CANADIAN GREAT LAKES NEARSHORE Assessment

DETAILED METHODOLOGY

Canada

Cat. No.: En164-71/1-2021E-PDF
ISBN: 978-0-660-39154-0
EC21052,01

Environment and Climate Change Canada
Public Inquiries Centre
12th Floor, Fontaine Building
200 Sacre-Coeur Boulevard
Gatineau QC K1A 0H3
Telephone: 819-938-3860
Toll Free: 1-800-668-6767 (in Canada only)
Email: ec.enviroinfo.ec@canada.ca

Aussi disponible en français

Table of Contents

Introduction

The Great Lakes, with their 16,000 kilometres of coastline, connecting river systems and watersheds is the world's largest freshwater ecosystem and socially, economically and environmentally significant to the region, the nation and the planet. While efforts to restore and protect the Great Lakes have been largely successful over the last 50 years, water quality and ecosystem health in many nearshore areas continues to be degraded. At numerous places along the Great Lakes nearshore, conditions are degraded due to a variety of human-induced, climate-induced and invasive species-induced stressors. Human activities in the landscape have a more direct influence on nearshore water quality than on offshore water quality[1]. Nearshore water quality may serve as a sentinel for the longer-term trajectory of offshore water quality and lake-wide condition[2]. Management of the nearshore is challenging because it is a complex, highly variable environment in which tributary inflows and open water processes vary spatially and across daily, seasonal and annual temporal scales. In addition, Great Lakes nearshore areas are especially vulnerable to the effects of climate change and impacts can result in loss of biodiversity of aquatic species and fundamental changes to ecosystem character, distribution, structure and function. Human-induced stressors on ecosystems further limit their ability to adapt and recover.

Although significant investment has been made in localized monitoring, assessment and restoration, the lack of a comprehensive assessment of the overall state of nearshore waters has meant that there was not a robust mechanism for identifying cumulative stress on nearshore ecosystems nor a way to identify and prioritize areas in need or remediation or protection. Action is needed to address stresses and threats in nearshore areas, as they are the source of drinking water for most communities within the basin, are the areas of the lakes where most human recreation (e.g. swimming, boating, fishing, wildlife viewing) occurs and are the critical ecological link between watersheds and the open waters of the Great Lakes.

Nearshore Framework

As envisioned by the updated Canada-U.S. Great Lakes Water Quality Agreement (GLWQA) of 2012, Canada is implementing a "Nearshore Framework" that provides an overall assessment of the state of the nearshore waters of the Great Lakes. The Nearshore Framework is a systematic, integrated and collective approach for assessing nearshore health and identifying and communicating cumulative impacts and stress. It is intended to inform and promote action at all levels in order to restore and protect the ecological health of Great Lakes nearshore areas.

The purpose of the Nearshore Framework is to address ongoing and emerging challenges to the nearshore waters of the Great Lakes, where restoration, protection and prevention activities are critical to improving and sustaining the ecological health of Great Lakes coastal areas and supporting attendant social, cultural, recreational and economic benefits. Nearshore assessments and communication of results provide the basis for determining factors and cumulative effects that are causing stress or threatening areas of high ecological value. Continued and strengthened coordination and collaboration are needed to manage and protect our nearshore waters and to prevent and minimize water quality and ecosystem impacts which may result from chemical, physical, or biological stresses within the Great Lakes Basin. The Nearshore Framework will support action for nearshore areas under stress and protection for nearshore areas of high ecological value by communicating results, establishing priorities and

[1] Yurista, P.M., Kelly, J.R., Cotter, A.M., Miller, S.E., and Van Alstine, J.D. 2015. Lake Michigan: Nearshore variability and a nearshore-offshore distinction in water quality. Journal of Great Lakes Research. 41:111-122.

[2] Yurista, P.M., Kelly, J.R. and Scharold, J.V. 2016 Great Lakes nearshore-offshore: distinct water quality regions. Journal of Great Lakes Research. 42: 375-385.

engaging organizations and entities that are developing and implementing prevention, restoration and protection strategies.

The scope of the Nearshore Framework includes the nearshore waters and embayments along the coast of the Canadian Great Lakes, the lakes' connecting river systems and the St. Lawrence River. The GLWQA recognizes the interconnectedness of the Great Lakes basin watersheds where material and water flow from problem areas into the lakes and connecting channels. The Nearshore Framework aims to consider this relationship between the zone of influence and zone of impact and the nearshore is generally defined as the area of the Great Lakes and connecting rivers near the coast where waters are subject to direct influences from watersheds, while recognizing that there are also off-shore influences.

Intended use of the Detailed Methodology

This report is intended for any organization or individual with an interest in the Overall Assessment of Nearshore Waters. The detailed methodology is meant to compliment each of the Canadian nearshore assessment results reports, by describing the data and methodology required to repeat or adapt the assessment, if desired.

In this report all of the information and source material upon which the assessment was made is outlined. This includes a summary of the methodology and datasets integrated into the overall assessment, any significant decision points and, based on continuous learning, recommendations for future improvements.

Practitioners may find their own local datasets or monitoring programs help to provide greater detail within a Regional Unit, and integration of additional information at an appropriate planning scale is encouraged. This report has been written for a technical audience with the intention that, if desired, the assessment could be re-run with alternative thresholds or measures.

Overall Approach of the Nearshore Assessment

Development of the Nearshore Assessment methodology involved many Great Lakes experts and from 2014 to 2016, bi-national workshops and meeting were held with science and technical experts to develop the approach. Existing Great Lakes habitat assessments were reviewed in order to leverage existing knowledge and data, where possible. The recommended approach integrated data related to nearshore stressors into an overall assessment using a three-phased approach: (1) classification of the nearshore into Regional Units by ecosystem type; (2) assessment of each Regional Unit; and (3) exploration of the results using additional information on the health and abundance of aquatic biota.

The implementation of this approach began in 2018 and based on experience gained in applying the framework to Lake Erie, the overall approach evolved. While the current Nearshore Framework veers slightly from the original three-phased approach, it follows a similar procedure:

- Phase 1: classify the nearshore into Regional Units by ecosystem type, using physical processes and lake characteristics that change at a relatively slow rate
- Phase 2: overall assessment of the state of each Regional Unit using a Weight of Evidence approach developed with consideration of the General Objectives of the GLWQA to identify nearshore areas that are or may become subject to high stress due to individual or cumulative impact

- Phase 3: integrate additional information and overlay with Areas of High Ecological Value to assist in establishing priorities for nearshore restoration and protection based on consideration of nearshore and whole-lake factors

As the data and information to support the Nearshore Framework are assembled and applied to complete the assessment, cumulative effects impacting the nearshore and future threats to areas of high ecological value will be better understood. Further, the knowledge shared will assist in priority setting for science and management at a meaningful and practical scale.

Assessment Categories

The purpose of the GLWQA is to restore and maintain the chemical, physical and biological integrity of the Waters of the Great Lakes. Nine General Objectives are set out to achieve this purpose, and they have been used to develop four assessment categories for the Overall Assessment of Nearshore Waters. Each of the assessment categories has two or three measures that were developed with consideration of the specific requirements of the Nearshore Framework.

Data used in the assessment has been obtained from existing monitoring programs, from a range of partners, and varies in type, format and resolution. Where available, data from long-term monitoring programs is used. Various monitoring and surveying programs were considered, and key considerations in the selection of data included the spatial and temporal resolution, the amount of processing required (e.g. technical expertise, software requirements) and the availability of the data. Considerable effort was given to identify high-quality data sets. Where possible, data from remote-sensing technologies were used as they provide high temporal resolution. Using GIS, disparate data that traditionally is evaluated separately has been integrated into the first cumulative assessment of the Canadian Great Lakes Nearshore waters.

Each of the four categories is described below and the detailed assessment methodology for each is outlined in the *Detailed Assessment Methodology* section below.

Coastal Processes

General Objectives of the GLWQA refer to the Waters of the Great Lakes supporting healthy and productive wetlands and other habitats to sustain resilient populations of native species and being free from materials or conditions that may negatively impact the chemical, physical or biological integrity of the Waters of the Great Lakes.

Functional nearshore ecosystems require maintenance of natural physical processes both in the watershed and along the coastline, as these processes create and moderate the ecosystem through transfers of energy, water and sediment. Processes that move water and nutrients along shore also provide ecological benefits and create habitat. Coastal margin and nearshore components such as river mouths, coastal wetlands, beaches, dunes, sediment supply and composition as well as shoreline orientation are maintained by the interaction of nearshore coastal processes with the landscape. Increasing shoreline development and physical alteration of the land-water interface is a significant factor stressing nearshore coastal processes.

Classified by measures that consider a nearshore ecosystem where the physical integrity is unimpeded, the Coastal Processes category is comprised of three measures: **Shoreline Hardening, Littoral Barriers**, and **Tributary Connectivity**. These measures also support specific requirements of the Nearshore Framework to include consideration of shoreline hardening and habitat loss.

- **Shoreline Hardening**

The nearshore provides a unique set of conditions and processes that together meet the life-stage requirements of aquatic species and biological communities. When a shoreline is hardened it can alter sediment dynamics, accelerate erosion, increase water turbidity, destroy local vegetation and deplete coastal areas in need of sediment replenishment. These coastal processes also play a significant role in determining the distribution and health of fish populations through impacts to their habitat including migration corridors, spawning grounds, nursery and feeding areas. Across the Canadian Great Lakes – in particular the southern lakes – much of the nearshore, waters edge, or back of beach has been altered with engineered structures or artificial material. In these areas, natural shoreline processes are altered and native vegetation communities may be absent. Hardening of the shoreline can reduce coastal resilience; in the absence of natural vegetation or features like coastal wetlands, the shoreline may no longer adapt to rising and falling water levels, leading to physical reductions of available aquatic habitat.

This measure is used to assign low, moderate or high stress based on the percent of shoreline within a Regional Unit that has been hardened.

- **Littoral Barriers**

The presence of littoral barriers can impede natural coastal processes related to sediment dynamics. A littoral cell is a conceptual shoreline compartment defined by the supply, transport and deposition of sediment. Within a littoral cell, there is an updrift supply area, a net direction of longshore sediment transport, a downdrift depositional area and no (or minimal) leakage of sediment at the cell boundaries. Sediment is supplied to the cell through sediment sources (e.g. cliff erosion, coastal dunes and longshore transport) and then transported alongshore through wave action where it is deposited or lost offshore. Artificial barriers that extend perpendicular from the shoreline into the nearshore can restrict sediment in various ways, such as by starving sediment from input, or creating sediment traps where sediment is essentially deposited at the barrier and not able to move out of a littoral cell. These littoral barriers act to disrupt the natural movement of sediment, ultimately affecting the functionality of nearshore ecosystems.

The Littoral Barrier measure only applies to Regional Units where littoral drift is an important physical process. In those areas where it is not, for example in Lake Superior where the nearshore is dominated by hard, rocky substrate, the measure does not apply. Depending on the number of littoral barriers within a Regional Unit, a measure of low, moderate or high stress is assigned.

- **Tributary Connectivity**

Tributary connectivity between watersheds and the nearshore zone supports healthy habitats and native species and promotes natural physical processes such as sediment deposition. Further, connectivity provides chemically and physically unobstructed routes to fulfill life history requirements of aquatic species, including access to intact refugia and opportunities for genetic exchange. Structures that impede tributary connectivity can restrict fish movement and alter these physical and chemical processes. Dams and other non-natural barriers can disrupt connectivity for aquatic species as well as the movement of woody debris, sediment and nutrients that are vital to the health of nearshore ecosystems.

Dams and barriers have been impacting the health of aquatic ecosystems in the Great Lakes for decades. In addition to limiting access of fishes to spawning and nursery habitats, loss of tributary connectivity impacts nutrient flows and coastal processes. Impediments to connectivity can occur in the watershed, at the confluence of rivers and lakes due to channelization, removal of wetland habitat or disruptions to sediment mixing and transfer from port and harbour structures. While dams are barriers disrupt natural processes, there are some that are considered to be important for maintaining control of sea lamprey. At the time of assessment, this data was not available and the potential benefits of sea lamprey control barriers have not been included in the assessment.

The Tributary Connectivity measure assigns low, moderate or high stress based on the percent of tributaries that remain hydrologically connected to the nearshore; that is, the percent of tributaries that are not upstream of a natural barrier (i.e. waterfall) nor upstream of a dam.

Contaminants in Water & Sediment

A number of General Objectives of the GLWQA refer to the Waters being free from pollutants in quantities or concentrations that could be harmful to human health, wildlife or aquatic organisms through direct or indirect exposure through the food chain. Sources of contaminants include those from current industrial and municipal discharges, legacy contamination from past practices that persist in the environment (in the water column, sediment and/or biota), air deposition and non-point sources from urban, industrial and agricultural practices. Some metal contamination (i.e. mercury) can be released to surface waters through leaching of rock and terrestrial flooding or draining of wetlands/peat bogs.

The assessment uses existing data from ongoing monitoring programs that provide long-term data for ambient conditions in the location of the sampling. Special studies designed for specific research or to measure progress in Great Lakes Areas of Concern (AOCs) have been excluded from the assessment because the sampling design has a specific purpose and are unlikely to be maintained for the long-term to measure progress over time. In this assessment, measures have been developed that aim to identify nearshore areas that are – or may become – degraded due to contaminants. These include: **Water Quality**, **Benthic Community** and **Sediment Quality**. These measures have been developed to consider specific requirements of the Nearshore Framework to take into account of impact on human health and the environment and to consider contaminated sediment issues.

- **Water Quality**

Contaminants in water can have acute and chronic impacts on aquatic organisms that depend on water for some part of their life cycle. The Canadian Water Quality Guidelines, published by the Canadian Council of the Ministers of the Environment, include science-based guidelines for the protection of freshwater life. These guidelines embody a national goal for environmental quality of no observable adverse effects on atmospheric, aquatic and terrestrial ecosystems over the long term and are based on the most current scientific information – they do not directly consider site-specific or management factors that may influence their implementation (CCME, 1987). Additionally, the Province of Ontario has established numerical and narrative criteria for surface waters and, where it discharges to the surface, groundwater. The Provincial Water

Quality Objectives are set at a level of water quality which is protective of all forms of aquatic life and all aspects of the aquatic life cycle during indefinite exposure to water[3].

This measure is used to assign low, moderate or high stress based on the number of exceedances in water quality guidelines within a Regional Unit.

- **Benthic Community**

The general health of an ecosystem may be reflected in the benthic communities living in an environment. Benthic community composition can vary substantially due to natural habitat conditions and human stressors. Contaminants in sediment dwelling organisms can also bioaccumulate or biomagnify in the food chain, representing a source of contamination to other aquatic life as well as to humans through fish/wildlife consumption.

This Benthic Community measure looks at the total benthos (i.e. density of macroinvertebrates), taxon richness (i.e. number of lowest level taxa) and either average tolerance to disturbance or evenness of the individuals at a site in order to characterize patterns of variation in benthic communities across Regional Units. The assessment produces a relative measure of quality, where higher values are associated with higher density and taxon richness, and decreasing taxon tolerance or evenness.

- **Sediment Quality**

Contaminants in bottom sediment have the potential to be released into the water column and to enter the food chain through benthic communities. Contaminant burden in benthic organisms may have toxic and reproductive effects that cause community shifts from less tolerant to more tolerant species, or to a severe loss of communities. Similarly, bioaccumulation and biomagnification of contaminants in aquatic life at higher trophic levels can result in toxic or reproductive effects and may also, ultimately, be a source of contamination to humans through fish/wildlife consumption.

Although sediment sampling techniques vary between federal and provincial programs, the overall objective of screening level sampling efforts is to measure levels which may indicate contamination that varies from reference/background conditions, contaminant source areas, temporal changes and spatial extent and those levels that may trigger detailed assessment for potential sediment management decisions.

This measure looks at median contaminant levels for three categories (metals, PCBs/organochlorine pesticides and PAHs) and assigns low, moderate or high stress based on the number of occurrences in exceedances of Provincial or Federal Guidelines at nearshore monitoring stations within a Regional Unit.

Nuisance & Harmful Algae

General Objectives in the GLWQA refer to the Waters of the Great Lakes being free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts that promote the growth of algae and cyanobacteria that interfere with aquatic ecosystem health, or human use of the ecosystem. Although algae occurs naturally and is part of a healthy

---

[3] Ontario Ministry of the Environment and Energy. 1994. Water management: policies, guidelines, provincial water quality objectives. Accessed from https://www.ontario.ca/page/water-management-policies-guidelines-provincial-water-quality-objectives#section-2

freshwater ecosystem, the Great Lakes have seen an increase in the occurrence of algal blooms. Algal blooms occur when there is excessive phytoplankton growth because of changes to water conditions – the most common of which is increases in nutrients (e.g. Phosphorus and Nitrogen).

Algal blooms can become a nuisance and in some cases, be harmful. A Harmful Algal Bloom (HAB) is characterized by an overgrowth in algae that becomes harmful when the blooming organisms contain toxins. In the Great Lakes, particularly in Lake Erie, cyanobacteria biomass can be at levels that produce concentrations of toxins that pose a threat to human or ecosystem health. HABs can be differentiated from nuisance algae by their impact on water quality and biota – including risk to humans – associated with the production of toxins. Generally, the effect of nuisance algae, such as *Cladophora*, is a negative impact to aesthetic or recreational use of an area.

In addition to the GLWQA, the draft Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, 2020 highlights the need to conduct science in order to better understand factors that lead to, and result from, algal blooms. This includes the need for coordinated and strategic responses to nutrient management issues in the Great Lakes. This category consists of measures that take into account the impact on ecosystem and human health resulting from algae and cyanobacteria. With the exception of Lake Erie there are two measures that contribute to the category: **Cyanobacteria** and ***Cladophora***; in Lake Erie, **Dissolved Oxygen/Hypoxia**. Each of these measures have been developed with specific requirements of the Nearshore Framework to consider bacterial contamination and sources of stress on the nearshore.

- **Cyanobacteria**

Cyanobacteria, also known as blue-green algae, are microscopic organisms found naturally in freshwater. An overgrowth of this algae can result in a Harmful Algae Bloom (HAB) which can deplete oxygen within a water body, block sunlight that other aquatic organisms need and, in some cases, release toxins that are dangerous to human health. Toxin producing cyanobacteria pose a significant risk to both ecological and human health.

This measure looks at the extent and severity of cyanobacteria within each Regional Unit and assigns a flag for those Regional Units where blooms were detected, as well as identifying cyanobacteria as a source of stress on the nearshore.

- ***Cladophora***

Cladophora is filamentous green algae that grows on hard substrates in all of the Great Lakes. While not toxic, it is a nuisance and can pose threats to human health. Beyond clogging water intakes and degrading fish habitat, odorous rotting mats of *Cladophora* on beaches encourage the growth of bacteria and can impact beach postings. The presence of *Cladophora* may create an environment conducive to the development of botulism, which results in bird and fish deaths. *Cladophora* is native to the Great Lakes, and was a significant problem in Lake Erie and Lake Ontario in the 1930's and 1950's. With legislation restricting phosphates in detergent in the 1970's, *Cladophora* biomass abated. Beginning in the early 2000's, it began a resurgence, coinciding with establishment of zebra and quagga mussels (dreissenid mussels). With increasing water clarity and alteration of nutrient flows due to dreissenid mussels, controlling *Cladophora* growth is a challenge. Binational scientific efforts are ongoing to understand its growth needed for developing recommendations for action.

For those Regional Units where conditions are suitable for *Cladophora* growth, a level of low, moderate or high stress is assigned based on the extent of submerged aquatic vegetation detected with satellite imagery.

- **Dissolved Oxygen/Hypoxia (Lake Erie)**

Dissolved oxygen (DO) is a measure of how much oxygen is in water – it is the amount of oxygen available to aquatic organisms. A side effect of the decomposition of algae can be the establishment of hypoxic conditions and these areas with little to no oxygen can have adverse impacts on aquatic species in the nearshore. Although hypoxic conditions can occur in other areas of the Great Lakes, the spatial and temporal scale at which they are found in Lake Erie warrants this additional measure in the Nuisance & Harmful Algae category.

Due to conditions related to bathymetry and temperature, hypoxia may occur naturally in the central basin of Lake Erie. However, throughout the western basin hypoxia is exacerbated by persistently high nutrient levels and extensive algae blooms. Excessive cyanobacteria (harmful algae blooms) in the Lake's western basin that moves towards the central basin can settle to the lakebed. As bacteria decompose dead algae, oxygen is depleted, contributing to the hypoxia. Additionally, seasonal changes and large storm events can result in the lake turning over (i.e. inverting) and bringing low oxygen water from the bottom up to the surface. This oxygen depleted water can then move into the nearshore and impact fish and other biota.

This measure looks at DO levels within Lake Erie Regional Units and assigns low, moderate or high stress based on whether they are within acceptable ranges for aquatic life. The dissolved oxygen measure is included in the Lake Erie assessment because of its linkage with harmful algae blooms.

Human Use

The General Objectives of the GLWQA state that the Waters should be a source of safe, high-quality drinking water, allow for swimming and other recreational use unrestricted by environmental quality concerns and allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants. The expectation of the Great Lakes being "fishable, swimmable and drinkable" is a well-known public sentiment and the nearshore is where much of this occurs. The nearshore is the source of drinking water for more than 80% of Ontarians[4], beaches are a significant draw for people during the summer months and sport fishing supplements the diet for many people while recreational fishing is enjoyed throughout the lakes. The Human Use category consists of measures that account for the risk to human health posed by these uses. Note that studies directly measuring human health impacts from drinking contaminated water, exposure to pathogens and bacteria at beaches or eating contaminated fish are complicated and challenging research topics, and not part of the Overall Assessment of Nearshore Waters.

The three measures that contribute to this category include **Beach Postings**, **Fish Consumption Advisories** and **Treated Drinking Water**. They have been developed with the specific requirements of the Nearshore Framework that take into account the impact on human health and the environment.

---

[4] Ontario's Great Lakes Strategy. Accessed from https://www.ontario.ca/page/ontarios-great-lakes-strategy

- **Beach Postings**

Public beaches are popular recreation spots for millions of people across the Great Lakes and poor water quality due to bacterial contamination can have negative effects on both human health and recreational use. The Provincial Objectives for the protection of recreational water use are based on risks to human health using sampling data collected for Escherichia coli (E.coli) as an indicator of contamination by bacteria and pathogens. The use of water for swimming, bathing and other recreational activities requiring immersion of the user should not cause disease nor should use of the water cause impairments which may lead to physical injury, irritation or loss of enjoyment of the water. Aesthetic considerations may also be a factor in the Public Health Unit's or the Province's decision to post a beach.

This measure assigns a level of low, moderate or high stress based on frequency of postings of beaches during the summer months (July and August) by Municipal Health Units or the Province, not the bacteriological sampling data itself.

- **Fish Consumption**

Fish of the Great Lakes provide a diverse and accessible source of food. Depending on the size, type and location, some fish may be more suitable for consumption than others as contaminants in fish may result in advisories. Harmful substances like mercury, dioxins and polychlorinated biphenyls (PCBs) have been entering the lakes for decades, where they make their way into the food web. They can work their way up from prey fish to predators and eventually pose a risk to human health. The Province of Ontario issues fish consumption advisories to help the public know how much of any given species is safe to eat in a given timeframe. Fish collected from the lakes are tested for contaminants of concern and those found in fish tissue form the basis of consumption advisories.

This measure looks at consumption advisories for nearshore species most commonly consumed from a Regional Unit and assigns low, moderate or high stress based on data from the Guide to Eating Ontario Fish.

- **Treated Drinking Water**

The Great Lakes are a source of high-quality drinking water for nearly 30% of all Canadians[5]. Both the Province of Ontario and Municipal governments monitor water at drinking water treatment plants in order to ensure that it is safe for human consumption. The Ontario Drinking Water Objectives (MECP, 1994) are applied to treated drinking water supplies to protect public health. Any water intended for human consumption should not contain disease-causing organisms (e.g. *E.coli*), or hazardous concentrations of toxic chemicals or radioactive substances. All waterbodies (i.e. lakes, rivers or any other surface waters) may be subject to contamination and the MECP recommends that no surface water be considered as safe for consumption without prior treatment, including disinfection.

---

5 Ontario's Great Lakes Strategy. Accessed from https://www.ontario.ca/page/ontarios-great-lakes-strategy

Weight of Evidence

A Weight of Evidence approach was used to develop a structured decision making process for the assessment. Weight of Evidence is a process for systematic and transparent integration of multiple datasets using 'evidence groups'[6].

Weight is assigned to each measure based on three factors: relevance, strength and reliability (Table 1). Each of the measures in a category receive a score of either high, moderate or low stress and are then rolled up into an overall category score using the Weight of Evidence approach. Each category was deemed to have equal importance on the overall condition score for a Regional Unit however a few measures are assigned a heavier weight based on the review of relevance, strength and reliability: Sediment Quality (++), Benthic Community (++) and Cyanobacteria (++).

For the Nearshore Assessment, the four categories (Coastal Processes, Contaminants in Water & Sediment, Nuisance & Harmful Algae and Human Use) comprise the 'evidence groups', and the measures are used to assess cumulative stress for each group and, subsequently, an overall level of stress for each Regional Unit based on integrating all four categories (evidence groups). Tables within each section below show the scoring keys for the Weight of Evidence approach for each category, based on the weight of each measure within the category; and Table 2 below outlines how the category results are rolled up into an overall category score.

Table 1. Description of Low, Moderate and High Stress thresholds for each measure in the assessment, as well as the weight it carries in the overall assessment. *Dissolved Oxygen/Hypoxia is only assessed in Lake Erie.

Measure	Weight	Low Stress	Moderate Stress	High Stress
Shoreline Hardening	+	<25% shoreline hardening	25-50% shoreline hardening	>50% shoreline hardening
Littoral Barriers	+	0 littoral barriers	1 littoral barrier	>1 littoral barrier
Tributary Connectivity	+	>75% tributary connectivity	25-75% tributary connectivity	<25% tributary connectivity
Water Quality	+	0 exceedances	1-2 exceedances	>2 exceedances
Benthic Community	++	Functional, high quality	Degraded, but functional	Severely degraded, not functional
Sediment Quality	++	Minimal (Metals) or no exceedances of contaminant groups	Some or minimal exceedances of contaminant groups	Exceedance of SEL (severe effect level)
Cyanobacteria	++	<20% coverage OR <2% coverage (depending on Regional Unit)	N/A	>20% coverage OR >2% coverage (depending on Regional Unit)
Cladophora	+	<20% SAV extent	20-35% SAV extent	>35% SAV extent
Dissolved Oxygen/Hypoxia*	+	>6 mg/L	2-6 mg/L	<2 mg/L
Beach Postings	+	<5% of days	5-20% of days	>20% of days

[6] Golder Associates Ltd. 2018. Great Lakes Nearshore Assessment Weight of Evidence. Prepared for Environment and Climate Change Canada.

Fish Consumption	+	>8 meals per month	Between 1 and 7 meals per month	Less than 1 meal per month
Treated Drinking Water	+	No Adverse Water Quality Incidents	N/A	Adverse Water Quality Incidents

The cumulative stress for each Category is assigned based on combining the evidence (individual measure results) and then integrating all four Categories into an overall rating score for each Regional Unit (Table 2). Each of the overall scores is further described as a narrative in the results reports providing the rationale and context for the rating. This approach links the outcomes to a conclusion and retains relevant information to ensure the overall goal of transparency is maintained. This structured process is to help communicate relative priorities rather than absolute risks and can be used to establish broad priorities for in-depth analysis as required.

Table 2. Weight of Evidence Scoring Key for the Overall Regional Unit Score (L: Low Stress; M: Moderate Stress; H: High Stress; VL: Very Low Stress; "?" refers to a category that has data gaps so cannot be scored). *VL is achieved when all of the measures – and therefore categories – are Low Stress

Category	Category	Category	Category	Overall Regional Unit Score	
L	L	L	L	L	VL*
L	L	L	M	L	
L	L	L	H	M	
L	L	M	M	M	
L	L	M	H	M	
L	L	H	H	M	
L	M	M	M	M	
L	M	M	H	M	
L	M	H	H	H	
L	H	H	H	H	
M	M	M	M	M	
M	M	M	H	M	
M	M	H	H	H	
M	H	H	H	H	
H	H	H	H	H	
?	L	L	L	L	
?	L	L	M	L	
?	L	L	H	M	
?	L	M	M	M	
?	L	M	H	M	
?	L	H	H	H	
?	M	M	M	M	
?	M	M	H	M	
?	M	H	H	H	
?	H	H	H	H	
?	?	L	L	L	
?	?	L	M	M	
?	?	L	H	M	
?	?	M	M	M	
?	?	M	H	H	
?	?	H	H	H	
?	?	?	L	?	

?	?	?	M	?
?	?	?	H	?
?	?	?	?	?

Regional Unit Delineation

Phase One of the Nearshore Assessment is to classify the nearshore into Regional Units by ecosystem type, using physical processes and lake characteristics that change at a relatively slow rate, as well as consideration of size and data coverage. Delineation of the nearshore into Regional Units is intended to provide ecologically relevant units of assessment at a regional scale.

Physical parameters and natural processes structure, organize and define nearshore ecosystems and regulate the biological and chemical elements of the system. The geomorphology of an area – bathymetry, substrate, shoreline sinuosity (i.e. degree of natural shoreline undulation) – influences structure and energy flows as well as processes related to the transfer of energy. Similarly, natural variability of hydrodynamic processes within an area can have an influential role in sediment supply, transport and deposition. Wave energy density and exposure provide an indication of how vulnerable an area may be to erosion and the presence/absence of aquatic vegetation. These slow-changing, or static, parameters have been used to delineate Regional Units that are internally homogeneous but functionally different from neighbouring nearshore areas.

The delineation of Regional Units also aids in the interpretation of data across an area at a reasonable scale, as well as in understanding the measures that may be most relevant for a particular stretch of the shore. For example, the physiographic conditions of adjacent Regional Units may differ enough that the *Cladophora* measure is applicable in one but not the other. There is no specific size threshold for the Regional Units, however two important consideration related to size include the resolution of available data and relevant management actions.

The Regional Unit delineation differs across each of the lakes due to ecosystem differences but generally follows a similar procedure where the onshore boundary is defined by a high water mark, the offshore boundary is defined by bathymetry and the lateral boundaries use wave energy density, substrate and shoreline morphology. Detailed description of Regional Unit delineation in each lake can be found in each specific lake results report.

Onshore & Offshore Boundaries

The onshore boundary of the Regional Units was defined by a high water mark. Historical monthly mean lake levels from Fisheries and Oceans Canada coordinated network of gauges for each lake were reviewed and the maximum monthly mean water levels were used as the onshore boundary (see Table 3). In addition to the high water mark, coastal wetlands were considered in the onshore boundary. In areas with coastal wetlands, a visual inspection of best available imagery and ecosystem classification data was used to determine whether the wetland is hydrologically connected to the nearshore. If a wetland was assessed as hydrologically connected, the wetland boundary became the onshore extent of a Regional Unit instead of the contour.

The offshore boundary of the Regional Units is based on each specific lake's bathymetry. With an average depth of approximately 64 m, Lake Erie is the shallowest Great Lake however a gradient exists from the shallow western basin to the deeper eastern basin. Based on this depth profile, 15 m was used as the offshore boundary. Lake Superior is the deepest Great Lake and features a very steep nearshore slope. This means that a 15 or 30 m nearshore depth is too narrow to characterize and an offshore limit of 100 m was used.

When finer resolution bathymetry is available from the recent LiDAR data collection (ECCC and DFO) in the Great Lakes nearshore, the offshore boundaries can be refined.

Table 3. Details related to Regional Unit boundaries, specific to each lake.

Physical Parameter or Characteristic	**SUPERIOR**	**HURON**	**ERIE**	**ONTARIO**	Data source
High water mark	183.91 m - 0.7 m above chart datum (183.2 m, IGLD'85)	177.5 m - 1.5 m above chart datum (176.0 m, IGLD'85)	175.04 m – 1.54 m above chart datum (173.5 m, IGLD'85)	75.8 m – 1.6 m above chart datum (74.2 m, IGLD'85); St. Lawrence River various water levels	ECCC Historical Monthly Mean Water Levels
Bathymetry	100 m depth	30 m depth	15 m depth	30 m depth	Great Lakes Aquatic Habitat Framework lakewide bathymetry
Wave energy density	Low: <4,000 kj/m2 Moderate: 4-6,000 kj/m2 High: >6,000 kj/m2	Low: <4,000 kj/m2 Moderate: 4-6,000 kj/m2 High: >6,000 kj/m2	Low: <100,000 joules/m2 Moderate: 1-300,000 joules/m2 High: >300,000 joules/m2	Low: <2,000,000 joules/m2 Moderate: 2-4,000,000 joules/m2 High: >4,000,000 joules/m2	Zuzek, Inc.

Lateral Boundaries

Regional Unit lateral boundaries were generated by assessing substrate data, shoreline morphology and wave energy. The nearshore areas of the Canadian Great Lakes and connecting channels are not homogeneous; variations in substrate and wave energy result in spatially explicit characteristics that were used to delineate Regional Units. The orientation and morphology of the shoreline can impact the presence (or absence) of coastal features and transitions in substrate.

Due to its influence on nearshore processes, wave energy was included as a physical variable in the delineation of lateral boundaries. Wave energy magnitude and direction can influence alongshore properties in various ways. On a lake-wide scale, the geologic properties of the coast and gradients in wave energy influence the magnitude and directionality of longshore sediment transport patterns and, ultimately, erosion and deposition patterns that shape the coastline. Exposure to wave energy is also a major factor in the presence or absence of submerged and emergent aquatic vegetation. Wave climate also influences substrate characteristics, with sheltered environments featuring finer grained sediment (e.g. silt and clay) and open coast areas that are subjected to higher energy wave action featuring coarser substrate. These substrate characteristics can in turn influence the type of invertebrate communities in the nearshore.

Wave energy density was calculated for each of the lakes and used to help delineate the lateral boundaries of each Regional Unit. In Lake Erie, average wave energy density for April and May was calculated at 1 km increments at the 5 m depth contour; in Lake Superior, Huron and Erie, average wave energy density was calculated based on annual conditions at 1 km increments at the 5 m depth contour. Refer to Table 4 for the Low, Moderate and High energy wave calculations in each of the lakes; note that Lake Superior and Lake Huron are characterized by much higher energy and are measured in kilojoules (kj).

Once the Regional Units have been delineated, a final step is to remove large islands from within the boundaries. There are some islands within the nearshore areas of the Canadian Great Lakes that are large enough to have small populated areas and infrastructure (e.g. Pelee Island in Lake Erie and St. Ignace Island in Lake Superior) and they should not be counted as nearshore “waters.” Professional judgement was exercised but as a general rule, any islands larger than 150 hectares were removed from Regional Units.

A total of 64 unique Regional Units were delineated for the Canadian Great Lakes and connecting channels. This includes 9 Regional Units in Lake Superior, classified as sheltered embayments and low/moderate/high energy nearshore; 23 Regional Units in Lake Huron and Georgian Bay, classified as connecting channels, sheltered embayments and low/moderate/high energy nearshore; 15 Regional Units in Lake Erie, classified as connecting channels, river mouths, sheltered embayments and low/moderate/high energy nearshore; and 17 Regional Units in Lake Ontario and the St. Lawrence River, classified as connecting channels, sheltered embayments and low/moderate/high energy nearshore.

Detailed Assessment Methodology

Phase Two is an assessment of the state of nearshore waters in each Regional Unit. The assessment relies on existing monitoring and research already being conducted by various government and non-government partner agencies and organizations. Knowledge of ecological thresholds and stressor information has been used to identify nearshore areas that are – or may become – subject to high stress. In addition, the assessment helps to determine cumulative effects that are causing stress to nearshore water quality and ecosystem health.

Coastal Processes

The physical integrity of the nearshore requires preservation of coastal processes such as erosion, sediment transport and deposition. Modification of these coastal processes can have adverse impacts on nearshore habitat features and water quality. The impact of shoreline modifications can be adverse for coastal processes that maintain habitat structure and coastal ecosystems and create stress on nearshore areas.

Shoreline Hardening

Assessment methodology:

In GIS (e.g. ESRI ArcMap), digitize a line along the onshore boundary of the Regional Units, and classify segments along the shoreline into:

1) "Natural" or "Hardened" (shoreline type):
   - **Natural Shoreline:** no engineered or artificial structures in the nearshore, at the waters edge, toe of bluff, backshore or back of the beach; rising and falling water levels result in natural changes in the shoreline position; wildlife usage and vegetation migration upslope and downslope can occur unimpeded; natural vegetation communities, consistent with local conditions, are generally present along the shore
   - **Hardened Shoreline:** the nearshore, waters edge, toe of bluff, backshore or back of beach has been altered with engineered structures or artificial material (e.g. offshore breakwaters, lakefill, groynes, seawalls, revetments, dumped concrete rubble, artificial channel, dikes, etc.); natural shoreline processes are altered, and native vegetation communities are generally absent
2) "Lake," "Sheltered" or "Connecting Channel" (shoreline exposure):
   - **Lake**: shoreline directly exposed to lake wave energy
   - **Sheltered**: shorelines with embayments, tributaries or the inside of jettied structures where there is protection from wave energy and currents
   - **Connecting Channel**: shorelines in the Great Lakes connecting channels (St. Mary's River, St. Clair River, Lake St. Clair, Detroit River, Niagara River and St. Lawrence River)

Once classified, calculate the length of each segment and summarize for each Regional Unit to determine the percent of shoreline that is hardened.

General Guidance

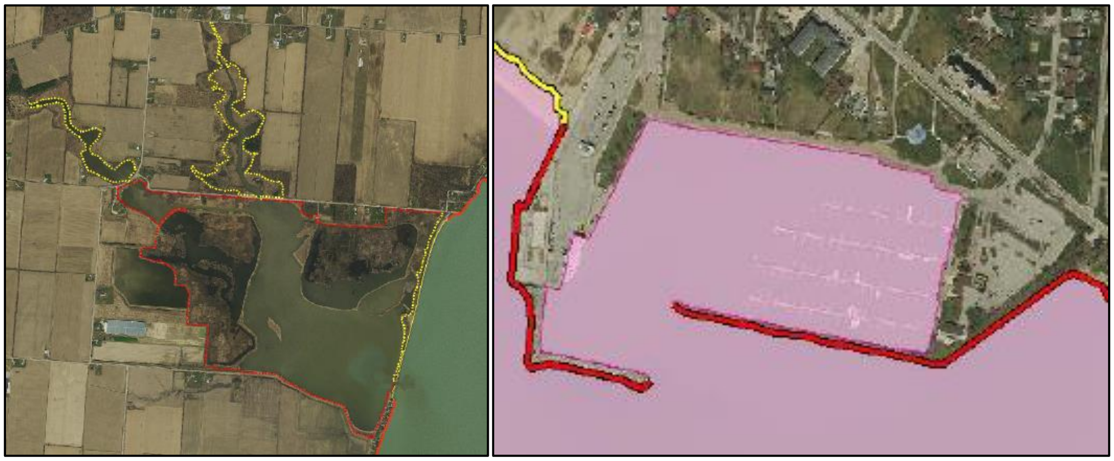
Best available, most recent aerial imagery should be used for reference; the date of source of the photography is documented in the metadata

- 2018 Lake Erie Assessment: Southwestern Ontario Orthophotography (SWOOP) 2015
- 2019 Lake Ontario Assessment: Southwestern Ontario Orthophotography (SWOOP) 2015, Southcentral Ontario Orthophotography (SWOOP) 2013, Google Earth and imagery from the Meteorological Service of Canada for Durham, Mississauga, Oakville and Toronto
- 2020 Lake Superior Assessment: 2019 Orthophotography
- 2021 Lake Huron Assessment: Southwestern Ontario Orthophotography (SWOOP) 2015 and ESRI World Imagery

The digitized line along the onshore boundary of the Regional Units should be digitized at a map scale large enough to distinguish between hardened and natural shorelines; this approximately 1:2,000

Embayment areas should be classified with "sheltered" shoreline exposure (e.g. Hillman Marsh in Lake Erie); in these areas, the shoreline type ("hardened" or "natural") is classified based on the Regional Unit boundary, even if the embayment extends onshore (Figure 1, left).

Figure 1. (Left) The Regional Unit boundary is used to classify the shoreline type at embayment areas such as the Hillman Marsh, w hich has diked (artificial) w etland cells; (Right) Only the outer edge of the Leamington Marine is digitized, and the entrance is left open.



For large artificial sheltered areas such as harbours and marinas, only the outer edge of the engineered infrastructure should be digitized; in the example below, the entrance of the navigation channel is left open (undigitized) and only the outer edge is classified (Figure 1, right)

River mouths should be classified as "sheltered" shoreline exposure; if it is protected with a jetty, the inside of the jetty is characterized

The minimum length of a classified segment should be approximately 100 metres; if a "natural" or "hardened" section of shoreline is less than 100 m, it should be classified based on the adjacent type. There may be areas where a line segment less than 100 m is justified, and these should be dealt with on a case by case basis.

Guidance for Classifying Hardened Shorelines

Shorelines with shore parallel and/or shore perpendicular protection are considered "hardened."

If a vertical wall is observed at the back of the beach and it is heavily developed, then it is considered hardened (see yellow arrows):

Revetment is a hardened shoreline:

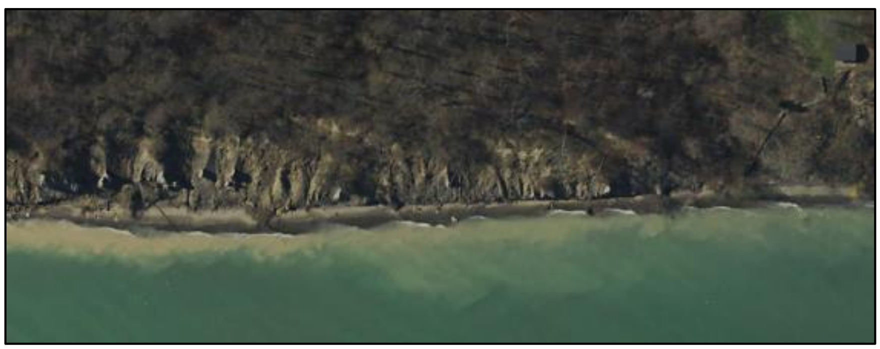
Mixed shore perpendicular and parallel protection is considered hardened:

Artificial canals, marinas and harbours are considered hardened:

Guidance for Classifying Natural Shorelines

Shorelines without shore protection and greater than 100 m are considered "natural."

Bluff environments:



Beach environments (sand and cobble/shingle):

Coastal wetlands:

Bedrock shoreline (e.g. Georgian Bay or the Thousand Islands Region):

Potential Improvements in Methodology for Future Assessments:

In areas with artificial canals (e.g. the Detroit River) or large embayments that have been delineated in the classification may be skewing the total length of shoreline in the Regional Unit

Shorelines with high erosion rates (e.g. east of Port Burwell on Lake Erie) may require updating as the onshore boundary may change as water levels fluctuate

Thresholds for Shoreline Hardening (all lakes):

LOW STRESS	MODERATE STRESS	HIGH STRESS
< 25% of the total shoreline length for the Regional Unit is hardened	25-50% of the total shoreline length for the Regional Unit is hardened	>50% of the total shoreline length for the Regional Unit is hardened
Thresholds based on professional judgement (Zuzek Inc.)		

Littoral Barriers

Assessment methodology:

Littoral barriers are assessed using the following steps:

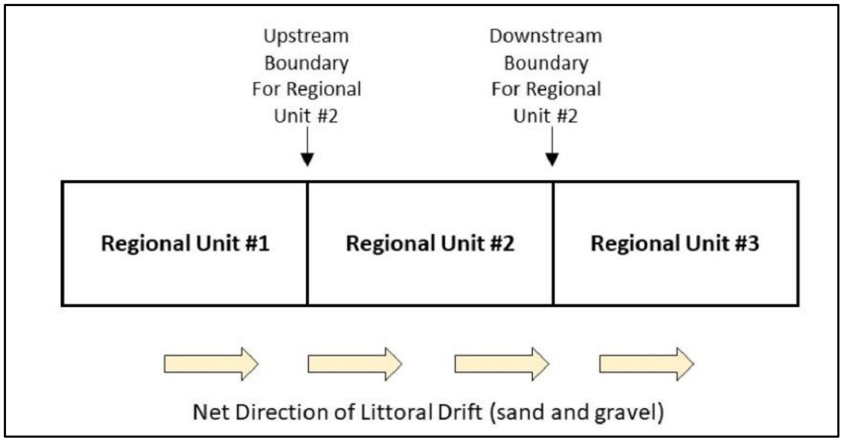
1. Is the transport of littoral drift (sand and gravel) along the coastline an important physical process for the majority of the Regional Unit? If no, this measure is not assessed and the assessment is complete for the Regional Unit (assign a score of “n/a”).
    a. For example, the littoral barriers measure does not apply to all Regional Units in Lake Superior as the transport of sand and gravel along the coastline is not an important physical process.
2. If yes, the net direction of littoral drift is estimated based on published literatures, technical reports, physical evidence (e.g. sand accumulation in fillet beaches) and expert opinion.
3. The number of artificial littoral barriers are counted, as follows:
    a. If there is a littoral barrier impeding sediment supply into the Regional Unit (upstream boundary), the barrier is counted. If there is no supply from the adjacent Regional Unit, the barrier has no impact on littoral drift and is not counted.
    b. If the upstream boundary of the Regional Unit features a barrier but it is also a divergent node for littoral transport (sand moves in both directions away from the littoral barrier), it is not counted.
    c. Barriers at the downstream boundary generally do not impact the Regional Unit, so they are not counted. For example, barriers at the downstream end result in the accumulation of sediment in the form of a fillet beach, which can diversify homogenous lake bottom habitat (sand and gravel substrate versus large expanses of exposed glacial till) and create popular recreational destinations. Such beaches are used for swimming, and in many cases the beaches would not exist if it were not for the littoral barrier. It can be a problem for the adjacent Regional Unit and would be enumerated accordingly as an upstream boundary. This approach avoids double counting the same littoral barrier in adjacent Regional Units.
    d. Natural littoral barriers are not counted.
    e. If artificial bypassing were adopted at a littoral barrier or harbour, the littoral barrier could be removed in future re-analysis.
4. Generally, littoral drift not assessed in connecting channels or sheltered embayments (not an important physical process).

General Guidance & Examples of Littoral Barriers

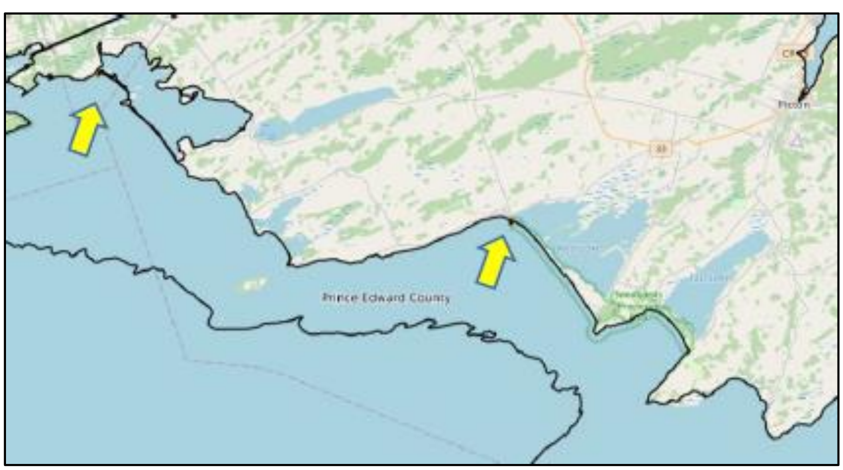
- Divergent littoral drift: where there is divergent littoral drift, a barrier is not counted; for example, on the west side of Port Dover (Lake Erie) sand moves west towards Turkey Point and on the east side sand is moving towards the east. In this case, the port is not counted as a littoral barrier since is moving away from it along both shorelines:

- Downstream and upstream barrier: in cases where a barrier is at the boundary of two Regional Units, the downstream impact should be considered and the barrier should only be counted once. For example, the Erieau jetty (brown line) defines the boundary between the Rondeau West and Rondeau East Regional Units (Lake Erie); in the Rondeau West Regional Unit, littoral drift is from the west towards the east, making the Erieau jetty a downstream boundary and not counted within the Rondeau West Regional Unit. However, the jetty is limiting littoral drift *into* the Rondeau East Regional Unit and therefore counted as a barrier:

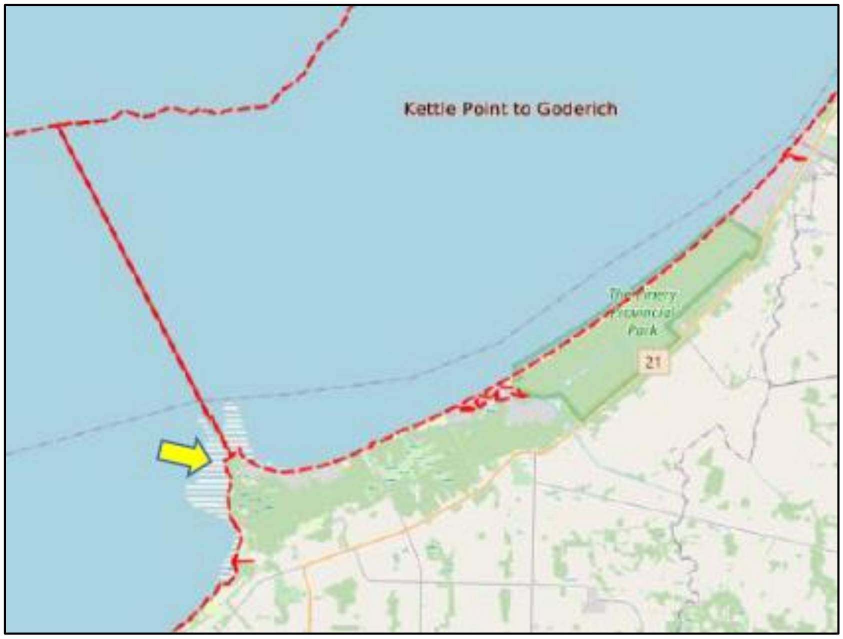
- Cobourg Harbour contains a barrier to littoral drift, however it is only counted in the Cobourg to Gull Island Regional Unit (Lake Ontario) as it is limiting littoral drift *into* the unit from adjacent St. Mary's Cement Pier to Cobourg Regional Unit:



- Barriers exist but littoral drift not an important physical process in the Regional Unit: in cases where the majority of the shoreline features either bedrock or embayments protected by stable barrier beaches, littoral drift is generally not an important physical process and even if barriers exist, they are not counted. For example, the Prince Edward County Regional Unit (Lake Ontario) features small jetties at the entrance to Wellers Bay and West Lake (see yellow arrows) that help stabilize barrier beaches but do not result in negative impacts downstream because littoral drift is not an important process; the sediment trapped adjacent to these jetties is not the dominant physical process controlling the shoreline – rather, the slow erosion rate of the bedrock at the waters edge and on the lake bottom are important physical processes:



- Only anthropogenic obstructions to littoral drift are counted: natural littoral drift barriers, such as at Kettle Point (Lake Huron) are not counted:



Limitations to the Methodology:

- The barrier must be at least 100 m in length to be considered in the assessment, so may not capture smaller barriers that could be obstructing or limiting sediment transfer
- Large barriers, such as the Leslie Street Spit, which is more than 5 km in length and has had impacts on the Toronto Islands, are weighted equally to smaller barriers that may not be having as adverse an impact
- The volume of sediment trapped is linked to the barrier size; the Port Burwell jetty on Lake Erie has trapped an estimated 12 million cubic metres of sand while the jetties at Port Newcastle on Lake Ontario have trapped approximately 21,000 cubic metres. Both of these barriers are longer than 100 m but the magnitude of their impacts vary, yet they are currently given equal weight in the assessment

Thresholds for Littoral Barriers (all lakes, where measure applies):

LOW STRESS	MODERATE STRESS	HIGH STRESS
0 littoral barriers in a Regional Unit where littoral drift is a physical process	1 littoral barrier in a Regional Unit where littoral drift is a physical process	>1 littoral barriers in a Regional Unit where littoral drift is a physical process
Thresholds based on professional judgement (Zuzek Inc.)		

Tributary Connectivity

Datasets:

- **Ontario Integrated Hydrology**

The Ontario Integrated Hydrology (OIH) provides a collection of related elevation and mapped water features that are used in combination for provincial-scale hydrology applications, such as the creation of watersheds and application to hydrology models. By integrating mapped vector water features, such as lakes and rivers, together with raster elevation and flow direction datasets, it is possible to more accurately create watersheds and represent several key parts of the water cycle. Integrated hydrology data is complete for the entire province making it possible to create a watershed for any location in Ontario. It is available on the Ontario GeoHub, with a Custom License.

Other available tributary data available from the Ontario GeoHub that does not require a Custom License to access and that may be used in this measure is the Ontario Hydro Network (OHN) – Watercourse dataset.

- **Fishwerks Barriers**

Fishwerks is a web-based GIS platform that integrates optimization tools to help maximize the efficiency of habitat improvement projects for migratory fish in the Great Lakes. It is the result of a collaboration between the McIntyre Lab at the University of Wisconsin Center for Limnology and the Optimization Group at the Wisconsin Institute for Discovery. Barriers can be queried in the database by basin, country and type (e.g. road crossing, dam or waterfall) and exported to an ESRI shapefile.

Assessment methodology:

Access the Fishwerks website (may need to create a login) and query the barriers for the relevant lake; export dams and waterfall barriers (or, download all barriers for relevant lake and query dams and waterfalls after) as new ESRI shapefile

In GIS (e.g. ESRI ArcMap), assemble the necessary data (Regional Units, tributary (OIH or OHN), barriers [dams and waterfalls from Fishwerks] and any supplementary information such as watersheds).

1. Assign each tributary to a Regional Unit: using watersheds and imagery as needed, determine which Regional Unit a tributary is hydrologically connected to, and assign it with the appropriate Regional Unit ID
2. Assign each tributary as “Connected,” “Naturally disconnected” or “Disconnected” based on the presence of a barrier (dam or waterfall):
   - **Connected**: tributary is downstream of any barrier and connected to the nearshore
   - **Naturally disconnected**: tributary is upstream of a waterfall and naturally disconnected to the nearshore
   - **Disconnected**: tributary is upstream of a dam and not connected to the nearshore

   Use aerial imagery and watersheds as needed to determine connectivity

Where necessary, use the Split Tool (Edit Features) to split a tributary at a barrier and assign different line segments different classifications based on upstream or downstream

3. Run the Dissolve Tool (by "connected," "naturally disconnected" and "disconnected" attribute and Regional Unit ID) and calculate the new length for each feature before exporting the table to excel
4. In excel, calculate tributary connectivity:
   - Tributary connectivity is calculated by assessing the percent of tributaries that are not naturally disconnected that remain connected to the nearshore:
     - Sum of "connected" and "disconnected" = total tributary length
     - total "connected" tributary length in Regional Unit/total tributary length = % of tributaries that are connected to the nearshore

Thresholds for Tributary Connectivity (all lakes):

LOW STRESS	MODERATE STRESS	HIGH STRESS
> 75% of the total length of tributaries (excluding upstream of waterfall) are connected to the Regional Unit	25-75% of the total length of tributaries (excluding upstream of waterfall) are connected to the Regional Unit	<25% of the total length of tributaries (excluding upstream of waterfall) are connected to the Regional Unit
Thresholds based on the State of the Great Lakes Sub-indicator report for Aquatic Habitat Connectivity		

Category Score for Coastal Processes

All measures in the Coastal Processes category are weighted equally.

Category Score:

- Assign a Category Score based on Table 4.

Table 4. Weight of Evidence Scoring Key for Coastal Processes
(H=High Stress; M=Moderate Stress; L=Low Stress; NA=Not Applicable)

Shoreline Hardening (+)	Littoral Barriers (+)	Tributary Connectivity (+)	Category Score
L	L	L	L
L	L	M	L
L	L	H	M
L	M	L	L
L	M	M	M
L	M	H	M
L	H	L	M
L	H	M	M
L	H	H	H
L	NA	L	L

L	NA	M	M
L	NA	H	M
M	L	L	L
M	L	M	M
M	L	H	M
M	M	L	M
M	M	M	M
M	M	H	M
M	H	L	M
M	H	M	M
M	H	H	H
M	NA	L	M
M	NA	M	M
M	NA	H	H
H	L	L	M
H	L	M	M
H	L	H	H
H	M	L	M
H	M	M	M
H	M	H	H
H	H	L	H
H	H	M	H
H	H	H	H
H	NA	L	M
H	NA	M	H
H	NA	H	H

Contaminants in Water & Sediment

A Note on Data*:* Federal and provincial monitoring programs are designed to measure contaminants in all media (air, water, sediment, fish, birds and benthos) but the temporal and spatial coverage as well as the parameters measured and purpose of various monitoring programs is diverse. Despite the diversity of the various monitoring programs, there is limited data available to measure Contaminants in Water & Sediment at a scale that is regionally appropriate and offers coverage at the lake scale. Due to the geographic scale of the Great Lakes, the short weather windows for sampling and the high cost of laboratory analysis especially for organochlorine contaminants (e.g. dioxins and furans), very limited data is available to measure contaminant-related overall nearshore health. Many recent and emerging contaminants, such as Per- and polyfluoralkyl substances [PFAS], of which there are nearly 5,000 types[7] are not understood well enough to set thresholds for safety or develop analysis methods. In addition, concentrations may be so low as to avoid detection with existing laboratory equipment.

[7] US FDA (United States Food & Drug Administration). 2020. Per and Polyfluoroalkyl Substances (PFAS). Accessed from https://www.fda.gov/food/chemicals/and-polyfluoroalkyl-substances-pfas

Water Quality

All water quality data used in the assessment were compared to both the Canadian Water Quality Guidelines and the Provincial Water Quality Objectives, where they existed. The final results were narrowed to only those contaminants that were detected above acceptable criteria.

Datasets:

- **MECP Great Lakes Nearshore – Water Chemistry**

The Ontario Ministry of Environment, Conservation and Parks (MECP) Water Chemistry data is an index station network whose objectives are:

- to identify temporal trends in water quality in the nearshore of the Great Lakes
- to use the information in identifying lakewide or regional changes in environmental conditions
- to establish sites removed from major point-source influences in each of the Great Lakes such that the data collected at the sites may be used as a reference when assessing environmental conditions at physically similar sites

The data includes index stations, which are likely to be similar to any other of a number of locations with common features; and reference stations, which are arbitrarily selected because of some special feature and/or where there is a natural integration of stressors from a larger area. Surveys are typically collected in one of the Great Lakes basins (including connecting channels) in each year of a 3-6 year cycle; approximately 10-18 stations are surveyed annually. Sampling occurs every 3 years in Lake Ontario and Lake Erie and every 6 years in Lake Superior and Lake Huron. The shorter sampling interval for Lake Ontario and Lake Erie reflects the higher level of anthropogenic stress on the lower lakes.

- 2018 Lake Erie Assessment: 2007, 2010, 2014 & 2016 Water Chemistry data
- 2019 Lake Ontario Assessment: 2006, 2009, 2010 & 2012 Water Chemistry data
- 2020 Lake Superior Assessment: 2011 Water Chemistry data

- **ECCC Great Lakes Water Quality Monitoring and Aquatic Ecosystem Health Data – Great Lakes Water Quality Monitoring and Surveillance Data**

Environment and Climate Change Canada (ECCC) collects water quality and ecosystem health data to meet federal commitments related to the Great Lakes. By conducting regular, systematic measurements of the physical, chemical and biological conditions of the Great Lakes, ECCC is able to:

- Measure natural changes and conditions of water quality and determine changes over time, at various locations, of water contaminants and/or threats
- Identify emerging issues and threats and track the results of remedial measures and regulatory decisions
- Report and assess science results through performance indicators to support an ecosystem approach to environmental and resource management in the Great Lakes

The ECCC Water Quality Monitoring and Surveillance Data was used to supplement areas where the MECP Water Chemistry was insufficient:

- 2020 Lake Superior Assessment: 2016 & 2019 Water Quality data
- 2021 Lake Huron Assessment: 2015-2018 Water Quality data

Note that in the 2019 Lake Ontario Assessment, ECCC's Niagara River Upstream/Downstream Monitoring Program Results[8] were used in the Niagara River to Welland Canal Regional Unit.

Assessment methodology:

Access the Great Lakes Nearshore – Water Chemistry data from the Ontario Ministry of Environment, Conservation and Parks (MECP) Data Catalog

Tip: each tab in the Excel table contains data specific to a lake (i.e. Erie, Ontario, Superior & Huron); for easier querying and exporting into GIS, first import the Excel table to Microsoft Access (or some other database program), query the relevant data (see below) and then export relevant records back into Excel

- For the Lake Erie and Connecting Channels assessment, query records from the Lake Huron Water Chemistry tab WHERE Body of Water = ST. CLAIR RIVER, LAKE ST. CLAIR or DETROIT RIVER and from the Lake Erie Water Chemistry tab WHERE Body of Water = LAKE ERIE
- For the Lake Ontario, Niagara and St. Lawrence Rivers assessment, query records from the Lake Ontario Water Chemistry tab WHERE Body of Water = BAY OF QUINTE, HAMILTON BAY, LAKE ONTARIO and ST. LAWRENCE RIVER
- For the Lake Superior assessment, query records from the Lake Superior Water Chemistry tab WHERE Body of Water = LAKE SUPERIOR
- For the Lake Huron and St. Marys River assessment, query records from the Lake Superior Water Chemistry tab WHERE Body of Water = ST. MARY'S RIVER and from the Lake Huron Water Chemistry tab WHERE Body of Water = GEORGIAN BAY, LAKE HURON or NORTH CHANNEL

Access the Great Lakes Water Quality Monitoring and Aquatic Ecosystem Health Data from the Government of Canada's Open Data Portal

1. Select relevant data and attribute a Regional Unit ID to each sample based on the sampling station location.

In GIS (e.g. ESRI ArcMap), import relevant data and plot stations using the Latitude and Longitude fields (e.g. Display XY Data); export as a new dataset.

Pre-processing of the data is needed to efficiently query the table:

- Add Field 'RegUnit_ID' (text)
    - Select by Location all of the index stations within a Regional Unit and assign appropriate ID
- Add Field 'YMD' (text)
    - Field Calculator on 'YMD' to parse the date without the time: LEFT([Collect_DATE],10)
        - This step is necessary in order to calculate mean daily values

[8] Hill, B. 2018. Niagara River Upstream/Downstream Monitoring Report 2005-2006 to 2014-2015. Environment and Climate Change Canada. For: Niagara River Monitoring Committee

- Select relevant survey years Select by Attributes samples taken at the surface (e.g. 'SampleDepth' <= 1)
- Select by Attributes parameters which are relevant to the assessment and have a provincial or federal guideline. See Tables 5 and 6.
- Export the results to Excel

2. Determine if any contaminants were found at levels above guidelines in any single sample.
    - Compare the result for each entry to the guidelines in Table 5 and 6.
    - Where the "Valuequalifier" column = Less than method detection limit (<W, <WE, <MDL) or Trace Value (<T, <TE) the result should be interpreted as zero.
        - Add new column to adjust for 0, where necessary
    - Note regarding mercury: the Ontario Ministry of Environment, Conservation and Parks mercury samples are unfiltered and were compared only with the Canadian Water Quality Guidelines for the Protection of Aquatic Life; the Provincial Water Quality Objectives are based on filtered mercury samples.
    - Note regarding chromium: provincial sampling does not distinguish between the trivalent or hexavalent form of chromium therefore they cannot be compared to guidelines.
    - Note regarding aluminum: provincial samples are not filtered (clay) therefore aluminum guideline cannot be applied.
3. For any single sample that was found at levels above guidelines, calculate the mean contaminant level detected for all samples taken on that survey date at that station. Compare this daily mean to the guideline (Tables 5 and 6) and if it exceeds count it as 1 "exceedance".

    Using the Regional Unit ID associated with each station count the total number of exceedances of any contaminant within the Regional Unit.
4. Apply thresholds to score stress level.

Table 5. Provincial Water Quality Objectives (PWQO)[9] used to check for exceedances

Parameter	PWQO (ug/L)	Comment
Antimony	20	
Arsenic	100	
Beryllium	11 1100	@ hardness <75 @ hardness >75
Boron	200	
Cadmium	0.2	

[9] Ontario Ministry of the Environment and Energy. 1994. Water management: policies, guidelines, provincial water quality objectives. Accessed from https://www.ontario.ca/page/water-management-policies-guidelines-provincial-water-quality-objectives#section-2

Copper	5	
Cobalt	0.9	
Iron	300	
Lead	1	@ hardness >30 @hardness 30-80 @hardness >80
Mercury	0.2	(for filtered sample)
Molybdenum	40	
Nickel	25	
Selenium	100	
Silver	0.1	
Thallium	0.3	
Tin (tributyltin?)	0.000005	
Tungsten	30	
Uranium	5	
Vanadium	6	
Zinc	30	

Table 6. Canadian Water Quality Guidelines[10] used to check for exceedances

Parameter	Guideline (ug/L)	Comment
Arsenic	5	
Boron	1,500	
Cadmium	http://st-ts.ccme.ca/en/index.html?lang=en&factsheet=20#aql_fresh_concentration	Calculation based on hardness
Chloride	120, 000	
Copper	http://st-ts.ccme.ca/en/index.html?lang=en&factsheet=71#aql_fresh_concentration	Calculation based on hardness
Fluoride	120	
Iron	300	
Lead	http://st-ts.ccme.ca/en/index.html?lang=en&factsheet=71#aql_fresh_concentration	Calculation based on hardness

[10] CCME (Canadian Council of Ministers of the Environment). 1987. Canadian Environmental Water Quality Guidelines. Accessed from http://ceqg-rcqe.ccme.ca/download/en/95

Manganese	http://www.ccme.ca/files/Resources/supporting_scientific_documents/Manganese%20CWQG%20SCD%20Appendix%20B_en.xlsx	Excel table calculator
Molybdenum	73	
Nickel	http://st-ts.ccme.ca/en/index.html?lang=en&factsheet=139#aql_fresh_concentration	
PH	6.5 – 9	
Selenium	1	
Silver	0.25	
Thallium	0.8	
Total Mercury	0.026	
Uranium	15	
Zinc	http://st-ts.ccme.ca/en/index.html?lang=en&factsheet=229#aql_fresh_concentration	

Thresholds for Water Quality (all lakes):

LOW STRESS	MODERATE STRESS	HIGH STRESS
0 contaminant exceedances in Regional Unit	1 or 2 contaminant exceedances in Regional Unit	>2 contaminant exceedances in Regional Unit
Thresholds set based on best professional judgement		

Sediment Quality

Datasets:

- **MECP Great Lakes Nearshore – Sediment Chemistry**

The Ontario Ministry of Environment, Conservation and Parks (MECP) Sediment Chemistry data is an Index station network whose objectives are:

- to identify temporal trends in sediment quality in the nearshore of the Great Lakes
- to use the information in identifying lakewide or regional changes in environmental conditions
- to establish sites removed from major point-source influences in each of the Great Lakes such that the data collected at the sites may be used as a reference when assessing environmental conditions at physically similar sites

The data includes index stations, which are likely to be similar to any other of a number of locations with common features; and reference stations, which are arbitrarily selected because of some special feature and/or where there is a natural integration of stressors from a larger area. Surveys are typically collected in one of the Great Lakes basins (including connecting channels) in each year of a 3-6 year cycle; approximately 10-18 stations are surveyed annually. Sampling occurs every 3 years in Lake Ontario and Lake Erie and every 6 years in Lake Superior and Lake Huron. The shorter sampling interval for Lake Ontario and Lake Erie reflects the higher level of anthropogenic stress on the lower lakes.

- 2018 Lake Erie Assessment: 2007, 2010, 2014 & 2016 Sediment Chemistry data
- 2019 Lake Ontario Assessment: 2012 Sediment Chemistry data
- 2020 Lake Superior Assessment: 2011 Sediment Chemistry data
- 2021 Lake Huron Assessment: 2009, 2011 & 2015 Sediment Chemistry data

Provincial guidelines establish three levels of effect:

- **No Effect Level (NEL)** indicates concentrations of a chemical in sediment that has no effect on fish or sediment-dwelling organisms; at this level, negligible transfer of chemicals through the food chain and no effect on water quality is expected. Sediment meeting the NEL are considered clean
- **Lowest Effect Level (LEL)** indicates a level of contamination that can be tolerated by the majority of sediment-dwelling organisms; sediment that meet the LEL are considered clean to marginally polluted
- **Severe Effect Level (SEL)** indicates a level of contamination that is expected to be detrimental to the majority of sediment-dwelling organisms; sediment exceeding the SEL are considered to be heavily contaminated

Federally, the Canadian Council of Ministers of the Environment (CCME) guidelines refer to a **Threshold Effect Level (TEL)** that represents the concentration below which adverse biological effects are expected to rarely occur and a **Probable Effect Level (PEL)** above which adverse effects are expected to occur frequently. The PEL is recommended as an additional sediment quality assessment tool that can be useful for identifying sediments in which adverse biological effects are more likely to occur[11].

In many Great Lakes Areas of Concern (AOC), under the Remedial Action Plan (RAP) program, localized sediment contamination triggered more detailed investigations using the *Canada-Ontario Decision-making Framework for Assessment of Great Lakes Contaminated Sediment*[12]. This guidance document, as well as the Provincial *Guidelines for Identifying, Assessing and Managing Contaminated Sediments in Ontario*[13] provide step-by-step guidance on decisions regarding sediment management in locations where screening levels indicated a need for more detailed quantitative investigations. RAP program managers have developed and are implementing sediment management plans in a number of AOCs.

The Overall Assessment of Nearshore Waters uses existing data from both federal and provincial sampling efforts in the Great Lakes at primarily ambient or long-term sensing sites. All sediment quality results used in this assessment have been compared to both federal and

[11] CCME (Canadian Council of Ministers of the Environment). 2001. Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Accessed from https://www.ccme.ca/en

[12] Environment and Climate Change Canada and the Ministry of the Environment. 2008. *Canada-Ontario Decision-making Framework for Assessment of Great Lakes Contaminated Sediment.* Accessed from https://publications.gc.ca/collections/collection_2010/ec/En164-14-2007-eng.pdf

[13] Ministry of the Environment. 2008. *Guidelines for Identifying, Assessing and Managing Contaminated Sediments in Ontario*. Accessed from https://www.ontario.ca/document/guidelines-identifying-assessing-and-managing-contaminated-sediments-ontario

provincial guidelines where they exist. The final results are narrowed to those contaminants that were detected above acceptable criteria.

Assessment methodology:

Access the Great Lakes Nearshore – Sediment Chemistry data from the Ontario Ministry of Environment, Conservation and Parks (MECP) Data Catalog

Tip: each tab in the Excel table contains data specific to a lake (i.e. Erie, Ontario, Superior & Huron); for easier querying and exporting into GIS, first import the Excel table to Microsoft Access (or some other database program), query the relevant data (see below) and then export relevant records back into Excel

For the Lake Erie and Connecting Channel assessment, query records from the Lake Huron Water Chemistry tab WHERE Body of Water = ST. CLAIR RIVER, LAKE ST. CLAIR or DETROIT RIVER and from the Lake Erie Water Chemistry tab WHERE Body of Water = LAKE ERIE

- For the Lake Ontario and St. Lawrence River assessment, query records from the Lake Ontario Water Chemistry tab WHERE Body of Water = BAY OF QUINTE, HAMILTON BAY, LAKE ONTARIO and ST. LAWRENCE RIVER
- For the Lake Superior assessment, query records from the Lake Superior Water Chemistry tab WHERE Body of Water = LAKE SUPERIOR
- For the Lake Huron and Connecting Channel assessment, query records from the Lake Superior Water Chemistry tab WHERE Body of Water = ST. MARY'S RIVER and from the Lake Huron Water Chemistry tab WHERE Body of Water = GEORGIAN BAY, LAKE HURON or NORTH CHANNEL

In GIS (e.g. ESRI ArcMap), import the Sediment Chemistry data and plot stations using the Latitude and Longitude fields; export as a new dataset.

1. Pre-processing of the data is needed to efficiently query the table:
    - Add Field 'RegUnit_ID' (text)
        - Select by Location all of the index stations within a Regional Unit and assign appropriate ID
    - Add Field 'Category' (text)
2. Extract relevant data (PCBs/Organochlorine Pesticides, PAHs, Metals and total organic carbon) and attribute with appropriate Category

    Note: relevant data is based on contaminants for which there are Provincial Sediment Quality Guidelines (Table 7)

    - Select by Attributes
        - ["Lims Parameter Name" = 'a-BHC (hexachlorocyclohexane)' OR " Lims Parameter Name" = 'Aldrin' OR " Lims Parameter Name" = 'b-BHC (hexachlorocyclohexane)' OR " Lims Parameter Name" = 'Dieldrin' OR " Lims Parameter Name" = 'Endrin' OR " Lims Parameter Name" = 'g-Chlordane' OR " Lims Parameter Name" = 'Hexachlorobenzene' OR " Lims Parameter Name" = 'Mirex' OR " Lims Parameter Name" = 'op-DDT' OR " Lims Parameter Name" = 'PCB; total' OR " Lims Parameter Name" =

'pp-DDD' OR " Lims Parameter Name" = 'pp-DDE' OR " Lims Parameter Name" = 'pp-DDT']

  - ‘Category’ = “PCBs/Organochlorine Pesticides”

- Select by Attributes
  - ["Lims Parameter Name" = 'Arsenic' OR " Lims Parameter Name" = 'Cadmium' OR " Lims Parameter Name" = 'Chromium' OR " Lims Parameter Name" = 'Copper' OR " Lims Parameter Name" = 'Iron' OR " Lims Parameter Name" = 'Lead' OR " Lims Parameter Name" = 'Manganese' OR " Lims Parameter Name" = 'Mercury' OR " Lims Parameter Name" = 'Nickel' OR " Lims Parameter Name" = 'Zinc']
    - ‘Category’ = “Metals”
- Select by Attributes
  - ["Lims Parameter Name" = 'Anthracene' OR " Lims Parameter Name" = 'Benzo(a)anthracene' OR " Lims Parameter Name" = 'Benzo(a)pyrene' OR " Lims Parameter Name" = 'Benzo(g,h,i)perylene' OR " Lims Parameter Name" = 'Benzo(k)fluoranthene' OR " Lims Parameter Name" = 'Chrysene' OR " Lims Parameter Name" = 'Dibenzo(a,h)anthracene' OR " Lims Parameter Name" = 'Fluoranthene' OR " Lims Parameter Name" = 'Fluorene' OR " Lims Parameter Name" = 'Indeno(1,2,3-c,d)pyrene' OR " Lims Parameter Name" = 'Phenanthrene' OR " Lims Parameter Name" = 'Pyrene']
    - ‘Category’ = “PAHs”
- Select by Attributes
  - " Lims Parameter Name" = 'Carbon; total organic'
    - ‘Category’ = “Carbon- total organic”

2. Create a new table with the relevant data:
   - Select by Attributes ‘Category’ = “PCBs/Organochlorine Pesticides” OR ‘Category’ = “PAHs” OR ‘Category’ = “Metals” OR ‘Category’ = “Carbon - total organic”
   - Select relevant survey years
     - Export selected features into excel
3. Remove samples that are time composites (provincial guidelines apply to grab samples only):
   - ‘Sample Type Code’ = 54
4. Adjust results that are at trace levels or less than method detection limit to Zero
   - Create a new column “ResultAdj”
   - For samples where ‘Value qualifier’ = “<=W”, “<=WE”, “<T”, “<TE”, “<MDL” → “ResultAdj” = “0”
   - Use “ResultAdj” for all following steps
5. For each contaminant (unique ‘Lims Parameter Name’) calculate the daily median at each station (‘StationNo’) for samples collected within appropriate assessment years

   Example:

Collect Date	Station No	Lims Param	Result	Category	RegUnit_ID
15/08/2007	1600010284	Arsenic	2.5	Metals	LE04
15/08/2007	1600010284	Arsenic	1.9	Metals	LE04
15/08/2007	1600010284	Arsenic	2.4	Metals	LE04
	DAILY STATION MEDIAN		**2.4**		
19/08/2010	1600010284	Arsenic	4.8	Metals	LE04
	DAILY STATION MEDIAN		**4.8**		
22/10/2014	1600010284	Arsenic	5.2	Metals	LE04
	DAILY STATION MEDIAN		**5.2**		
15/08/2007	1600010370	Arsenic	5.9	Metals	LE04
15/08/2007	1600010370	Arsenic	6.8	Metals	LE04
15/08/2007	1600010370	Arsenic	5.8	Metals	LE04
	DAILY STATION MEDIAN		**5.9**		

6. Next, calculate the station median (median of daily station median calculated in previous step):

   Example:

Collect Date	Station No	Lims Param	Result	Category	RegUnit_ID
15/08/2007	1600010284	Arsenic	2.4	Metals	LE04
19/08/2010	1600010284	Arsenic	4.8	Metals	LE04
22/10/2014	1600010284	Arsenic	5.2	Metals	LE04
	STATION MEDIAN		**4.8**		
15/08/2007	1600010370	Arsenic	5.9	Metals	LE04
	STATION MEDIAN		**5.9**		

7. Finally, calculate Regional Unit median values for each contaminant, by station (median of station median calculated in previous step)

   Example:

Station No	Lims Param	Result	Category	RegUnit_ID
1600010284	Arsenic	**4.8**	Metals	LE04
1600010370	Arsenic	**5.9**	Metals	LE04
REGIONAL UNIT MEDIAN		**5.3**		

   The result of calculating the daily, station and Regional Unit medians should be a table (or new tab) containing Regional Unit medians for each contaminant (2007 and on)

8. For each contaminant, compare the Regional Unit median to Provincial No Effect Level (NEL *PCBs only), Lowest Effect Level (LEL) and Severe Effect Level (SEL) as well as Federal Probable Effect Level (PEL) to assess whether contaminants are above or below published guidelines (Table 5); create new columns or tabs as necessary to keep a tally of the Regional Unit median contaminant levels that exceed guidelines.

   - Assess whether the PCBs median is above the NEL

- Assess whether the median is above the LEL
- Assess whether the median is above the PEL
- Assess whether the median is above the SEL

In the example, the Regional Unit median contaminant level for Arsenic was 5.3 ug/L; Table 7 indicates that the Lowest Effect Level (LEL) for Arsenic is 6 ug/L therefore the median contaminant level of 5.3 ug/L does not exceed any guidelines.

Note that the Severe Effect Level (SEL) changes based on the percent of total organic carbon (%TOC), so an additional calculation is required for each contaminant in the PCB/Organochlorine Pesticides and PAH categories to properly interpret the threshold. For instructions on how to apply the thresholds in Table 7, refer to the Provincial and Federal websites:

- Federal Water Quality Guidelines for the Protection of Aquatic Life: http://ceqg-rcqe.ccme.ca/en/index.html#void
- Provincial Guidelines for Identifying, Assessing and Managing Contaminated Sediments in Ontario: https://www.ontario.ca/document/guidelines-identifying-assessing-and-managing-contaminated-sediments-ontario/identification-and-assessment#fna2a

9. For each category (Metals, PCBs/Organochlorine pesticides and PAHs) count the number of exceedances for each guidelines (NEL, LEL, PEL and SEL):
    - A station that exceeds NELs, LELs, PELs and SELs is assigned to the Regional Unit as a source of stress
    - Count the number and type of exceedances within each Regional Unit

Table 7. Published exceedance levels; note that for SEL, %TOC is required for interpretation of PCBs/Organochlorine pesticides and PAHS

Contaminant	Unit	LEL	PEL	SEL
Metals				
Arsenic	UG/G DRY	6	17	33
Cadmium	UG/G DRY	0.6	3.5	10
Chromium	UG/G DRY	26	90	110
Copper	UG/G DRY	16	197	110
Iron	%	2%	No Value	4%
Lead	UG/G DRY	31	91.3	250
Manganese	UG/G DRY	460	No Value	1100
Mercury	UG/G DRY	0.2	0.486	2
Nickel	UG/G DRY	16	No Value	75
Zinc	UG/G DRY	120	315	820
Organochlorine pesticides				
a-BHC (hexachlorocyclohexane)	UG/G DRY	0.006	No Value	12 * %TOC

Aldrin	UG/G DRY	0.002	No Value	8 * %TOC
b-BHC (hexachlorocyclohexane)	UG/G DRY	0.005	No Value	21 * %TOC
Dieldrin	UG/G DRY	0.002	0.0067	21 * %TOC
Endrin	UG/G DRY	0.003	0.0624	130 * %TOC
g-Chlordane	UG/G DRY	0.007	0.0087	6 * %TOC
Hexachlorobenzene	UG/G DRY	0.02	No Value	24 * %TOC
Mirex	UG/G DRY	0.007	No Value	13 * % TOC
op-DDT	UG/G DRY	0.008	No Value	71 * %TOC
pp-DDD	UG/G DRY	0.008	0.00851	6 * %TOC
pp-DDE	UG/G DRY	0.005	0.007	19 * %TOC
pp-DDT	UG/G DRY	0.008	0.005	71 * %TOC
Nutrients				
Carbon; total organic	% For Thresholds Interpretation			
PAHs				
Anthracene	UG/G DRY	0.220	0.245	370 * %TOC
Benzo(a)anthracene	UG/G DRY	0.32	0.385	1480 * %TOC
Benzo(a)pyrene	UG/G DRY	0.370	0.782	1440* %TOC
Benzo(g,h,i)perylene	UG/G DRY	0.17	No Value	320* %TOC
Benzo(k)fluoranthene	UG/G DRY	0.24	No Value	1340* %TOC
Chrysene	UG/G DRY	0.340	0.862	460 * %TOC
Dibenzo(a,h)anthracene	UG/G DRY	0.06	0.135	130*%TOC
Fluoranthene	UG/G DRY	0.75	2.355	1020*%TOC
Fluorene	UG/G DRY	0.190	0.144	160*%TOC
Indeno(1,2,3-c,d)pyrene	UG/G DRY	0.200	No Value	320*%TOC
Phenanthrene	UG/G DRY	0.560	0.515	950* %TOC
Pyrene	UG/G DRY	0.490	0.875	850 * %TOC
PCBs				
PCBs; total	UG/G DRY	0.07	0.277	530*%TOC
PCBs pose a significant threat due to the increased risk of bioaccumulation in the food web therefore the No Effect Level (NEL 0.01 UG/G Dry) was used as the minimal acceptable level to be considered Low Stress.				

Thresholds for Sediment Quality (all lakes):

LOW STRESS	MODERATE STRESS	HIGH STRESS
• PCBs < No Effect Level	• PCBs > No Effect Level OR • Organochlorine pesticides and PAHs >	Any contaminant > Severe Effect Levels

• Organochlorine pesticides and PAHs < Lowest Effect Levels • Metals < Probable or Severe Effect Levels	Lowest Effect Levels but < Severe Effect Levels OR • Metals > Probable Effect Levels but < Severe Effect Levels	
Thresholds based on Provincial (No Effect Level [NEL], Lowest Effect Level [LEL] & Severe Effect Level [SEL]) and Federal (Probable Effect Level [PEL]) Guidelines, and best professional judgement		

Benthic Community

Other influences on benthic invertebrate communities include substrate type, sample depth and nutrients (e.g. NH3 ammonia levels can be toxic to benthic organisms). While this measure does give some indication of overall health of the community and serves its purpose in the assessment as a measure of nearshore stress, there may be need for additional more detailed investigations in priority areas to assess risk such as toxicity and potential for biomagnification.

Datasets:

- **Erie Comprehensive Collaborative Study (ECCS) 2004**

The ECCS sampled 280 sites by Ponar grab (soft bottom) or airlift (hard bottom) across Lake Erie between May and August 2004 as part of a benthic community assessment. Data from the survey include densities (number per m2) of 53 benthic taxa identified to lowest taxonomic level possible. There is also some habitat and general water quality data for most locations.

- 2018 Lake Erie Assessment: 160 sites from the ECCS 2004 data

- **ECCC CABIN Canadian Aquatic Biomonitoring Network**

The Canadian Aquatic Biomonitoring Network is an aquatic biomonitoring program for assessing the health of fresh water ecosystems in Canada. Benthic macroinvertebrates are collected at a site location and their counts are used as an indicator of the health of that water body. Reference sites represent habitats that are closest to "natural" before any human impact.

- 2019 Lake Ontario Assessment: 2006, 2007, 2010-2012 & 2014 Great Lakes Action Plan Area of Concern and Reference Sites
- 2021 Lake Huron Assessment: 2010-2014 Great Lakes Action Plan Area of Concern and Reference Sites

*Note that the CABIN data is not available for public download.

- **MECP Benthic Invertebrate Community (Great Lakes Nearshore Areas)**

Contains information on benthic invertebrate community structure of samples collected from nearshore index monitoring stations within a Great Lake basin each year. The composition of benthic invertebrates found in a sample is used as a biological indicator of trophic status and general environmental conditions to help understand ecosystem function, structure and change.

Surveys typically conducted in one of the Great Lakes basins each year; in most cases, five replicate samples were collected at each station.

- 2019 Lake Ontario Assessment: 2006, 2009 & 2012 MECP data
- 2020 Lake Superior Assessment: 2011 MECP data

Assessment methodology:

The assessment for this measure follows the same general methodology but is slightly different for each lake. Generally, the methodology is to characterize benthic communities by total benthos (density of all macroinvertebrates), taxon richness (number of lowest level taxa at a site) and average tolerance to disturbance* or evenness of the individuals present at a site:

- Conduct a Principle Components Analysis (PCA) on the three benthos descriptors – total benthos, lowest level taxon richness and site sensitivity score (Lake Erie) or evenness (Lake Ontario, Lake Superior, Lake Huron)
- Lake Erie: Based on the first 2 axes from the PCA, calculate a gradient (range the axes from 0 to 1 and then multiply Axis 1 by Axis2) aligned with increasing total benthos, increasing taxon richness and increasing sensitivity of site individuals (= decreasing tolerance)
- Lake Ontario: Based on the first 2 axes from the PCA, a quality gradient aligning with increasing total benthos, increasing taxon richness and increasing evenness
- Lake Superior & Lake Huron: Based on the first 2 axes from the PCA, a quality gradient aligning with increasing total benthos, increasing taxon richness and increasing evenness was assigned to the line through the origin; scores were projected perpendicularly onto the quality gradient line
- Calculate 33rd and 67th percentiles of the gradient values to divide the range of values into thirds, which define low, moderate and high quality benthic communities
- The number of sites in each low, moderate and high quality categories tallied for each Regional Unit
- The category that divided the sites in half was identified to characterize the "median" quality of the Regional Unit and assign a relative measure of quality for each site

*Average tolerance to disturbance of individuals at a site calculated using taxon tolerance values (obtained from literature) and densities of various taxa at a site. Site tolerance scores calculated by multiplying the density of each taxon at a site by its tolerance score, summing the product for each site and dividing by the total benthic density of the site.

For detailed methodology on each lake's Benthic Community measure assessment, refer to the:

- Lake Erie Canadian Nearshore Assessment 2018 Results Report
- Lake Ontario Canadian Nearshore Assessment 2019 Results Report
- Lake Superior Canadian Nearshore Assessment 2020 Results Report
- Lake Huron Canadian Nearshore Assessment 2021 Results Report

Thresholds for Benthic Community (all lakes):

LOW STRESS	MODERATE STRESS	HIGH STRESS
Benthic community condition is functional	Benthic community condition is degraded	Benthic community condition is severely degraded and not

and of high diversity (top 67th percentile of scores)	but functional (33rd to 67th percentile of scores)	functional (bottom 33rd percentile of scores)
Thresholds based on statistical analysis by Environment and Climate Change Canada		

Category Score for Contaminants in Water and Sediment

Not all measures in this category have equal weight in the assessment. Water Quality was assigned less weight because a small number of water samples collected at a limited number of points in time are not necessarily representative of chronic exposure conditions. Although water chemistry measures are generally collected and analyzed using standardized procedures and therefore are reliable, they are not necessarily linked to the specific input from a Regional Unit. On the other hand, sediment chemistry data is less dynamic and integrates the cumulative inputs of chemical stressors from a Regional Unit. Lake sediment is a sink for particles and contaminants that enter from the watershed, from point and non-point source discharges or from atmospheric deposition but can also be a source to the water column or biota. Benthic Community measurements provide an additional level of integration of chemical stressors with physical stressors and assigned a higher weight. The approach of assigning lower weight to static, point in time measurements of chemistry (which measure exposure) and higher weight to field measurements in the biological community (which measure effect) is common in Weight-of-Evidence Assessments (Golder Associates Ltd. 2018).

Category Score:

- Assign a Category Score based on Table 8

Table 8. Weight of Evidence Scoring Key for Contaminants in Water & Sediment (H=High Stress; M=Moderate Stress; L=Low Stress; ?=No Data) Note: Sediment Quality and Benthic Community are assigned a higher weight (++) than Water Quality

Water Quality (+)	Sediment Quality (++)	Benthic Community (++)	Category Score
L	L	L	L
L	L	M	L
L	L	H	M
L	L	?	L
L	M	L	L
L	M	M	M
L	M	H	M
L	M	?	M
L	H	L	M
L	H	M	M
L	H	H	H
L	H	?	M
L	?	L	L
L	?	M	M
L	?	H	M
L	?	?	?
M	L	L	L
M	L	M	M
M	L	H	M

M	L	?	L
M	M	L	M
M	M	M	M
M	M	H	M
M	M	?	M
M	H	L	M
M	H	M	M
M	H	H	H
M	H	?	H
M	?	L	L
M	?	M	M
M	?	H	H
M	?	?	?
H	L	L	L
H	L	M	M
H	L	H	M
H	L	?	M
H	M	L	M
H	M	M	M
H	M	H	H
H	M	?	M
H	H	L	H
H	H	M	H
H	H	H	H
H	H	?	H
H	?	L	L
H	?	M	M
H	?	H	H
H	?	?	?
?	L	L	L
?	L	M	M
?	L	H	M
?	L	?	L
?	M	L	M
?	M	M	M
?	M	H	H
?	M	?	M
?	H	L	M
?	H	M	H
?	H	H	H
?	H	?	H
?	?	L	L
?	?	M	M
?	?	H	H
?	?	?	?

Nuisance & Harmful Algae

Cyanobacteria

Datasets:

- **NOAA Harmful Algal Bloom Monitoring System**

The Harmful Algal Bloom (HAB) – Forecasting Branch is a research group within the National Oceanic and Atmospheric Administration (NOAA), National Center for Coastal Ocean Science tasked with forecasting and monitoring HABs. This is done through satellite based monitoring to provide a synoptic view at high temporal resolution. Water colour can be used as a proxy for various geophysical parameters and several standardized products are generated from mapped reflectance by the HAB – Forecasting Branch. One such product, a Cyanobacteria Index (CI), detects large monospecific blooms of cyanobacteria in the Great Lakes, primarily *Microcystis aeruginosa*.

- 2018 Lake Erie Assessment: 10-day composite images from the MODIS satellite, with Cyanobacteria Index algorithm; June to October, 2012-2017
- 2019 Lake Ontario Assessment: 10-day composite images from the MODIS satellite, with Cyanobacteria Index algorithm; June to October, 2016-2018
- 2020 Lake Superior Assessment: 7-day composite images from the OLCI sensor with Cyanobacteria Index algorithm; June to October, 2019
- 2021 Lake Huron Assessment: 7-day composite images from the OLCI sensor with Cyanobacteria Index algorithm; June to October, 2019

Raster composites provided to ECCC from NOAA. For more information on NOAA's HAB Forecasting Branch, see:

Harmful Algal Bloom Forecasting Branch Ocean Color Satellite Imagery Processing Guidelines - NCCOS Coastal Science Website (noaa.gov)

Assessment methodology:

NOAA file description:

<composite>_yyy_mmdd_mmdd_<edited>_<ftype>.tif

<composite>	image is a composite
yyyy	4-digit year
mmdd	month of year (zero-prefixed); day of month (zero-prefixed) START
mmdd	month of year (zero-prefixed); day of month (zero-prefixed) END
<edited>	imagery has been edited
<ftype>	file type

Version:	1.0
Description:	Chlorophyll Cyanobacteria Index
Scaling:	DN=100*(log10(CI)+4)
Reverse Scaling:	CI=10^(DN/100-4) e.g. DN=100 (translates to original value of .0010)
Type:	1-band dataset

Data Key:

0: no coverage

1: no detection

2-249: scaled, valid data
250: above range
252: land
253: cloud
254: mixed/invalid

Assessment Methodology

In GIS (e.g. ESRI ArcMap), assemble the relevant composites

1. Cyanobacteria composites are single band raster datasets, need to add an attribute table to extract values
    - In ArcMap, use Build Raster Attribute Table tool on each composite
2. *Microcystin* produce noxious and toxic compounds that can cause a range of detrimental impacts to both ecosystem and human health; NOAA's Cyanobacteria Index (CI) is effective at identifying these severe cyanobacterial blooms and appears to be able to differentiate cyanobacteria from high sediment loads. Severity is defined here by pixels whose value exceeds the World Health Organization guideline (guideline value for total *microcystin* (toxin) is 1 ug/L in drinking water, which is equal to 100 on the CI scale)
    - Extract by Attributes <composite> WHERE 'value' >99 AND <250
        - Output is new bloom composite (only pixels whose value is 100-249)
3. For each bloom composite, generate MIN, MEAN, MAX, RANGE, AREA statistics to further analyze the data
    - Zonal Statistics as Table tool to summarize the extent of the bloom within each zone (Regional Unit)
4. For each bloom composite, use statistics to calculate the area of the bloom and the percent of the Regional Unit that is covers (extent)
    - Extent= BloomArea_km2/RegUnit_km2
5. Identify any 10-day or 7-day composites where the bloom extent exceeded the assigned thresholds to assess whether there are concerns to human and ecosystem health due to Cyanobacteria

Binational and domestic nutrient management effort under the GLWQA and the (draft) Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (COA), 2020 focus on limiting cyanobacteria blooms in the western basin of Lake Erie to levels below those seen in 2012, which was considered a mild bloom year. This corresponds to 20% of Canada's portion of the western basin (Western Basin Regional Unit). Outside of the Western Basin, the occurrence of a bloom of any size is considered to be high stress, however to account for the level of accuracy of the satellite imagery, a 2% extent threshold was adopted for all other Regional Units to avoid false positives.

Thresholds for Cyanobacteria (lake specific):

LAKE ERIE		
LOW STRESS	MODERATE STRESS	HIGH STRESS – Flag (!)
Western Basin Regional Unit: cyanobacteria bloom covers	n/a *Cyanobacteria considered a concern to*	Western Basin Regional Unit: cyanobacteria bloom covers

less than 20% of the total Regional Unit area in any 10-day composite in June-October 2012 to 2017 All other Regional Units: cyanobacteria bloom covers less than 2% of the total Regional Unit area in any 10-day composite in June-October 2012 to 2017	*human and ecosystem health so any bloom detected is flagged as a source of stress*	more than 20% of the total Regional Unit area in any 10-day composite in June-October 2012 to 2017 All other Regional Units: cyanobacteria bloom covers more than 2% of the total Regional Unit area in any 10-day composite in June-October 2012 to 2017
LAKE ONTARIO		
LOW STRESS	MODERATE STRESS	HIGH STRESS – Flag (!)
No Cyanobacteria bloom detected for any 10 day composite in 2016, 2017 or 2018 that exceeds 2% of the total Regional Unit area.	n/a *Cyanobacteria considered a concern to human and ecosystem health so any bloom detected is flagged as a source of stress*	Cyanobacteria bloom detected for any 10 day composite in 2016, 2017 or 2018 that exceeds 2% of the total Regional Unit area.
LAKE SUPERIOR & LAKE HURON		
LOW STRESS	MODERATE STRESS	HIGH STRESS – Flag (!)
No Cyanobacteria bloom detected for any 7 day composite in 2019 that exceeds 2% of the total Regional Unit area.	n/a *Cyanobacteria considered a concern to human and ecosystem health so any bloom detected is flagged as a source of stress*	Cyanobacteria bloom detected for any 7 day composite in 2019 that exceeds 2% of the total Regional Unit area.
Thresholds based on the World Health Organization cyanobacteria guidelines		

Cladophora

Datasets:

- **MTRI Satellite-Derived Lake Submerged Aquatic Vegetation (SAV) Mapping**

Michigan Tech Research Institute (MTRI) has generated satellite-derived submerged aquatic vegetation (SAV) maps for the Great Lakes that represent the extent of SAV in the optically shallow areas. The SAV is predominantly *Cladophora* with localized areas of vascular plants, other filamentous macro algae or diatoms. The mapping has a 30 m resolution and was generated using an MTRI depth variant algorithm using Landsat satellite data, collected during the vegetative growing season. It is intended serve as a baseline and enable communities to monitor changes in the spatial extent of SAV. Note that this data was received via personal communication.

- 2018 Lake Erie Assessment: 2016-2018 (Landsat 8) SAV mapping
- 2019 Lake Ontario Assessment: 2016-2018 (Landsat 8) SAV mapping
- 2020 Lake Superior Assessment: no data available
- 2021 Lake Huron Assessment: 2016-2019 (Landsat 8) SAV mapping

Assessment methodology:

NOTE the *Cladophora* measure does not apply to Regional Units that are dominated by unconsolidated substrate, highly erosive coastlines and embayments characterized by coastal wetlands nor connecting channels. In areas where coastal wetlands are prevalent, consider that areas classified as either sparse or dense SAV in the MTRI mapping may actually be wetland associated SAV and not nuisance *Cladophora.*

Cladophora is assessed using the following steps:

In GIS (e.g. ESRI ArcMap), assemble the MTRI SAV mapping and Regional Units

1. Create a polygon file from the raster MTRI SAV mapping geotiff
    - Conversion Tool (From Raster to Polygon) using the gridcode value
    - Add Field to the output polygon file and assign a MTRI classification to each gridcode:
        i. Add Field 'descr' (text)

    WHERE gridcode = 1, 'descr' = "sparse SAV" or "less dense SAV"

    WHERE gridcode = 3, 'descr' = "uncolonized substrate"

    WHERE gridcode = 7, 'descr' = "dense SAV"

    WHERE gridcode = 9, 'descr' = "not classified due to turbidity"
2. Assign SAV mapping to Regional Units
    - Intersect tool to compute the geometric intersection of SAV polygon (from Step 1) with Regional Units
    - Output polygon should have all attributes of both the Regional Units and MTRI SAV polygons
3. Determine the extent of SAV mapping within each Regional Unit
    - Dissolve polygon derived in Step 2 by RegUnit_ID, RegUnit_Type and MTRI classification (descr assigned in Step 1)
    - Output polygon should have no more then 3 records for each Regional Unit, one each for sparse SAV, unconsolidated substrate and dense SAV (where detected):
    - Add Field 'areaHA' (double) to output polygon and calculate the area of each polygon
4. Summarize the extent of SAV within the total MTRI mapped area:
    - Extent of MTRI mapped area within Regional Unit = sparse SAV + unconsolidated substrate + dense SAV
    - Extent of *Cladophora* within Regional Unit: sparse SAV + dense SAV

    The MTRI SAV mapping is satellite-derived (Landsat 8) and therefore limited to the optical depth of the satellite; for Landsat 8 this is approximately between 6 and 8 m. Additionally, *Cladophora* needs light for optimal growth, so generally prefers the shallower photic zone of nearshore waters. For these reasons, it is not appropriate to calculate the extent of SAV detected as a percent of the total area of a Regional Unit since the offshore boundaries exceeds 8 m in all lakes. Instead, the area of SAV detected and classified as sparse or dense within each

Regional Unit is calculated as a percent of only the total extent of the MTRI mapped area (sparse SAV + unconsolidated substrate + dense SAV).

5. Calculate the percent of the total MTRI mapped area that is classified as SAV, within each Regional Unit
   - (Sparse SAV + dense SAV)/(Sparse SAV + unconsolidated substrate + dense SAV) = % SAV extent
6. Assign stress, using the following thresholds:
   - <20% SAV extent = Low Stress
   - 20-35% SAV extent = Moderate Stress
   - >35% SAV extent = High Stress

Data Limitations: The employment of satellite based products provides an opportunity for regular, extensive mapping of the nearshore for *Cladophora*. The temporal and spatial scale of satellite mapping is not achievable through traditional boat based monitoring programs. The *Cladophora* product would be enhanced if high-resolution substrate mapping existed for each Great Lake. It's well documented that *Cladophora* needs to be attached for growth, this typically occurs on cobble, boulders, and bedrock substrate. By overlapping areas mapped as unconsolidated or sandy substrates, with detectable SAV, those areas could be eliminated from the product, further refining potential habitat the from the observed *Cladophora* growth areas. Dreissenid mussels and theirs shells are also known to be suitable substrate for growth. Substrate mapping that includes dreissenid mussel beds would again, refine the assessment by mapping suitable *Cladophora* growth habitat.

MTRI analyzed SAV for each Great Lake between 2016 and 2018. By expanding the analysis annually, changes in extent of *Cladophora* could be detected, leading to better understanding of interannual variability and growth patterns, and reduce uncertainty in models.

Cladophora is known to impact ecosystem health by growing on and smothering fish spawning reefs, and providing growth opportunities for bacteria such as botulism. From a human use perspective, sloughed material is having an equal if not larger impact by fouling area beaches, clogging water intakes and reducing property values along the coast. Researching the transport and deposition of sloughed *Cladophora* has been identified as an important gap to be filled such that nutrient reduction efforts are having their intended response in *Cladophora* growth. Citizen scientists along the Niagara portion of Lake Erie's coast are surveying *Cladophora* wash-up throughout the summer months, to help researchers understand where and when *Cladophora* is causing problems locally. There is interest in expanding this community based monitoring to Lake Ontario. Incorporating this data into the *Cladophora* measure may provide a more robust nearshore assessment.

While there have been a number of caveats identified regarding the inclusion of *Cladophora* as measure in the overall assessment, disregarding it would be a greater gap. It is a significant stressor of not only nearshore ecosystem health, but the social and economic co-benefits provided by the lakes. Bi-nationally, communities, governments and stakeholders are interested in improving their understanding of the drivers of *Cladophora* growth and ways it can be controlled. The intent is to share results with both Lake Erie and Lake Ontario communities, scientists and researches, as supplementary science and to determine priorities for action.

Thresholds for *Cladophora* (all lakes, where measure applies):

LOW STRESS	MODERATE STRESS	HIGH STRESS
<20% SAV Coverage	20-35% SAV Coverage	>35% Coverage
Thresholds based on best professional judgement (ECCC Nutrients Team)		

Dissolved Oxygen (Lake Erie only)

Datasets:

- **ECCC Great Lakes Water Quality Monitoring and Surveillance Data**

Water quality data collected by ECCC to meet commitments related to the Great Lakes Water Quality Agreement. The data is to determine baseline water quality status, long term trends and spatial distributions, effectiveness of management actions, compliance with water quality objectives and to identify emerging issues.

The Water Quality Monitoring and Surveillance Data is water quality and ecosystem health data collected in the Great Lakes and priority tributaries to determine baseline water quality status, long term trends and spatial distributions, the effectiveness of management actions and to determine compliance with water quality objectives

Assessment methodology:

Access the Great Lakes Water Quality Monitoring and Surveillance Data from the Government of Canada Data Catalog

1. In excel, query records for dissolved oxygen samples taken between 2012 and 2014 (‘FULL_NAME’=OXYGEN, CONCENTRATION DISSOLVED)
2. Add the queried records to GIS (e.g. ESRI ArcMap) and plot records using latitude and longitude; export to new data set
3. Assign appropriate Regional Unit ID to each record, based on the unit it falls within
4. Convert the table back to excel and sort the ‘VALUE’ field in order to identify stations where dissolved oxygen concentrations are below acceptable ranges for aquatic life
    - A sample that has levels of dissolved oxygen (DO) below the acceptable threshold for aquatic life is assigned to the Regional Unit as a source of stress
        - The Canadian Water Quality Guidelines for the Protection of Aquatic Life lowest acceptable dissolved oxygen concentration is 6000 ug/L (6 mg/L)
    - Count the total number of samples below acceptable thresholds within each Regional Unit

Data Limitations*:* This measure relied on dissolved oxygen data collected by Environment and Climate Change Canada’s Water Quality Monitoring Program. This is a ship-based sampling program that can be limited spatially and temporally by the size of the Great Lakes and by weather that restricts sampling effort. Large research vessels typically used for this program cannot always access the nearshore waters due to depth limitations. As a result, it would be very unlikely that monitoring vessels would be in the vicinity to capture the hypoxic waters reaching the nearshore.

NOAA's Great Lakes Environmental Research Laboratory in collaboration with the City of Cleveland Division of Water, Purdue University, and U. S. Geological Survey, has launched a five year project using buoyed instrumentation to model and forecast hypoxic episodic events impacting the nearshore of Lake Erie, both in the US and Canada. Hypoxic water that enters water treatment plants can lead to taste, odour and discolouration problems in drinking water. The models are providing advanced warning to treatment plant operators (US currently), so adjustments can be made to the water treatment process. As part of the effort, moorings at eight locations in Lake Erie capture temperature and dissolved oxygen at multiple levels in the water column. If possible, this additional source of data may be used to fill spatial and temporal data gaps across Lake Erie. The overall assessment has used remote sensing data and point-measurement data, but has not yet incorporated modelling data. Work would be required to ensure that modelled results are successfully ground-truthed. The NOAA project began in 2017, and is expected to have detailed results in 2022. This could lead to improvements in the dissolved oxygen measure in the nearshore assessment for Lake Erie.

Thresholds for Dissolved Oxygen/Hypoxia (Lake Erie only):

LOW STRESS	MODERATE STRESS	HIGH STRESS
All DO samples are greater than 6 mg/L in a Regional Unit	One or more DO samples are between 2 and 6 mg/L in a Regional Unit	One or more DO samples are less than 2 mg/L in a Regional Unit
Thresholds adopted from the Canadian Water Quality Guidelines for the Protection of Aquatic Life		

Category Score for Nuisance and Harmful Algae

Assessment Methodology:

- Assign a Category Score based on Table 9
- Apply a Flag "**!**" for the Regional Unit Category score where Cyanobacteria exceeds the thresholds given the imminent risk to human and ecosystem health

Table 9. Weight of Evidence Scoring Key for Nuisance & Harmful Algae
(H=High Stress; M=Moderate Stress; L=Low Stress; ?=No Data) Note: Cyanobacteria is assigned a higher weight (++) than *Cladophora* and Dissolved Oxygen

Cyanobacteria (++)	*Cladophora* (+)	Dissolved Oxygen (+)	Category Score
L	L	L	L
L	L	M	L
L	L	H	M
L	L	?	L
L	H	L	M
L	H	M	M
L	H	H	M
L	H	?	M
L	?	L	L
L	?	M	L
L	?	H	M

L	?	?	L	
L	M	L	L	
L	M	M	M	
L	M	H	M	
L	M	?	L	
H	L	L	H	! Concern to Human and Ecosystem Health due to Cyanobacteria
H	L	M	H	
H	L	H	H	
H	L	?	H	
H	M	L	H	
H	M	M	H	
H	M	H	H	
H	M	?	H	
H	H	L	H	
H	H	M	H	
H	H	H	H	
H	H	?	H	
H	?	L	H	
H	?	M	H	
H	?	H	H	
H	?	?	H	
?	L	L	L	
?	L	M	M	
?	L	H	M	
?	L	?	?	
?	H	L	M	
?	H	M	H	
?	H	H	H	
?	H	?	?	
?	?	L	?	
?	?	M	?	
?	?	H	?	
?	?	?	?	

Human Use

Beach Postings

Public beaches are monitored by provincial Health Units and, in Provincial Parks by Ontario Parks. Beaches may be closed for reasons such as physical safety, however this measure focuses on beach postings related to Escherichia coli (E.coli) as an indicator of contamination by bacteria and pathogens. The Health Units and Ontario Parks compare water samples to provincial standards.

In 2018 there was a change in provincial guidelines from 100 *E.coli*/100 ml to 200 *E.coli*/100 ml. Current provincial guidelines for recreational water quality can be found here: http://www.health.gov.on.ca/en/pro/programs/publichealth/oph_standards/docs/protocols_guidelines/Operational_Approaches_to_Rec_Water_Guideline_2018_en.pdf

Although many Health Units monitor beaches from May to September, this measure considers postings only for the months of July and August as these months represent the time of year when beaches are most heavily used and when higher temperatures may exacerbate recreational water quality issues. Not all publically accessible beaches are monitored and those beaches were not considered in this assessment.

Datasets:

- **The Swim Guide**

A website managed by Swim Drink Fish Canada which shares the results of recreational beach monitoring done by local Health Units and Provincial Parks in a common web mapping platform; provides summaries of postings by month (percent of time 'pass' or 'fail' during a specific interval).

- 2018 Lake Erie Assessment: July and August, 2016-2017
- 2019 Lake Ontario Assessment: July and August, 2018
- 2020 Lake Superior Assessment*: July and August, 2015-2019
- 2021 Lake Huron Assessment: July and August, 2016-2020

*Note that for the 2020 Lake Superior Assessment, monitoring information for beaches within the Thunder Bay District Health Unit are not on the Swim Guide; data for these beaches was obtained directly from the Health Unit.

Assessment methodology:

1. Access the Swim Guide
    - Navigate to the *Beach Finder page and use the map to identify all beaches that are on the coast of the Great Lake or connecting channel*
    - Select each beach icon and click *More Data* to launch a new page with the beach details
2. Create an database table (e.g. Microsoft Excel) and extract the following information for each beach:
    - Name: located in the top left corner
    - Latitude and Longitude: select the *Get directions to this beach* link which directs user to Google Maps and copy & paste the geographic coordinates
    - Percent time that the beach was posted in July and August, for relevant assessment years: use the Water Quality Graph in the bottom right of the page, select 'INTERVAL' to be 'Monthly' and use the 'TIME PERIOD' menu to select the appropriate month and year (see Figure 2)
3. Calculate the percent of July and August that beaches were posted for each Regional Unit, during the relevant assessment years
    - Calculate the average % posted for all months for each beach
    - Calculate the average % posted for all beaches within a Regional Unit (see Table 10)
    - Note: on Lake Superior, beaches within the Thunder Bay District Health Unit do not appear in the Swim Guide; the number of days that a beach was posted as unsafe for swimming was interpreted from sampling data provided directly by the Thunder Bay District Health Unit and then summarized by month

4. Apply thresholds where applicable; if a Regional Unit has no monitored beaches then it is scored as N/A (Not Applicable)

Figure 2. Sample Water Quality graph from the Swim Guide, used to extract the percent of time that a beach is posted

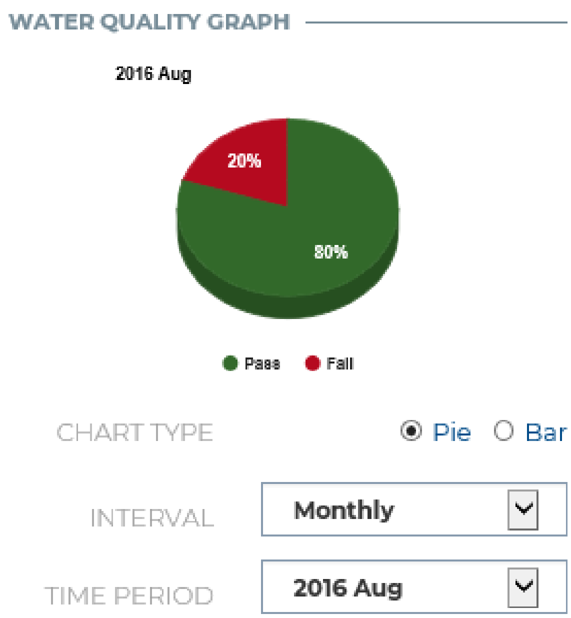


Table 10. Example of calculating the average % of time in July and August that beaches were posted, and the average % of time that all beaches in a Regional Unit were posted

Beach Name	RU ID	% Posted July 2018	% Posted Aug 2018	Average % Posted July & Aug 2018	Regional Unit Average
Centre Island Beach	LO06	3	7	5	4.30
Cherry Beach	LO06	0	13	6.5	
Gilbraltar	LO06	3	0	1.5	
Hanlan's Point Beach	LO06	0	7	3.5	
Ward's Island Beach	LO06	0	10	5	

Data Limitations*:* Not all areas accessible for swimming are regularly monitored for recreational water quality. Increasing monitoring locations would improve understanding of water quality at the Regional Unit scale. Some beaches are only sampled weekly or greater. Increasing the frequency of sampling at existing sites would provide a more accurate count of how many days of July and August the water does not meet provincial standards. Modelling water quality may provide a method for improving the temporal and spatial resolution of the data compared to the current site sampling.

Thresholds for Beach Postings (all lakes):

LOW STRESS	MODERATE STRESS	HIGH STRESS
Beaches posted 5% or less days during summer months (July/August)	Beaches posted 5 to 20% of days during summer months (July/August)	Beaches posted more than 20% of days during summer months (July/August)
Thresholds were set using best professional judgement		

Fish Consumption

This measure reports on potential risk to human health from eating nearshore fish species most likely consumed from each Great Lake. Note that the fish consumption measure is a compilation of consumption advisories for multiple nearshore species and is not to be used for advice on fish consumption for the public. The Provincial Guide to Eating Ontario Fish[14] provides information to help choose fish to minimize exposure to toxins and can be found online and is based on guidelines provided by Health Canada. While the Guide provides consumption advice for both the General and Sensitive population, this measure is precautionary and focuses on the Sensitive population. Women of child-bearing age, including pregnant and nursing mothers, can affect the health of their baby through a diet elevated in contaminants such as mercury and polychlorinated biphenyls and children under the age of 15, including fetuses, can be affected by contaminants at lower levels than the General population. Due to these higher risks, the Sensitive population is advised to only eat the least contaminated fish. Further, this measure does not include consumption advice for Indigenous people, who may have a subsistence diet comprised largely of fish. The fish consumption measure is only intended to quantify differences in consumption advisories across nearshore regional units.

With varying ecosystems and nearshore habitat, each of the Canadian Great Lakes support different nearshore fish communities. Lake Erie's warm, nutrient rich waters and coastal wetlands support Walleye, Yellow Perch and Smallmouth bass; Lake Ontario and Lake Huron are colder, oligotrophic lakes whose embayments and coastal wetlands provide habitat for nearshore species such as Walleye, Yellow Perch and Northern Pike; and Lake Superior, with its cold, deep, oligotrophic water supports nearshore populations of Lean Lake Trout and Lake Whitefish as well as Yellow Perch in some of the embayments. The fish selected for each lake assessment are based on consultation with provincial experts (e.g. MECP, MNRF) and are intended to reflect local conditions (i.e. fish that are primarily restricted to nearshore waters) and known angling and consumption preferences according to recent creel surveys. Although the Fish Consumption measure is not focused on a specific contaminant of concern, in the Great Lakes, those most responsible for fish consumption advisories are mercury, PCBs, dioxins/furans and toxaphene.

[14] Ontario Ministry of Environment, Conservation and Parks. Guide to Eating Ontario Fish: advisory database. Accessed from Guide to Eating Ontario Fish: advisory database - Datasets - Ontario Data Catalogue

Datasets:

- **MECP Guide to Eating Ontario Fish Advisory Database**

The Guide to Eating Ontario Fish is a biennial publication of consumption advisories for fish from Ontario's lakes and rivers that provides essential human health information. This includes data on levels of contaminants in fish which are collected to assess the health implications of consuming fish. Raw contaminant concentrations are compared to consumption limits based on Health Protection guidelines from Health Canada.

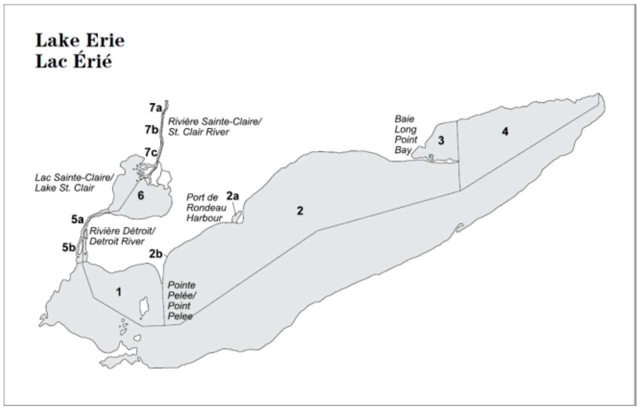
The advisory table houses all consumption advisory values in meals per month of fish. Advisories are based on power series regressions of contaminant concentrations versus length, for a particular year/collection and are produced for 13 size categories, each spanning 5 cm intervals (15 cm to > 75 cm).

- 2018 Lake Erie Assessment: Walleye (35-55 cm), Yellow Perch (20-30 cm) and Smallmouth Bass (20-45 cm); Sensitive Population; Guide Years 2015 & 2017
- 2019 Lake Ontario Assessment: Walleye (35-55 cm), Yellow Perch (20-30 cm) and Northern Pike (50-70 cm); Sensitive Population; Guide Years 2015 & 2017
- 2020 Lake Superior Assessment: Lake Trout (40-70 cm), Yellow Perch (20-30 cm) and Lake Whitefish (40-60 cm); Sensitive Population; Guide Year 2015, 2017, 2020
- 2021 Lake Huron Assessment: St. Mary's River/North Channel/Manitoulin & Eastern Georgian Bay (LH01-LH10) – Yellow Perch (20-30 cm), Walleye (35-60 cm)Smallmouth Bass (30-50 cm); Christian Island to St. Clair River (LH11-LH23) – Yellow Perch (20-30 cm), Walleye (35-60 cm), Rainbow Trout (40-70 cm) and Lake Trout (45-70 cm); Sensitive Population; Guide Year 2020

Assessment Methodology:

1. Identify which Fish Guide Sampling Block corresponds to which Regional Unit
    - Access the Guide to Eating Ontario Fish and use geographic description on the map of the Sampling Blocks to identify which Regional Unit it corresponds to (see Figure 3); use best professional judgement to visually assess which Regional Unit that a Sampling Block falls primarily within
    - As a general rule, if a Sampling Block covers less than 20% of the Regional Unit, it should not be considered to correspond to the Regional Unit
    - Embayments at river mouths draining directly into the lake should be included
    - There may be additional information for small embayments on the regularly updated interactive web tool that can be referenced to identify embayments with advisories that correspond to Regional Units

Figure 3. Example of Sampling Block map and corresponding descriptions



Lake Erie Block Descriptors

1. **Western Basin** – from the Detroit River mouth to Point Pelee
2. **Central Basin** – from east of Point Pelee to just west of Long Point Bay

2a. **Rondeau Bay** – Rondeau Harbour and immediate surrounding area

2b. **Wheatley Harbour** – Harbour and immediate vicinity

3. **Long Point Bay** – inner and outer bay area
4. **Eastern Basin** – from east of Long Point Bay to the Niagara River

Detroit River Block Descriptors

5a. **Upper** – from Lake St. Clair to Fighting Island

5b. **Lower** – from south of Fighting Island to Lake Erie

6. Lake St. Clair

St. Clair River Block Descriptors

7a. **Upper** – from Lake Huron to just north of Ethyl Corp.

7b. **Middle** – from Ethyl Corp./Stag Island to just north of Lambton Generating Station

7c. **Lower** – from Lambton Generating Station to Lake St. Clair

2. Access the MECP Guide to Eating Ontario Fish advisory database
3. Query relevant advisory data
    - In Microsoft Excel, extract relevant data from the Guide to Eating Ontario Fish Advisory Database; each lake has different parameters:
        - Sampling Blocks identified in Step 1 (‘GUIDE_LOCNAME_ENG’)
        - Sensitive Population (‘POPULATION_TYPE_DESC’)
        - Guide Years (‘GUIDE_YEAR’)
        - Fish Species (‘SPECNAME’)
        - Class Sizes (‘LENGTH_CATEGORY_LABEL’)
        - Number of meals (‘ADV_LEVEL’)
4. Assign Regional Unit ID to each record based on Sampling Block ID
    - Add a new column for ‘RegUnit_ID’
5. Calculate the average number of meals for each species in each Regional Unit
    - For each of the fish species in the assessment (e.g for Lake Erie: Yellow Perch, Walleye and Smallmouth Bass) calculate the average number of meals for all of the relevant class sizes, for each Regional Unit
    - For Regional Units with more than one Sampling Block, calculate the average number of meals for each class size by Sampling Block, and then average the Sampling Blocks within the Regional Unit (see Table 11)
6. Calculate the average number of meals for each Regional Unit
    - For each Regional Unit, calculate the average meals for all of the fish species (see Table 11)
7. Apply thresholds by rounding the results to the nearest whole number (meal)

Table 11. Sample calculation of the average number of meals for a single species when the Regional Unit has more than one Sampling Block

RU_ ID	Sampling Block	Species	Class Size	Meals	Avg meals of Class Size	Average meals of Species
LO01	Lake Ontario 1a - Upper Niagara River	Walleye	35-40cm	8	8	6
LO01	Lake Ontario 1b - Lower Niagara River	Walleye	35-40cm	8		
LO01	Lake Ontario 1a - Upper Niagara River	Walleye	40-45cm	8	8	
LO01	Lake Ontario 1b - Lower Niagara River	Walleye	40-45cm	8		
LO01	Lake Ontario 1a - Upper Niagara River	Walleye	45-50cm	4	4	
LO01	Lake Ontario 1b - Lower Niagara River	Walleye	45-50cm	4		
LO01	Lake Ontario 1a - Upper Niagara River	Walleye	50-55cm	4	4	
LO01	Lake Ontario 1b - Lower Niagara River	Walleye	50-55cm	4		

Thresholds for Fish Consumption (all lakes):

LOW STRESS	MODERATE STRESS	HIGH STRESS
≥8 meals per month	Between 1 and 7 meals per month	Less than 1 meal per month
Thresholds developed through consultation with the Ontario Ministry of Environment Conservation and Parks		

Treated Drinking Water

The Overall Assessment of Nearshore Waters uses available Provincial data on adverse water quality incidents (AWQIs) at drinking water treatment plants. If there is an exceedance in any of the Ontario Drinking Water Quality Standards (O. Reg. 169/03)[15] then an AWQI is triggered. A notice is sent to the relevant Health Unit who take further action on advising the public, as needed. The purpose of the Treated Drinking Water measure is to assess whether the public is restricted from consuming treated drinking water. In most cases, the occurrence of a single AWQI is not considered to be a problem. Therefore, for the purposes of this assessment, AWQI's that lasted for two or more consecutive samples were used to assign High Stress. There is no Moderate Stress assigned to this measure, as restrictions on treated drinking water

[15] O. Reg. 169/03: Ontario Drinking Water Quality Standards under *Safe Drinking Water Act, 2002, S.O. 2002, c. 32*. Accessed from https://www.ontario.ca/laws/regulation/030169

are considered to be a serious concern to human health. If there are no treated drinking water plants within a Regional Unit, no level of stress is assigned.

Assessment methodology:

1. Determine which Regional Unit each Drinking Water System facility is in
2. For each of the Drinking Water System facilities, query data to assess whether AWQI's were reported that lasted for two or more consecutive samples

Tally the number of AWQI lasting for two or more consecutive samples in a Regional Unit to assign a condition score.

Thresholds for Treated Drinking Water (all lakes):

LOW STRESS	MODERATE STRESS	HIGH STRESS
No adverse water quality incidents reported within Regional Unit	Does not apply - any incident is considered a high stress	1 or more adverse water quality incidents
Thresholds based on Ontario Drinking Water Quality Standards		

Category Score for Human Use

In the Human Use category all measures are weighted equally.

Assessment Methodology:

- Assign a Category Score based on Table 12

Table 12. Weight of Evidence Scoring Key for Human Use
(H=High Stress; M=Moderate Stress; L=Low Stress; ?=No Data; NA=Not Applicable [either no monitored beaches, or no treated drinking water plants in Regional Unit)

Beach Postings (+)	Fish Consumption (+)	Drinking Water (+)	Category Score
L	L	L	L
L	L	H	M
L	L	NA	L
L	M	L	L
L	M	H	M
L	M	NA	M
L	H	L	M
L	H	H	H
L	H	NA	M
L	?	L	L
L	?	H	M
L	?	NA	Data Gap
M	L	L	L
M	L	H	M
M	L	NA	M
M	M	L	M
M	M	H	M

M	M	NA	M
M	H	L	M
M	H	H	H
M	H	NA	H
M	?	L	M
M	?	H	H
M	?	NA	Data Gap
H	L	L	M
H	L	H	H
H	L	NA	M
H	M	L	M
H	M	H	H
H	M	NA	H
H	H	L	M
H	H	H	H
H	H	NA	H
H	?	L	M
H	?	H	H
H	?	NA	H
NA	L	L	L
NA	L	H	M
NA	L	NA	NA
NA	M	L	M
NA	M	H	H
NA	M	NA	NA
NA	H	L	M
NA	H	H	H
NA	H	NA	NA
NA	?	L	Data Gap
NA	?	H	Data Gap
NA	?	NA	NA

Data Gaps and Limitations

Table 13. Data gaps identified in the assessment, and the page on which they are described

Category	Measure	Comment	Page #
Contaminants in Water and Sediment	Water Quality	Limited data available at a scale that is regionally appropriate and offers coverage at a lake scale. Lacking thresholds and data for recent and emerging contaminants (eg. PFAS).	28
	Sediment Quality	Limited data available at a scale that is regionally appropriate and offers coverage at a lake scale	28
	Benthic Communities	Limited data available at a scale that is regionally appropriate and offers coverage at a lake scale	28
Nuisance and Harmful Algae	Cyanobacteria	10-day satellite composites not available for every Regional Unit	43-44
	Cladophora	High resolution substrate mapping would improve interpretation of satellite imagery Research on transport and deposition of sloughed *Cladophora*	47 47
	Dissolved Oxygen (Lake Erie only)	Limited spatial and temporal data. Hypoxic waters not always captured by sampling by ECCC ship-based monitoring due to depth. Potential for improvements based on use of buoyed instrumentation and modeling.	48
Human Use	Beach Postings	Not all public beaches are monitored and existing monitored beaches have limited spatial and temporal data.	52