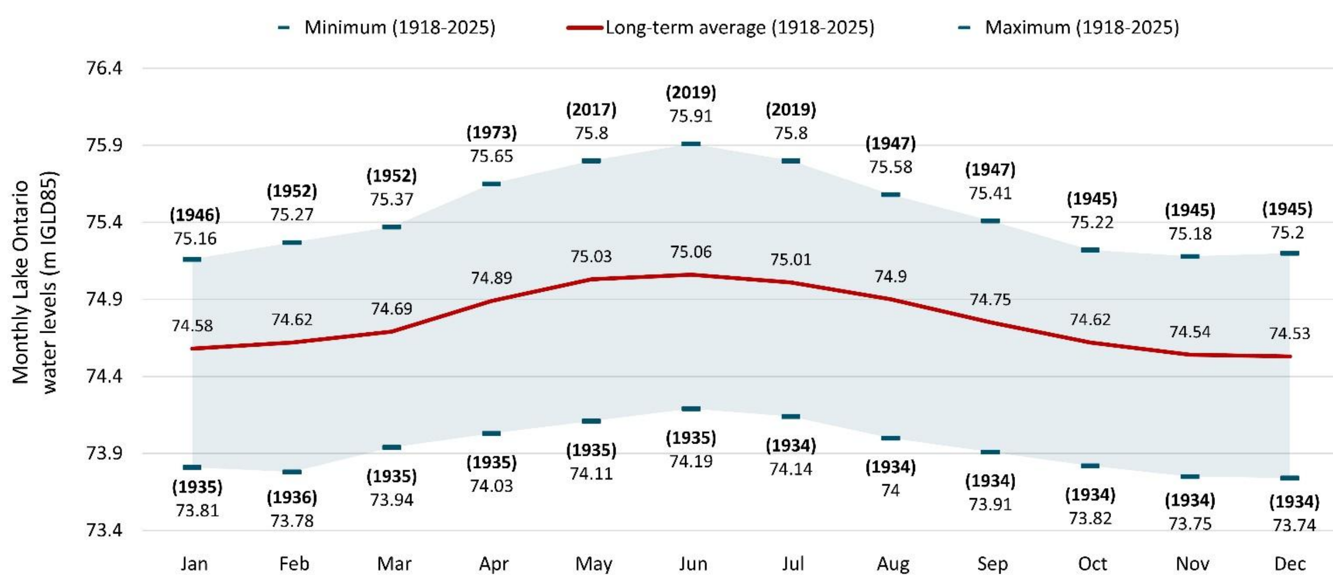


Figure 16. Range in Lake Ontario water levels between 1918-2025 by month (m IGLD85) based on data from the Great Lakes Coordinating Committee

In addition to lakewide averages, there are four hydrometric stations with historical water level data in Western Lake Ontario (Figure 17), which are operated by Environment and Climate Change Canada and partners of its national hydrometric program.

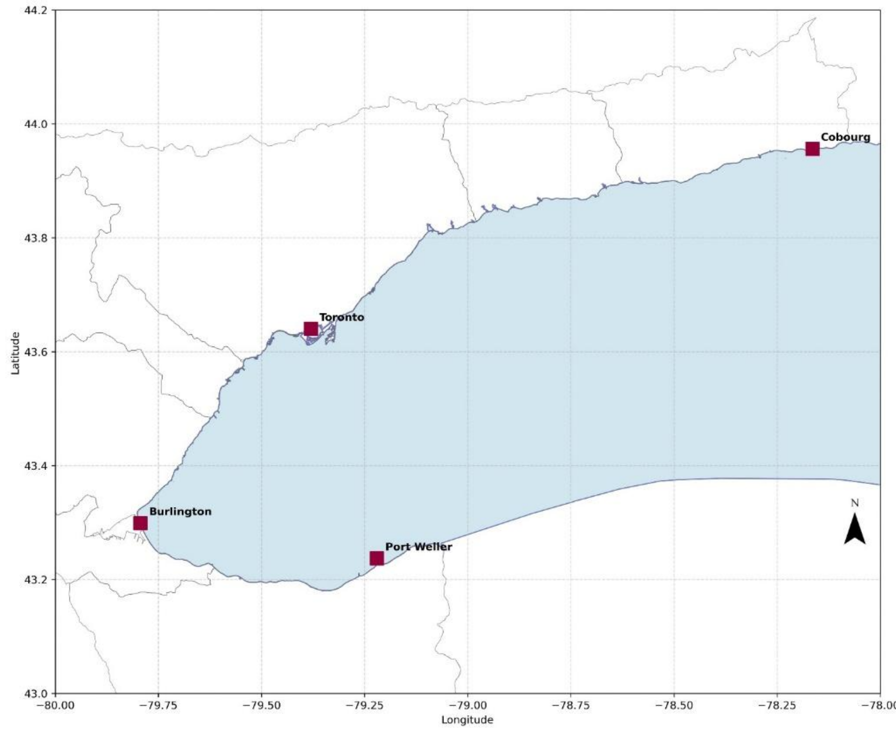


Figure 17. Map of four hydrometric stations with historical water level data in Western Lake Ontario

Daily water level records at these four stations vary in length, with the longest record pertaining to the Toronto station, which began in 1906. Figure 18 presents daily records starting with the earliest year with the most complete set of records for each month (i.e., 1911 for Toronto, 1956 for Port Weller, 1957 for Cobourg, and 1971 for Burlington).

Across the four hydrometric stations, periods of high and low water levels have been recorded. The Low Water Datum, or chart datum, is the lowest lakewide static water level that water levels in Lake Ontario rarely fall below (Great Lakes Coordinating Committee, n.d.). Extreme low water levels were more common prior to outflow regulation, which began in 1960. While there is no definitive threshold for high water levels in Lake Ontario, the static water level used by TRCA (Flood Emergency Management, 2026; TRCA, 2020) and Conservation Halton (n.d.) for shoreline hazard watches is used in Figure 18 as an example. Across the four stations, the **highest daily water levels** were all recorded during June 2019:

- Port Weller: 75.98 m IGLD85;
- Burlington: 75.98 m IGLD85;
- Toronto: 75.95 m IGLD85; and
- Cobourg: 75.91 m IGLD85.

Figure 18. Daily historical water levels at Port Weller (1956-2024), Burlington (1971-2024), Toronto (1911-2024), and Cobourg (1957-2024) relative to the low water datum (74.2 m IGLD85) and the static water level used by TRCA and Conservation Halton for shoreline hazard watches (75.5 m IGLD85)

Public engagement survey

An online engagement survey was launched in the summer of 2025 to seek input from members of the community and partner organizations to help understand climate and weather-related impacts on coastal areas along Western Lake Ontario and potential opportunities for more nature-based approaches. The survey was actively promoted through our project webpage, TRCA's social media, and with members of the L2L Advisory Committee and other partners. It remained available on our webpage throughout fall of 2025.

Over 100 responses were received, but upon closer inspection, approximately 80 responses offered sufficient details for analysis. Most of the respondents identified as private individuals (68%), and the rest were affiliated with an organization such as conservation authorities, municipalities, port authorities, nature steward groups, recreational clubs, and more.

Over half of the responses (51%) were from people who identified as living or working in Toronto (Figure 19). Responses were also received from across the region, including people who live or work outside of the Western Lake Ontario region, including Kawartha Lakes and Belleville.

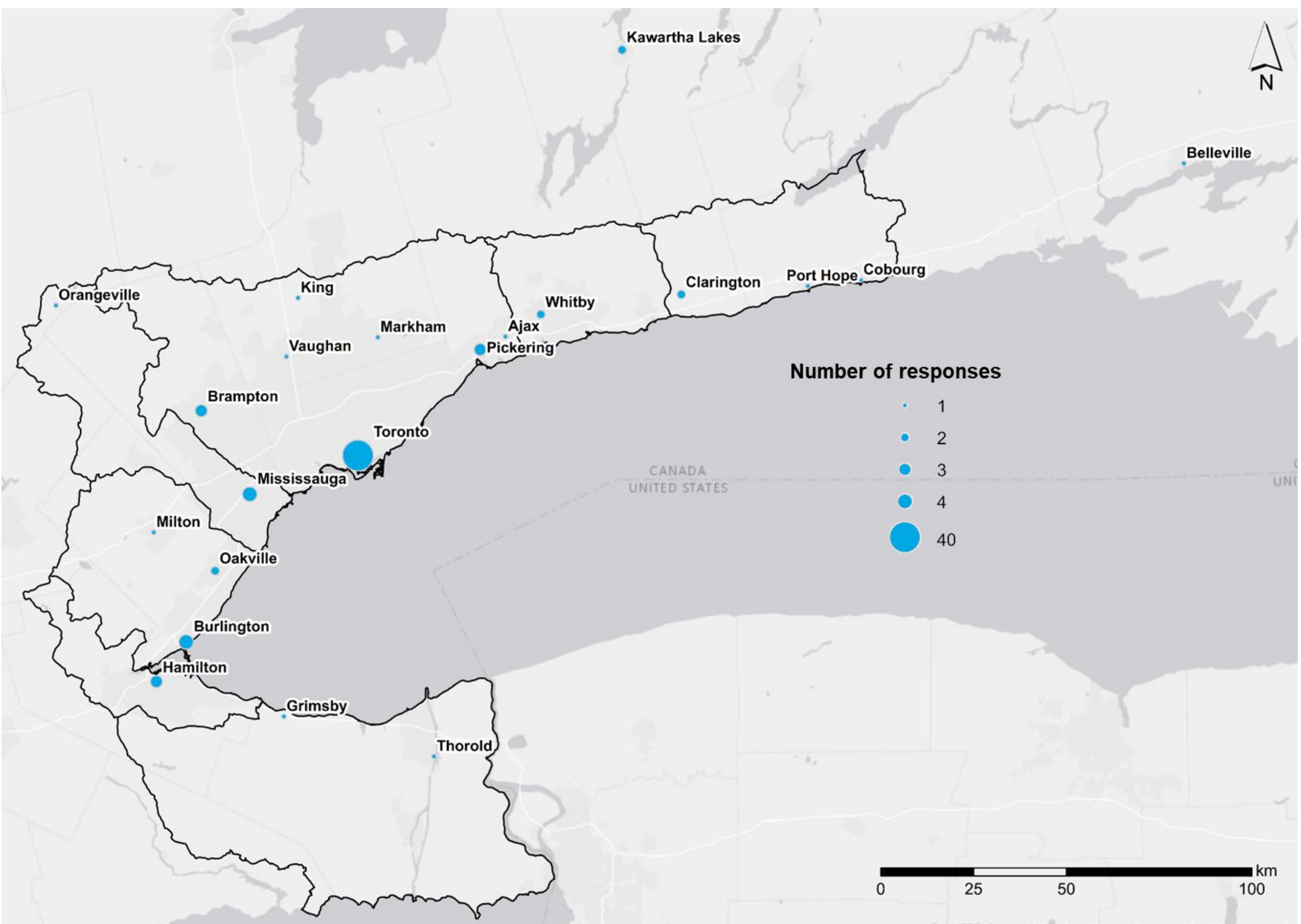


Figure 19. Map of survey respondents based on where they live or work

Stories of past climate and weather-related impacts

When asked if their local coastal area has been affected by climate change or extreme weather, **70% of people said yes, especially in recent years**. Many shared place-based stories of how climate change or extreme weather has affected their coastal areas, including the 2017 and 2019 record high lake levels, decline in ice cover, and high air and water temperatures that are contributing to more algal blooms. Table 2 presents a summary of these stories by geographic area within Western Lake Ontario, which have been edited for clarity.

Table 2. Summary of past climate and weather-related impacts and high-risk areas shared by survey respondents

Geographic area	Past climate and weather-related impacts and high-risk areas
Niagara to Hamilton Harbour	• Higher lake levels, flooding, and shoreline erosion affecting coastal municipalities such as Grimsby, Lincoln, St. Catharines, and Niagara-on-the-Lake. • Temperature changes impacting water quality and ecosystems, including increased algal blooms. • Damages due to flooding and high lake levels in 2017, 2019, and 2021. • Areas with sandy bluffs (e.g., St. Catharines) are especially vulnerable.
Hamilton Harbour	• Coastal erosion from high lake levels in 2017 and 2019 affected western areas of Hamilton Harbour. On-shore facilities were flooded; trails were damaged. • High air and water temperatures are contributing to extensive algal blooms, including more Harmful Algal Blooms (HABs). HABs were especially bad in 2001 and 2004. • Algal blooms occur annually, but are now starting earlier and lasting longer. • No freeze-over in the harbour, indicating warmer water temperatures, with impacts on recreation and local economies (e.g., ice fishing). • Increased weather variability, affecting recreational uses. • Extreme rainfall events are becoming more prevalent. Within the watershed, this has led to flooding and overtopping of stormwater management ponds. • Areas on the south shore that have poor water circulation are especially vulnerable. Harbour breakwater designs amplify this problem, contributing to water quality issues and flooding. • Development and pollution near sensitive areas (e.g., Cootes Paradise) amplify risk.
Burlington to Mississauga	• The record high water levels in 2017 and 2019 have been the biggest coastal issue in the last 10 years. During these high-water events, static water elevations were higher than the expected 100-year high water level. • High water levels caused private landowner shoreline protection work failures, road closures on Lakeshore Road, and flooding in the mouths of both Bronte Creek and Sixteen Mile Creek, causing infrastructure damage at the harbours and operational disruptions. • Most of Burlington Beach Waterfront Park was underwater, limiting the ability to use and enjoy the beach, which is heavily used for recreation. The Waterfront Trail also failed along a portion of the beach. • Major flooding and storms caused damage to lake tributaries in Halton in 2017, 2019, and 2024.

Geographic area	Past climate and weather-related impacts and high-risk areas
	• Extreme weather events in 2013 (July 18) and 2024 (July 16 and August 17) caused significant flooding on public and private lands in Mississauga. • Storm-driven wave runup and more variable water levels have resulted in shoreline erosion. • Stormwater runoff has caused erosion at creek mouths (e.g., in summer 2025). • Lack of ice is contributing to larger winter storms affecting the shoreline, causing increased erosion and flooding during a time of year when it is not typically expected. • We have been swimming in the same location every Saturday for the past 20 years at Lakeside Park beach in downtown Oakville, and the main issue has been water levels and erosion. Stones that have been added for shoreline erosion protection make the shoreline and the beach inaccessible and unsafe for recreational users. • The Joseph Brant Hospital has experienced some flooding in the past. • Increased extreme heat, poor air quality days, and water quality issues are affecting use and enjoyment of coastal areas. • Warmer air temperatures and warmer river waters are reducing the amount of flow in the rivers and their tributaries. • Low water levels and fewer fish and wildlife species have been observed. • Warmer waters are leading to increased Harmful Algal Blooms (HABs). • Ice-free lakes in the winter lead to more shoreline erosion. • Development within large creek mouths (low-lying areas) is especially vulnerable. • Areas with high pollutant loads (e.g., from industry, urban development) are especially vulnerable, including pollution and runoff from the Credit River. • Areas with steeper slopes and high bluffs are especially vulnerable to erosion. • River mouths are vulnerable to erosion and sediment deposition.
Toronto Waterfront	• Recurring flooding in the spring and summer have caused damage to dock walls and other infrastructure, as well as power outages. • Heat stress, heavy rainfall, and fluctuating lake levels contribute to increased risk. • High water levels in 2017 and 2019 led to significant infrastructure damage at the Outer Harbour Marina, including boardwalks, utilities, etc. Other boat clubs were also affected. Certain areas of Billy Bishop Airport were flooded, with risk to airport operations. • Woodbine Beach was flooded in 2017 and 2019. The shoreline has been eroding since the park's inception in 1977 and has experienced water quality issues. • Humber Bay Park (both East and West), and the parks between Mimico Creek and Etobicoke Creek have experienced erosion, especially over the past five years. Houses along the shoreline have also been affected. • The downtown west area, near Marilyn Bell Park, has been impacted by shoreline overtopping. • More flooding in the Don River (e.g., in 2024). • Flooding at the Rouge River mouth, with an increase in invasive Phragmites growing in the area. • Snow and ice-free winters in 2023/24 and 2022/23. • Trees at Coronation Park have been damaged by intense windstorms. • The Toronto Islands have experienced intense flooding.

Geographic area	Past climate and weather-related impacts and high-risk areas
	• Dramatic increases in invasive species, impacting native species and pollinators. • Since the early 2000s, there has been a shorter time period between extreme high and low lake levels, more significant storms, and reduced lake ice causing shoreline erosion and flooding. These have accelerated in the last 10 years. • Shoreline hardening in response to flooding and erosion exacerbates overall risk in the future and contributes to environmental degradation. • Warming temperatures are leading to earlier leaf out and more days above 30°C. • Water is much warmer and seems to be getting warmer every year, especially in the past few years. • More poor air quality days due to wildfire smoke. • Hotter summers and colder winters have been observed. • Extreme temperature fluctuations are causing more drought conditions and flash flooding, especially in the past five years. • Extreme storms that cause overland and storm sewer flooding also cause deterioration in water quality in the lake. • Increased algae growth makes the water unsafe for people and wildlife. • Beaches (e.g., Woodbine Beach) and some areas along the southern shoreline are especially vulnerable to flooding, erosion, and water ponding. • Parks that have been created from lakefill are especially vulnerable. For example, Tommy Thompson Park has experienced shoreline erosion, especially in the past few years, reducing habitat for birds and reducing the size of Pipit Point. • Loss of vegetation and habitat, shoreline hardening, paved areas in the watershed, and pollution contribute to increased risks. • Fish die-offs have been observed. • Toronto Islands and river mouths are especially vulnerable to erosion and extreme weather events. • Embayments with shallow water are particularly at risk to algal blooms due to warmer water and poor circulation. • Erosion has affected the Scarborough Bluffs, as well as invasive species that crowd out native species that might hold soil down better with deeper roots. • Bluffs along Petticoat Creek are also vulnerable.
Ajax to Cobourg	• With the extremely high lake water levels and wave action of 2017 and 2019, much of Pickering's waterfront sustained significant damage. The boardwalk in Beachfront Park, which formed part of the Waterfront Trail, was damaged beyond repair and had to be removed by City staff. • Record high lake levels within the last 10 years have increased erosion of the Ajax shoreline, putting municipal infrastructure at risk. A large section of the Waterfront Trail had to be relocated and rebuilt. Extreme wind and rain continue to speed up erosion rates. • Reduced ice cover along the Ajax waterfront has exacerbated erosion impacts and water levels. • High water levels in Lake Ontario have caused significant erosion to bluffs and dynamic beach locations, including loss of vegetation and trees. • The shoreline at Liverpool Rd at Frenchman's Bay has experienced erosion. • Areas in Bowmanville experienced flooding around 2018.

Geographic area	Past climate and weather-related impacts and high-risk areas
	• Changes in water levels are impacting shoreline erosion, riparian vegetation, and human access to the water (e.g., due to flooding of docks and paths), which have become more noticeable in recent years. • Changes in lake temperature have required changes to the operational and permit conditions for power plant operations. • Extreme weather, extreme heat, and poor air quality days are impacting recreation along the waterfront, forcing people to stay indoors and cancel organized recreation (e.g., soccer). • Disruptions to longshore sediment transport due to historical and ongoing shoreline hardening. • Storm impacts on coastal wetland barrier beaches, which have become even more sensitive to disturbance after high lake levels in 2017 and 2019. • The Bowmanville Water Supply Plant and intakes are especially vulnerable to algae growth. • Areas close to Rotary Park (just east of the Duffins Marsh) and areas located around outfall pipes are especially vulnerable. • The Ajax Shoreline EA completed recently identified certain shoreline reaches that are at higher risk. • Many coastal wetlands have become degraded due to water level regulation, urban development, and land conversion, making them especially vulnerable to climate change and extreme weather events. Many are also increasingly impacted by coastal squeeze due to development in upland areas. • Bluff environments in Bowmanville, Oshawa, and Whitby are especially vulnerable. • Historical development in flooding and erosion-prone coastal areas is at higher risk. • Trees and forests impacted by invasive pests (e.g., Emerald Ash Borer) are especially vulnerable.

Perceptions of current and future risks

Participants were asked to rate how much risk different factors (e.g., stormwater runoff, warmer air and water temperatures, and severe storms) currently pose to their local coastal area and how these risks may change in the future. On a scale from low to high, most factors were currently perceived to pose at least a moderate risk (Table 3a).

On average, the **top current risks** that participants were most concerned about include stormwater runoff from the land that ultimately enters Lake Ontario; the loss of fish and wildlife habitat and native species; warmer air and water temperatures and extreme heat; severe storms such as heavy rain, strong winds, and ice storms; and invasive species.

Table 3. Perceptions of (a) current risks and (b) current and future risks combined for the Lake Ontario shoreline

(a) Perceptions of current risks	Average rating		(b) Current + future risks	Average rating
Stormwater runoff from the land that ultimately enters Lake Ontario	2.53	(↑ 2)	Warmer air and water temperatures and very hot days (extreme heat)	5.40
Loss of fish and wildlife habitat and native species	2.50	(↓ 1)	Stormwater runoff from the land that ultimately enters Lake Ontario	5.37
Warmer air and water temperatures and very hot days (extreme heat)	2.49	(↑ 1)	Severe storms (e.g., heavy rain, strong winds, and ice storm)	5.35
Severe storms (e.g., heavy rain, strong winds, and ice storm)	2.49	(↓ 2)	Loss of fish and wildlife habitat and native species	5.30
Invasive plant species	2.48	–	Invasive plant species	5.29
Invasive fish and other aquatic species	2.48	–	Invasive fish and other aquatic species	5.24
Untreated/partially treated sewage entering Lake Ontario	2.38	(↑ 1)	Algal blooms	5.24
Algal blooms	2.36	(↑ 1)	Coastal erosion, including recession of the shoreline and slope stability	5.14
Coastal erosion, including recession of the shoreline and slope stability	2.30	(↓ 2)	Untreated/partially treated sewage entering Lake Ontario	5.05
High lake levels	2.16	(↑ 2)	Decreasing lake ice cover	4.92
Coastal flooding, including the impacts of high lake levels, storm surge, wave runup, and overtopping along the shoreline	2.11	–	Coastal flooding, including the impacts of high lake levels, storm surge, wave runup, and overtopping along the shoreline	4.89
Decreasing lake ice cover	2.08	(↓ 2)	High lake levels	4.78
Low lake levels	1.69	–	Low lake levels	4.17

When combined with perceptions of how these risks might change in the future, the **top current and future risks** that participants were most concerned with are warmer air and water temperatures and extreme heat; stormwater runoff; severe storms; the loss of fish and wildlife habitat and native species; and invasive species. Concern for algal blooms, coastal erosion, and changes in ice cover increase slightly, while the level of concern for coastal flooding and low lake levels remain unchanged when future risk is considered.

Opportunities for nature-based solutions

This survey also sought participants' feedback on whether they think their local coastal area needs more natural cover and habitat and what kinds of natural cover and habitat they would like to see more of. On a scale from 1 to 5, most people (87% out of 63 responses) agreed that their local coastal area needs more natural cover and habitat, especially those in dark green (Figure 20).

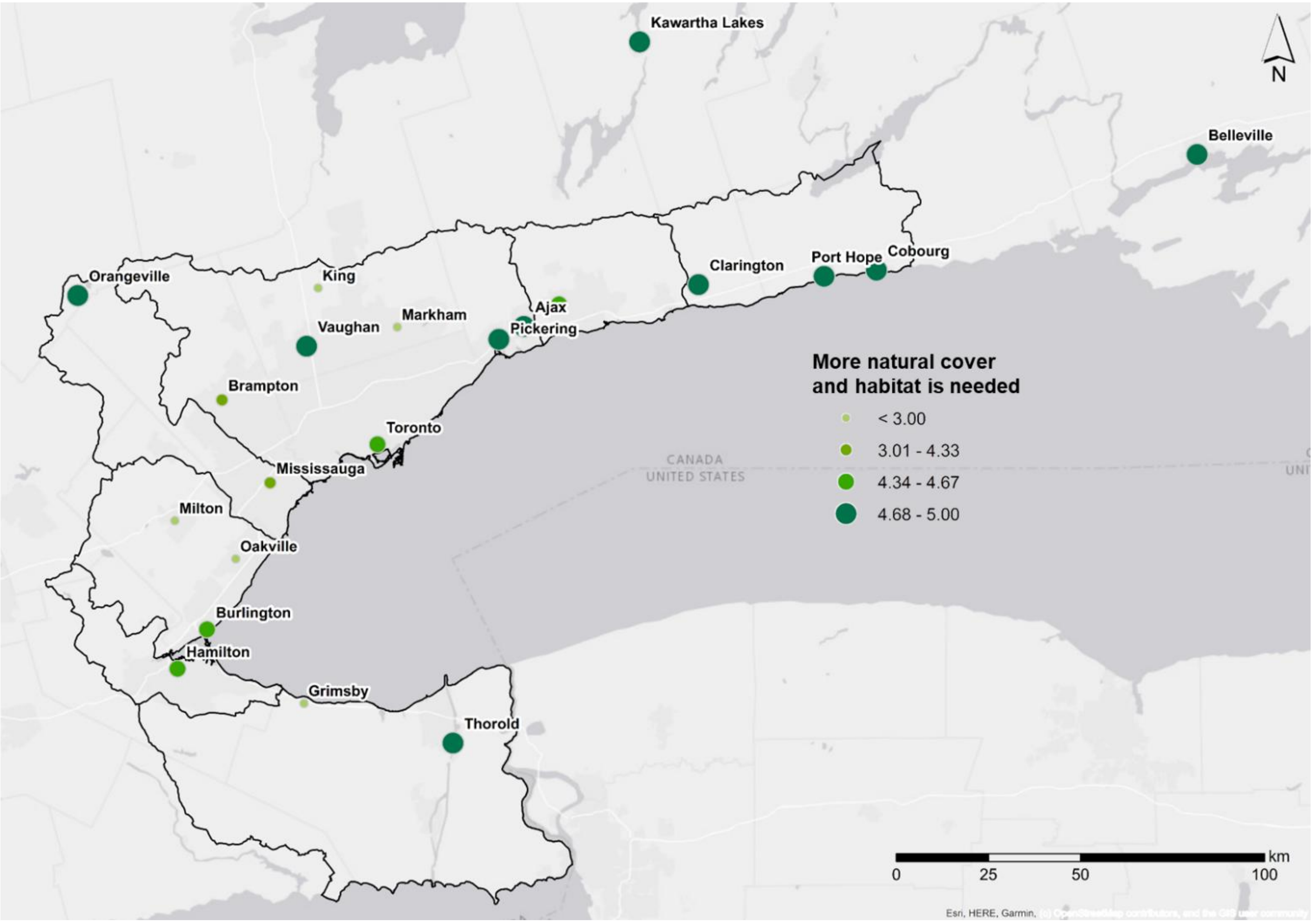


Figure 20. Map of survey responses indicating where people think more natural cover and habitat is needed in their local coastal areas on a scale from 1 to 5 (with greater values indicating higher perceived need)

Most participants believed that more natural cover and habitat along the shoreline in their local area would help reduce the risks of climate change and extreme weather (87% out of 63 responses). Most were satisfied with the available public recreational spaces/amenities along the shoreline in their local area (60% out of 63 responses). However, less than half of the respondents (44%) think that their shoreline has a good mix of natural (e.g., vegetation, beach, and/or wetlands) and hard features (e.g., large rocks, and/or concrete).

Many examples of nature-based solutions were shared by participants such as the restoration of wetlands and dunes, increased connectivity, maintaining buffer strips around the lake and establishing linear parks, and more blended approaches. Table 4 presents a summary of these opportunities by geographic area within Western Lake Ontario. These responses help to identify areas where people see opportunities for more nature-based and hybrid solutions and where more nature-based approaches may be beneficial, which can help inform future interventions.

Table 4. Summary of opportunities for more nature-based solutions and shoreline enhancements shared by survey respondents

Geographic area	Desired nature-based solutions and shoreline enhancements
Niagara to Hamilton Harbour	• Increase public access to the shoreline in the Grimsby and Lincoln areas. • Increase natural cover on the shoreline in St. Catharines and Grimsby, including more native trees and grasses, no-mow areas, and woody debris.
Hamilton Harbour	• More wetlands in the west end of the harbour and at river mouths (similar to the Don Mouth naturalization, for example). • Increase connectivity of shallow nearshore areas. • The open coast needs more stepping-stone habitats to connect remaining fragmented habitats. • Riparian planting and maintaining natural buffers along the lake is key. These buffers can be made publicly accessible for equal access to the lake. • More blended approaches that integrate sufficient protection against wind and wave action are needed, while providing aquatic habitat.
Burlington to Mississauga	• Increase public access and habitat along the shoreline in Burlington and Oakville (e.g., more of Oakville's linear parks). • Move towards a softer approach to shoreline protection works (e.g., from concrete and steel walls to groynes and cobble beaches that allow for increased habitat opportunities). • Increase the use of offshore reefs or islands for shoreline protection, which are prevalent on the U.S.-side of Lake Ontario. • Increase the use of more natural materials to enable recreational water activities and improve access to the water. • Increase natural cover, native plants, and pollinator gardens. • More wetland restoration initiatives.
Toronto Waterfront	• More innovative approaches such as headland beach shorelines, island beach shorelines, and offshore rocky shoals that reduce erosion, while providing more habitat and access opportunities. • More resources to remove and remediate invasive plants, including more opportunities for community involvement. • More public access to the shoreline. • Fewer mowed lawns at the edge of the water and more rewilding. • Make habitat creation and the use of nature-based solutions the first option instead of concrete. • More sand beaches and more berms and protected habitat on beaches. • Restore more wetlands and dunes between Ashbridges Bay and Cherry Street. • More pollinator-friendly plants. • Less hardened shoreline and more habitat enhancement at Coronation Park and at the yacht club and airport. • Remove highways beside waterways. • More dune habitats along beaches. • Continue and/or create more spaces like Tommy Thompson Park. • Less human disturbance and access in sensitive areas.

Geographic area	Desired nature-based solutions and shoreline enhancements
	• More natural cover and habitat is needed along the lake, especially along downtown Toronto and Ontario Place. • Replicate the Don Mouth naturalization along other portions of Lake Ontario.
Ajax to Cobourg	• Convert manicured grass areas into meadow nodes. • More nature-based protective features for coastal wetland barrier beaches (e.g., at Bowmanville Marsh, Westside Marsh, Lynde Creek Marsh, and Cranberry Marsh) that preserve the dynamic nature of these systems (e.g., learning from Hillman Marsh on Lake Erie). • More nature-based solutions in place of groynes and jetties around harbour entrances to encourage natural sediment transport. • Planting native beach and dune grasses to help stabilize and build up the beach (e.g., learning from Darlington). • The shoreline areas along Clarington extending to Northumberland include some of the highest quality coldwater streams and coastal wetlands. Riparian enhancement through plantings would improve habitat quality for coldwater fish species (e.g., at Wesleyville Creek). • Increase protection and enhancement of all wetlands, regardless of their evaluation status. • More wetland restoration initiatives (e.g., like those at Lynde Shores Conservation Area). • Wildlife underpasses should be a standard requirement for roads and other infrastructure. • More investment to protect turtle nesting habitat. • More conservation designations and partnerships to increase shoreline protection (e.g., designated marine protected areas around the world), restricting incompatible uses and providing nursery areas for fish and other wildlife. These would extend into the coastal wetlands and their upland areas. • More enhanced and protected riparian habitat, with a minimum of 30-m buffers. • More trees and wetlands. • More naturalized shoreline areas and deeper setbacks, including around major tributaries (e.g., like Second Marsh).

PART 2: TYPOLOGY OF NATURE-BASED AND HYBRID SOLUTIONS FOR WESTERN LAKE ONTARIO

Literature review

A total of 1,173 shoreline NbS terms were extracted from 53 documents published between 1995 and July 2025 (Figure 21; see Appendix B for the full list of publications reviewed).

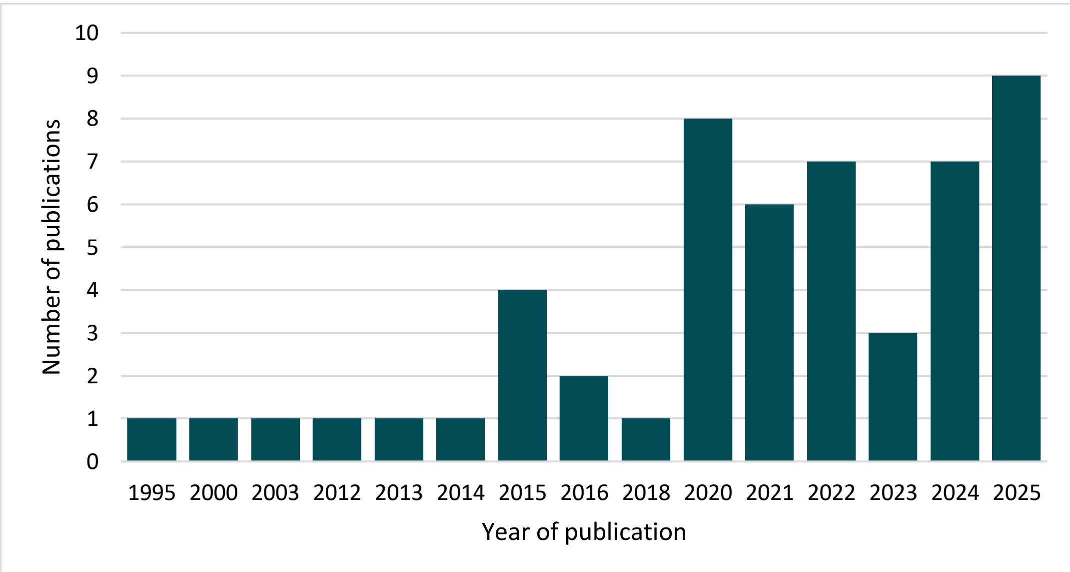


Figure 21. Overview of publications reviewed from 1995 to 2025

Trends

Increased specificity

Earlier terms like "wetland restoration" or "dune restoration" have evolved into more specific phrases such as "wetland creation and restoration" and "dune system rehabilitation". Some concepts like "living shorelines" have remained consistent across decades (1995-2025), suggesting standardization in certain areas.

Rise of branding and frameworks

Terms like "Engineering with Nature®", "Building with Nature", and "Nature-based Solutions (NbS)" appear more frequently in recent years, reflecting institutional frameworks and branded approaches.

Hybridization language

The 2020s saw a surge in terms like "hybrid green-grey infrastructure", "eco-enhanced hard infrastructure", and "living breakwaters", indicating a blending of natural and engineered solutions.

Ecological function emphasis

Newer terms often highlight ecological roles such as "blue carbon ecosystems", "vegetation-based wave attenuation systems", or "habitat suitability-based NbS planning".

IUCN Standard for nature-based solutions

The IUCN Global Standard (2020a, b) provides eight criteria that can help teams plan, design, and steward NbS (Table 5). These criteria were used to guide the classification of interventions within this compendium. Only those techniques that meet the Standard's definition of a nature-based solution have been grouped under the nature-based component of the typology. Interventions that rely on a significant grey-infrastructure component to function were placed in the "Hybrid solutions" category. Meanwhile, actions that enable, support, or create the conditions for NbS delivery, but are not themselves NbS (e.g., policy tools, capacity building, monitoring frameworks), have been categorized as "Enablers."

Table 5. The IUCN Global Standard's criteria for nature-based solutions

Criterion 1
NbS effectively address societal challenges: 1. Climate change mitigation and adaptation 2. Disaster risk reduction 3. Economic and social development 4. Human health 5. Food security 6. Water security 7. Environmental degradation and biodiversity loss
Criterion 2
The NbS should result in a measurable enhancement of biodiversity
Criterion 3
NbS result in a net gain to biodiversity and ecosystem integrity
Criterion 4
NbS are economically viable
Criterion 5
NbS are based on inclusive, transparent and empowering governance processes
Criterion 6
NbS equitably balance trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits
Criterion 7
NbS are managed adaptively, based on evidence
Criterion 8
NbS are sustainable and mainstreamed within an appropriate jurisdictional context

Overview of the typology

The list of 1,173 NbS terms was pared down by removing irrelevant terms (e.g., marine or riverine), duplicate values, synonyms, and overlapping concepts. A total of **27 types of nature-based and hybrid solutions** emerged under **nine themes** that may be applicable to the Western Lake Ontario study region (Table 6).

Table 6. Overview of typology of 27 nature-based and hybrid solutions for Western Lake Ontario

Rivers and Connectivity	1. Reconnected rivers and streams 2. Channel naturalization and realignment	**Sediment Management**	14. Sediment re-use 15. Sediment capture and accretion
Wetlands and Floodplains	3. Constructed or restored wetlands 4. Floating wetlands 5. Floodplain restoration and reconnection	**Habitat Creation and Structural Complexity**	16. Habitat islands or mounds 17. Habitat connectivity corridors
Aquatic and Riparian Vegetation	6. Riparian vegetation and buffers 7. Coastal forests or windbreak planting 8. Invasive species control and removal	**Urban Green Infrastructure**	18. Coastal parks and greenways 19. Floodable parks
Beaches, Dunes, and Bluffs	9. Beach and dune restoration 10. Bluff stabilization	**Hybrid Solutions**	20. Engineered habitat structures 21. Beach nourishment and dynamic cobble berms 22. Hybrid dunes 23. Constructed or artificial islands 24. Hybrid breakwaters and shoals 25. Artificial reefs 26. Vegetated armour and revetments 27. Eco-engineered materials and surfaces
Shoreline Softening and Bioengineering	11. Bioengineering and live staking 12. Shoreline regrading 13. Sills		

Recognizing the importance of upstream and downstream connections, the typology begins with “Rivers and Connectivity”. It also consists of different geomorphic categories such as wetlands, floodplains, beaches, dunes, and bluffs. The themes also focus on biotic and abiotic elements such as aquatic and riparian vegetation, habitat creation, sediment management, and shoreline softening.

Hybrid solutions are interventions that deliberately combine NbS with engineered, or “grey” infrastructure to deliver coastal resilience and other societal benefits. They integrate living systems with conventional materials and designs such as rock revetments, seawalls, or drainage systems, creating a complementary approach that leverages the strengths of both. The natural components provide ecosystem services such as habitat creation, water quality improvement, and adaptive capacity under climate change, while the engineered elements offer structural stability, precision control, or rapid performance under extreme conditions. By blending green and grey approaches, hybrid solutions can address complex challenges more effectively than either type alone, particularly in settings where space, risk level, or stakeholder priorities require a balance between ecological function and engineered reliability.

The following provides a brief description of the 27 NbS and hybrid solutions that form part of the typology, including the challenges that they can help address and where they may be suitable at a high level. To support alignment with existing typologies in Western Lake Ontario, linkages to four broad habitat types (or ecotypes) are also identified based on the Toronto Waterfront Aquatic Habitat Restoration Strategy (2003) and TRCA's Waterfront Integrated Restoration Prioritization (2024):

- **Open coast:** shorelines that are exposed to the open lake;
- **Embayment:** a partially enclosed body of water sheltered from the open lake;
- **Coastal wetland:** an area of land that is either permanently or seasonally inundated with water that generally occurs at the intersection between rivers and the shoreline of lakes; and
- **River mouth:** the connecting outlet where a river flows into another larger body of water. Upstream areas are also noted to emphasize the importance of land to lake connections where applicable.

For graphical illustrations of these techniques, please see the accompanying visual guide and online StoryMap.

Rivers and connectivity

1. **Reconnected rivers and streams**
    - **Ecotype:** River mouth (and upstream areas)

Human-made structures such as dams, weirs, and undersized or improperly designed culverts alter the natural flow of water and sediment from tributaries to the lake (TRCA, 2026a; Lomas, 2023). These impact water quality and create barriers for fish and other aquatic wildlife to move up and downstream.

When a dam, weir, or culvert is failing, needs to be decommissioned, or is no longer needed (The River Restoration Centre, 2025), consider removing or retrofitting them to restore the natural movement of water and sediment from tributaries to the lake, while considering the risk of unintentionally facilitating the spread of aquatic invasive and non-native species (e.g., Arkilanian et al., 2026; Dolan et al., 2026; Walter et al., 2021). Through integrated and careful planning, barriers can be prioritized for removal where reconnected rivers and streams can help re-establish fish passage, improve channel function, and reconnect upstream habitats, while minimizing unintended consequences such invasive species spread.

2. Channel naturalization and realignment

- **Ecotype:** River mouth (and upstream areas)

Since European settlement in the region, historical patterns of land conversion, development, and urbanization have led many rivers and streams to be straightened, buried, or re-routed (Bernstein and Chung, 2024; TRCA, 2016). Once meandering rivers and streams now run through concrete channels, culverts, and underground pipes, reducing habitat, biodiversity, and water quality. Water is often moved more quickly downstream and at greater volumes, which can increase flooding and erosion in downstream areas (Trice, 2016).

Flooding is the costliest natural hazard in Ontario and Canada, with growing impacts due to increasingly extreme weather events, aging infrastructure, and the increasing concentration of people and assets in urban areas (Ministry of Emergency Preparedness and Response, 2025b; Canada's Task Force on Flood Insurance and Relocation, 2022; Beltan, 2021). As the cost and damages of flooding continue to rise, channel naturalization and realignment not only help to improve habitat, connectivity, biodiversity, and water quality, but can also form part of comprehensive flood risk reduction strategies by restoring floodplain connection, increasing flood storage capacity, reducing peak flows, and slowing stormwater runoff. Where room is available, consider re-meandering or reshaping modified channels, uncovering or daylighting buried sections of rivers and streams, and re-creating vegetated, low-energy outlets at lake interfaces.

Wetlands and floodplains

3. Constructed or restored wetlands

- **Ecotype:** Coastal wetland

Across southern Ontario, over 70% of inland and coastal wetlands are estimated to be lost since European settlement (Mayne et al., 2022). Great Lakes coastal wetlands are directly influenced by the waters of the Great Lakes and are among the most ecologically diverse and productive ecosystems. They provide many important services and benefits such as carbon capture and storage, nutrient cycling, stormwater retention, water quality improvements, and habitat for many birds, fish, amphibians, and other wildlife.

Where existing coastal wetlands remain, it is important to protect and restore them where they have been degraded. In low-lying floodplain areas and sheltered coasts, consider creating new wetlands to retain stormwater, filter nutrients, and support fish and wildlife habitat.

These include wetlands that are located at river mouths or along major channels that flow into the lake (i.e., riverine wetlands), wetlands in protected or open bays (i.e., lacustrine wetlands), and wetlands that are protected behind a physical barrier that is created from sand and other sediment deposits from wind and wave action (i.e., barrier-protected wetlands).

4. Floating wetlands

- **Ecotypes:** Embayment, coastal wetland, and river mouth/upstream areas (where waters are calm)

In urban areas, space is often limited for the creation of new wetland basins and natural areas at the interface of the land and water. Meanwhile, the water quality of urban rivers, streams, and lakes is often impaired due to high loads of pollutants carried by stormwater runoff (Sustainable Technologies Evaluation Program, 2019; Environmental Commissioner of Ontario, 2016).

In areas with calm or slow-moving water, consider creating floating wetlands (or floating treatment wetlands) using buoyant planting mats or modular rafts anchored in the water to provide water quality treatment and aquatic habitat. The root zones of emergent vegetation can help absorb nutrients and trap fine sediments, while the floating structures offer refuge for fish and invertebrates.

Often used in stormwater retention ponds, floating wetlands tend to require regular inspection and maintenance (e.g., replanting, debris removal; City of Brampton, 2026; Landon and Hunt, 2024). Protective fencing and other preventative measures may be required to deter overuse by Canadian geese and other species that may have detrimental impacts on vegetation, water quality, and ecosystem health.

5. Floodplain restoration and reconnection

- **Ecotype:** River mouth (and upstream areas)

Levees, dikes, embankments, or berms refer to a long wall, bank, or mound built to prevent flooding (TRCA, 2026b), disconnecting the channel from its natural floodplain (Knox et al., 2022). This results in the loss of floodplain functions (e.g., the exchange of nutrients, sediment, and organisms between the channel and floodplain), reducing water quality, habitat, and biodiversity. Levees can also exacerbate flooding downstream or cause flooding in surrounding areas when they are breached.

Where room is available, consider removing or modifying levees to allow rivers to access their natural floodplains, increasing flood storage capacity, ecological productivity, and wildlife habitat. Restoring floodplain connections enables floodwater and sediment to spread across low-lying areas.

Aquatic and riparian vegetation

6. Riparian vegetation and buffers

- **Ecotypes:** Open coast, embayment, coastal wetland, and river mouth/upstream areas

To provide and protect aquatic habitat, the establishment of vegetated riparian buffers of at least 30 m on either side of a watercourse is often recommended (Bryan and Henshaw, 2013). Riparian vegetation along rivers, streams, and lakes can also help stabilize banks, reduce erosion, and improve water quality.

In areas where room is available, consider maintaining and expanding existing buffers and planting appropriate native vegetation along the water or further upland. This may include the establishment of continuous or heterogenous strips of native trees, shrubs, and herbaceous plants to filter runoff, stabilize banks, shade aquatic habitat, and adapt to changing water levels. These buffers form vital transitions between human land uses and aquatic ecosystems, improving water quality, thermal regimes, and wildlife corridor connectivity.

7. Coastal forests or windbreak planting

- **Ecotypes:** Open coast, embayment, coastal wetland, and river mouth

Strategically planted coastal forests can serve as windbreaks or shelterbelts, protecting coastal and riverside development and sensitive ecosystems such as dunes and bluffs from wind, wave, and ice action (Small-Lorenz et al., 2017).

Where space is available, consider planting native coastal tree and shrub species along the shoreline to buffer against wind and wave energy. Vegetation in backdune areas or along the backshore or upland areas of a beach can also help prevent erosion, support sediment buildup, and stabilize sandy or bluff-top soils. These plantings enhance microclimate, provide wildlife shelter, and protect built assets behind active dune or beach systems.

8. Invasive species control and removal

- **Ecotypes:** Open coast, embayment, coastal wetland, and river mouth/upstream areas

Across the Great Lakes, many invasive species are causing harm to native plants and wildlife and disrupting local ecosystems and economies (The Nature Conservancy, 2026). For example, invasive Phragmites (*Phragmites australis*) can grow and spread quickly, crowding out other species and impeding their growth through the release of toxins into the soil, affecting wetlands, beaches, and biodiversity (Ministry of Natural Resources, 2026b). Climate change is accelerating the introduction and spread of invasive and non-native species (Invasive Species Centre, 2026).

To achieve protection objectives and restoration success, consider implementing targeted removal, suppression, or containment of invasive species to enable native vegetation recovery and improved ecosystem function in high-value ecological areas. This may be done as part of a restoration project (e.g., site preparation, carp exclusion barriers) or as part of ongoing management to protect ecologically important or sensitive areas.

Beaches, dunes, and bluffs

9. Beach and dune restoration

- **Ecotypes:** Open coast, embayment, and coastal wetland

Beaches and dunes are dynamic systems that fluctuate in size and shape due to wind, waves, storms, and ice (Natural Resilient Communities, 2017). Freshwater coastal dunes are among the most rare and sensitive ecosystems in Ontario and Canada (Ontario Biodiversity Council, 2025; Parks Canada, 2022), which can sometimes be found backing sandy beaches in Western Lake Ontario. As popular destinations for recreation, beaches and dunes are often affected by human disturbance and activities.

In areas where sand or sediment is supplied naturally (e.g., through watersheds or bluffs), consider restoring natural beach and dune systems to buffer waves, reduce erosion, and provide habitat for coastal plants and wildlife. This may involve re-grading, planting native dune grasses (e.g., Marram grass), and managing sediment supply through natural geomorphic processes (e.g., source-to-sink or littoral cell management). In some cases, sediment may need to be replenished through beach nourishment (#21) by bringing in natural materials such as sand and gravel.

10. Bluff stabilization

- **Ecotypes:** Open coast and embayment

Bluffs are characteristic of the diverse shorelines of the Great Lakes coast, which were primarily formed by the retreat of a glacial ice sheet that ended tens of thousands of years ago (Ministry of Natural Resources, 1996a). These range from high towering bluffs with steep slopes (e.g., Scarborough Bluffs) to low bluffs of sand, silt, and clay. Materials eroded from shoreline bluffs contribute to sediment along the shore, including beaches and dunes that are backed by bluffs (Ministry of Natural Resources, 1996b). High water levels, winds, storms, waves, surface runoff, and groundwater seepage can all increase slope instability and erosion (Conservation Ontario, 2026; TRCA, 2017).

Maintaining existing vegetation can help reduce surface runoff and support slope stability. In areas where the slope is not too steep and can support vegetation establishment, consider using native grasses, shrubs, and deep-rooted prairie plants to stabilize bluffs. Where engineering approaches are needed to stabilize eroding bluffs and steep slopes, consider integrating habitat and natural elements, where possible. These nature-based approaches blend erosion control with biodiversity enhancement, creating dry, open habitats characteristic of Great Lakes bluffs.

Shoreline softening and bioengineering

11. Bioengineering and live staking

- **Ecotypes:** Embayment and river mouth/upstream areas

While erosion is a natural process, erosion along rivers, streams, and lakes can be accelerated due to changes in land use, vegetation removal, and shoreline/channel modification (Ministry of Emergency Preparedness and Response, 2025a). Bioengineering (or soil bioengineering) combines engineering techniques with natural materials or structures to stabilize soils (Green Communities Guide, 2026; Patterson, 1999).

Along rivers, streams, and sheltered bays, consider employing biodegradable materials and live woody stems or branches to stabilize banks, enhance infiltration, and encourage natural revegetation. Used mainly along stream banks, river mouths, and sheltered lake edges, this method provides immediate soil retention that transitions to vegetative stability over time.

12. Shoreline regrading

- **Ecotypes:** Open coast, embayment, coastal wetland, and river mouth

Gradual, gentle slopes can help dissipate waves and reduce erosion (Department of Environmental Conservation, 2010). Achieving this effect may require recontouring the shoreline and removing shoreline armouring or failing hardened structures (e.g., retaining wall).

Where room is available, consider converting hardened or steep, eroding shorelines into gentle, vegetated slopes that restore natural processes and access. This method often re-uses on-site fill or rubble to create stable planting benches and transition zones.

13. Sills

- **Ecotypes:** Embayment and coastal wetland

A sill is a low-profile, shore-parallel structure located in the water just off the shoreline to dissipate wave energy and reduce erosion along vegetated shorelines, including coastal marshes (Shea et al., 2021; NOAA Living Shorelines Workgroup, 2015). Marshes are characterized by non-woody emergent vegetation and are the most common type of coastal wetland in the Great Lakes (Maynard and Wilcox, 1997). While coastal marshes require fluctuating water levels (Quesnelle et al., 2022), high water levels, waves, and storms can increase the erosion of marsh edges (Braun and Theuerkauf, 2021), which can lead to wetland loss or functional decline.

To protect eroding margins or a newly planted marsh, consider installing low, nature-friendly edge structures off the shoreline of a marsh to reduce wave energy, promote sediment deposition, and support plant establishment. Typically composed of rock, woody debris, or biodegradable materials and backfilled with sand, these features can help stabilize eroding marsh edges along low to moderate energy shorelines, while maintaining ecological connectivity (especially when they are designed with gaps or are allowed to overtop).

Sediment management

14. Sediment re-use

- **Ecotypes:** Open coast, embayment, coastal wetland, and river mouth

Dredging or the removal of accumulated bottom sediments in waterways is often necessary in the Great Lakes to maintain adequate depth for navigation (Great Lakes Commission, 1999; Sly, 1977). The beneficial re-use of clean dredged sediment is often more cost-effective than disposal.

With proper testing and permitting based on applicable provincial and/or federal legislation, dredged or excavated sediments can be re-used in many ways (e.g., to build wetland berms or renourish beaches), supporting both habitat creation and erosion control. Thin-layer placement may be applied where subtle elevation gain is required for marsh establishment.

15. Sediment capture and accretion

- **Ecotypes:** Open coast, embayment, coastal wetland, and river mouth

Across Western Lake Ontario, the natural movement of sediment along the shoreline is often disrupted by shoreline armouring and human-made structures and landforms (e.g., harbours, jetties, and lakefill), trapping sediment that would otherwise be deposited in natural sediment sinks (Zuzek Inc. et al., 2023; W.F. Baird & Associates Coastal Engineers Ltd., 2022, 2009; Zuzek, 2020; Credit Valley Conservation, 2018).

In low-energy shorelines where sediment is deposited, consider designing vegetated foreshores or marsh edges that slow water velocity, trap fine sediment, and build natural elevation over time. In Western Lake Ontario, this process is integral to living shorelines and wetland projects, aiding resilience under fluctuating lake levels.

Habitat creation and structural complexity

16. Habitat islands or mounds

- **Ecotypes:** Embayment, coastal wetland, and river mouth

Much of the shoreline along Western Lake Ontario has been hardened (e.g., with large rock or concrete structures) to protect against coastal flooding and erosion, limiting available habitat. The natural features and areas that do exist along these shorelines are highly fragmented.

Small stepping-stone habitats can be created along low to moderate energy shorelines by adding small, elevated features in open-water or wetland settings to provide nesting, refuge, and feeding areas for birds, amphibians, and reptiles. These are commonly constructed from dredged material or clean fill and may include various habitat features such as shrub clumps, rocky mounds, or woody debris piles to aid the dispersal of coastal species, reduce predation risk, and expand available habitat. Continued monitoring and management may be required to ensure that the habitats are being used by intended species.

17. Habitat connectivity corridors

- **Ecotypes:** Open coast, embayment, coastal wetland, and river mouth/upstream areas

With habitats fragmented by infrastructure and development (e.g., roads, railways, and residential areas), wildlife movement is often constrained (TRCA, 2026c). This limits the ability of wildlife to move between habitats (e.g., forests and wetlands) and access essential resources.

In areas where greater habitat connectivity is needed, consider maintaining or establishing continuous or stepping-stone habitat linkages along the coastal zone to allow for species movement and migration. In Western Lake Ontario, these corridors connect fragmented wetlands, beaches, and riparian areas, improving biodiversity resilience across urbanized and modified shorelines.

Urban green infrastructure

18. Coastal parks and greenways

- **Ecotypes:** Open coast, embayment, coastal wetland, and river mouth/upstream areas

In highly developed areas, access to green space is often limited. Given the importance of green space access to people's health and well-being (e.g., physical activity, mental health, and sleep quality; Yang et al., 2021; Egorov et al., 2016), there is a need to increase urban green spaces where access is currently limited.

In areas where parks and green spaces exist along the shoreline, maintaining and enhancing these spaces help safeguard their many environmental, social, and economic benefits. Where parks and green spaces are lacking but room is available (or made available, e.g., through lakefilling), consider designing coastal parks and greenways to link tributaries, wetlands, and shoreline habitats to create continuous ecological and recreational corridors. These often serve as regional attractions (e.g., Waterfront Trail and Tommy Thompson Park) and provide important habitats, recreational opportunities, and stormwater retention and cooling benefits.

19. Floodable parks

- **Ecotypes:** Open coast, embayment, coastal wetland, and river mouth

Conventional flood protection often relies on hard, engineered infrastructure to hold water back or direct it away from developed areas as quickly as possible (Environment and Climate Change Canada, 2017). As the frequency and intensity of flooding continues to rise, enhancing flood resilience may require reshaping our relationship with water.

Where room is available, consider creating multi-use green spaces that can safely store or convey floodwaters when needed, while delivering ecological and social benefits. These areas are often designed with resilient plantings and gentle grades to attenuate high flows, recharge groundwater, and provide accessible parkland during dry conditions.

Hybrid solutions

In areas where engineered, hard infrastructure is required, there may be opportunities to integrate natural materials or living systems to support habitat, biodiversity, and coastal resilience.

20. Engineered habitat structures

- **Ecotypes:** Open coast, embayment, coastal wetland, and river mouth

Along low to moderate energy shorelines, consider incorporating artificial benches, rootwads, logs, or rough substrates into engineered shorelines to create complex microhabitats for fish and invertebrates. These structures are often used in harbours and channelized reaches to offset habitat losses from hard infrastructure.

In areas affected by *Cladophora*, a green filamentous alga that is native to the Great Lakes, careful management is needed to balance shoreline stabilization, habitat creation, and the risk of nuisance algae in shallow, well-lit waters with high phosphorous levels and hard substrates (e.g., submerged rocks or logs) where *Cladophora* tends to grow (e.g., Environment and Climate Change Canada, 2022; Harris, 2005). This also applies to other hybrid solutions such as hybrid breakwaters and shoals (#24) and artificial reefs (#25).

21. Beach nourishment and dynamic cobble berms

- **Ecotypes:** Open coast, embayment, and coastal wetland

Where beach erosion is significant (e.g., with impacts on recreational usage, property, and infrastructure), beach nourishment may be needed. Consider placing compatible sand or gravel to rebuild eroded beaches and replicate the function of natural beaches to buffer against waves and high water levels. Dynamic berms composed of gravel or cobbles can be placed on the upper beach to further protect backshore areas from erosion and waves, while adjusting naturally to changing lake levels.

22. Hybrid dunes

- **Ecotypes:** Open coast, embayment, and coastal wetland

In areas where there is a sufficient supply of sand or sediment, consider constructing protective dune ridges using imported sand or fill and vegetating them with native species to combine engineered stability with natural storm buffering. These dunes are designed to absorb wave runup and ice loading, while sustaining plant and wildlife communities.

23. Constructed or artificial islands

- **Ecotypes:** Open coast and embayment

Along moderate to high energy shorelines where wave attenuation is needed, consider creating artificial island landforms using clean fill or dredged material to attenuate waves and expand habitat. The outer slopes of these islands are often vegetated for stability and habitat creation.

24. Hybrid breakwaters and shoals

- **Ecotypes:** Open coast and embayment

Where shoreline protection is needed to reduce erosion and dissipate waves, consider constructing low, submerged, or emergent features to attenuate waves and enhance aquatic habitat, combined with vegetation for enhanced ecological restoration. These may come in the form of vegetated floating breakwaters, vegetated cobble shoals, or landward vegetation adjacent to breakwaters or shoals. Depending on the design, this technique may be suitable for low to high energy shorelines.

25. Artificial reefs

- **Ecotypes:** Open coast and embayment

Along moderate to high energy shorelines where the lakebed is not too steep, consider combining low underwater ridges or non-plastic reef modules with vegetation or rough natural material (e.g., cobbles or larger stones) to dissipate wave energy and support aquatic life. In Western Lake Ontario, these hybrid systems can be found in nearshore and offshore environments, providing dual benefits of erosion control and ecological enhancement.

26. Vegetated armour and revetments

- **Ecotypes:** Open coast, embayment, and river mouth

Where shoreline protection is needed to reduce erosion, stabilize banks, and attenuate waves, consider integrating rock or concrete protection with soil pockets, plantings, and habitat shelves to combine structural stability with ecological benefits. These systems provide both flood defense and habitat complexity.

27. Eco-engineered materials and surfaces

- **Ecotypes:** Open coast and embayment

Along existing hardened shorelines or where seawalls need to be rehabilitated or constructed, consider applying textured, porous, or modular concrete and armour units to seawalls, revetments, and breakwaters to increase habitat and hydraulic roughness. Designed to improve ecological performance, these materials and surfaces provide surface complexity, voids, or bio-receptive coatings that help promote algal, invertebrate, and fish colonization, while maintaining required structural stability. In Western Lake Ontario, this technique has also been used to create artificial habitats for Bank Swallows to mimic their natural nesting environments (Case study #12).

Linkages between nature-based and hybrid solutions and hazard impacts

Two matrices were developed to link the typology of nature-based and hybrid solutions to climate-related hazards and impacts. The first matrix (Table 7) links common coastal hazards (e.g., extreme high and low water levels, storm surges) with impacts that have been observed across Western Lake Ontario based on existing literature and engagement survey results (e.g., beach loss or dune destabilization, bluff retreat, sediment mobilization). The second matrix (Table 8) links the identified hazard impacts with nature-based and hybrid solutions and their potential to help mitigate these impacts on a scale from low mitigation potential to high mitigation potential based on the authors' best judgement.

Table 7. Hazard-Impacts matrix linking common coastal hazards with impacts observed across Western Lake Ontario

Hazard / Impacts	Beach loss / dune destabilization	Bluff retreat / structural undermining	Sediment mobilization	Coastal / urban inundation	Wetland loss / function decline	Habitat fragmentation	Invasive species spread	Turbidity increase / water quality impairment	Algal bloom risk	Property / infrastructure risk
High-energy waves	■	■	■	■	■	■		■	■	■
Storm surges	■	■	■	■	■			■	■	■
Overtopping of structures		■	■	■	■			■	■	■
Extreme high water levels	■	■	■	■	■	■	■	■	■	■
Extreme low water levels					■	■	■			
Rapid fluctuations (seiche / wind setup)	■	■	■	■				■		■
Beach, dune & bluff erosion	■	■	■		■	■		■		■
Sediment deficit / littoral transport disruption	■				■	■				
Ice shove & winter wave attack	■	■	■			■				■
Thermal & water-quality stress					■	■	■	■	■	
Property / infrastructure exposure		■							■	■

Table 8. Impact-NbS Response matrix linking hazard impacts with nature-based and hybrid solutions and their potential to help mitigate these impacts from low mitigation potential (lighter colour) to high mitigation potential (darker colour)

NbS Response	Reconnected rivers & streams	Channel naturalization & realignment	Constructed / restored wetlands	Floating wetlands	Floodplain reconnection	Riparian vegetation & buffers	Coastal forests / windbreak planting	Invasive species control & removal	Beach & dune restoration	Bluff stabilization	Bioengineering & live staking	Shoreline regrading	Sills	Sediment re-use	Sediment capture & accretion	Habitat islands / mounds	Habitat connectivity corridors	Coastal parks & greenways	Floodable parks	Engineered habitat structures	Beach nourishment & dynamic cobble berms	Hybrid dunes	Constructed / artificial islands	Hybrid breakwaters & shoals	Artificial reefs	Vegetated armour & revetments	Eco-engineered materials & surfaces
Impact	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Beach loss / dune destabilization																											
Bluff retreat / structural undermining																											
Sediment mobilization																											
Coastal / urban inundation																											
Wetland loss / function decline																											
Habitat fragmentation																											
Invasive species spread																											
Turbidity increase / water quality impairment																											
Algal bloom risk																											
Property / infrastructure risk																											

Case studies of existing nature-based and hybrid solutions

A total of 30 case studies were compiled across Western Lake Ontario to showcase existing examples of NbS and hybrid solutions that have been implemented across the region. These case studies were gathered through a combination of virtual observations using Google Earth, web searches, communications with subject matter experts, and site visits. For presentation purposes, the case studies are presented by region. Each table illustrates the types of NbS and hybrid solutions that have been employed by each case study (see Appendix C and our online StoryMap for more detailed summaries of each case study).

From Niagara to Hamilton Harbour

Table 9. Examples of existing nature-based and hybrid solutions from Niagara to Hamilton Harbour

Typology	Reconnected rivers & streams	Channel naturalization & realignment	Constructed / restored wetlands	Floating wetlands	Floodplain reconnection	Riparian vegetation & buffers	Coastal forests / windbreak planting	Invasive species control & removal	Beach & dune restoration	Bluff stabilization	Bioengineering & live staking	Shoreline regrading	Sills	Sediment re-use	Sediment capture & accretion	Habitat islands / mounds	Habitat connectivity corridors	Coastal parks & greenways	Floodable parks	Engineered habitat structures	Beach nourishment & dynamic cobble berms	Hybrid dunes	Constructed / artificial islands	Hybrid breakwaters & shoals	Artificial reefs	Vegetated armour & revetments	Eco-engineered materials & surfaces
Case Study	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Grimsby Wetlands			■			■		■									■			■							
Fifty Point		■	■			■	■											■									
Windermere Basin		■	■			■		■						■	■	■		■		■			■				
Bayfront Park, Macassa Bay, and Pier 4 Park			■			■	■		■			■						■		■						■	
Cootes Paradise		■	■	■	■	■		■							■		■	■									
Grindstone Marsh		■	■					■			■						■	■									
LaSalle Park						■			■		■	■			■	■		■	■	■	■		■	■	■		
Northeastern Bird Islands																■							■				

From Burlington to Toronto

Table 10. Examples of existing nature-based and hybrid solutions from Burlington to Toronto

Typology / Case Study	Reconnected rivers & streams 1	Channel naturalization & realignment 2	Constructed / restored wetlands 3	Floating wetlands 4	Floodplain reconnection 5	Riparian vegetation & buffers 6	Coastal forests / windbreak planting 7	Invasive species control & removal 8	Beach & dune restoration 9	Bluff stabilization 10	Bioengineering & live staking 11	Shoreline regrading 12	Sills 13	Sediment re-use 14	Sediment capture & accretion 15	Habitat islands / mounds 16	Habitat connectivity corridors 17	Coastal parks & greenways 18	Floodable parks 19	Engineered habitat structures 20	Beach nourishment & dynamic cobble berms 21	Hybrid dunes 22	Constructed / artificial islands 23	Hybrid breakwaters & shoals 24	Artificial reefs 25	Vegetated armour & revetments 26	Eco-engineered materials & surfaces 27
Beachway Park						■	■	■	■						■			■			■						
Burloak Waterfront Park						■		■			■							■					■	■		■	
South Shell Park Nesting Wall										■		■						■		■							■
Coronation Park		■				■									■			■									
Tannery Park and Waterworks Park						■			■			■			■		■	■						■			
Rattray Marsh			■		■	■	■	■							■		■	■		■							
Serson Creek Reconnection and Wetland	■	■	■		■	■		■				■		■			■	■	■								
Applewood Creek Extension and Wetland		■	■		■	■		■						■	■		■	■	■				■				
Samuel Smith Wetland			■			■		■								■		■		■				■			
Gibraltar Point						■	■		■											■	■	■			■		
Tommy Thompson Park			■			■	■	■	■		■	■	■		■	■	■	■		■			■	■	■		
Don Mouth Naturalization		■	■		■	■	■	■	■		■	■	■	■	■	■	■	■	■	■			■	■	■	■	
Woodbine Beach							■	■	■						■	■		■			■			■			
Bluffer's Park			■			■	■		■	■		■		■	■			■		■	■	■		■			

From Pickering to Cobourg

Table 11. Examples of existing nature-based and hybrid solutions from Pickering to Cobourg

Typology	Reconnected rivers & streams	Channel naturalization & realignment	Constructed / restored wetlands	Floating wetlands	Floodplain reconnection	Riparian vegetation & buffers	Coastal forests / windbreak planting	Invasive species control & removal	Beach & dune restoration	Bluff stabilization	Bioengineering & live staking	Shoreline regrading	Sills	Sediment re-use	Sediment capture & accretion	Habitat islands / mounds	Habitat connectivity corridors	Coastal parks & greenways	Floodable parks	Engineered habitat structures	Beach nourishment & dynamic cobble berms	Hybrid dunes	Constructed / artificial islands	Hybrid breakwaters & shoals	Artificial reefs	Vegetated armour & revetments	Eco-engineered materials & surfaces
Case Study	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Frenchman's Bay (South Shore)						■		■	■					■		■		■		■							
Lynde Creek Marsh			■			■		■	■								■	■									
Second Marsh			■					■									■										
McLaughlin Bay Marsh			■			■		■	■						■			■		■	■						
Bowmanville Westside Marshes		■			■	■		■										■		■							
Wilmot Creek Marsh						■		■									■	■									
Wesleyville Marsh	■							■									■	■		■							
Victoria Beach									■			■		■							■						

DISCUSSION AND NEXT STEPS

As illustrated by the case studies, multiple NbS and hybrid solutions are often used in restoration and conservation projects. These examples showcase how different techniques can work together to provide a wider range of benefits. Across Western Lake Ontario, many NbS and hybrid solutions have already been implemented, demonstrating their effectiveness at addressing a variety of issues from shoreline erosion protection to inland flood risk reduction and water quality remediation.

This guide offers a menu of possible NbS and hybrid solutions that may be relevant for Western Lake Ontario. While potential suitable environments have been identified for the different techniques, further research is needed to assess feasibility, cost, and maintenance requirements. Every shoreline is different, and not all NbS will be appropriate everywhere. As the fastest developing area in the Great Lakes Basin, there is a continued need to balance environmental, economic, social, cultural, and recreational objectives among coastal communities along Western Lake Ontario.

With grant funding from the Canada Water Agency's Great Lakes Freshwater Ecosystem Initiative, the next phase of this study (2026/28) will focus on:

- Conducting a **coastal climate risk and vulnerability assessment**, with a focus on the shoreline stretching from Mississauga and Cobourg to align with the Lake Ontario Coastal Resilience Project, a parallel project led by Niagara Peninsula Conservation Authority (NPCA), Hamilton Conservation Authority (HCA), and Conservation Halton (CH).
- Working with the National Research Council (NRC) to undertake **coastal modelling** to inform the risk and vulnerability assessment and identification of priority areas for enhanced coastal resilience by combining regional- and local-scale modelling to evaluate the detailed performance of NbS at select locations.
- Developing a **map-based prioritization tool** in partnership with researchers at the University of British Columbia (UBC) to identify strategic locations for nature-based and hybrid solutions, building on the results of this compendium.
- Integrating these results into an integrated **Coastal Resilience Options Guide** to provide further place-based information to support the practical implementation of NbS and hybrid solutions where they are needed most.

Throughout this next phase, continued engagement with members of the Land to Lake partnership initiative and other interested parties will be essential to build on existing initiatives, strengthen collaboration, and leverage new funding opportunities to accelerate the adoption of nature-based approaches and turn priorities into projects on-the-ground. Together, these tools will help scale up the implementation of nature-based approaches and advance coordinated coastal adaptation across Western Lake Ontario.

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