Partnering on Achieving Phosphorus Loading Reductions in Lake Erie from Canadian Sources

A Draft Canada-Ontario Lake Erie Action Plan

November 2017

Lake Erie needs your help!

Harmful and nuisance algal blooms and zones of low oxygen have been increasing in Lake Erie over the past decade, causing significant impacts to both the environment and the Canadian economy. The risks to human health resulting from the toxins produced by these algal blooms are also a significant concern.

At the root of the problem is excess phosphorus. Targets for reducing phosphorus loads to Lake Erie from Canadian and U.S. sources to the lake have been established to tackle these issues. Although a tremendous amount of work has already been completed to achieve these targets, much more still needs to be done, with collective action required by all levels of government, First Nations and Métis communities, conservation authorities, key sectors, interest groups and the public.

Development of this action plan was a joint effort between the following federal and provincial government agencies and partners:

Led by:

- Environment and Climate Change Canada
- Agriculture and Agri-Food Canada
- Ontario Ministry of the Environment and Climate Change
- Ontario Ministry of Natural Resources and Forestry
- Ontario Ministry of Agriculture, Food and Rural Affairs

Additional actions provided by:

- ALUS Elgin
- Conservation Ontario
- City of London
- Ducks Unlimited Canada
- Fertilizer Canada and the Ontario Agri-Business Association Lake Erie Conservation Authorities
- Lake Erie Conservation Authorities
- Land Improvement Contractors of Ontario
- Municipality of Leamington

- Ontario Cover Crops Steering Committee led by Grain Farmers of Ontario
- Ontario Federation of Agriculture and Grow Ontario Together - a coalition of vested commodity associations
- Ontario Greenhouse Vegetable Growers

Executive summary

Partnering on Achieving Phosphorus Loading Reductions in Lake Erie from Canadian Sources sets out an action plan for reducing phosphorus loadings to Lake Erie with the goal of decreasing the presence of harmful and nuisance algal blooms as well as the zones of low oxygen (hypoxia) that threaten both the ecosystem and human health.

Based on robust scientific evidence, this plan includes cost-effective, high-impact actions that reflect a collective responsibility for environmental management. It proposes a variety of federal, provincial and partner actions that need to be co-ordinated and implemented by all sectors and communities in the Lake Erie basin, organized into five categories: reduce phosphorus loadings; ensure effective policies, programs and legislation; improve the knowledge base; educate and build awareness; and strengthen leadership and co-ordination.

The guiding principles of this plan include adaptive management, which will provide a mechanism for tracking progress and periodically adjusting management strategies as necessary, as well as broad engagement to ensure an open and accountable process throughout. Targets for engagement include governments at all levels, First Nations and Métis communities, conservation authorities, key sectors, interest groups and the general public.

Why phosphorus in Lake Erie is a problem

A combination of physical characteristics and surrounding land use make Lake Erie the most susceptible of the Great Lakes to eutrophication (the effect of excess phosphorus). This situation is further complicated by a changing climate, hydrological patterns and invasive species, all of which are resulting in shifting ecological systems.

Eutrophication in Lake Erie has promoted harmful blooms of cyanobacteria (blue-green algae) in the western basin; hypoxia in the central basin caused by the decomposition of dying algae; and nuisance algae in the eastern basin that can clog water intakes, impede recreational uses and degrade aquatic habitat. Cyanobacterial blooms also produce potent toxins that may threaten drinking water sources, fish populations, beach quality, coastal recreation and the overall ecological health of the lake.

There is broad consensus among the scientific community that the primary and most manageable driver of these impacts in Lake Erie is phosphorus, a nutrient that enters the lake from a number of Canadian and U.S. sources.

Canada and the United States have worked together to reduce phosphorus loadings to Lake Erie for more than 40 years, resulting in significant improvements through the 1970s and 1980s. However, a warming climate and changes in the lake ecosystem, land use and management have all contributed to a resurgence of algal blooms, demanding a new approach.

New phosphorus loading targets for Lake Erie

This action plan reflects commitments by Canada and Ontario and their partners under the *Great Lakes Water Quality Agreement, 2012* (GLWQA) and the *Canada–Ontario Agreement on*

Great Lakes Water Quality and Ecosystem Health, 2014 (COA) to reduce phosphorus entering Lake Erie.

New phosphorus reduction targets for Lake Erie's western and central basins and nearshore priority areas, adopted by Canada and the United States in February 2016, include:

- a 40 per cent reduction (from 2008 levels) in spring loads of total phosphorus and soluble reactive phosphorus for the Maumee River to minimize harmful algal blooms in the western basin
- a 40 per cent reduction from 2008 loadings to the central basin, with a new target total binational loading of 6,000 tonnes per year of total phosphorus
- a 40 per cent reduction (from 2008 levels) in spring loads of total phosphorus and soluble reactive phosphorus for priority tributaries to minimize harmful algal blooms in the nearshore areas

In the absence of scientific certainty, Canada and Ontario will take a precautionary approach to address phosphorus loads in Lake Erie's eastern basin until such time that the science evolves to inform the establishment of a reduction target. In the spirit of adaptive management, the viability of setting science-based numeric targets for the eastern basin will be revisited in 2020.

Proposed actions for reducing phosphorus levels in Lake Erie

The rationale behind this plan's five overarching categories is as follows:

- **Reduce phosphorus loadings:** Cutting down phosphorus loadings from urban, agricultural and rural sources, and encouraging good environmental stewardship are core to reversing the present state of Lake Erie.
- **Ensure effective policies, programs and legislation:** Efforts by federal and provincial governments to reduce phosphorus loadings over the years have proven effective. Enhancing, strengthening and building on these tools will help manage excess phosphorus inputs to aquatic ecosystems.
- **Improve the knowledge base:** Research, modelling and monitoring programs provide essential data to help us understand the effectiveness of our actions, how phosphorus enters Lake Erie, and the factors (such as climate change) contributing to the development of algal blooms and hypoxia. This data is also used to track spatial and temporal changes in the nearshore and offshore waters of Lake Erie and in the lake's watersheds.
- **Educate and build awareness:** Advancing awareness of and knowledge about phosphorus sources and impacts — as well as what can be done by the Lake Erie community to address phosphorus loadings from these sources — will contribute to reducing phosphorus in the lake.

- **Strengthen leadership and co-ordination:** Successful implementation of the plan will entail expanding partnerships to include implementation partners external to government, enhancing the current level of co-ordination by clarifying roles and responsibilities, as well as strengthening the effectiveness of existing committees and other governance structures.

Making this action plan a reality

Achieving the phosphorus reduction targets and Canada's commitments under the GLWQA will require significant change across the Lake Erie basin, including the adoption of a multi-barrier approach across all phosphorus sources.

In addition to Ontario's joint effort with Canada, the Province has a number of other nutrient commitments relating to Lake Erie, which will also be delivered through this action plan, including the Great Lakes Protection Act, 2015, the Western Basin of Lake Erie Collaborative Agreement between the Premier of Ontario and the Governors of Michigan and Ohio, and the Great Lakes Commission's Joint Action Plan for Lake Erie with U.S. states.

Implementation therefore requires:

- **Adaptive management:** Such an approach — supported by strong monitoring, research and modelling efforts for Lake Erie — will provide a framework for ongoing assessment of progress toward targets and adjustments to management actions over time.
- **Strong governance:** Because managing phosphorus loads is a complex and challenging task that bridges many levels of government as well as multiple agencies and private sector organizations, a broad network of partners will be essential for successful implementation.
- **Effective engagement of accountable partners:** Excess phosphorus and the associated algal blooms pose a threat to water quality and drinking water supplies for hundreds of thousands of Ontarians in the Lake Erie basin. Effective engagement of partners and the general public must be an integral part of implementing the action plan.

Next steps for the Lake Erie action plan

As our knowledge of the lake's ecosystem improves, adaptive management will encourage regular plan review and guide adjustments to its management strategies to increase their effectiveness and ensure continued progress.

To that end, this action plan will be reviewed and revised every five years, beginning in 2023 and every five years thereafter. .

Each participating agency has its own system for data management and reporting, and each is committed to making this data available to a broader audience through the COA. In the future, this may involve the development of portals to support the sharing of scientific data and reports across different platforms. Reporting will be co-ordinated through the COA Nutrients Annex Committee and made available to partners, stakeholders and the public.

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1 Taking action on phosphorus levels in Lake Erie

Partnering on Achieving Phosphorus Loading Reductions in Lake Erie from Canadian Sources sets out an action plan for reducing phosphorus loadings to Lake Erie with the goal of decreasing the presence of harmful and nuisance algal blooms as well as the zones of low oxygen (hypoxia) that threaten both the ecosystem and human health.

Based on robust scientific evidence, this plan includes cost-effective, high-impact actions that reflect a collective responsibility for environmental management. It proposes a variety of federal, provincial and partner actions that need to be co-ordinated and implemented by all sectors and communities in the Lake Erie basin.

To inform the plan's development, the agencies involved worked in close collaboration with First Nations and Métis communities, agriculture and other key sectors, municipalities, conservation authorities, interest groups and the public.

1.1 Why action is needed

While phosphorus is a naturally occurring element that is part of all plant and animal tissue, high levels of it can promote excessive algal growth and result in low-oxygen zones in lakes and rivers. In Lake Erie, the increased number of harmful and nuisance algal blooms over the past decade has resulted in significant economic, social and ecological impacts: water quality, fish and wildlife populations and habitats are degraded; beaches are fouled; water intakes are clogged; and the commercial fishery is increasingly at risk. Toxins produced by some species of algae also pose a risk to human health.

The problems facing Lake Erie are not new. Canada and the United States have been working together for more than 40 years to control the impacts of human activities on the water quality and ecosystem health of the Great Lakes. These efforts have often focused on controlling phosphorus loadings[1] in the lakes — especially in the case of Lake Erie.

Government at all levels, including First Nations and Métis communities as well as conservation authorities, key sectors, interest groups and others have helped realize dramatic improvements to Lake Erie's ecosystem since the establishment of the first *Great Lakes Water Quality Agreement* in 1972. But problems have resurfaced in recent years, including a resurgence of harmful cyanobacteria blooms in nearshore areas and in the western basin of Lake Erie, low oxygen levels in the deep waters of the central basin, and the growth of nuisance algae *Cladophora* along the Canadian shoreline of the eastern basin.

The causes of these renewed issues in Lake Erie are complex. They include interactions among factors such as a warming climate, altered hydrologic patterns, changes in land use and management, availability of substrate, and the arrival of invasive zebra and quagga mussels. It

[1] Section 2 provides more detail on phosphorus in the Lake Erie ecosystem.

has become clear that past and current actions are no longer enough to manage the problem — and a new approach is needed to safeguard the lake from the environmental and economic impacts associated with loadings of excessive phosphorus.

1.2 New phosphorus loading targets for Lake Erie

In 2012, Canada and the United States signed the amended *Great Lakes Water Quality Agreement, 2012* (GLWQA), which commits the two countries to updating phosphorus loading targets and developing strategies and domestic action plans for achieving specific nearshore and open-water ecosystem objectives — starting with Lake Erie. Under the new GLWQA, these strategies and action plans are to be developed in co-operation and consultation with state and provincial governments, First Nations and Métis communities, conservation authorities, municipalities, key sectors and the public.

Canada and the United States adopted their new phosphorus reduction targets for Lake Erie's western and central basins and nearshore priority areas in February 2016. The new targets include:

- a 40 per cent reduction (from 2008 levels) in spring loads of total phosphorus and soluble reactive phosphorus for the Maumee River to minimize harmful algal blooms in the western basin
- a 40 per cent reduction from 2008 loadings to the central basin, with a target total binational loading of 6,000 tonnes per year of total phosphorus
- a 40 per cent reduction (from 2008 levels) in spring loads of total phosphorus and soluble reactive phosphorus for priority tributaries to minimize harmful algal blooms in the nearshore areas

These binational targets and the Canadian share of each, as well as commitments related to Lake Erie's eastern basin (see sidebar), are discussed in more detail in Section 3.5.

Reduction targets for Lake Erie's eastern basin

Addressing excessive algal growth and shoreline fouling in Lake Erie's eastern basin remains a priority, but additional research and modelling efforts are needed to support setting a reduction target. Until such support is available, Canada and Ontario will take precautionary actions to reduce phosphorus loads to the Grand River watershed and the eastern basin. This will help maintain levels of algal biomass below a level that would constitute a nuisance condition in the nearshore waters of the eastern basin.

In the spirit of adaptive management, the viability of setting evidence-based numeric targets for the eastern basin will be re-evaluated in 2020. In the interim, there will be support for targeted research efforts intended to improve the scientific understanding of how to effectively manage the *Cladophora* problem in the eastern basin and elsewhere in the Great Lakes.

1.3 How Canada and Ontario will meet their targets and commitments

As there are many sources of phosphorus entering Lake Erie, immediate and collective action by governments, sectors and communities is needed to achieve these phosphorus load reductions.

Canada and Ontario are committed to working together and in partnership with others to develop a single plan for reducing phosphorus loads in Lake Erie. The Canadian and Ontario governments and their partners will work together through the *Canada–Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, 2014* (COA) to meet Canada's share of the targets and commitments under the GLWQA.

The COA is the federal–provincial agreement supporting the restoration, conservation and protection of the Great Lakes basin ecosystem. The governments of Canada and Ontario have worked together since the first COA was signed in 1971 and through subsequent COAs to improve the water quality and ecosystem health of Lake Erie and the other Great Lakes. The agreement is updated regularly; the most recent version was signed in 2014 and will remain in force until December 17, 2019.

Annex 1 of the COA sets out specific goals related to the reduction of excess nutrients as well as harmful and nuisance algal blooms. Current activities under that annex span a broad range of federal and provincial regulatory and policy initiatives.

Because the environment of such a large lake takes time to adapt and respond to action, it may take some time for the actions contained in this plan to result in the desired change. The challenge is significant — but with co-ordinated action, the health of Lake Erie can be improved.

How the plan aligns with key Ontario initiatives

This action plan will also help the Government of Ontario achieve its other nutrient commitments, including those outlined in the *Great Lakes Protection Act, 2015* (GLPA).

The GLPA provides tools that can help address algal blooms in Lake Erie and enables partners to come together to achieve shared goals in a particular watershed or geographic area in the Great Lakes–St. Lawrence River basin. Under the GLPA, Ontario's Minister of the Environment and Climate Change must set at least one target by November 2017 to help reduce algal blooms in all or part of the basin. To satisfy that obligation, in October 2016 the Minister adopted a target of 40 per cent phosphorus load reduction (from 2008 levels) by 2025 for the Ontario portion of the western and central basins of Lake Erie, as well as an aspirational interim goal of a 20 per cent reduction by 2020. The GLPA also states that the Minister will prepare a plan setting out the actions to be taken to achieve those targets. This action plan for Lake Erie will serve as the Minister's plan for meeting the GLPA targets to help reduce algal blooms in the lake.

In keeping with the need for early action, Ontario also signed the *Western Basin of Lake Erie Collaborative Agreement* with the U.S. states of Michigan and Ohio on June 13, 2015. The signatories collectively committed to work to achieve, through an adaptive management process, a recommended 40 per cent total load reduction in the amount of total and dissolved reactive phosphorus entering Lake Erie's western basin by 2025, with an aspirational interim goal of a 20 per cent reduction by 2020 (from 2008 base year).

Working with the U.S. states bordering Lake Erie through the Great Lakes Commission, Ontario collaborated on the development of a joint action plan for Lake Erie, which aligns with other binational and domestic nutrient efforts currently underway.

1.4 Geographic scope of this action plan

The geographic scope of this action plan (see Figure 1) includes Canadian sources that flow into the Huron–Erie corridor: the St. Clair River, Lake St. Clair (which also experiences significant algal blooms) and the Detroit River. It also covers Canadian sources that flow directly into the western, central and eastern basins of Lake Erie.

Nearshore areas are affected by phosphorus loadings from local tributaries. In Canada, the Thames River and the small tributaries around Leamington, Ontario, have been identified as priority tributaries contributing to harmful algal blooms on the south shore of Lake St. Clair and the north shore of the western basin near Point Pelee.

Actions will be undertaken across the Canadian portion of the basin, focusing on sources and tributaries that contribute the most phosphorus to the lake.

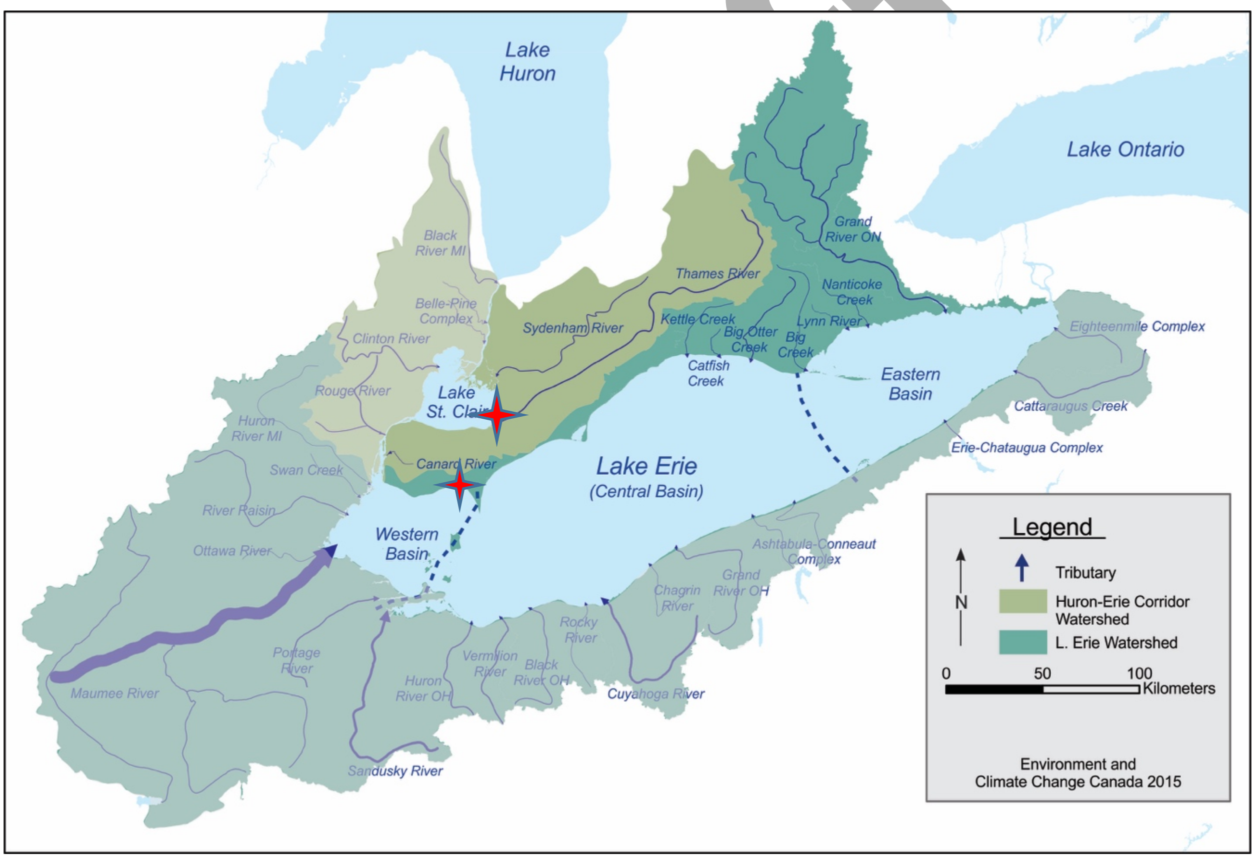

Figure 1: Map of Huron–Erie corridor and Lake Erie, showing its three basins and major tributaries. The red stars indicate priority tributaries that contribute to nearshore algal blooms.
Source: Environment and Climate Change Canada.

1.5 Principles behind the plan

Four key principles, intended to ensure actions are effective, balanced and sustainable over time, guide this plan:

- science-based foundation
- continuous improvement
- shared responsibility
- economic sustainability

Science-based foundation

The actions and priorities in this action plan were developed based on more than 40 years of field data, published reports and current scientific understanding. A bibliography at the end of this document lists a wide variety of sources that contributed to the plan's development.

Continuous improvement

As a living document, this plan will be reviewed and updated every five years as knowledge of Lake Erie improves and phosphorus reduction actions are put in place. Continuous improvement through an adaptive management framework is discussed in more detail in Section 5.1.

Shared responsibility

As set out in the COA, the governments of Canada and Ontario share a commitment to restoring, protecting and conserving the Canadian portion of Great Lakes waters. Accordingly, this action plan endorses a collaborative approach that values the efforts of all levels of government, First Nations and Métis communities, as well as partners and the public. Consistent with water policy elsewhere in Canada and other parts of the world, this plan adopts a watershed perspective in evaluating potential actions and impacts.

Economic sustainability

This plan aims for economic sustainability by mitigating negative economic impacts where they might occur and protecting the economic value of Lake Erie's water quality and ecosystem integrity for future generations. Where possible, it builds on and links existing activities to add value and leverage resources.

2 Why phosphorus is an issue in the Lake Erie basin

A combination of physical characteristics and surrounding land use make Lake Erie the most susceptible of the Great Lakes to eutrophication (the effect of excess phosphorus). This situation is further complicated by a changing climate, hydrological patterns and invasive species, which have resulted in shifting ecological systems.

Eutrophication in Lake Erie has promoted harmful blooms of cyanobacteria (blue-green algae) in the western basin; zones of low oxygen (hypoxia) in the central basin caused by the decomposition of dying algae that use up the oxygen at the lake bottom; and nuisance algae in the eastern basin that can clog water intakes, impede recreational and commercial uses and degrade aquatic habitat. Cyanobacterial blooms also produce potent toxins that can threaten drinking water sources, fish populations, beach quality, coastal recreation and the overall ecological health of the lake.

There is broad consensus among the scientific community that the primary and most manageable driver of these impacts in Lake Erie is phosphorus, a nutrient that enters the lake from a number of Canadian and U.S. sources.

2.1 The economic impacts of harmful and nuisance algal blooms

Harmful and nuisance algal blooms have a wide range of impacts on the natural environment, human health and Canada's economy. These include:

- increased water treatment costs (especially for municipal drinking water systems) for manufacturers (including food processing)
- potential increased health care costs resulting from the ingestion of or skin exposure to algal toxins — especially microcystin, which is the toxin produced by the cyanobacteria *Microcystis*
- altered food web structure and ecosystem function, including the structure of fish communities — where an altered species mix or changes in average catch size could have a dramatic impact on the important recreational and commercial fisheries
- degradation of nearshore, wetland and tributary habitats caused by excessive algal growth (especially *Cladophora*) and thus loss of the ecosystem services and healthy habitats they provide
- reduced property values due to loss of recreational opportunities and impaired aesthetic value
- reduced tourism revenue due to beach closures, reduced fishing opportunities and associated human health concerns

One study estimates that, in a business-as-usual scenario, harmful and nuisance algal blooms could cost the Canadian Lake Erie basin economy $272 million annually.[2] Achieving the new phosphorus loading reduction targets would scale back this cost impact significantly.

The tourism industry, property owners and recreational users of Lake Erie face the greatest costs. Other significant consequences include economic impacts on municipal drinking water treatment plants, which are already occurring and could worsen due to increased water treatment costs associated with harmful algal blooms. Physical clogging of water intakes by dense *Cladophora* growth imposes additional costs on municipal, industrial and agricultural water users.

Algal blooms have so far had little impact on the economic health of the commercial fishery, the 2015 landed value (i.e., not including the value of associated food processing, packaging and shipping industries) of which exceeded $30 million. Nevertheless, the potential for direct and indirect negative impacts remains. Algal biomass throughout the lake can foul commercial fishing gear, making the netting visible to fish and diminishing its effectiveness. This issue is particularly acute in the western basin, where the bulk of the fishery and the most prevalent cyanobacteria blooms co-occur. Algal blooms also have the potential to alter the distribution of fish species across the lake.

Changes to commercially important fish species are also possible if ecological conditions deteriorate and cyanobacterial blooms become more common in the central and eastern basins. The economic impact of these changes could exceed $100 million over the next 25 years — and may be further compounded if perceptions of contamination affect consumer demand.

Studies undertaken in both Canada and the U.S. indicate that investing in actions to improve the health of the Great Lakes could have an economic return of up to two dollars for every dollar spent. Therefore, reducing harmful and nuisance algal blooms has the potential to produce both environmental and economic benefits.

2.2 What is phosphorus?

Phosphorus is a naturally occurring and biologically active element that is a component of all biological tissue. It is an essential nutrient for plant and animal life, making it necessary for maintaining a healthy lake ecosystem.

Total phosphorus is a combination of dissolved and particulate forms. Particulate phosphorus is bound to soil particles and is readily transported by water and wind erosion, but is much less bioavailable and is less accessible to plants and algae. The dissolved form (known as "soluble reactive phosphorus") is highly bioavailable and rapidly taken up by plants. High levels of soluble reactive phosphorus in water promote rapid growth of algae.

[2] Estimates are from *Economic Costs of Algal Blooms,* a 2015 consultancy report authored by Midsummer Analytics (in collaboration with EnviroEconomics) and submitted to Environment and Climate Change Canada.

Phosphorus naturally cycles through air, water and soil and can change forms many times before it reaches Lake Erie as well as once it is within the lake. Phosphorus is stored in and released from biological tissues and mineral particles in soils and sediments on lake and stream bottoms, flood plains, urban water systems and agricultural fields. These "legacy" sources of phosphorus can be re-mobilized and thus add to loadings — even when current practices are geared to phosphorus reduction. Actions to reduce phosphorus over time will help reduce the amount of legacy phosphorus available to the Lake Erie ecosystem.

Phosphorus enters Lake Erie from point sources, such as treated effluent from municipal and industrial wastewater treatment facilities, as well as non-point sources such as runoff from urban and agricultural landscapes. These sources contain a mixture of soluble reactive phosphorus and particulate phosphorus, with the proportion of each dependent on the particular activity and geographic location.

How phosphorus is measured

Concentration is the mass of a substance present in a given volume of water expressed in units such as milligrams per litre. Concentration is particularly useful when a substance has biological consequences, such as toxicity or eutrophication.

Load is the total mass of a substance delivered to a water body over a given time period. Loading rate is expressed in units of mass per unit time (e.g., kilograms/year) and is calculated as the product of concentration (mass of a substance per unit volume of water) and flow rate (water volume per unit time). Load is a useful measure when there is potential for accumulation of a substance over time or when there is limited assimilative capacity in the receiving water. Load is also an important way of measuring the total pollutant contribution from a given source.

Some sources of phosphorus (such as human sewage, animal manures and fertilizers) are very high in soluble reactive phosphorus and thus highly bioavailable. Controls of these sources can involve containment (e.g., manure storage) and often specialized treatment (e.g., wastewater treatment plants). Effective control of non-point sources can be more complex and involves special attention to prevention actions (e.g., right timing, placement and rate of manure and fertilizer application) in addition to addressing hydrological factors in the landscape.

Total phosphorus arising from soil erosion, streambank erosion and similar sources contains much less soluble reactive phosphorus than phosphorus from sources like human sewage, animal manure and fertilizers. Soil and streambank erosion contribute mostly particulate phosphorus that is bound to and transported with soil. Controlling these sources requires building soil health and streambank stability, increasing infiltration, and reducing movement of water over open soils to keep as much water and soil as possible on-site. Most soil erosion and runoff in the Lake Erie basin occurs during snowmelt, winter rainfall and extreme storm events.

As much as 90 per cent of the total phosphorus load to a river can be delivered during storm events. This is especially evident during the spring runoff period, when soils are saturated and typically bare of vegetation. Water flowing over bare soils can cause soil erosion as well as facilitate the loss of manure or fertilizer that was surface-applied in the fall, winter or early spring. Figure 2 demonstrates that the majority of nutrient loadings occur outside the summer growing season.

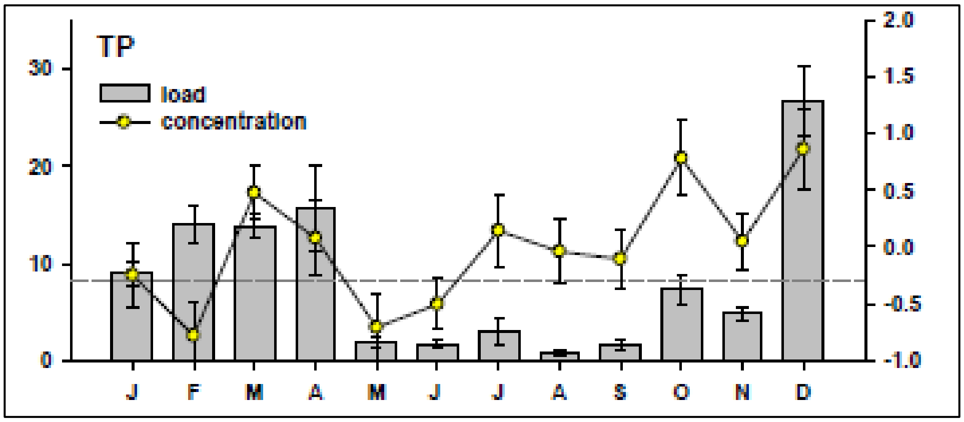

Figure 2: Phosphorus loadings and concentrations by month.

Data is drawn from *Water quality of 15 streams in agricultural watersheds of southwestern Ontario during 2004–09. Seasonal patterns, regional comparisons, and the influence of land use.* The dashed grey line represents the annual average monthly load. Error bars are the standard error of the mean.

Source: Ontario Ministry of the Environment and Climate Change (2012).

2.3 The most susceptible of the Great Lakes

Lake Erie's physical characteristics and human activities in its watershed make it the most susceptible of the Great Lakes to eutrophication.

2.3.1 How Lake Erie's physical structure contributes

With a total surface area of 25,700 square kilometres and an average depth of only 19 metres, Lake Erie is the shallowest, smallest (by volume) and warmest of the Great Lakes — and the most reactive to weather changes and phosphorus inputs.

Each of Lake Erie's basins (see Figure 1) has different average depths and ecological conditions. The western basin is the smallest and shallowest, with an average depth of 7.4 metres; the central basin has an average depth of 18.5 metres; and the eastern basin has the greatest average depth at 24.4 metres. By comparison, the average depths of the other Canadian Great Lakes are much greater, with Lake Huron at 59 metres, Lake Ontario at 86 metres and Lake Superior at 147 metres. See Figure 3 for a comparison.

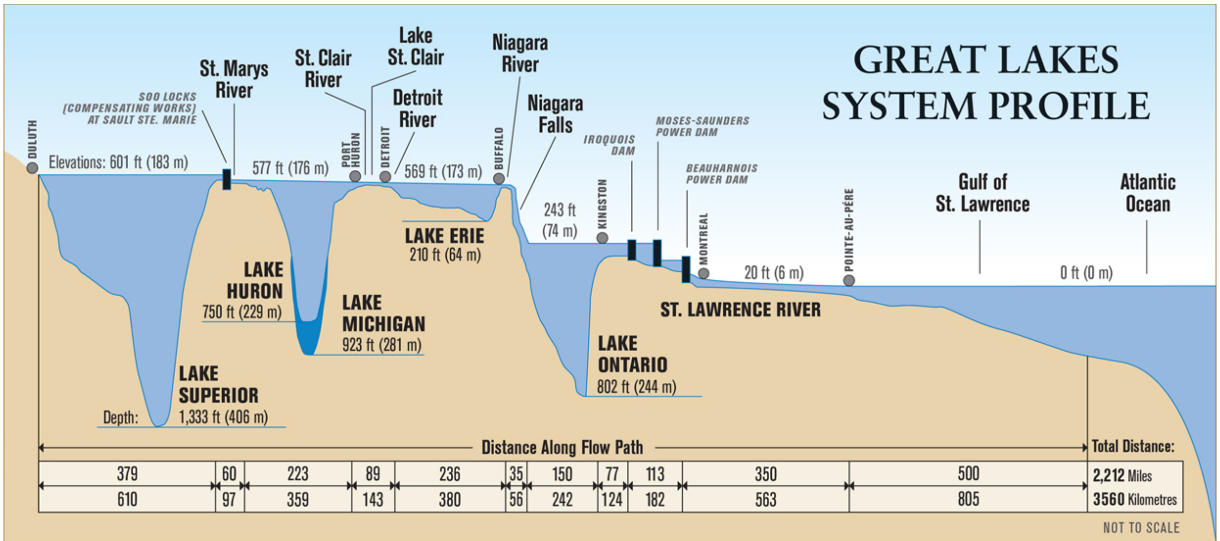

Figure 3: Relative depths of the Great Lakes.

Source: Michigan Sea Grant.

Lake Erie’s shallow depth allows its waters to mix thoroughly in spring and fall, warm rapidly in the summer and freeze over during most winters. The central and eastern basins thermally stratify (i.e., they form a warmer, less dense upper layer of water [the epilimnion] overlying a colder, denser bottom layer [the hypolimnion]) every year in the summer. The western basin can also stratify, but its shallow depth means it is easily mixed to depth by wind and wave action, so stratification usually does not last long. The presence or absence — and especially the persistence — of stratification is important because it can limit the capacity of bottom waters to mix with oxygen-rich surface waters. This in turn interferes with nutrient cycling and can result in low dissolved oxygen concentrations in deeper portions of the lake.

2.3.2 How land use affects the lake’s water quality

Human activities have contributed to the alteration of aquatic and terrestrial habitats throughout the Lake Erie basin — and have changed its structure and function. Eutrophication is one of the most significant human-induced changes in the lake.

A good understanding of the type and location of the basin’s varied land use and land activities must be at the foundation of any new phosphorus reduction actions.

Population

While Lake Erie’s watershed is the most densely populated of the Great Lakes, most of that population is located in the U.S. portion of the basin. There are fewer urban centres on the Canadian side, which accounts for about one third of the basin’s land area and supports 2.68 million people, 53 per cent of them in eight urban areas (i.e., populations over 50,000) and the rest in smaller towns and rural areas.

Services

Lake Erie provides a number of important ecological, economic and social services (especially drinking water supply for municipal residents); diverse commercial and recreational opportunities; and important food, spawning, nursery and refuge habitat for aquatic and terrestrial species.

The lake's shallow depth and warm temperature also make it the most biologically diverse and productive of the Great Lakes. It is home to more than 130 fish species, some of which (like Walleye and Yellow Perch) support large commercial and recreational fisheries.

Activities

Agricultural production accounts for about three-quarters of the land use on the Canadian side of the basin. The region's fertile soils, proximity to major water bodies and temperate climate make it well suited for agricultural use. Urban centres, settlements and roads make up only 12 per cent of land area, with natural areas accounting for another 13 per cent. Figure 4 provides an overview of Lake Erie basin land use.

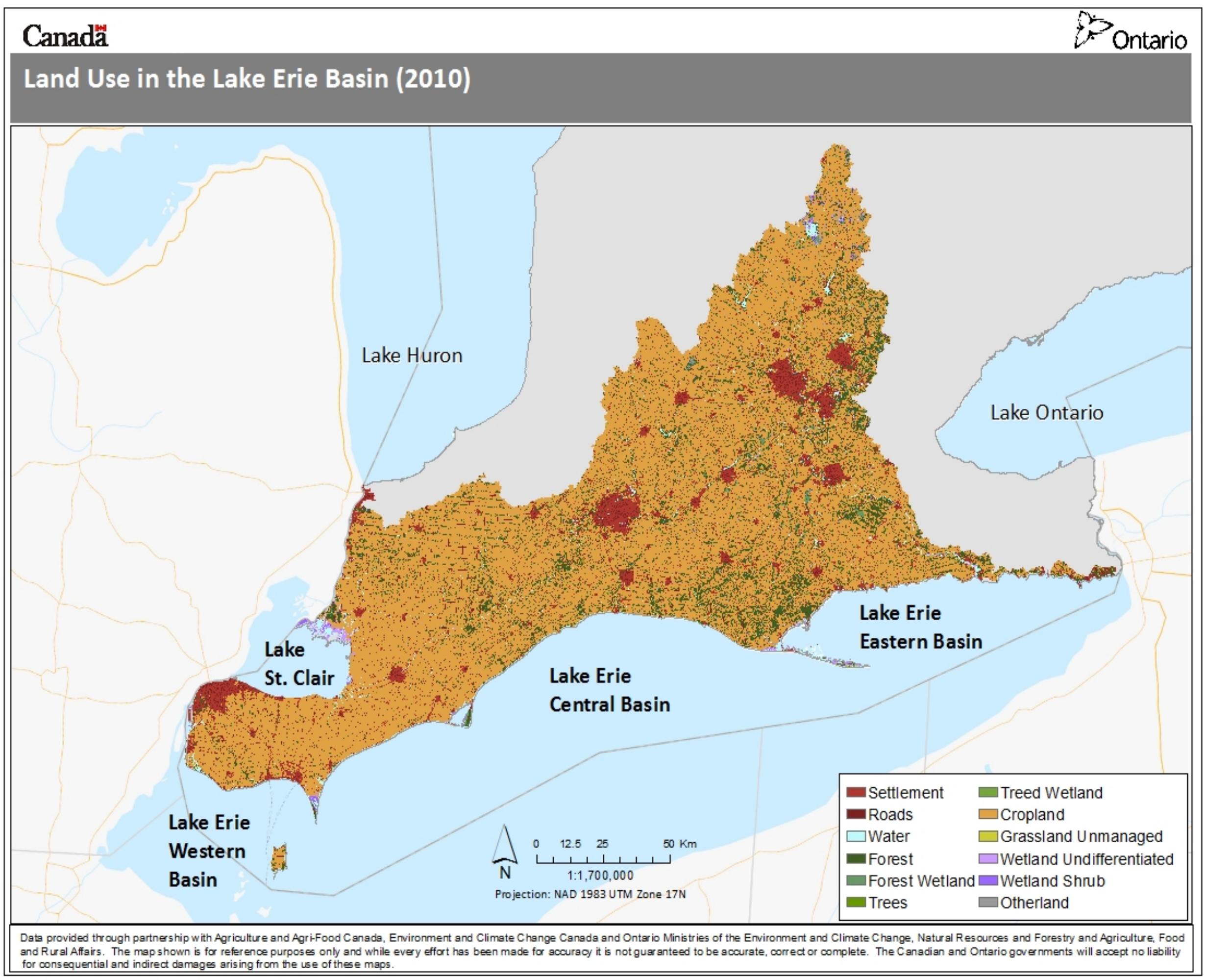

Figure 4: Overview of land use and land cover in the Lake Erie basin, 2010.
Source: Agriculture and Agri-Food Canada.

Mid-sized (quaternary) watersheds within the Canadian portion of the Lake Erie basin have been characterized by land use/land activity as part of a scientific review to inform this action plan. The following land use/land activity categories were selected: urban, agricultural-crop, agricultural-livestock and natural heritage (see Figure 5).

The coloured watersheds are in the higher end of the distribution of their respective category relative to the other watersheds on the Canadian side of the basin. The assigned category does not mean that a watershed only has or is dominated by that land use/land activity category; there are varying levels of urban, agricultural and natural heritage land uses in each watershed — especially in those that did not meet any of the category thresholds (i.e., “uncategorized”).

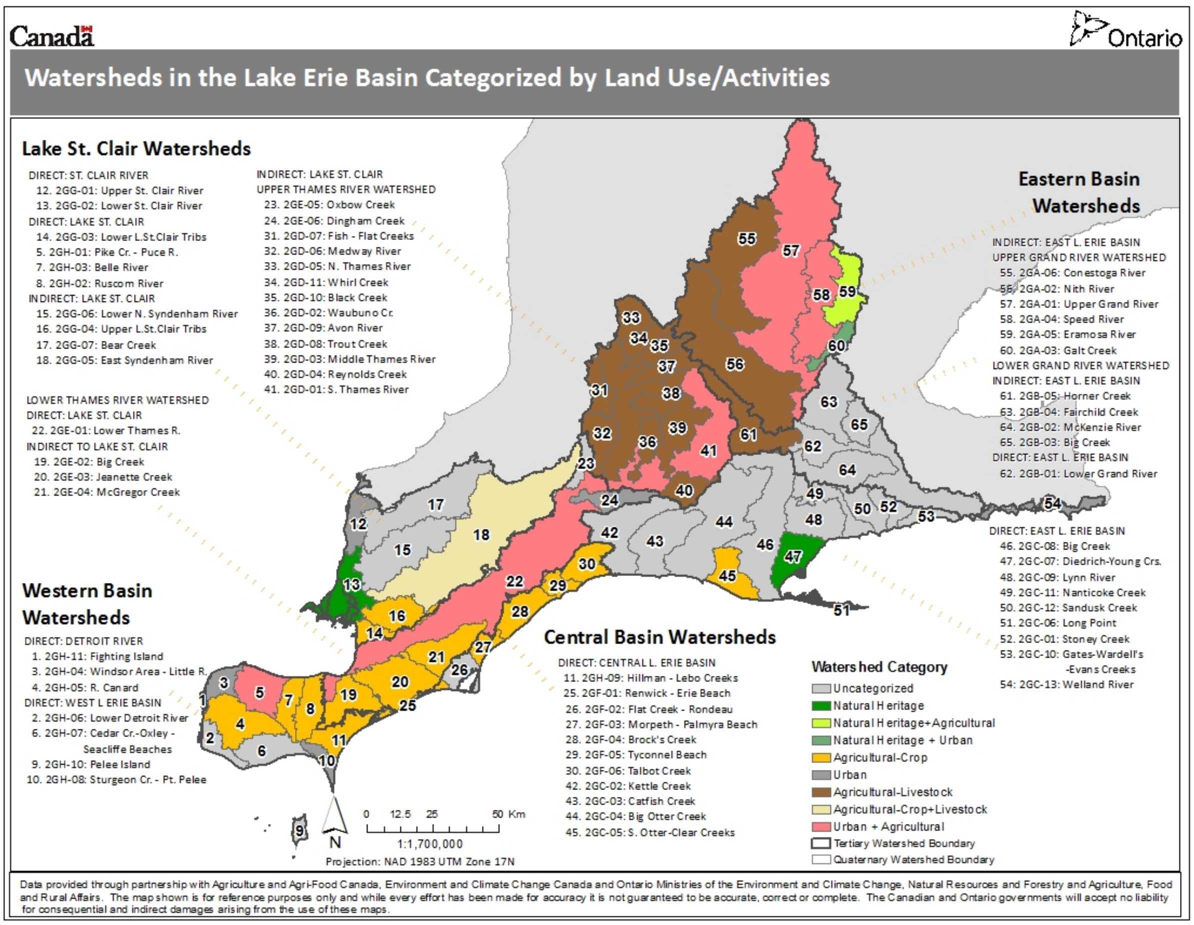

Figure 5: Lake Erie basin watersheds categorized by land use/activity.
Source: Agriculture and Agri-Food Canada

The characterization process also identified landscape characteristics that could render a watershed more vulnerable to phosphorus loss, including the risk of soil erosion and the risk of surface runoff. The distribution of average tributary total phosphorus concentration among watersheds was also mapped. For more information on the characterization process and results, see Appendix A.

2.4 History of phosphorus in Lake Erie

Between the time of European settlement in North America and present day, annual phosphorus loads to Lake Erie have increased dramatically.

Before European settlement, the estimated phosphorus load from sources in Canada and the United States was about 3,000 tonnes per year. By 1900, it is estimated that the load increased to about 9,000 tonnes per year. The majority of phosphorus entering the lake at that time came from continuous inputs from untreated municipal and industrial wastewater. A significant proportion also came from spring runoff, conveyed via tributaries, largely as a result of land use changes (deforestation and draining of wetlands) that occurred after 1850.[3]

From about 1900 onward, steady population growth resulted in rising total phosphorus loadings, largely from sewage and phosphorus-based detergents. Loadings from agricultural land also increased due to deforestation and land use changes. This was especially the case after the Second World War, when innovations in agricultural technology and fertilizer production allowed the expansion of hybrid corn production and increased application of commercial fertilizers. By 1968, phosphorus loadings had reached a peak of approximately 28,000 tonnes per year and had a clear impact on algal blooms and hypoxia, resulting in media speculation that Lake Erie might be "dead."

2.4.1 Reducing phosphorus in Lake Erie and the other Great Lakes

Since the 1970s, governments at all levels, First Nations and Métis communities, and others have all played a significant role in protecting and restoring the Great Lakes.

In the 1970s and 1980s, Canada and the U.S. and their partners invested billions of dollars in point source pollution control, especially wastewater treatment plant upgrades. Governments also enacted legislation to limit phosphorus concentrations in household detergents, which came into effect in 1989 under the *Canada Water*

Addressing non-point sources of phosphorus

With point sources well controlled, most of the phosphorus entering the lake now comes from non-point sources such as agricultural, rural and urban stormwater runoff. Controlling those sources can be challenging because solutions require changes on thousands of individual sites instead of a small number of known point sources, and must be tailored to particular land management and biophysical site characteristics.

[3] The phosphorus content of this runoff was largely attributable to soil chemistry rather than to added manure or fertilizer. Population density in rural areas was very low and agricultural sources of phosphorus at that time would have been minimal.

Act. These controls were continued under the 1999 *Canadian Environmental Protection Act* (CEPA). Phosphorus concentration limits were also applied to additional products under CEPA in 2010.

While the focus of total phosphorus controls through this period was largely on point sources, considerable work was also done to reduce non-point sources — in particular, agricultural runoff. In 1972, in response to a request from the International Joint Commission, the Pollution from Land Use Activities Reference Group (PLUARG) was established to investigate the impact of land-based activities on pollutant loadings. PLUARG involved a significant experimental and data-collection effort on a variety of watershed types, exploring how land management practices could be adjusted to reduce loadings of sediment and phosphorus.

That work and the subsequent federal–provincial Soil and Water Environmental Enhancement Program formed the basis for agricultural stewardship programs developed through the 1980s and 1990s to support farmers in implementing best/beneficial management practices (BMPs) for reducing non-point source pollution.

These binational efforts to control phosphorus loadings had a dramatic impact on the lake's water quality. As shown in Figure 6, by the mid-1980s, phosphorus loadings to Lake Erie were less than half the levels of the early 1970s and the frequency and extent of nuisance and harmful algal blooms had declined considerably. By the early 1990s, the annual phosphorus load to Lake Erie had dropped to 10,000 tonnes. From 1981 to 2013, the GLWQA binational total phosphorus loading target (11,000 tonnes) was achieved in 19 of the 27 years.

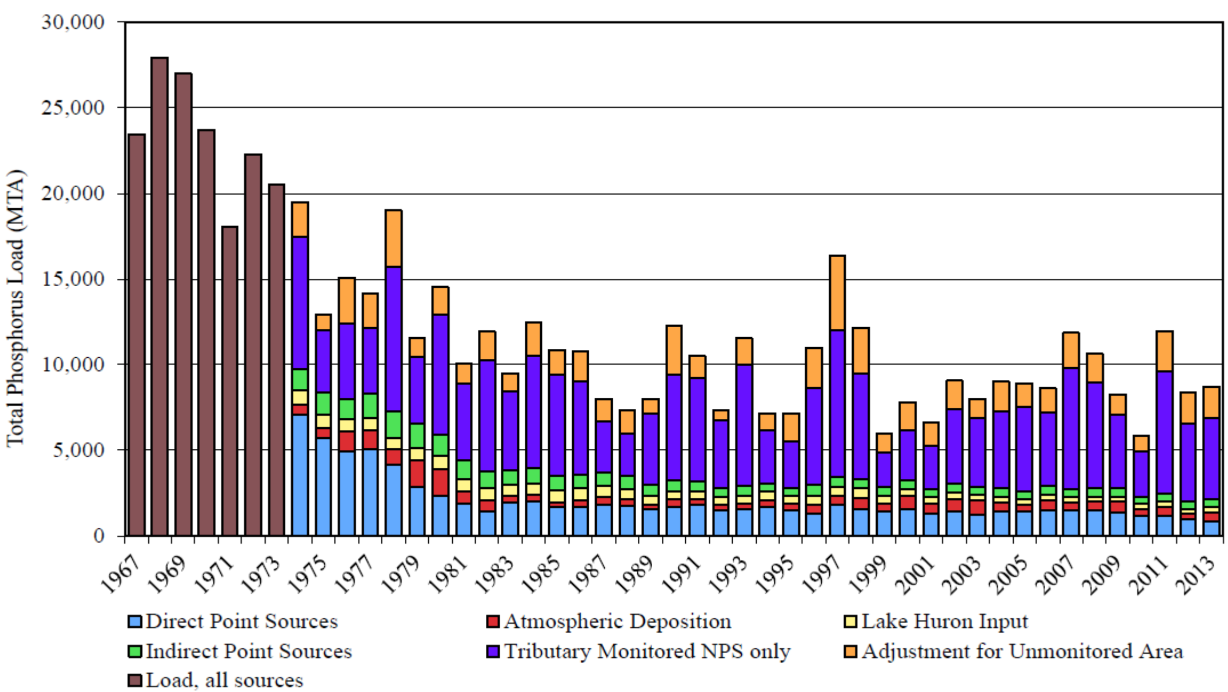

Figure 6: Annual loads of total phosphorus to Lake Erie from Canada and the U.S.

Source: Maccoux et al., 2016.

2.4.2 The re-emergence of eutrophication in Lake Erie

Despite successes in reducing total annual phosphorus loads to Lake Erie, and without any noticeable increases in loadings, by the mid-1990s algal blooms had re-emerged as a problem in Lake Erie — and has continued to worsen ever since. As a result, the lake now experiences widespread harmful algal blooms with the potential to cause significant human health impacts via the toxins produced mainly by the cyanobacteria species *Microcystis*.

Microcystis blooms in Lake Erie have been increasing in size and frequency over the last 20 years and mainly occur during warm, calm periods. Blooms are larger and more persistent in wet years, when tributary inflows of phosphorus are greater. In dry years, such as 2012 and 2016, blooms are much smaller because there is less rainfall, less snowmelt, less runoff and thus less phosphorus washing off the land surface into receiving waters. In 2015, heavy rainfall events followed by several days of warm temperatures resulted in an algal bloom that occupied most of the western basin and extended into the central basin.

2.5 How changes in the Lake Erie basin are affecting phosphorus loadings

A number of factors have changed in the Lake Erie basin since the first GLWQA was signed in 1972 that now confound phosphorus load-reduction efforts. These factors, which are increasingly influencing algal growth and hypoxia in the lake, include:

- climate change
- altered lake ecology and the increased presence of invasive species
- changes to agriculture in Ontario
- population growth, employment and land use trends

2.5.1 Climate change

A warming climate is increasing average water temperatures, reducing the duration and extent of winter ice, altering nutrient cycling dynamics and aquatic food web structures, and creating opportunities for new species invasions.

The impacts of a changing climate are already apparent in altered precipitation patterns and the timing and frequency of major storm events. Extreme weather events are now more frequent and have the potential to increase the volume of runoff and associated phosphorus loads. Current climate model projections suggest that over the next 25 years, Lake Erie will experience slightly greater precipitation during the winter, spring and fall.

A warming climate is also expected to decrease snowfall events and increase rainfall events, which will increase runoff and stream flow in the winter. The summers will likely be drier, with more frequent extreme storm events leading to flash floods. Increased rainfall and flooding could also lead to more combined sewer overflow and treatment plant bypass events.

These patterns are of particular concern because of the potential for more extreme weather events to occur throughout the winter and early spring, when soils are saturated, thawed, uncovered and do not support growing vegetation. Bare saturated soils are more susceptible to runoff and erosion during this period, which could result in a greater amount of phosphorus being carried off the land.

Warmer air will also result in warmer lake water temperatures over a longer period of the year, extending from earlier in the spring to later in the fall. This longer warm period could encourage more algae production and blooms in the nearshore and elsewhere in the lake as well as increase the metabolic rate of bacteria, resulting in greater biological productivity and longer periods of stratification — and therefore more episodes of hypoxia and accelerated algae growth.

The overall impact of climate change on phosphorus loadings is still highly uncertain. Multi-barrier approaches combined with adaptive management can help to offset these future uncertainties.

2.5.2 Altered lake ecology and increased presence of invasive species

Quagga mussels have become the dominant dreissenid mussel in Lake Erie and continue to alter the lake's nutrient cycling and food web structures.

Invasive zebra and quagga (dreissenid) mussels first arrived in Lake Erie in the late 1980s via ballast water from oceangoing ships. Zebra mussels were initially the dominant dreissenid mussel in Lake Erie but were outcompeted by the quagga mussel due to the latter's ability to colonize deeper waters and soft substrates.

The impact of dreissenid mussels is thought to be especially significant in promoting the growth of the attached nuisance algae species *Cladophora*. Dreissenid mussels' efficient filter feeding has resulted in greater water clarity, which allows *Cladophora* to grow at greater depths and therefore across a broader area than before mussel establishment. There is also evidence that the presence of these mussels has resulted in an increase in the proportion of soluble reactive phosphorus in nearshore waters close to the lake bed.

2.5.1 Changes to agriculture in Ontario

As Ontario's agriculture sector continues to change in response to factors, including broader market forces (e.g., commodity prices), and increased demand for quality products they must also adapt to changing climate including extreme weather events and warmer winters. Farming practices, whether for livestock, field crop, or greenhouse production, must also change to support environmental and economic sustainability.

Changes in agricultural practices in Ontario, in combination with a changing climate, have led to increased erosion of nutrient-rich soils — especially in the non-growing season. Improving nutrient management, building soil health and slowing the flow of water off the land's surface are essential to reducing environmental impacts.

Over the past decades, farm size has increased and production has intensified to create more efficient food production and respond to the demands of a growing population. Fencerows and windbreaks have also been removed from many farms to accommodate the larger equipment that has helped increase productivity but adds to the risk of wind and water erosion.

Over the last 30 years, beef production in the Lake Erie basin has declined, with a corresponding decline in the need for hay and pasture-land that perennially cover the soil. Field crop production in the basin has also shifted. For example, soybean production increased from 16 to 34 per cent of cropland from 1981 to 2011, respectively. Relative to most other crops, there is less crop residue associated with soybeans after harvest. Without winter cover (e.g., winter wheat), more land in soybean production can result in greater soil erosion.

Changing practices to enhance environmental sustainability

Healthy soil retains water and nutrients while reducing runoff that can carry nutrients to waterways. Better soil health also helps deal with climate change and weather extremes. It is estimated that 82 per cent of farmland in Ontario is losing organic matter — an important component of healthy soil — and 68 per cent of Ontario's cropland has a risk of erosion above the annual rate of soil regeneration.[4] Practices such as diverse crop rotation, conservation tillage and cover crops are all important in building and maintaining soil health.

Recognizing the need to improve soil health across the province, the Ontario government, working with a diverse group of agricultural partners including farmers, is creating a roadmap for protecting and improving agricultural soil. The draft Agricultural Soil Health and Conservation Strategy recognizes that managing soil health is fundamental to growing and sustaining Ontario's capacity to produce food in a changing climate for a growing population. Among many benefits, managing for healthy soils will help reduce greenhouse gas emissions and build soil carbon over the long term while enhancing their long-term productivity.

While Ontario soils can supply many of the nutrients needed by crops, to help optimize productivity, additional nutrients from sources such as commercial fertilizer, biosolids and manure may be required. Advancements in nutrient management planning, manure storage, precision application and, more recently, the 4R Nutrient Stewardship approach (applying the right source of nutrients at the right rate, right time and right place), have all improved the judicious application and use of nutrients and reduced the risk of nutrient runoff into waterways. Today, Ontario's agricultural sector is using significantly less fertilizer per unit of crop produced compared to the 1970s and 1980s. However, historical applications of nutrients are responsible for accumulation of soil phosphorus in some parts of the basin.

Subsurface agricultural drainage has been critical to improving crop productivity in Ontario. Drainage promotes plant uptake of nutrients, improves the health of the soil and minimizes compaction. Drainage also reduces surface runoff and erosion and helps reduce phosphorus loss to surface waters by drawing the water through the soil. However, drain outlets can still

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[4] Clearwater, R. L., T. Martin, and T. Hoppe, eds. *Environmental sustainability of Canadian agriculture: Agri-environmental indicator report series – Report #4*. Ottawa: Agriculture and Agri-Food Canada, 2016.

discharge phosphorus in solution or attached to soil particles into receiving waterbodies. Better management of surface inlets and improved crop-management practices will help minimize nutrient loss to drains. Advanced drainage design and the addition of landscape features (e.g., green infrastructure) to trap sediment will minimize the transport of phosphorus from tile drainage systems into natural watercourses.

Increased greenhouse vegetable production

The area in which vegetable greenhouse production occurs in Ontario nearly doubled between 2001 and 2011. Half of Ontario's greenhouses are located in watersheds within the western basin of Lake Erie.

Many greenhouse vegetable operations deliver water and fertilizer, including phosphorus, to greenhouse crops that are grown without the use of soil. Historically, when this nutrient-rich water could no longer be circulated, it was often released into the natural environment. When the greenhouse vegetable sector realized this practice was contributing to water quality issues in Lake Erie, they began efforts to reduce their impact on the environment, for example, by reducing fertilizer consumption and the release of phosphorus into the environment. Through significant education and outreach as well as investments in technology development, ninety percent of greenhouse acreage represented by Ontario greenhouse vegetable growers now recycle the nutrient rich water and have been able to reduce their fertilizer consumption by about 40 per cent on a per acre basis.

At the same time, the Greenhouse Nutrient Feedwater Regulation *(Nutrient Management Act)* was introduced to allow registered greenhouses to apply the nutrient solution on agricultural land to support growth of field crops. Despite these gains, greenhouses need to continue to move toward increased recycling as well as proper treatment and disposal to continue to reduce their impacts on Lake Erie.

Environmental stewardship: incentives and improving knowledge

Ontario agriculture's long history of environmental stewardship can be credited with helping to abate further deterioration of Lake Erie's water quality.

These efforts trace back to the early 1980s, when agricultural agencies promoted a wide range of BMPs for conserving a farm's soil, water and other natural resources. BMPs are proven, practical and affordable approaches to conserve soil, water and other natural resources that can also reduce phosphorus loss from agriculture sources. Most BMPs are site-specific, meaning not every BMP will be suitable for every source and form of phosphorus, nor will they be applicable to every farm operation. By adopting BMPs such as conservation tillage, restricted livestock access to waterways, improved manure storage and application, improved crop nutrient management including soil testing to determine appropriate nutrient application requirements for crops and the planting of buffer strips, Ontario's farmers have helped reduce non-point source phosphorus loadings to Lake Erie over the last few decades.

A changing climate increases the risk of phosphorus loss and the need for multiple BMPs to be selected for each site to maximize their effectiveness under variable conditions. The existing knowledge base for these practices and their collective impact needs to be updated as climate change progresses, consistent with an adaptive management approach.

In Ontario, education resources and cost-share programs have been available to farmers since the 1990s to help them identify their farm's environmental strengths and risks as well as realistic BMPs they can implement to improve environmental conditions. The federal and provincial governments have also supported agri-environmental education and awareness initiatives to teach farmers about BMPs and regulatory requirements for reducing their on-farm environmental risks through initiatives such as the Environmental Farm Plan (EFP) and the Great Lakes Agricultural Stewardship Initiative (GLASI) Farmland Health Check-Up programs.

More than 70 per cent of Ontario's farmers have participated in the EFP program, which asks them to voluntarily assess their environmental strengths and risks and then set realistic plans to improve environmental conditions on their farms.

Since 2005, through cost-share programs associated with the EFP, about 24,700 on-farm improvements have been funded with almost 11,000 cost-shared environmental improvement projects completed on Ontario farms between 2008 and 2016. Such investments reduce nutrient loss, improve soil and pollinator health, and help agricultural producers adapt to climate change.

A new approach to voluntary stewardship: targeted, supported and risk-based

Recognizing the significant contribution of agricultural activities to Lake Erie non-point source phosphorus loading, Ontario and Canada explored a new approach for fostering awareness and accelerating implementation of environmentally sustainable farm practices to reduce phosphorus loading to Lake Erie.

Through the Great Lakes Agriculture Stewardship Initiative (GLASI) — geographically targeted to the Lake Erie basin and the southeast shores of Lake Huron — professional support was provided to farmers to help them identify environmental risks specific to their farms as well as appropriate BMPs to reduce these risks. Farmers could then seek government cost-share funding to implement risk-reduction practices, including equipment modification, soil erosion control structures, cover crops, residue management, buffer strips and field windbreaks/wind strips.

Through GLASI's Priority Subwatershed Project (PSP), governments are partnering with the Ontario Soil and Crop Improvement Association and four conservation authorities — Ausable Bayfield, Essex Region, Lower Thames Valley and Upper Thames River — to pilot and evaluate the effectiveness of targeted stewardship approaches. This includes installing monitoring equipment to collect edge-of-field and water quality monitoring data in defined subwatersheds and collecting site-specific data on best management practices adoption, land management data and economic information.

The PSP is collecting this valuable information about soil health and water quality improvement to inform modelling approaches. This information will be used to evaluate measurable changes and examine the costs to reduce phosphorus loss from the agricultural landscape using a targeted stewardship approach. In 2018, results of the PSP will be available to inform ongoing stewardship program development and support continuous improvement in targeting approaches to achieve phosphorus reduction goals.

2.5.2 Population growth, employment trends and land use trends

The number of people living in the Ontario portion of the Lake Erie basin is expected to increase over the next 25 years from 2.68 million (2016) to 3.31 million (2041). Most of this growth will occur in urban centres.

This population growth will result in higher sanitary sewage flows but also a small increase in basin impervious land surface (all in urban areas), leading to slightly higher stormwater runoff volumes and peak flow rates. A small amount of agricultural land is expected to be lost to urbanization in this process, increasing the amount of impervious land surface.

No significant shifts in the patterns of employment location (and therefore land use or phosphorus release) are anticipated over the next 25 years.

2.6 How natural heritage features aid water quality

Natural heritage features are the “green infrastructure” of the natural environment and play an important role in trapping, storing and processing phosphorus.

Natural heritage features that aid in phosphorus reduction include stream channels, wetlands and riparian areas. These features trap and store runoff and the sediment and phosphorus it contains.

Lake Erie’s wetlands and riparian zones in particular are important to its water quality.

What are natural heritage features?

Natural heritage features include structures such as natural channel formations, wetlands and the riparian zone: the area of land adjacent to tributaries and the lake, where vegetation may be influenced by flooding or elevated water tables.

Each type of feature provides a range of ecosystem services. For example, a healthy stream channel offers habitat for a range of aquatic species and also provides essential nutrient-processing services.

Wetlands

Wetlands along streambanks and shorelines and throughout the watershed are of particular importance in filtering and retaining runoff and nutrients. These areas are typically saturated most of the year and support plant and animal species adapted to those conditions. Significant quantities of snowmelt and runoff can be stored in these systems and gradually released over time, providing an important buffer against flooding and groundwater depletion and building resilience against impacts of extreme weather events resulting from climate change. Wetlands also regulate temperature and reduce the heat-island effect.

Wetlands are also recognized for their important role in carbon sequestration and storage. Their conservation and restoration can be an important factor in mitigating climate change by supporting and contributing greenhouse gas emissions reductions. Wetlands provide some of the earth’s most biologically diverse and useful habitat for plants and animals. Healthy and biologically diverse wetlands are public assets and important components of green infrastructure that provide multiple ecosystem services to Ontarians.

Riparian zones

These natural heritage features provide a critical connection between the land and the water, supporting a variety of habitats for aquatic and terrestrial species. The complex vegetative structure of these zones protects against erosion and can control the runoff of sediment, phosphorus and other pollutants, reducing impacts on water quality.

2.6.1 How human activity affects "green infrastructure"

Natural heritage features can be affected by human activities such as dredging, filling, channel hardening (such as concrete lining), and the construction of dams and other water control structures. These changes can significantly reduce the resiliency of natural heritage features and limit their capacity to provide a full range of ecological functions. For example, disturbances to riparian areas most commonly arise from removal of vegetation and compaction of porous soils. These changes degrade wildlife habitat, reduce shade (and therefore cooling potential), and reduce the ability of the riparian zone to slow runoff as well as store water and associated pollutants. As a result, water from rainfall and snowmelt moves quickly over the land surface, causing more frequent and severe flooding, and little water is stored to replenish stream flows in dry weather. As the water flows, it picks up heat, sediment, microorganisms and pollutants, including phosphorus. These patterns are most apparent in watersheds with a high proportion of impervious surface (e.g., roads, roofs, parking lots) and where streams have been straightened and hardened.

Ontario's wetlands — past and present

Estimates suggest 68 per cent of wetlands that were present in Ontario before European settlement were drained to accommodate agricultural, industrial and residential land uses by the early 1980s, and an additional four per cent has been lost since that time.

Fortunately, the rate of wetland loss in southern Ontario has dropped over the last decade. Recent assessments show a total of 64,487 wetlands in the Lake Erie basin, covering 187,158 hectares.

Efforts to improve the health and functions of ecosystems in southern Ontario are ongoing; however, more work is needed to increase the extent of natural cover — including wetlands — in areas where losses have been highest. Improvements in these areas will support ongoing phosphorus reduction efforts in the Lake Erie basin.

Protecting and restoring natural features such as riparian areas and wetlands from drainage and alteration provides an additional barrier to the discharge of phosphorus and other pollutants to Lake Erie. Perhaps equally important, green infrastructure protects the functionality of these systems and provides many co-benefits in terms of wildlife habitat, erosion protection, carbon storage and other ecological services.

3 What we know about phosphorus loadings to Lake Erie

This section describes our current understanding of phosphorus loads by source, sector and basin. Implementation and adaptation of this action plan, which is based on more than 40 years of science, will change over time as understanding evolves.

3.1 How we add to our understanding

Routine and intensive monitoring of phosphorus loadings is essential for the development of science-based targets and management strategies. Computer simulation (modelling) of watershed and in-lake processes is needed to better understand the physical, chemical and biological influences on harmful and nuisance algae blooms and hypoxia.

There are a number of monitoring and modelling efforts currently underway by government agencies and partner organizations. These projects are steadily improving information about Ontario's point and non-point loadings of phosphorus.

While some aspects of the system are well understood, additional research is needed to understand the factors that influence the growth of harmful and nuisance algae; the relative importance of nearshore, offshore and legacy sources of phosphorus; the role of invasive species in nutrient cycling; and how these factors may be affected by a changing climate.

3.2 The state of Lake Erie's offshore waters, nearshore waters and tributaries

Of all the Great Lakes, concentrations of total phosphorus are highest and most variable in Lake Erie. While concentrations have declined overall since the 1970s, the recent temporal trend for total phosphorus in the lake is unclear due to high variability both within and between years.

This variability in total phosphorus loadings from year to year (see Figure 6) is largely the result of hydrological influences. Loads typically exceed the new load reduction targets in years with higher precipitation and runoff (see section 3.4 for more details).

Estimates of phosphorus loading from Lake Huron, point sources and atmospheric sources have remained relatively stable since 1982. However, non-point sources discharged via the tributaries continue to contribute the largest portion of the phosphorus load and are mostly responsible for the periodic exceedances of the Lake Erie loading target during high-flow years.

Reductions in Canadian non-point sources are needed — especially in high-flow years — to reduce nutrient-related algal blooms in nearshore waters and contribute to improvements to hypoxia in offshore waters.

3.2.1 Phosphorus in Lake Erie's offshore waters

According to the binational 2017 *State of the Great Lakes* report, Lake Erie's nutrient status is rated as "poor" due to concentrations exceeding targets — and its trend is considered to be "deteriorating" due to a possible increase in concentrations and the resurgence of harmful algal blooms. Similarly, the Canadian Environmental Sustainability Indicator on phosphorus levels in the Great Lakes rates the western and central basins of Lake Erie as “poor” due to concentrations that exceed water quality objectives.

3.2.2 Phosphorus in Lake Erie’s nearshore waters

The nearshore phosphorus situation is complex and dynamic and varies widely across Lake Erie’s three basins and many tributaries.

The primary sources of phosphorus to the nearshore waters include loads from tributaries and inputs from shoreline land uses, runoff and municipal wastewater treatment plant outflows. Nearshore waters tend to flow parallel to the shore and are strongly affected by local inputs, water currents, depth, water and sediment chemistry, and biology. Weather is also an important factor. High offshore winds can cause nearshore waters to mix with offshore waters, carrying sediment and phosphorus from the nearshore into the open lake. These processes are highly variable and difficult to predict, and are the focus of ongoing research and monitoring.

3.2.3 Phosphorus in Lake Erie’s tributaries

Most Ontario tributaries in the Lake Erie basin would benefit from reductions in phosphorus, as most of the monitored streams in the Lake Erie basin exceed the provincial water quality objective for phosphorus concentrations.

Loadings to each of Lake Erie’s basins are dominated by tributary loadings (see Figure 1), which are highly variable from year to year due to hydrological and other factors (by contrast, point sources are relatively consistent from year to year). In Canada, the most significant contributors are the Thames River, which flows into Lake St. Clair, and the Grand River, which flows into the eastern basin. The Sydenham River, which discharges to Lake St. Clair, and Kettle and Big Otter Creeks, which discharge to the central basin, are also significant sources. These larger rivers contain a mix of non-point source pollution (including agricultural, rural and urban runoff) and point source pollution (including treated effluent from municipal wastewater treatment plants).

Reducing the phosphorus load from the Thames River is a priority because it contributes to nearshore cyanobacteria blooms in Lake St. Clair and hypoxia in the central basin. The phosphorus load from the Grand River is potentially a factor in nuisance *Cladophora* blooms in the nearshore zone of the eastern basin.

Smaller tributaries are also important on more localized scales. In particular, a group of smaller tributaries in the Leamington area of Ontario, where there is a large concentration of vegetable production greenhouses, contributes to adverse impacts to the Canadian shoreline and nearshore zone of the western basin.

While more research and monitoring of these systems are necessary, especially to determine the status and trend of soluble reactive phosphorus, it is clear that some watersheds require focused action to reduce phosphorus loads.

Figure 7 illustrates Canadian tributary loadings of total phosphorus by watershed; Figure 8 illustrates Canadian tributary loadings of soluble reactive phosphorus by watershed.

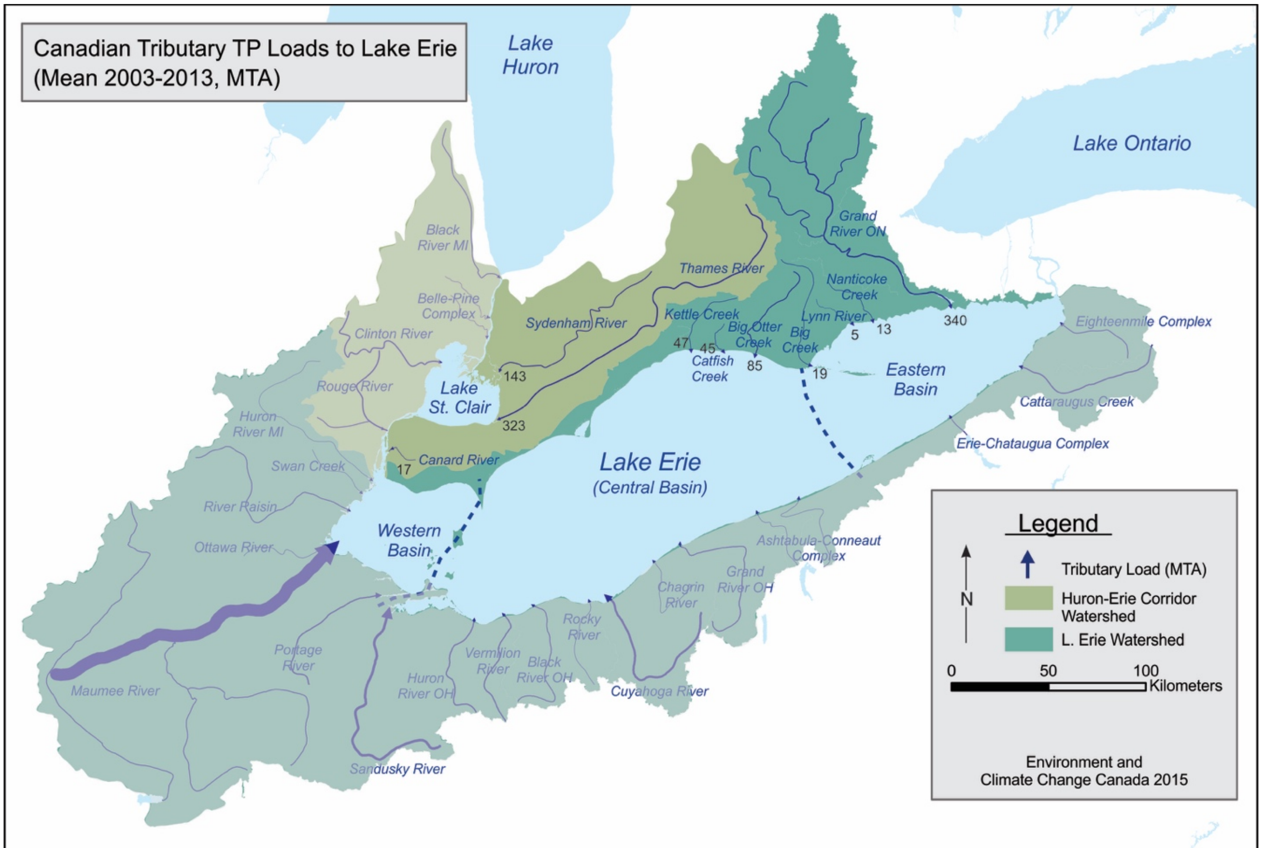

Figure 7: Canadian tributary annual loadings of total phosphorus in tonnes by watershed.

Arrows indicate Lake Erie tributaries. The width of each arrow indicates the relative amount of total phosphorus loading to Lake Erie. Numbers at the mouths of the Canadian tributaries indicate mean (2003–13) total phosphorus loads in metric tonnes per year.

Source: Environment and Climate Change Canada.

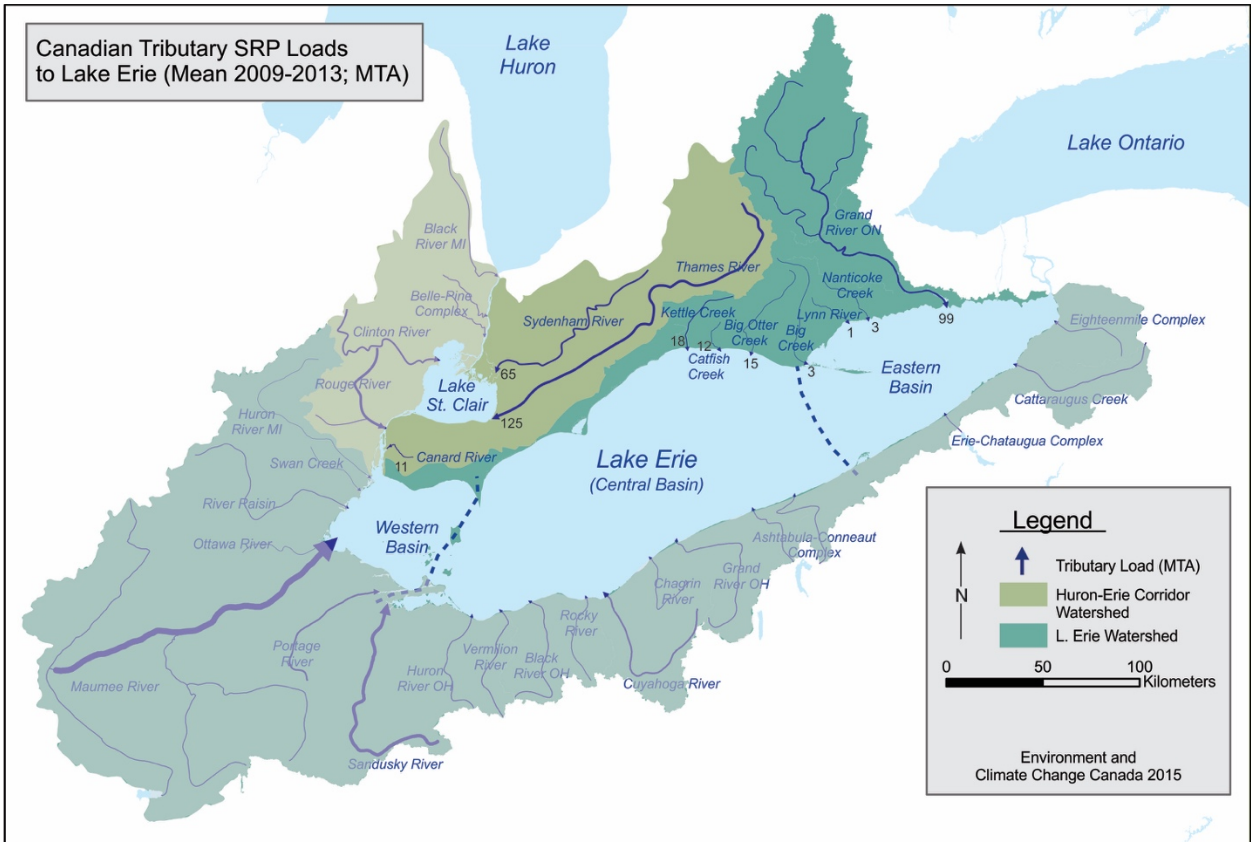

Figure 8: Canadian tributary loadings of soluble reactive phosphorus by watershed.

Arrows indicate Lake Erie tributaries. The width of each arrow indicates the relative amount of total phosphorus loading to Lake Erie. Numbers at the mouths of the Canadian tributaries indicate mean (2003–13) total phosphorus loads in metric tonnes per year.

Source: Environment and Climate Change Canada.

The proportion of soluble reactive phosphorus in the total phosphorus load varies significantly from year to year and from tributary to tributary. For instance, in 2012, soluble reactive phosphorus was 50 per cent of the total phosphorus load from the Thames River, but only 25 per cent of the total load from the Grand River.

3.3 Sources currently contributing phosphorus to Lake Erie

In the Ontario portion of the Lake Erie basin, similar to the U.S., the majority of the loads are from non-point sources. Because the amount of phosphorus going into Lake Erie is dependent in large part on runoff from the land — a non-point source that is heavily influenced by weather — this leads to variability from season to season and from year to year.

Defining non-point and point sources

Sources of phosphorus entering Lake Erie are generally considered to be either point sources or non-point sources.

Point sources include, for example, municipal and industrial wastewater treatment plants. They tend to be measured on a regular basis and their variability is relatively low because treatment processes are controlled, resulting in discharges with a fairly constant quality.

Non-point sources include, for example, agricultural and stormwater runoff. They are highly variable in quality and quantity

Phosphorus loads tend to be highest in late winter and spring, and years that receive more rain will generally have higher loads of phosphorus than drier years. For example, high runoff from land can cause high phosphorus loadings during wet weather, while loadings are lower in dry conditions.

Given the number and types of sources, multi-jurisdictional and multi-stakeholder collaboration and partnerships are essential for reducing nutrient loads to Lake Erie. In 2008, Canadian federal and provincial agencies undertook a significant data compilation effort to update loading information. Those results were further updated and reported in 2016. The estimated loadings reported in this section are based on this dataset, which is considered to be the most accurate and comprehensive available.

3.3.1 How Ontario's non-point sources contribute to phosphorus loadings

From 2003 to 2013, Canadian non-point sources contributed an average of 71 per cent of the Canadian soluble reactive phosphorus load and 93 per cent of the total phosphorus load to Lake Erie.

These non-point sources include overland runoff and subsurface (tile) drainage from agricultural lands**,** malfunctioning septic systems, and stormwater runoff from residential properties, golf courses, commercial and industrial property, and impervious surfaces. With about three-quarters of Ontario's Lake Erie basin in agricultural production, farmland is considered a substantial contributor to the total non-point source phosphorus load (as described in Section 2.5.2).

3.3.2 How Ontario's point sources contribute to phosphorus loadings

The relative contribution from urban point sources, including municipal wastewater treatment plants, combined sewer overflows (CSOs) and industrial direct discharges, is estimated to be only 10 to 15 per cent of the total phosphorus load across the Lake Erie basin. This is true despite the large volumes of discharge because phosphorus discharges from Ontario's municipal wastewater treatment plants are currently well controlled.

Wastewater treatment plants

Most of the 21 large secondary wastewater treatment plants (representing a capacity of at least 3.78 million litres per day) in the Lake Erie basin already conform to the recommendation under the *Great Lakes Water Quality Agreement, 2012* (GLWQA) for these facilities to achieve a maximum effluent concentration of 0.5 mg/L of total phosphorus. All municipal wastewater treatment plants in the basin currently provide at least secondary treatment; a significant number of tertiary (advanced) treatment plants discharging to sensitive

Wastewater treatment levels

Primary treatment involves the retention of wastewater to allow some settling of solids.

Secondary treatment uses biological processes and additional settling to remove dissolved organic compounds that escape primary treatment.

Tertiary treatment uses specialized processes to remove specific compounds. Phosphorus removal might involve chemical methods (such as adding iron salts) or biological methods using polyphosphate surface waters also provide enhanced phosphorus removal, below the 0.5 mg/L monthly average limit.

Ongoing treatment plant upgrades and treatment process optimization in a number of municipalities have reduced total phosphorus loadings from these sources by 35.5 tonnes between 2008 and 2014. Effluent discharge data from 2008 indicate that 118 municipal wastewater treatment plants in the Lake Erie basin discharged 99 tonnes, 5.9 tonnes and 40 tonnes of total phosphorus into the western, central and eastern basins, respectively. In 2014, however, corresponding loadings were 65 tonnes, 5.6 tonnes and 39 tonnes. Further reductions may have been achieved beyond 2014, and these numbers are being analyzed.

Combined sewer overflows

It is estimated that the total phosphorus loads contributed by CSOs and wastewater treatment plant bypasses basin-wide are a small fraction (10 to 15 per cent) of the total phosphorus load coming from the treatment plants. In certain municipalities, however, the contribution of these wet weather sources may be much greater.

CSOs release an untreated mixture of sanitary sewage and stormwater into receiving waters. These discharges can be a significant source of sediment, phosphorus, bacteria and other pollutants — especially where discharges are frequent and volume is high. CSOs occur mainly in the older parts of large cities and require investments to control. Cities such as Windsor, Ontario, have recently undertaken system improvements to increase storage and treatment of wet weather flows and reduce the impact of CSOs on receiving waters.

Industrial facilities

There are very few direct discharges of phosphorus to Lake Erie from industrial facilities. Most commercial and industrial plants discharge into municipal sewer systems.

3.4 Phosphorus loads to Lake Erie by basin

From both Canadian and U.S. sources, the western basin receives almost two-thirds (61 per cent) of the lake's annual phosphorus load, the central basin receives about 28 per cent and the eastern basin only 12 per cent.[5] The direction of flow through the lake is west to east, so loadings to the western basin also have a significant impact on conditions in the central and eastern basins.

About 84 per cent of total phosphorus loads and 82 per cent of soluble reactive phosphorus loads to Lake Erie are contributed by the United States. Canadian sources comprise about 32 per cent of the load to the Huron-Erie corridor, less than one per cent of the loads to the western basin (not including the corridor) and only 10 per cent of the load to the central basin. In the eastern basin, Canadian sources contribute about 54 per cent of the total phosphorus load (see Figure 9).

[5] Average over the period 2003–13.

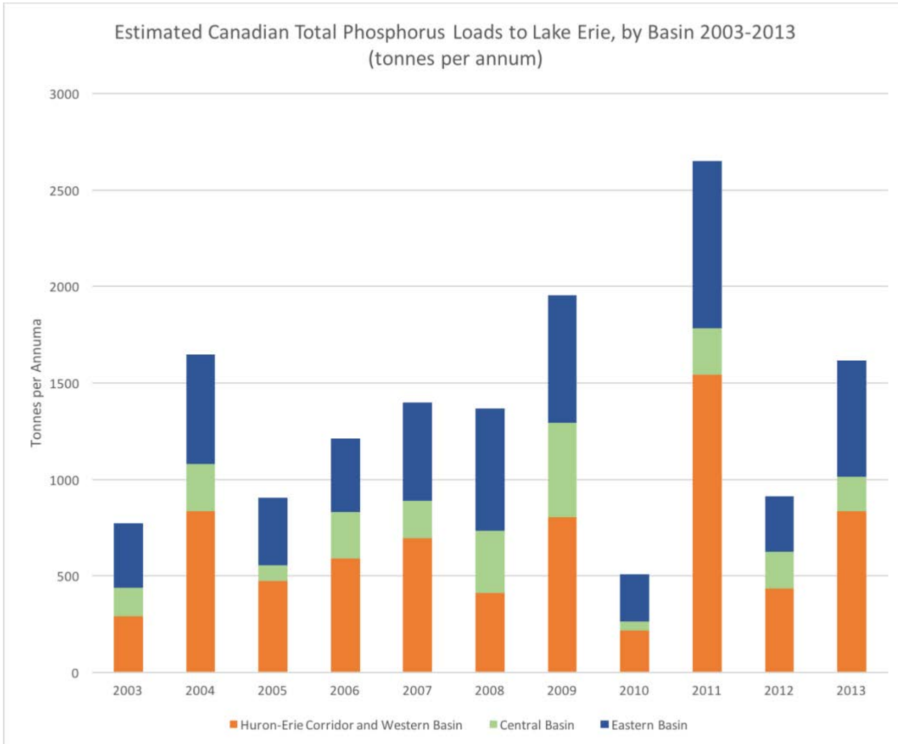

Figure 9: Total Canadian tributary phosphorus loads to Lake Erie divided by basin, 2003–13. Loads do not include contributions from atmospheric deposition or Lake Huron.

Source: Maccoux et al., 2016.

3.4.1 Western basin

The majority of total surface water inflow to Lake Erie's western basin (an average of 94 per cent of total inflow over 2011–13) comes from the Detroit River, the connecting channel that carries the combined outflows from Lakes Superior, Michigan, Huron and St. Clair (the last including discharge from Ontario's Thames River) into Lake Erie. An additional four per cent of flow enters the lake from the Maumee River (Ohio), with the remaining two per cent contributed by smaller tributaries.

Binationally, the western basin receives on average 61 per cent of the total Lake Erie phosphorus loads (5,492 tonnes total phosphorus annually) with Canada contributing 647 tonnes (12 per cent) and the U.S. contributing 4,407 tonnes (80 per cent). Phosphorus loading from the atmosphere and Lake Huron make up the remainder. Of the western basin load from Canadian sources, more than 99 per cent are discharged to the Huron-Erie corridor. By contrast, the majority of the U.S. loads (60 per cent) are discharged directly to the western basin and 22 per cent to the Huron-Erie corridor.

3.4.2 Central basin

Due to the small area of Canadian watershed draining to the central basin, all of the major sources of phosphorus to the central basin are U.S. tributaries, most of them located in Ohio. On average U.S. tributaries discharging to the central basin — which include the Sandusky, Huron, Vermillion, Cuyahoga and Grand rivers — contribute 2,059 tonnes of total phosphorus per year.

Canadian tributaries contribute about eight per cent of the total phosphorus load to the central basin. Altogether, Canadian sources contribute an average of 229 tonnes annually to the central basin, with Kettle Creek, Catfish Creek and Big Otter Creek — the three largest tributaries — annually contributing 47 tonnes, 45 tonnes and 85 tonnes, respectively.

3.4.3 Eastern basin

Canadian sources contribute 54 per cent of the total phosphorus load to the eastern basin, with the majority of this coming from one tributary: the Grand River. Due to its large watershed area, the Grand River contributed an average of 373 tonnes of total phosphorus annually (about 35 per cent of the total loading to the eastern basin of Lake Erie) for the period of 2003–13 and is therefore a significant contributor to phosphorus loads to the lake.

3.5 Binational phosphorus targets, objectives and commitments

The GLWQA sets out a number of lake ecosystem objectives it expects the parties to achieve by reducing phosphorus loads to the Great Lakes. For Lake Erie, the relevant objectives are to:

- maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in the waters of the Great Lakes
- minimize the extent of hypoxic zones in the waters of the Great Lakes associated with excessive phosphorus loading
- maintain the levels of algal biomass below the level constituting a nuisance condition
- maintain algal species consistent with healthy aquatic ecosystems in the nearshore waters of the Great Lakes

The 2016 binational phosphorus targets reflect the complexity of the Lake Erie ecosystem and its sources of phosphorus by establishing targets for each of Lake Erie's basins that are based on the distinctive characteristics of each.

At the time of writing, there is insufficient information to allow a target for the eastern basin to be established. As research and monitoring proceeds, it is expected that a target will also be established for that basin.

Three key metrics were established as ecosystem response indicators of the associated ecosystem objectives and have guided the development of the new reduction targets:

- **cyanobacteria blooms in the western basin and nearshore areas** — as measured by the maximum 30-day western basin cyanobacteria biomass (metric tonnes)
- **hypoxia in the central basin** — as measured by the average hypolimnion dissolved oxygen concentration during August and September, the number of hypoxic days and the average area extent

- ***Cladophora* in the nearshore areas of the eastern basin** — as measured by algal dry weight biomass and tissue phosphorus concentration

For more information about the 2016 binational phosphorus targets, refer to the May 2015 technical report *Recommended Phosphorus Loading Targets for Lake Erie* and associated documents at binational.net.

3.5.1 Why 2008 was selected as the baseline year

It was necessary to select a baseline year against which future loading reductions toward the new binational targets could be evaluated. The parties of the GLWQA selected 2008 as the baseline year because data for that year are the most consistent, accurate and comprehensive available. According to this data, the 2008 whole-lake annual total phosphorus load was 10,627 tonnes, which is very close to the Lake Erie target total phosphorus load of 11,000 tonnes per year set in the 1978 GLWQA amendment.

3.5.2 Targets to reduce western basin cyanobacteria blooms

For the western basin of Lake Erie, where cyanobacteria and associated algal toxins are the predominant problem, meeting the relevant GLWQA lake ecosystem objective was quantitatively interpreted as reducing algae to non-severe levels (less than 9,600 tonnes) — such as those experienced in 2012 — 90 per cent of the time.

A 40 per cent reduction (from 2008 levels) in the spring total and soluble reactive phosphorus loads from the Maumee River in the U.S. to the western basin is necessary to achieve this outcome.

3.5.3 Targets to reduce central basin hypoxia

For the central basin of Lake Erie, where expansion of the natural hypoxic zone above the lake bottom (the hypolimnion) is the predominant problem, meeting the relevant GLWQA lake ecosystem objective was quantitatively interpreted as maintaining dissolved oxygen levels at or above 2 mg/L in the hypolimnion during the August to September period.

To achieve this outcome, an annual total phosphorus load reduction down to 6,000 tonnes entering the central basin of Lake Erie from the United States and Canada is necessary. This is equivalent to a 40 per cent reduction from 2008 loads and requires a reduction from the United States and Canada of 3,316 tonnes and 212 tonnes, respectively.

3.5.4 Targets for priority tributaries to reduce nearshore cyanobacteria blooms

For nearshore areas of Lake Erie — including river mouths and embayments where excess algae occurs as the result of localized discharge from the up-stream watershed — a 40 per cent reduction in spring total and soluble reactive phosphorus loads (from 2008 levels) from the following watersheds is recommended: in Canada, the Thames River and Leamington tributaries; and in the United States, Maumee River, River Raisin, Portage River, Toussaint Creek, Sandusky River and Huron River.

3.5.5 Targets/commitments to reduce eastern basin *Cladophora*

For the eastern basin of Lake Erie, where the accumulation of the nuisance algae *Cladophora* on the lake bed, in the water, and along the shores is the predominant problem, there is currently insufficient science to quantify of the relationship between phosphorus loads and *Cladophora* levels.

Specifically, the extent to which the excessive growths of *Cladophora* in the nearshore area of the eastern basin are driven by open-lake phosphorus concentrations and/or by local tributary phosphorus loading to the nearshore area is currently unknown. The complex interactions between the substrate, presence of invasive mussels, and hydrodynamics hinder the ability to predict with confidence if and how reductions in loading from eastern basin sources would effectively curb *Cladophora* production.

In the absence of scientific certainty, Canada and the United States will take a precautionary approach to address phosphorus loads from sources in the Lake Erie's eastern basin until such time that the science evolves to inform the establishment of a target.

The two countries have agreed to the following precautionary actions:

- In Canada:
  - continue work already underway to reduce phosphorus loads in the Grand River watershed through the implementation of the Grand River Watershed Management Plan and determine the impact such reductions have on nearshore *Cladophora* growth
  - pursue opportunities to reduce spring phosphorus concentrations in the nearshore waters
- In the United States:
  - begin work to develop a watershed-based restoration plan for Cattaraugus Creek in New York and design the plan to meet both watershed and nearshore water quality goals
  - conduct monitoring and assessments to better understand phosphorus contributions from other U.S. tributaries

In the spirit of adaptive management, the viability of setting science-based numeric targets for the eastern basin will be revisited in 2020. In the interim, there will be support for targeted research efforts aimed to improve our scientific understanding of how to effectively manage the *Cladophora* problem in the eastern basin and elsewhere in the Great Lakes.

3.5.6 Reducing total phosphorus versus soluble reactive phosphorus

Different non-point source reduction actions will emphasize different total phosphorus components; selection of phosphorus reduction actions should take these differences into account.

The proportion of soluble reactive phosphorus in the total phosphorus load is highly variable from one watershed to the next, and can range up to 50 per cent of the total load. Soluble reactive phosphorus is virtually 100 per cent bioavailable, which makes reducing it an efficient way to cut down nuisance and harmful algal growth. Accordingly, reducing soluble reactive phosphorus should be a priority in planning management strategies, although reducing particulate phosphorus is still important.

It would be prudent to aim for 40 per cent reduction in Canadian soluble reactive phosphorus and total phosphorus loads, consistent with the overall goal of 40 per cent loading reduction.

4 Actions to achieve phosphorus reduction targets

This action plan reflects commitments by Canada and Ontario and their partners to reduce phosphorus entering Lake Erie. The plan fulfills commitments Canada and Ontario have under the *Great Lakes Water Quality Agreement, 2012* (GLWQA) and the *Canada–Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, 2014* (COA).

Actions have been organized into five categories:

- reduce phosphorus loadings
- ensure effective policies, programs and legislation
- improve the knowledge base
- educate and build awareness
- strengthen leadership and co-ordination

See Table 1 for a summary of the actions that fall under each of these broad categories. The actions are expected to achieve the primary objective of reducing phosphorus loadings in Lake Erie as well as important co-benefits such as mitigating and adapting to the changing climate; reducing greenhouse gases; protecting soil health, wetlands and ecosystems; propelling development of innovative technologies and solutions; reducing economic impacts; and strengthening Canada's global competitiveness.

The actions identified by the governments of Canada and Ontario include initiatives already in place, as well as new activities designed specifically to address nutrient issues facing Lake Erie. While the governments of Canada and Ontario led development of the plan and will co-ordinate the implementation of its actions, they cannot achieve its goals without the important work being done by their partners and the public.

Canada and Ontario will take an adaptive management approach to implementing this action plan. New government or partner actions may be considered as knowledge of the situation expands or new opportunities become available.

Working together to save Lake Erie

During the development of this action plan, Canada and Ontario established a multi-sectoral Lake Erie Nutrients Working Group, and also engaged First Nations and Métis communities, municipalities, conservation authorities, environmental organizations, members of the agricultural community, and the public.

Early actions and a draft plan were posted online in October 2016 and March 2017, respectively, to gather additional feedback from the public, partners and stakeholders. Significant input was also gathered through in-person engagement sessions and written submissions.

The feedback gathered was used to enhance the plan with new partner-led actions added to the existing Canada-Ontario actions in cases where a partner is committed to playing a significant role.

Notwithstanding the formal partner commitments described above, Canada and Ontario recognize that successful implementation of all the actions in this plan rely on the ongoing work being done by their many partners across the Lake Erie basin.

Table 1: Summary of the Lake Erie action plan

GOAL: Reduce Canadian phosphorus loadings by 40 per cent	
CATEGORY OF ACTION	**ACTIONS**
A. Reduce phosphorus loadings	**A1.** Support watershed and nearshore-based strategies and community-based planning for reducing phosphorus loadings **A2.** Reduce phosphorus loadings from urban areas **A3.** Reduce phosphorus loadings from agricultural and rural areas
B. Ensure effective policies, programs and legislation	**B1.** Support and strengthen policies, programs and legislation **B2.** Strengthen decision-making tools
C. Improve the knowledge base	**C1.** Conduct monitoring and modelling **C2.** Conduct research to better understand nutrient dynamics in the Lake Erie basin **C3.** Conduct research to better understand and predict the impact of climate change on the Lake Erie ecosystem **C4.** Conduct research to improve existing practices and develop new innovative practices and technologies for phosphorus loss reduction
D. Educate and build awareness	**D1.** Enhance communication and outreach to build awareness, improve understanding and influence change **D2.** Share data and information
E. Strengthen leadership and co-ordination	**E1.** Improve communication and co-ordination **E2.** Establish an adaptive management framework

Category A: Reduce phosphorus loadings

This action plan identifies a range of on-the-ground actions to reduce phosphorus loadings from urban, agricultural and rural lands, and to encourage good environmental stewardship. These actions need to be co-ordinated with and linked to current federal, provincial and municipal government initiatives, as well as initiatives conducted by conservation authorities, key sectors and others.

A1: Support watershed and nearshore-based strategies and community-based planning for reducing phosphorus loadings

The nearshore zone is the area where shoreline discharges and tributary flows have the greatest impact, particularly on the growth of harmful and nuisance algal blooms (the impacts of which are described in section 2.1).

Wetlands and nearshore areas are also important habitats for many plant and animal species. Wetlands are recognized for their important role in carbon storage — an important factor in mitigating climate change — and provide some of the most biologically diverse and useful habitats for plants and animals. Significant quantities of snowmelt and runoff can be stored in these systems and gradually released over time, providing an important buffer against flooding and groundwater depletion.

Several watershed plans, such as the Grand and Thames rivers, already exist for the tributaries throughout the Lake Erie basin. Supporting the development of additional plans — and linking them to nearshore-based strategies and other phosphorus reduction actions at a community level — will avoid duplication of effort and ensure resources are efficiently used.

Actions under this category:

1. Canada and Ontario will continue to collaborate with landowners, municipalities, conservation authorities, First Nations and Métis communities, and others on a co-ordinated approach to watershed planning for reducing phosphorus loadings.
2. Canada and Ontario will continue to work with conservation authorities, municipalities and other partners to promote implementation of existing watershed plans focused on reducing phosphorus loadings in the Lake Erie basin and develop new ones as required.
3. Canada, with Ontario's support, will continue to work with conservation authorities and other partners to identify phosphorus sources and develop phosphorus reduction management strategies and plans for selected tributaries/regions in the Lake Erie watershed, including the Sydenham River and Thames River as well as the Essex Region tributaries including the Leamington tributaries, Kettle Creek, Catfish Creek and the Grand River.
4. Canada and Ontario will, starting in 2017, work with First Nations and Métis communities in the Lake Erie watershed to support efforts to identify phosphorus sources and develop appropriate phosphorus reduction strategies for these communities.
5. Canada, starting in 2017 and with Ontario's support, will lead the implementation of the binational nearshore assessment and management framework for Lake Erie.
6. Within the eastern basin, Canada and Ontario will focus phosphorus reduction efforts in the Grand River watershed in the absence of an eastern basin target.
7. Canada and Ontario will explore the development of initiatives that support the implementation of local actions within high-risk areas for phosphorus loadings in the western and central basins of Lake Erie, including the high-risk areas in the binational priority areas of the Thames River watershed and Leamington tributaries.

Watershed Planning

Watershed planning is encouraged across the Province through the Provincial Policy Statement (2014). Under the Growth Plan for the Greater Golden Horseshoe (2017), municipalities are required to undertake watershed planning to help inform land use and infrastructure planning and decision making and protect water. Ontario is also developing guidance to support watershed planning that will be completed in 2018.

8. Canada and Ontario will continue to support the conservation and restoration of Ontario’s wetlands through programs such as the Ontario Eastern Habitat Joint Venture, the Habitat Stewardship Program and the National Wetland Conservation Fund.
9. Ducks Unlimited Canada, in partnership with the Ministry of Natural Resources and Forestry, will implement a wetland restoration initiative in the Lake Erie basin to support conservation efforts with landowners and local organizations that help reduce phosphorus loads entering Lake Erie.

A2: Reduce phosphorus loadings from urban areas

While municipal point sources are well controlled (see sections 2.4.1 and 3.3.2), there are still opportunities to optimize the performance of treatment plants, reduce the volume and frequency of bypasses and overflows, and reduce loads from urban stormwater.

Since 2008, the baseline year upon which phosphorus reduction targets have been established, treated effluent quality has improved through a combination of treatment upgrades and operational improvements at many municipal wastewater treatment plants. Some of the actions below are intended to achieve further reductions from municipal wastewater treatment plants. For instance, there may be new technology retrofits or process modifications that can be made to existing secondary wastewater treatment plants that can approach or match the effluent phosphorus concentrations attainable through conventional tertiary treatment (i.e., chemically-assisted filtration) at lower cost.

Action to promote green infrastructure and low-impact development (LID), as well as those to reduce phosphorus at the source (e.g., elimination of phosphorus from most residential lawn fertilizers by the fertilizer industry), are expected to achieve phosphorus load reductions from urban landscapes. Stormwater green infrastructure and LID systems reduce phosphorus loads to lakes and streams by managing rainwater where it falls so less phosphorus is washed off surfaces (e.g., from properties, streets) and transported into waterbodies. Overall, stormwater green infrastructure and LID

Optimizing wastewater infrastructure in the Grand River watershed

The Ontario Ministry of the Environment and Climate Change and the Grand River Conservation Authority (GRCA) are partnering with municipalities to deliver the Grand River Watershed-wide Wastewater Optimization Program. This program provides assistance to municipalities to optimize their wastewater treatment plants and improve effluent quality.

Participants are aiming to achieve voluntary targets for phosphorus and ammonia beyond legal requirements. These targets are based on the Grand River Water Management Plan, which recommends voluntary total phosphorus and total ammonia nitrogen targets for municipal wastewater treatment plants in the watershed. For example, through optimization, the City of Brantford’s secondary treatment plant is achieving 0.2 milligrams per litre or less total phosphorus in effluent (which approaches the performance of chemically assisted filtration). Brantford has reduced total phosphorus and total ammonia nitrogen by 94 per cent and 56 per cent, respectively, and saved $27.8 million in budgeted plant upgrades since initiating its optimization program in 2011.

Other municipalities pursuing optimization in the Grand River watershed include the County of Brant, the City of Guelph, Haldimand County, Southgate, the Region of Waterloo, Centre Wellington and Wellington North.

systems help maintain and restore the natural water cycle.

Using green infrastructure to manage rainwater and snow melt increases the resiliency of urban communities to the changing climate. It also establishes green space people can enjoy and reduces instances of beach closures due to high pathogen levels. Helping to locally maintain and restore the natural water cycle increases the protection of ecosystems such as wetlands and riparian areas as well as the retention of water for shared use by communities and sectors such as agriculture.

Actions under this category include:

1. Canada and Ontario will continue to promote eligible investments for the reduction of excess phosphorus from sources (such as municipal wastewater treatment systems or municipal stormwater effluent) under applicable infrastructure and other funding programs.
2. Ontario will work with municipal partners to establish by 2020 a legal effluent discharge limit (in Environmental Compliance Approvals) of 0.5 milligrams per litre of total phosphorus for all municipal wastewater treatment plants (WWTPs) in the Lake Erie basin that have an average daily flow capacity of 3.78 million litres or more per day (see B1).
3. Ontario will, where feasible, work with municipal partners toward reducing loadings through:
    a. upgrades, including incorporation of innovative technologies and other modifications to secondary WWTPs that have an average daily flow capacity of 3.78 million litres or more per day in the Lake Erie basin, with an objective of approaching the phosphorus effluent concentrations achievable through a tertiary level of treatment
    b. improvements to wastewater treatment and collection infrastructure to reduce combined sewer overflows and bypasses
    c. improvements to stormwater management systems (including facility rehabilitation and incorporation of green infrastructure and innovative treatment technologies)
4. Ontario will continue to collaborate with municipal partners to promote and encourage optimization of wastewater treatment as a way for municipalities to improve treatment plant performance (including lower phosphorus discharges) and achieve operational efficiencies.
5. Ontario will continue to support area-wide optimization programs for municipal WWTPs to reduce phosphorus loads, with Lake Erie the priority geography for this effort.
6. Ontario will work with developers, municipalities, conservation authorities and others to promote and support the use of green infrastructure and LID systems for stormwater management, including clarifying and enhancing policies as well as developing green

standards. Ontario's draft stormwater LID guidance manual is aimed at helping proponents implement LID and green infrastructure and will be available in 2018.

7. The Municipality of Leamington, located in the priority area of the Leamington tributaries, will work with partners to explore opportunities to reduce phosphorus loadings through upgrades to their wastewater collection system to service commercial facilities (including greenhouse operations) and residential properties currently serviced by septic systems.

8. The City of London will undertake a pilot project using new technologies as an alternative to conventional tertiary treatment with the objective of achieving effluent quality of 0.1 milligrams per litre. Upon successful completion of the pilot project, the City of London will then develop a plan to rollout phosphorus reduction technologies to the five major treatment plants.

9. The City of London will accelerate plans to separate combined sewers, including the design and construction of necessary stormwater outlets, with the target of separating 80 per cent (17 kilometres) of its combined sewer system by 2025.[6]

10. The City of London will circulate for agency and public review by the end of Q2 2018 an implementation plan that provides the scope and timing for managing the highest priority sanitary sewer overflows as identified in its pollution prevention and control plan. To support implementation, the City will facilitate a proof-of-concept, in-field pilot project of high-rate treatment technologies with the support of industry (Trojan Technologies) and academic (Western University) partners, and will continue its private property weeping tile disconnection program.

11. The City of London will incorporate LID and adaptive environmental management principles into the Ministry of the Environment and Climate Change's Dingman Creek subwatershed area-wide Environmental Certificate of Approval pilot project. The City will also implement a program to maximize the treatment and infiltration of stormwater using LID technologies in built-out areas in co-ordination with its linear infrastructure renewal program.[7]

Reducing the impact of greenhouses on the Great Lakes

To help the province's agriculture sector reduce phosphorus discharges and drive water quality improvements, Ontario initiated a greenhouse environmental compliance plan that includes support for education and awareness, information on new technologies, annual water monitoring activities, and inspections. Where significant impacts are found, the Ministry of the Environment and Climate Change requires operators to take action.

Ontario actively engaged the greenhouse sector when it developed a new greenhouse nutrient feedwater regulation that came into effect in 2015. To drive water quality improvements, greenhouses discharging into Leamington area tributaries or the Thames River watershed were required to submit applications to the Ministry for wastewater and stormwater discharge approvals by March 31, 2017. Remaining greenhouses are to submit their required applications by March 31, 2018. The Ministry will apply a risk-based approach to address non-compliance beyond the deadlines.

[6] Contingent upon funding.
[7] Contingent upon funding.

12. The City of London will expand its current monitoring program to prioritize the retrofitting of stormwater ponds and will develop a stormwater pond retrofit program to improve operational performance and legacy phosphorus removal. To support this program, the City will evaluate the need to develop a stormwater sediment handling facility with the goal of repurposing stormwater pond sediment and appropriately managing the legacy phosphorus contained within it.[8]

A3: Reduce phosphorus loadings from agricultural and rural areas

When focusing efforts for phosphorus reduction in the Lake Erie basin, it is important to build on the many tools already available to agriculture and rural communities that support sustainability and stewardship (e.g., education and awareness, cost-shared investments, regulation).

A significant amount of work has been done over the past several decades to develop and implement best/beneficial management practices (BMPs) that enhance nutrient, soil and water stewardship on privately owned agricultural and public lands. However, widespread action by agriculture and rural communities to adopt a multi-BMP approach (i.e., more than one BMP used in combination) — customizable to individual properties and agriculture operations — will be critical to achieving targets.

The majority of the municipalities on the Canadian side of Lake Erie are rural. These municipalities have partnered with the Ontario government to encourage and implement progressive design and construction of drainage systems that will help reduce the transport of phosphorus to the Great Lakes. Through the Great Lakes and St. Lawrence Cities Initiative, municipalities have partnered with the Ontario Federation of Agriculture to reduce phosphorus loss from farmland by improving water management on private land and in the municipal drainage system. Considerable government and industry effort has also been made to reduce the impact of greenhouses on the Great Lakes (see sidebar).

Actions to reduce phosphorus loadings from agricultural and rural areas are directed at effecting changes to the ways in which nutrients, soils and water are managed. This includes:

- managing nutrients (manure and commercial fertilizer) applied to the farm field and used in greenhouse operations to optimize yield while minimizing losses to waterways (e.g., applied at the right time, place, rate and source)
- managing agricultural soils in ways that help build and sustain soil health, increase infiltration and reduce nutrient loss, particularly in the non-growing season
- improving runoff water quality by slowing the flow of water and increasing resilience in response to storm events on agricultural lands (drainage) and surrounding rural areas (rural stormwater) using natural and human-made green infrastructure

[8] Contingent upon funding.

Actions under this category include:

1. Canada and Ontario will continue to leverage existing funding initiatives (e.g., Species at Risk Farm Incentive Program) to support the implementation of agricultural BMPs and environmental investments in targeted regions of the Lake Erie basin.
2. Canada will create an application-based funding program in 2018 that provides $3.55 million over four years in financial support for projects demonstrating effectiveness of BMPs and innovative approaches to reducing phosphorus loads to Lake Erie.
3. Canada and Ontario will pursue, under the next federal–provincial Canadian Agricultural Partnership, initiatives that support a multi-BMP, whole-farm approach to achieve phosphorus runoff reduction from farmland in the western and central basins.
4. Canada and Ontario will ensure public land is managed to minimize phosphorus losses.
5. Canada and Ontario will encourage dam owners to explore managing dams to reduce phosphorus outputs (without compromising aquatic invasive species management or hydroelectric power generation).
6. Ontario will continue to work with greenhouse growers to encourage nutrient recycling and reduce phosphorus levels in discharges to watercourses that flow into Lake Erie and Lake St. Clair, with a priority on the Leamington area and Thames River. Actions include education and awareness, innovation, monitoring, cost-shared investments, and regulatory compliance and enforcement.
7. Ontario will work with the Lake Erie community to carry out measures to restore native habitats (including wetlands and riparian habitat), focusing efforts in priority watersheds where phosphorus loadings are high and natural cover is low.
8. Ontario will encourage stewardship activities on private lands that support phosphorus reduction in Lake Erie by providing incentives for landowners through programs such as the Conservation Land Tax Incentive Program and the 50 Million Tree Program.
9. Ontario, with Canada's support, will work with the agriculture sector to harmonize and streamline planning tools (e.g., Environmental Farm Plan, Farmland Health Check-Up, nutrient management planning, soil management BMPs, evaluation and monitoring tools) to support an integrated, whole-farm approach to environmental sustainability.
10. 4R Ontario[9] will lead the implementation of a voluntary 4R Nutrient Stewardship program based on the internationally-recognized 4R Nutrient Stewardship system. The program will promote the adoption of nutrient management in Ontario to help farmers

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[9] 4R Ontario is an industry-led collaboration that includes Fertilizer Canada, the Ontario Agri Business Association and the Ontario Ministry of Agriculture, Food and Rural Affairs. It receives additional support and engagement from Grain Farmers of Ontario, the Ontario Federation of Agriculture, the Christian Farmers Federation of Ontario, Conservation Ontario, The Nature Conservancy and the Ministry of the Environment and Climate Change.

reduce nutrient losses into the environment and improve productivity through efficient nutrient application.

11. The Ontario Greenhouse Vegetable Growers will continue its work through the Ontario Greenhouse Environmental Strategy working group, in collaboration with municipal and regional partners, to explore options for sanitary sewer expansion projects to serve greenhouse, industrial and residential needs to reduce the potential for phosphorus loss. The organization will explore options for monitoring, research and remediation of priority subwatersheds, and will continue to support compliance efforts by providing educational material and templates to assist the agriculture sector in adhering to regulatory requirements.
12. The Ontario Cover Crops Steering Committee, led by Grain Farmers of Ontario, will implement the Ontario Cover Crops Strategy to encourage widespread adoption of cover crops on farms in Ontario.
13. The Ontario Federation of Agriculture will work within the Thames River Phosphorus Reduction Collaborative partnership and with Grow Ontario Together — a coalition of vested commodity organizations — to promote a suite of effective land management and drainage solutions for agriculture to reduce phosphorus loss and improve water quality in the Thames River. The federation will continue to support other relevant initiatives such as the Ontario Cover Crops Strategy, the Timing Matters initiative and 4R Nutrient Stewardship.
14. ALUS Elgin will use marginal environmentally sensitive and inaccessible parcels of land to mitigate and reduce phosphorus loading into Lake Erie and the Thames River by prioritizing sites with active erosion occurring and that are situated along a watercourse or wetland.
15. Conservation authorities will manage their lands to minimize phosphorus losses.
16. Conservation authorities will continue to provide local expertise in support of the delivery of rural water quality, natural heritage and soil health programs that reduce nutrient loading in the Lake Erie basin.

Category B: Ensure effective policies, programs and legislation

Policies and legislation are effective tools for reducing phosphorus inputs to the environment.

Efforts by federal and provincial governments to reduce phosphorus loadings over the years through regulation and policies have proven effective. Examples include federal regulation of the phosphorus content of detergents under the *Canadian Environmental Protection Act*, municipal wastewater discharge quality requirements under Ontario's *Environmental Protection Act* and *Ontario Water Resources Act*, and nutrient management controls under the Ontario's *Nutrient Management Act*. (See section 2.4.1 for more information.)

The actions under this category will enhance, strengthen and build on these tools to manage excess phosphorus inputs to aquatic ecosystems.

B1: Support and strengthen policies, programs and legislation

Essential to ensuring policies and legislation aimed at reducing phosphorus in Lake Erie are effective is making sure they are working to their full potential. There are also opportunities to identify gaps and explore innovative policy approaches for reducing phosphorus loadings.

Actions under this category include:

1. Canada and Ontario will, in collaboration with the United States, in 2020, reassess the viability of setting science-based numeric targets for the eastern basin.
2. Canada will continue to work on revisions to the *Feeds Regulations* that would remove minimum nutrient levels for livestock feeds (including phosphorus). This is anticipated to be enacted in 2018 and will enable the industry to be more flexible and decrease levels of phosphorus in feeds where it makes sense to do so. The revised regulations will likely result in a corresponding reduction in phosphorus content of manure.
3. Ontario will engage with key sectors as it considers further restrictions on the application of nutrients during the non-growing season.
4. Ontario will continue to phase in farms under the *Nutrient Management Act* through building permit approvals.
5. Ontario will, in 2018, release and begin the implementation of a long-term Agricultural Soil Health and Conservation Strategy, developed in collaboration with stakeholders, to support agricultural soil management practices that provide economic, environmental and social benefits to Ontario.
6. Ontario will, in 2018, begin a review of the province's approach to rural stormwater and agricultural drainage management using an integrated watershed approach. This will include an examination of the interactions between runoff from rural lands and roads, outlet drainage from agricultural lands, and municipal drains with the objective of identifying opportunities to improve the sustainable management of water.
7. Ontario will, as part of the hauled sewage policy and program review, develop and post for public comment in early 2018 a draft policy framework for managing hauled sewage in the province.
8. Ontario will work with partners to update provincial policies for Lake Erie by 2019 to provide the basis for establishing a legal effluent discharge limit (in Environmental Compliance Approvals) of 0.5 milligrams per litre of total phosphorus for all municipal WWTPs in the Lake Erie basin that have an average daily flow capacity of 3.78 million litres or more per day.
9. Ontario will update existing wastewater policies (i.e., F-series guidelines and procedures) and develop stormwater management policies and supporting guidance (e.g., LID and green infrastructure) by 2021 to enhance environmental protection, including reduction of nutrient loadings.

10. Ontario will provide updated guidance related to stormwater management and municipal planning, to be completed in 2018, to support the implementation of policies in the Provincial Policy Statement (2014).
11. Ontario will, through the implementation of the Wetland Conservation Strategy for Ontario, improve wetland conservation to achieve a net gain of wetlands and sustain ecosystem services, including improved water quality.
12. Ontario will, where feasible, streamline processes for environmental assessment and approvals related to wastewater and stormwater projects with a phosphorus reduction component within the Lake Erie basin.

B2: Strengthen decision-making tools

Continuous improvement of decision-support tools will strengthen capacity for science-based decision-making. Examples include development or enhancement of economic analysis tools, computer simulation (modelling) tools, and graphical and communication tools.

Actions under this category include:

1. Ontario will, with Canada's support, make publicly available in 2018 a digital elevation model of the Lake Erie watershed (based on LiDAR technology) to assist all members of the Lake Erie community in making evidence-based decisions (e.g., flood mapping, areas of soil erosion risk identification, precision agriculture) to ensure healthy lands and waters.
2. Ontario will work with municipalities to encourage the use (e.g., LID guidance) and development (e.g., bylaws) of decision-making tools that help reduce phosphorus through management of urban stormwater at the source.
3. Conservation authorities will continue to support analysis and reporting of information and data for decision making, including optimizing rural BMPs to improve water quality and using advanced GIS technologies and approaches to target locations for improved soil and nutrient management.

Category C: Improve the knowledge base

A strong science and monitoring foundation underlies this action plan and will continue to inform its implementation. Long-term monitoring programs have provided essential data to track spatial and temporal changes in the nearshore waters of Lake Erie and in its watersheds (see sidebar on page 44). These monitoring programs can be enhanced to gather information specific to particular sources or activities, while new or enhanced monitoring tools can facilitate better data collection.

As part of adaptive management, available information and research questions continually evolve, introducing the need to co-ordinate research activities and share information generated across government agencies, stakeholder groups and other partners.

C1: Conduct monitoring and modelling

Long-term monitoring is the cornerstone of an adaptive management approach. Programs in the Lake Erie watershed are continually being assessed to ensure priority locations and high phosphorus loading conditions, such as large storm events, are being monitored. In some cases, emerging technology is being incorporated to enhance existing monitoring efforts.

Actions under this category include:

1. Canada, with support from Ontario and conservation authorities, will use monitoring and modeling to provide annual assessments of phosphorus loads entering Lake Erie from Canadian sources.
2. Conservation authorities will continue to work with other stakeholders at the watershed, subwatershed and catchment levels to conduct research, monitoring and modelling activities on an annual basis to improve scientific efforts toward phosphorus reduction.
3. Canada, starting in 2016 and in collaboration with partners, will develop a decision-making tool to improve and standardize the calculation of phosphorus loads to Lake Erie and the other Great Lakes.
4. Canada, Ontario and conservation authorities will implement in 2017 a nested watershed monitoring approach in the Thames River to model and track nutrient dynamics and changes over time.
5. Canada will monitor and assess the temporal trends and spatial distributions of nutrient concentrations in the offshore waters of Lake Erie.
6. Canada will monitor and assess the temporal trends and spatial distributions of nutrient concentrations and nuisance algae (*Cladophora*) biomass in the nearshore areas of Lake Erie's eastern basin.
7. Canada will develop and apply remote sensing tools to detect and forecast harmful algal blooms in Lake Erie.
8. Canada will collect and co-ordinate hydraulic and hydrologic data, including maintaining Canada's role on the Canada–U.S. Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, to ensure accurate flow information is available to calculate seasonal and annual phosphorus loads.

A sampling of the science informing this plan

Ontario has undertaken several monitoring and research studies as part of its Great Lakes Nearshore Monitoring Program. These include tracking the influence of the Grand River in the nearshore of Lake Erie's eastern basin (2010), investigating the impacts and causes of the 2012 fish kill along the north shore of the central basin, and monitoring the extent and causes of harmful algal blooms along the shoreline of the western and central basins (2013).

Canada, through its Great Lakes Nutrient Initiative, has made significant investments in monitoring to improve our understanding of phosphorus loadings from Canadian tributaries and the health of biota and water quality conditions in the nearshore of Lake Erie. Models have been developed to help set phosphorus load reduction targets and to improve understanding of the linkages between land use and phosphorus loadings to tributaries and, ultimately, Lake Erie.

9. Conservation authorities will continue to work with other stakeholders, Canada and Ontario at the watershed/subwatershed/catchment level to conduct research, monitoring and modelling actions to improve scientific efforts toward phosphorus reduction on an annual basis.
10. Conservation authorities will collect, maintain, compile and share hydraulic and hydrologic data in partnership with Canada and Ontario, for example, through the Water Survey of Canada Hydrometric Monitoring Network Agreement.
11. Ontario, with support from Conservation Ontario and conservation authorities, will continue long-term monitoring programs in the watershed including the Provincial Water Quality Monitoring Network and the Provincial Groundwater Monitoring Network.
12. Ontario will continue to implement the long-term Great Lakes water intake and nearshore monitoring programs.
13. Canada and Ontario will deploy real-time monitoring systems in Lake Erie to monitor temperature, dissolved oxygen and algal pigments to enable tracking of hypoxia and lake stratification.
14. Canada will continue to produce an annual national field-scale crop inventory map using remotely-sensed imagery.
15. Canada, with support from its partners, will continue to develop, improve and apply Soil and Water Assessment Tool models for the Grand and Thames rivers to identify and provide advice to partners on strategies for optimizing BMPs.
16. Canada, with support from conservation authorities, will continue to improve models and tools at two scales for risk of phosphorus loss: the soil-landscape scale (Indicator of Risk of Water Contamination by Phosphorus [IROWC-P]) and the field scale (P-Index).
17. The City of London will co-ordinate its water quality monitoring with the Upper Thames River Conservation Authority to aid river improvement efforts and studies.

C2: Conduct research to better understand nutrient dynamics in the Lake Erie basin

There is a long history of research on nutrient dynamics and associated ecosystem changes in Lake Erie. A variety of research initiatives are currently underway — both in Canada and the United States — by government agencies, academic institutions and non-governmental organizations. It is important to incorporate available knowledge and work with research partners to develop and refine research questions over time.

Actions under this category include:

1. Ontario will continue a multi-watershed nutrient study to assess the interaction between agricultural land use and nutrient loadings in streams in the Great Lakes basin.
2. Ontario will support and conduct research on the use of sensor-based technology for monitoring phosphorus and associated parameters.
3. Canada and Ontario will conduct research to improve understanding of factors contributing to toxic and nuisance algae growth and their impacts on water quality and ecosystem health.
4. Ontario, with support from Canada, will undertake a monitoring and research project to better understand the source and types of phosphorus that are contributing to nearshore algal blooms in Lake St. Clair.
5. Canada, with Ontario's support, will lead research and monitoring to improve understanding of invasive mussels and their influence on phosphorus dynamics and *Cladophora* growth in the eastern basin of Lake Erie.
6. Ontario will work with the Lake Erie community to conserve and manage aquatic habitat and the fish community to maintain fish population health and resiliency.
7. Ontario will lead research on the bioaccumulation of the algal toxin microcystin in fish tissue to better understand its impact on human health.
8. Canada will investigate how land use changes in small Lake Erie tributaries are affecting instream water quality conditions, including the role of episodic wastewater releases and factors that have an impact on the effectiveness of agricultural BMPs.
9. Canada, in collaboration with partners, will investigate how nutrients in addition to phosphorus, particularly nitrogen, may contribute to harmful algal bloom development and toxicity.
10. Canada, in collaboration with partners, will investigate the potential role that internal loading and nutrient exchanges may have on the recovery of Lake Erie as external loads are reduced.
11. Canada will develop and apply next-generation physical limnology and ecological models — including integrated watershed-lake models — for Lake Erie and Lake St. Clair to improve understanding of the causal factors affecting the development of algal blooms and hypoxia (and how phosphorus reductions from tributaries will affect those factors).
12. Canada will improve and apply the *Cladophor*a growth model to determine the relationship between *Cladophora* growth and phosphorus loadings.

C3: Conduct research to better understand and predict the impact of climate change on the Lake Erie ecosystem

Climate change is a cross-cutting issue that needs to be integrated into research activities conducted in the Lake Erie basin. As the climate changes, earlier winter thaws, increased spring stream flows and more intense rainfall events can result in more nutrients being washed into the lake. These, combined with longer warm water periods, create the potential for increased algal blooms.

The synergies and co-benefits of actions under Ontario's Climate Change Action Plan (see sidebar) and this action plan for Lake Erie will be co-ordinated and maximized where possible.

Actions under this category include:

1. Canada, starting in 2017 and with support from conservation authorities, will run watershed simulation models under different climate change scenarios to understand how phosphorus loss from the land may change.
2. Canada will deploy long-term climate buoys in the Great Lakes to determine the influence of climates change on the Great Lakes, including nutrient loading and in lake conditions. Data sets will be made publically available.
3. Canada, starting in 2017, will investigate the exchange of nutrients between groundwater and surface water in the Thames River watershed to better understand the relationship between seasonal and year-to-year nutrient fluxes, land use and climate variations.
4. Ontario will take climate change into account in all of its research and monitoring efforts relating to Lake Erie. Ontario will also encourage municipalities to apply to the Municipal GHG Challenge Fund to fund eligible projects that have significant GHG and phosphorus reductions.

Federal and provincial plans to address climate change

Published in 2016, Ontario's Climate Change Action Plan is a five-year plan that outlines specific actions to help Ontario households and businesses reduce harmful greenhouse gas pollution.

Also in 2016, the federal government worked with provincial and territorial governments to develop the Pan-Canadian Framework on Clean Growth and Climate Change, which outlines the Government of Canada's commitment and plan to reduce greenhouse gas emissions and build resilience to adapt to a changing climate.

The framework builds on the actions taken individually and collectively by provinces and territories, and works to ensure Canadians are engaged in order to strengthen and deepen action on clean growth and climate change. The plan includes a pan-Canadian approach to carbon pricing, measures to reduce greenhouse gas emissions in all sectors, adaptation to climate impacts, and increased technology development and adoption to help Canada move toward a low-carbon economy.

5. Ontario will develop and implement initiatives that encourage soil health management practices which reduce net greenhouse gas emissions and reduce agricultural soil erosion.

C4: Conduct research to improve existing practices and develop new innovative practices and technologies to reduce phosphorus loadings

Ongoing research to improve and develop new practices and technologies to reduce, recycle and recover phosphorus from point and non-point sources will be important for achieving the targets. The proposed actions will build on a strong foundation of past and ongoing research supported through partner research projects.

Actions under this category include:

1. Ontario will continue to leverage government research programs and initiatives (e.g., New Directions; Ontario Ministry of Agriculture, Food and Rural Affairs–University of Guelph partnership) to fund needed research and new technologies to test and improve agricultural BMPs for phosphorus reduction.
2. Canada and Ontario, in partnership with others, will continue to research the effectiveness of BMPs in reducing phosphorus losses from agricultural land during typical and extreme weather events.
3. Canada will continue to identify the capacity and progress of different agricultural production systems in implementing activities that reduce the risk of nutrient loss.
4. Canada will continue to develop and assess methods for evaluating sustainable phosphorus levels in soils.
5. Canada and Ontario, in partnership with others, will continue to conduct research to improve modelling capability to quantify phosphorus reductions from BMPs at a landscape scale.
6. Canada and Ontario, in partnership with others, will investigate current (baseline) and future adoption of BMPs within the Lake Erie basin and selected subwatersheds to inform

Ongoing research on phosphorus loading reduction technologies and practices

Canada and Ontario continue to invest in research and demonstration initiatives to improve knowledge and understanding of the effectiveness of BMPs for reducing nutrient loss and improving nutrient- and water-use efficiency in agriculture production. This ongoing research will inform government and the agriculture sector of which actions will give the largest loss reduction. Canada and Ontario have also provided funding to demonstrate greenhouse nutrient feedwater recycling, which has led to the adoption of new technologies and reduction of phosphorus loadings to the environment.

One of the most promising research areas relates to the development of innovative practices to capture and store — and in some cases, recover — phosphorus from point and non-point sources. In support, Ontario has partnered on an innovative technology competition (the George Barley Water Prize) to reduce and recover phosphorus from water bodies and will host the pilot stage in Ontario to demonstrate cold climate application. Ontario has taken action to maintain its regulation-making authority (under the *Ontario Water Resources Act*) that could enable water quality trading as a potential future tool monitoring efforts and action plan progress.

7. Ontario will investigate the social, economic and environmental determinants affecting BMP adoption.
8. Ontario will support studies that improve understanding of the correlation between phosphorus load reduction and high uptake of LID/green infrastructure.
9. Canada and Ontario will work with partners to measure the effectiveness of wetlands and other natural heritage features in reducing phosphorus through overland flow into watercourses.
10. Canada and Ontario will evaluate the feasibility of using economic instruments to achieve phosphorus reductions.
11. Canada and Ontario will work with partners to explore opportunities to adopt innovative technologies that encourage phosphorus recovery and reuse.
12. Conservation authorities will continue to leverage their expertise and initiatives at the watershed, subwatershed and local levels to research, innovate and evaluate technologies for improved agricultural BMPs, LIDs and natural green infrastructure. This is in addition to research that aims to understand the social, economic and environmental determinants affecting BMP adoption.

Category D: Educate and build awareness

All levels of government, First Nation and Métis communities, conservation authorities, non-governmental organizations, other stakeholder groups and the public have worked hard to communicate the importance of reducing phosphorus loadings to Lake Erie. As audience needs and communication technologies evolve, there is a need to review and adjust communication strategies for maximum impact to ensure the message is reaching the intended audience.

As citizens become more aware of and interested in environmental issues, they become more engaged in their communities through activities such as citizen science (e.g., data collection, analysis, monitoring, promoting awareness), which can further help the effort to save Lake Erie.

D1: Enhance communication and outreach to build awareness, improve understanding and influence change

These actions focus on advancing awareness of and knowledge about phosphorus sources and impacts — as well as what can be done by the Lake Erie community to contribute to reducing phosphorus loadings.

Actions under this category include:

1. Canada and Ontario will develop a digital marketing campaign that includes social media to build awareness of the need for actions to reduce phosphorus in the Lake Erie basin.
2. Canada and Ontario, in partnership with others, will support the development and implementation of tools, techniques and programming to enhance communication,

education and awareness of the phosphorus issue in the Lake Erie watershed and the practices available for effective management.

3. Ontario will continue to work with partners to connect teachers, students and school boards with opportunities to use Lake Erie and its watersheds as a context for teaching and learning.
4. Ontario will work with the agriculture sector and partners to communicate best practices through educational materials, events, technology demonstrations, peer-to-peer learning opportunities and demonstration farms that foster the adoption of BMPs (such as responsible nutrient management including soil testing, crop rotation, erosion control structures and green infrastructure) and lead to a reduction of phosphorus loss to the environment.
5. Ontario, in partnership with the agriculture industry, will continue to develop and deliver information and tools to increase cover crop use in the non-growing season to improve soil health and reduce field runoff.
6. Ontario's livestock and poultry sector will lead the establishment of peer-to-peer regional advisory committees to provide education and awareness to producers that timing matters for the application of nutrients, with the goal being to effect behavioural change and reduce risk of nutrient loss to the environment.
7. Ontario will, by 2018, deliver enhanced drainage and erosion control education and training to increase awareness of causes of nutrient loading in runoff and how to manage drainage to reduce phosphorus loads.
8. Land Improvement Contractors of Ontario will continue to focus on proper drain installation to minimize phosphorus movement to the watercourse through its annual convention, newsletter articles and continuous training of those involved in drain installation to ensure phosphorus movement impacts remain a high priority.
9. Ontario, through the Premier's Award for Agri-Food Innovation Excellence, will continue to encourage the recognition of excellence, innovation and leadership in demonstrating environmental action at the farm level in the Lake Erie basin.
10. Ontario will facilitate an event, in 2018, showcasing the adoption of leading municipal approaches to integrated stormwater management.

D2: Share data and information

Canada and Ontario are committed to making their data available to the public in an accessible form. As part of this commitment, Canada and Ontario intend to periodically report on progress toward achieving the goals of this action plan.

Actions under this category include:

1. Canada and Ontario, along with their partners, will make relevant long-term data and information on Lake Erie public as it becomes available.

2. Ontario will report on Lake Erie every three years under the *Great Lakes Protection Act, 2015* and work with its partners to provide an annual update through its website.
3. Ontario will encourage partners to make relevant information on Lake Erie accessible through various online platforms.
4. Conservation Ontario will continue to undertake a partnership with the Great Lakes Observing System to help enable conservation authorities to make their data discoverable and accessible.
5. Conservation authorities will continue to develop, maintain and share data management systems and services for use in various aspects of hydrologic, water budget and water quality analyses, ground water monitoring, and climate change and other watershed studies.

Category E: Strengthen leadership and co-ordination

The actions in this category are intended to enhance the current level of co-ordination by clarifying roles and responsibilities as well as by strengthening the effectiveness of existing committees and other governance structures.

Effective leadership and co-ordination are essential for successful reduction of phosphorus loadings to Lake Erie. This co-ordination is already apparent in a variety of collaborative working arrangements, research partnerships and similar initiatives.

E1: Improve communication and co-ordination

Making this action plan a reality will require engaging a number of sectors and communities to help reduce phosphorus from various sources. There must be mechanisms in place to co-ordinate these efforts as well as opportunities to communicate on progress being made.

Actions under this category include:

1. Canada and Ontario will continue to engage First Nations and Métis communities to facilitate their participation and input in the development and implementation of this action plan. This will include consideration of traditional ecological knowledge from First Nations and Métis if offered. Youth engagement will be encouraged in particular.
2. Canada and Ontario will continue to engage youth to seek their participation and input on the implementation of the action plan.
3. Canada and Ontario will update the Great Lakes community on the progress of implementing the action plan through webinars, forums, meetings and other opportunities.
4. Canada and Ontario will work with partners to co-ordinate research, monitoring and modelling activities to improve scientific efforts towards phosphorus reduction.

5. Canada, with Ontario's support, will co-ordinate with the United States the implementation of nutrient-related commitments under the *Great Lakes Water Quality Agreement.*
6. Conservation authorities will continue to provide local watershed-level leadership in partnership with Canada, Ontario, municipalities and all stakeholders to address the phosphorus challenge in Lake Erie.

E2: Establish an adaptive management framework and governance structure for implementation

A guiding principle of this action plan, adaptive management is a systematic, iterative process through which management objectives, approaches and policies can be adjusted and improved over time, providing a mechanism for continuous improvement.

In an adaptive management framework, the implementation and results of management actions are monitored and evaluated by regulatory agencies and partners, and used to inform the next cycle of monitoring and management — including the research agenda.

Actions under this category include:

1. Canada and Ontario will build on existing governance structures to ensure partner participation in the implementation of the action plan. Parties identified in the plan will work together to develop a workplan that establishes timelines for actions, expected phosphorus reductions (as applicable), identifies lead agencies and determine program dollars required.
2. Canada and Ontario will assess and report on progress toward achieving phosphorus reduction targets and actions in 2023 and every five years thereafter.
3. Canada and Ontario will establish a suite of performance measures to track the impacts of actions over time, including changes to phosphorus loadings. Actions will be adjusted as necessary based on an adaptive management framework.
4. Canada and Ontario will work with U.S. federal and state agencies and other partners (e.g., through the GLWQA's "Nutrients" annex and the Great Lakes Commission's Blue Accounting ErieStat pilot project) to develop a binational information platform to track progress toward meeting the phosphorus reduction targets.

5 Making the action plan a reality

Achieving the phosphorus reduction targets and Canada's phosphorus reduction commitments under the *Great Lakes Water Quality Agreement, 2012* (GLWQA) will require significant change across the Lake Erie basin and the adoption of a multi-barrier approach across all phosphorus sources.

Implementing this action plan therefore requires:

- adaptive management
- strong governance
- effective engagement of accountable partners

Widespread, on-the-ground action is needed urgently, but it will take time to implement actions to the extent that significant phosphorus load reductions are achieved — just as it will take time for the aquatic environment to respond. It is also important to note that the legacy effects of past activities in urban and rural settings may delay the observable effects of implementation of new phosphorus mitigation activities.

Key performance measures for adaptive management

Performance measures track the progress of actions being taken and assess phosphorus loads and water quality to determine the effects of those actions. This information is used to guide management decisions.

For this action plan, the following performance measures will be monitored and reported on:

- reductions to phosphorus loadings
- improvements to lake water quality — blooms, oxygen levels, attached algal growth
- changes to land use and land cover — urban, agricultural, naturalized areas and wetlands
- adoption of agricultural best/beneficial management practices (BMPs) — nutrient management, modeling to assess change in risk of phosphorus loss, measures to manage wastewater
- adoption of municipal BMPs — reduction in loads from water pollution control plants, stormwater improvements and reductions in stormwater loads

5.1 How an adaptive management strategy will help implementation

An adaptive management approach supported by a strong monitoring, research and modelling efforts for Lake Erie will provide a framework for ongoing measurement of progress towards established target loads and adjustment of actions over time (see Figure 10).

This approach is necessary because natural systems are inherently variable and the impacts of management actions are difficult to predict accurately across Lake Erie's diverse landscape. Uncertainty is even greater with a changing climate and ecosystem changes caused by invasive species.

The proposed adaptive management strategy incorporates:

- annual routine monitoring of loads, total phosphorus and soluble reactive phosphorus concentrations in key Canadian tributaries leading into Lake Erie and in-lake nutrient-eutrophication response indicators

- an intensive monitoring, research and modelling program that will allow the plan partners to review progress every five years
- evaluation of whether phosphorus mitigation activities have been immediately effective in meeting targets, effective but with a delay in meeting targets due to legacy effects, or ineffective at current adoption levels
- a report every five years based on a series of performance measures[10] covering both the intended long-term outcomes — the reduced extent and frequency of harmful algal blooms, reduced hypoxia in the central basin, and reduced nuisance algal blooms in the nearshore zone of the eastern basin — and the short-term actions necessary to achieve those outcomes
- a five-year review cycle

Figure 10: The adaptive management cycle.

[10] Performance measures are a key component of adaptive management. Providing a regular measure of progress will aid in making new management decisions over the duration of the action plan. A set of performance measures will be selected to enable assessment of the effectiveness of the action plan every five years.

5.2 How the plan will be governed

Managing phosphorus loads to Lake Erie is a complex and challenging task that bridges many orders of government, First Nations and Métis, and multiple agencies as well as private sector organizations. As such, a broad network of partners and stakeholders will be essential for successfully implementing this action plan.

To accomplish this, Canada and Ontario will lead the development of an implementation framework based on a collaborative governance model. The implementation team that is established will consist of partner agencies and organizations with actions in this plan and will be responsible for overseeing the successful implementation of the plan, including:

- developing detailed work plans
- tracking progress toward plan implementation
- assessing progress against phosphorus reduction target,
- facilitate co-ordinated action across agencies and partners
- evaluating information as it becomes available and recommending changes to actions as required
- providing ongoing engagement opportunities for stakeholders, partners and the general public (see section 5.3)

Canada and Ontario are exploring options to ensure co-ordination and collaboration of implementation efforts.

5.3 The importance of effectively engaging stakeholders and partners

Excess nutrients and associated algal blooms pose a threat to water quality and drinking water supplies for hundreds of thousands of Ontarians in the Lake Erie basin. It is vital, then, that effective engagement of First Nations and Métis communities, stakeholders, partners and the general public be an integral part of action plan development and implementation.

A Lake Erie Nutrients Working Group has been established, and will continue, as a platform for sharing multi-sectoral perspectives, identifying potential actions, and for providing input and advice on the development and implementation of this action plan.[11]

Working group membership includes representation from:

- First Nations and Métis communities
- municipalities

[11] COA Nutrients Annex Committee partners are also engaging a variety of sectors and interests through sector-based meetings and working groups including those related to agriculture, municipalities, conservation authorities, First Nations and Métis communities, and others.

- agricultural organizations
- conservation authorities
- non-governmental organizations
- industry and commerce
- academia
- the tourism industry
- cottage associations
- commercial and recreational fisheries interests
- the general public

Canada and Ontario are committed to continued engagement with this working group as well as the broader Great Lakes community in the development and implementation of the action plan. This may include additional engagement with First Nations and Métis communities based on their interest.

5.4 How review, revisions and reporting will be handled

The action plan will be reviewed and revised every five years, beginning in 2023 and every five years thereafter. .

The plan will be supported by and linked to other key documents and related work, including:

- Lake Erie Lakewide Action and Management Plan reports
- federal and provincial climate change action plans, wetland and biodiversity strategies
- Cooperative Science and Monitoring Initiative[12] reports
- Ontario's Great Lakes Protection Act implementation
- the water quality and natural heritage components of conservation authority watershed plans and municipal natural heritage strategies
- municipal and provincial reporting of wastewater treatment plant upgrades and optimization
- documentation of agricultural BMP adoption

Each participating agency has its own system for data management and reporting, and each is committed to making its data available to a broader audience through COA. Canada and

[12] The Cooperative Science and Monitoring Initiative is a collaborative binational assessment of the Great Lakes conducted periodically with an intensive focus on one lake each year, with the full cycle completed every five years.

Ontario, in co-operation with partners, will explore the potential of central web-accessible portals to support sharing of information across different platforms.

Reporting will be co-ordinated through the COA Nutrients Annex Committee and made available to partners, stakeholders and the public. Information to be shared in this way could include scientific data, metadata (e.g., location, timing and contact information associated with science data) and reports.

6 Immediate action is needed to save Lake Erie

While we continue to build on our knowledge of phosphorus and its impacts, it is critical that we act now to improve the health of Lake Erie to minimize the impact on the natural environment, human health and the economy.

Reducing phosphorus loadings to Lake Erie is a challenging task that will require collective action by many partners throughout the region. Factors such as climate change, legacy sources of phosphorus and shifting human activity on the landscape make it difficult to predict the rate at which we can expect to see significant changes in the lake. We must undertake actions in recognition of this time lag, monitoring key performance measures to track progress toward phosphorus loading reduction targets.

As our knowledge of the lake ecosystem improves, adaptive management will encourage regular plan review and guide adjustment of management strategies to increase their effectiveness and ensure continued progress.

Bibliography

Anbumozhi, V., J. Radhakrishnan, and E. Yamaji. 2005. Impact of riparian buffer zones on water quality and associated management considerations. Ecol. Eng. 24: 517–23.

Bertram, P.E. 1993. Total phosphorus and dissolved oxygen trends in the central basin of Lake Erie, 1970–1991. J. of Great Lakes Research. 19: 224–36.

Canada and the United States. International Joint Commission. *A Balanced Diet for Lake Erie: Reducing Phosphorus Loadings and Harmful Algal Blooms. A Report of the Lake Erie Ecosystem Priority*. International Joint Commission, 2014.

Charlton, M.N., et al. Lake Erie offshore in 1990: Restoration and resilience in the central basin. J. of Great Lakes Research. 19: 291–309.

Clearwater, R.L., T. Martin, and T. Hoppe, eds. *Environmental sustainability of Canadian agriculture: Agri-environmental indicator report series – Report #4*. Ottawa: Agriculture and Agri-Food Canada, 2016.

Daloğlu, I., K.H. Cho, and D. Scavia. 2012. Evaluating causes of trends in long-term soluble reactive phosphorus loads to Lake Erie. Environ. Sci. Technol. 46: 10660–6.

Dolan, D.M., and S.C. Chapra. 2012. Great Lakes total phosphorus revisited: 1. Loading analysis and update (1994-2008). J. of Great Lakes Research. 38, 4: 730–40.

Dornbusch, D.M., S.M. Barrager, and F.H. Abel. Benefit of Water Pollution Control on Property Values, EPA-600/5-73-005. Washington: U.S. Environmental Protection Agency, 1973.

"Lake Erie Lakewide Action and Management Plan Work Group Annual Report 2015." Available online at https://binational.net//wp-content/uploads/2016/01/LE-2015-Annual-Report-FINAL-EN.pdf. 2015 [cited July 31, 2016].

"Land Use 1990, 2000 & 2010." Available online at http://open.canada.ca/data/en/dataset/18e3ef1a-497c-40c6-8326-aac1a34a0dec. Ottawa: Agriculture and Agri-Food Canada [cited October 25, 2016].

Maccoux, M.J., et al. 2016. Total and soluble reactive phosphorus loadings to Lake Erie: A detailed accounting by year, basin, country, and tributary. J. of Great Lakes Research. 42, 6: 1151–65.

Makarewicz, J.C. 1993. Phytoplankton biomass and species composition in Lake Erie, 1970 to 1987. J. of Great Lakes Research. 19: 258–74.

Munawar, M., and I.F. Munawar. 1976. A lakewide study of phytoplankton biomass and its species composition in Lake Erie, April–December 1970. J. Fish. Res. Bd. 22, 3: 581–600.

"Recommended Phosphorus Loading Targets for Lake Erie: Annex 4 Objectives and Targets Task Team Final Report to the Nutrients Annex Subcommittee." Available online at https://binational.net/2016/02/22/finalptargets-ciblesfinalesdep/. May 11, 2015

Reichenberger, S., et al. 2007. Mitigation strategies to reduce pesticide inputs into ground- and surface water and their effectiveness; a review. Sci. Total. Environ. 384: 1–35.

Reid, D.K., et al. Phosphorus. Pages 131–42 in Clearwater, R.L., T. Martin, and T. Hoppe, eds. *Environmental sustainability of Canadian agriculture: Agri-environmental indicator report series – Report #4*. Ottawa: Agriculture and Agri-Food Canada, 2016.

"Report for 2013 by the Lake Erie Walleye Task Group." Available online at http://www.glfc.org/lakecom/lec/WTG_docs/annual_reports/WTG_report_2014.pdf. Windsor, Ont.: Great Lakes Fishery Commission, 2014 [cited July 31, 2016].

"Report of the Lake Erie Yellow Perch Task Group 2013." Windsor, Ont.: Great Lakes Fishery Commission, 2014.

Richards, R., et al. 2010. Unusually large loads in 2007 from the Maumee and Sandusky Rivers, tributaries to Lake Erie. J. of Soil and Water Conservation. 65: 450-462.

Scavia, D., et al. 2014. Assessing and addressing the re-eutrophication of Lake Erie: Central basin hypoxia. J. of Great Lakes Research. 40: 226–46.

"Water quality of 15 streams in agricultural watersheds of Southwestern Ontario 2004-2009: Seasonal patterns, regional comparisons, and the influence of land use." Available online at https://www.ontario.ca/document/water-quality-15-streams-agricultural-watersheds-southwestern-ontario-2004-2009-seasonal-patterns. Ottawa: Ministry of the Environment and Climate Change, 2012.

Yuan, Y., R.L. Bingner, and M.A. Locke. 2009. A review of effectiveness of vegetative buffers on sediment trapping in agricultural areas. Ecohydrology. 2: 321–36.

Acronyms

BMP	Best/beneficial management practice
CEPA	*Canadian Environmental Protection Act*
COA	*Canada–Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, 2014*
CSO	Combined sewer overflow
EFP	Environmental Farm Plan
GLASI	Great Lakes Agricultural Stewardship Initiative
GLPA	*Great Lakes Protection Act, 2015*
GLWQA	*Great Lakes Water Quality Agreement, 2012*
HSG	Hydrological soil group
LID	Low-impact development
PLUARG	Pollution from Land Use Activities Reference Group
PSP	Priority Subwatershed Project
WWTP	Wastewater treatment plant
PWQMN	Provincial Water Quality Monitoring Network

Glossary

Adaptive management	An iterative process through which management objectives, approaches and policies can be adjusted over time for continuous improvement based on monitoring, performance measures, and evolving science and information.
Bioavailable	Readily assimilated by plants and algae and used for growth.
Biophysical characteristics	The living and non-living environmental factors that influence the growth of biological organisms.
Best/beneficial management practices	Proven, practical and affordable approaches to conserving or protecting soil, water and other natural resources in urban and rural areas.
Cladophora	An attached algae species that can cause dense mats in standing water, clogging intake pipes as well as fouling shorelines and fishing equipment. *Cladophora* is the primary cause of nuisance algal blooms in Lake Erie's eastern basin.
Combined sewer overflows	A discharge to the environment from a combined sewer system (a single pipe system of sewers that carry both sanitary sewage and stormwater runoff) that usually occurs as a result of a precipitation event when the carrying capacity of the system is exceeded. Combined sewer overflows can contain high levels of floatables, pathogenic microorganisms, suspended solids, oxygen-demanding organic compounds, nutrients (including phosphorus), oil and grease, toxic contaminants and other pollutants. (Combined sewer systems are designed to allow overflows following intense precipitation events to protect residential, commercial and industrial property from sewer backups.)
Concentration	The mass of a substance present in a given volume of water expressed in units such as milligrams per litre.
Cyanobacteria	Also called blue-green algae, a type of bacteria that undergoes photosynthesis and thus can be influenced by excessive phosphorus concentrations. An example is *Microcystis*. Cyanobacteria can produce toxic substances — called cyanotoxins — with the potential to harm humans and other organisms.
Cyanotoxins	Toxic biological compounds produced by cyanobacteria such as *Microcystis,* which produce the toxin microcystin. Cyanotoxins have potentially significant human health

	consequences if ingested or through skin exposure and may also be toxic to other organisms.
Dreissenid mussels	A collective term used for zebra and quagga mussels, which are non-native, invasive species in the Great Lakes basin.
Ecosystem components	Biological organisms and the non-living parts of the environment in which they live (e.g., fish, plants, air, water, soil).
Ecosystem services	The natural services provided by a healthy ecosystem. These include provisioning services such as production of food, fiber, timber, oxygen and water; production of pharmaceutical, biochemical and industrial raw materials; regulating services including climate regulation, flood and erosion control, water and air purification, and absorption and storage of gases; ecosystem support services including soil formation, photosynthesis and nutrient cycling, pollinating crops and plants, and dispersing seeds; and cultural services such as creating intellectual, artistic and recreational opportunities, aesthetic enjoyment and spiritual fulfillment.
Effluent	Discharge from municipal or industrial wastewater treatment plants following treatment.
Epilimnion	The oxygen-rich upper layer of water in a stratified lake; see stratification.
Eutrophication	Excess nutrient enrichment causing nuisance and harmful algal blooms that in turn can cause low dissolved oxygen levels and associated fish kills.
Extreme weather event	A weather event that is unexpected, unusual, severe or unseasonal. Weather at the upper or lower extremes of the historical distribution (typically a 30-year period).
Food web	The natural connections between species — what eats what — in a biological community.
Green infrastructure	Natural and human-made elements that provide ecological and hydrological functions and processes. Green infrastructure can include components such as natural heritage features and systems including wetlands or riparian areas, parklands, stormwater management systems, street trees, urban forests, natural channels, permeable surfaces and green roofs.
Harmful algal blooms	See cyanobacteria.

Hauled sewage	Hauled sewage (or “septage”) is untreated waste material removed from portable toilets, sewage holding tanks and septic systems.
Huron-Erie corridor	The flows from Lake Huron through the St. Clair River, Lake St. Clair and the Detroit River. Flows from the Huron-Erie corridor discharge into Lake Erie’s western basin.
Hypolimnion	The bottom layer of water in a stratified lake. In the summer, the hypolimnion is colder than surface waters. In the winter, surface waters are frozen or close to freezing, while the hypolimnion is somewhat warmer — typically a few degrees above freezing. The hypolimnion can experience low levels of dissolved oxygen under certain conditions; see stratification.
Hypoxia	An area with low levels of oxygen. Late summer hypoxia — the reduction of oxygen to less than two parts per million — occurs naturally in Lake Erie’s central basin due to the stratification of layers by temperature, with the warmer layers on top.
Lakewide Action and Management Plan	Established under the Canada–U.S. *Great Lakes Water Quality Agreement, 2012*, these are lake-specific binational action plans for restoring and protecting Great Lakes ecosystems.
Legacy sources	Phosphorus from past activities contained in biological tissues as well as in sediments in lake and stream beds, flood plains and agricultural fields. Legacy sources of phosphorus can be re-mobilized and add to loadings even when current practices are geared to phosphorus reduction.
Load	The total mass of a substance delivered to a water body over time expressed in units of mass per unit time, such as tonnes per year. Load is the product of concentration (mass per unit volume) and flow rate (water volume per unit time).
Low-impact development	Urban stormwater management measures that seek to retain rainwater on the site through collection and infiltration. Examples include rain barrels, green roofs, infiltration trenches, rain gardens and permeable pavement.
Microcystis	A genus of cyanobacteria, known to produce the toxin microcystin.
Microcystin	Toxins produced by cyanobacteria.

Multi-barrier approach	For this action plan, "multi-barrier" refers to a systems based approach that implements multiple management practices that work together to reduce phosphorus loading from source to receiving water body.
Natural heritage features	The green infrastructure of the natural environment; see green infrastructure. Natural heritage means features and areas — including wetlands; coastal wetlands; habits of fish, wildlife, threatened species and endangered species; woodlands and valleylands; and areas of natural and scientific interest — that are important due to their environmental and social values as a legacy of the natural landscapes of an area.
Non-point source	Sources of pollution that are many and diffuse, in contrast to point source pollution, which results from a single source. Non-point source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrological modification where tracing the pollution back to a single source is difficult.
Nuisance algal blooms	Blooms of algae such as *Cladophora* that can cause fish kills (see eutrophication), degrade fish and wildlife habitat, clog water intake pipes, and foul shorelines and fishing equipment but which do not produce toxins.
Nutrient cycling	The natural movement and transformation of nutrients such as phosphorus through soil, water and air, and in different chemical forms.
Point source	Sources of pollution that enter a water body through a pipe or similar outlet, such as a municipal or industrial wastewater treatment plant discharge. Point sources have usually undergone some level of treatment before discharge; an exception is most combined sewer overflows.
Riparian zone	The area of land adjacent to tributaries and the lake where vegetation may be influenced by flooding or elevated water tables. A healthy riparian zone provides habitat for a variety of aquatic and terrestrial species. Its complex vegetative structure protects against erosion and can control the runoff of sediment, phosphorus and other pollutants, reducing impacts on water quality under certain conditions.
Runoff	The flow of water that occurs when excess stormwater, meltwater or other sources flow over the Earth's surface. This might occur because soil is saturated to full capacity, rain arrives more quickly than soil can absorb it or impervious areas send their runoff to surrounding soil that cannot absorb all of it. Surface runoff is a major component

	of the water cycle and the primary agent in soil erosion by water.
Soluble reactive phosphorus	Phosphorus in dissolved form. The term "reactive" refers to the reaction of phosphorus with a colour agent during the analysis of phosphate concentrations in a laboratory.
Stormwater	Water that originates during precipitation events and snow or ice melt. Stormwater can soak into the soil, be held on the surface and evaporate, or run off and end up in nearby streams, rivers and other water bodies.
Stratification	The formation of layers in a lake — typically a well-mixed, warmer, oxygen-rich surface layer (epilimnion); a transitional zone (metalimnion or thermocline); and deeper, colder waters that can become oxygen-poor (hypolimnion). Strong winds in spring and fall thoroughly mix the waters of all but the deepest lakes. Stratification occurs in the summer, with a warm layer at the surface overlying colder waters, and in the winter, where colder waters or ice overlie somewhat warmer waters at depth. Shallow lakes may never stratify, or stratification may not persist.
Wetlands	Lands that are seasonally or permanently covered by shallow water, as well as lands where the water table is close to or at the surface. In either case, the presence of abundant water has caused the formation of hydric soils and has favoured the dominance of either hydrophytic plants or water-tolerant plants. The four major types of wetlands are swamps, marshes, bogs and fens.
Whole-farm approach	An approach that considers an entire farming operation. A whole-farm approach considers a farm's production type (e.g., cropping, livestock), biophysical characteristics (e.g., soil type, slope, proximity to water, woodlots), infrastructure (e.g., wells, manure storages, barns), biodiversity (e.g., wildlife) and management (e.g., nutrient management planning). This approach also seeks to balance these aspects to operate a financially viable operation for the long-term.

Appendix A: Characterization of the Lake Erie basin

A multi-agency federal and provincial science subcommittee under the *Canada–Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, 2014* (COA) “Nutrients” annex has characterized watersheds within the Lake Erie basin according to the basin-wide distribution of distinguishing land use/activities.

A good understanding of the type and location of land use and land activities within the basin is an important basis for the development of actions for phosphorus reduction in Lake Erie. This is because the type of land use or land activity within an area, in combination with the susceptibility of the landscape to soil erosion or surface water runoff, can suggest different sources and pathways of phosphorus loss within that area. If all areas within the basin are characterized by the same method, the inferred sources and pathways of phosphorus loss within the Lake Erie basin can be compared.

Watersheds within the Lake Erie basin were characterized by the following land use/activity categories:

- urban
- agricultural-crop
- agricultural-livestock
- natural heritage
- uncategorized

The distribution among watersheds of landscape characteristics that could render a watershed more vulnerable to phosphorus loss was also identified and included the risk of soil erosion and surface runoff. The distribution among watersheds of an environmental quality parameter (water phosphorus concentrations) was also identified.

How datasets were selected

The characterization of the Lake Erie basin was conducted at the quaternary watershed scale since it represents a uniform biophysical scale that can be rolled up into management units. New data from quaternary watersheds were not generated for this characterization process; data were instead obtained from multiple different agency program datasets, with each program having its own specific objective.

Data were solicited from federal and provincial government agencies as well as from conservation authorities and municipalities within the Lake Erie basin. Criteria for dataset use included:

- basin-wide
- comparable among all quaternary watersheds
- direct relationship to land use/activity or landscape vulnerability categories

- unique (not redundant with other datasets)
- high quality (consistently collected and subjected to quality assurance and control)
- recentness (2008 or later)

Based on these criteria, 35 out of more than 100 parameters from datasets from five federal and provincial government agencies[13] were selected for use in the characterization. Types of data included:

- field survey (soils, landscape)
- remotely sensed land use/crop type
- measured loads (urban point sources)
- estimated loads (urban and agricultural non-point sources)
- estimated nutrient application rates
- measured water concentrations

The available provincial and federal soluble reactive phosphorus and total phosphorus loading data did not meet the selection criteria because there are no reliable basin-wide data or no data suitable for comparing among quaternary watersheds.

The distribution of each of the 35 parameters among all watersheds within the Lake Erie basin was assessed using the Jenks natural breaks classification method,[14] which groups data such that the variability within a class is less than the variability among classes. For each parameter, three classes (high, medium and low) were created based on the statistical distribution of the data among all 65 Lake Erie quaternary watersheds.

There is no inherent value or judgment to any class because the three classes are simply the low, medium and high ends of the data distribution within the Lake Erie basin for any given parameter; however, there were three exceptions where existing risk-based thresholds were used. Water quality, per cent natural heritage cover and soil erosion were grouped into three classes using predetermined thresholds based on aquatic health, ecological health and modelled risk thresholds, respectively.

How Lake Erie's watersheds were categorized

Once the data were grouped into high, medium and low classes, expert judgment was used to identify those parameters most directly related to land use/activity categories and most

[13] The provincial and federal government agencies were Agriculture and Agri-Food Canada; Environment and Climate Change Canada; the Ontario Ministry of Agriculture, Food and Rural Affairs; the Ontario Ministry of Environment and Climate Change; and the Ontario Ministry of Natural Resources and Forestry.

[14] Jenks, J.F. 1967. The data model concept in statistical mapping. Intl. Yearbook of Cartography. 7: 186–90. As cited in Esri. "FAQ: What is the Jenks optimization method?" Available online at http://support.esri.com/ja/knowledgebase/techarticles/detail/26442. 2012.

descriptive or distinguishing so they could be used as criteria to allocate watersheds to categories.

This process reduced the original 35 parameters to 10. Watersheds that fell into the high class in one or more of these 10 parameters were included in a given land use/activity category. Watersheds were selected by the high class because it is the most descriptive of what is (versus what is not) in the watershed, as many of the parameters are not mutually exclusive.

It is important to note that the categorization of a watershed does not mean the watershed has only (or is dominated by) the land use/activity category it is in; it means characteristics in the watershed fall into the high end of the use/activity distribution across the Lake Erie basin. There can still be varying levels of urban, agriculture types or natural heritage in each categorized watershed. These categories are also not mutually exclusive; that is, the same watersheds can fall into more than one category.

Category criteria

Criteria were used to create the land use/activity, landscape vulnerability and environmental state categories to be applied to Lake Erie's watersheds.

Land use/activity categories

Categories for land use/activities were created using the following criteria:

Natural heritage — watersheds with:

- > 30 per cent natural heritage land cover (wetlands, forest and prairie)

This parameter was selected because it is a direct measure of natural heritage land cover; > 30 per cent cover was considered the minimum threshold that could be linked to aquatic ecosystem health.[15] Data were derived from remotely sensed imagery from 2010.[16]

Urban — watersheds in the high end of the distribution in any one of the following:

- per cent of watershed area in urban land use (> 13 per cent)
- total annual urban point source load of phosphorus (> 10,900 kilograms phosphorus)
- total urban non-point source load of phosphorus (> 4,840 kilograms phosphorus)
- per cent of total watershed phosphorus load from urban point source (> 27 per cent)
- per cent of total watershed phosphorus load from urban non-point source (> 10 per cent)

Parameters are from 2008–10 datasets and include remotely sensed imagery, measured point source loads and estimated non-point source loads from land-use coefficients.[17]

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[15] Environment Canada. *How much habitat is enough*? Toronto: Environment Canada, 2013.

[16] Southern Ontario Land Resource Information System (SOLRIS) 2.0: https://www.ontario.ca/data/southern-ontario-land-resource-information-system-solris-20

Agricultural-crop — watersheds in the high end of the distribution in any one of the following:

- per cent of watershed area in continuous corn and/or continuous soybean and/or a corn-soybean rotation over four years (> 27 per cent)
- per cent of watershed area in vegetable and/or potato in at least one of four years (> 13 per cent)

These parameters were selected because they were distinctive of annual crop systems in the basin and represent production systems with potential nutrient and soil management challenges. Data were derived from remotely sensed imagery from 2012–15.[18]

Agricultural-livestock — watersheds in the high end of the distribution in any one of:

- Rate of phosphorus applied from manure (> 13 kg phosphorus per hectare)
- Total amount of phosphorus from manure applied in the watershed (> 638,000 kilograms phosphorus)

These parameters were selected because manure phosphorus is directly related to the management of livestock production systems. Data were derived from the 2011 Interpolated Census of Agriculture.[19]

Landscape vulnerability categories

These categories describe the state of the physical environment in the watershed, meaning they are not indicative of inferred potential phosphorus loss from individual source types. They were developed using the criteria listed below:

Risk of soil erosion — watersheds with high to very high risk of soil erosion (> 22 tonnes soil/hectare/year).

High runoff soils — watersheds in the high end of the distribution of per cent of watershed area with soils in hydrological soil group (HSG) D (> 54 per cent).

These parameters were selected because they represent the two dominant transport pathways for phosphorus: erosion of soil by water and surface runoff. Data for the soil erosion risk parameter comes from an erosion risk model.[20] The parameter used to describe surface runoff was the per cent of soils in HSG D. HSG D soils have the highest potential for runoff because, once wet, water infiltrates (permeates) very slowly through them, with the excess running over

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[17] Ministry of the Environment and Climate Change source data from Municipal Utility Monitoring Information System and Sample Results Data Store.

[18] Annual Crop Inventory: http://open.canada.ca/data/en/dataset/ba2645d5-4458-414d-b196-6303ac06c1c9

[19] Interpolated Census of Agriculture: http://open.canada.ca/data/en/dataset/1dee8513-5c73-43b6-9446-25f7b985cd00

[20] Lobb, D.A., S. Li, and B.G. McConkey. 2016. Soil Erosion. Pages 77–89 in Clearwater, R.L., T. Martin, and T. Hoppe, eds. 2016. *Environmental sustainability of Canadian agriculture: Agri-environmental indicator report series – Report #4*. Ottawa: Agriculture and Agri-Food Canada, 2016.

the soil surface.[21] Data for per cent of soils in HSG D were derived from the provincial soil database.

Environmental state category

One environmental state category was created and defined as:

- **Water quality —** the low, medium and high classes for this dataset (< 30 micrograms [µg] phosphorus/litre [L], 30–90 µg phosphorus/L and > 90 µg/L) are based on the interim Provincial Water Quality Objective for phosphorus for streams and rivers (30 µg/L).[22]

The water quality dataset used was the total phosphorus concentrations from the Ministry of the Environment and Climate Change Provincial Water Quality Monitoring Network (PWQMN) database[23] from the time period 2009–12. The highest median (concentration median from each station between 2009–12) from all the stations within a watershed was used to determine the representative value for each quaternary watershed.

There are a number of watersheds for which there are no water quality data. The PWQMN was deemed acceptable for use because the data exist for the majority of quaternary watersheds, are consistently collected and analyzed, and there is a good understanding of what the PWQMN concentration data represent and how they can be interpreted. These data tell us about how in-stream concentrations during the growing-season compare among watersheds, but they cannot be used to infer trends in loading (the total mass delivered per unit time), which requires frequent measurements over all seasons.

Results of Lake Erie's watershed characterization

Using this process, 44 of the 65 watersheds (70 per cent of the Lake Erie basin) fell into one or more of the four land use/activity categories. Of the 44 categorized watersheds, 35 fell into a single land use/activity category (e.g., natural heritage, urban) and nine fell into two categories (e.g., urban *and* natural heritage, agricultural-crop *and* agricultural-livestock).

To reiterate, categorization of a watershed does not mean that a watershed has only or is dominated by a single land use/activity; there still can be varying levels of urban, agriculture types or natural heritage in each categorized and uncategorized watershed. It also cannot be assumed that there is the same potential level of phosphorus loss within and among watersheds within a land use/activity category.

[21] Drainage Guide for Ontario – Publication 29 (see http://www.omafra.gov.on.ca/english/landuse/facts/drain_p29.htm for information on obtaining a hard copy)
[22] "Water Management: Policies, Guidelines, Provincial Water Quality Objectives." Available online at https://www.ontario.ca/document/water-management-policies-guidelines-provincial-water-quality-objectives. 1994.
[23] For more information, visit http://www.ontario.ca/data/provincial-stream-water-quality-monitoring-network.

The distribution of watersheds that fell into the landscape vulnerability categories generally had a southwest-northeast bimodal distribution as would be expected from soil types and landscape features in the Lake Erie basin (see Figure A.1). The 20 watersheds with high (> 22 tonnes soil/hectares/year) to very high (> 33 tonnes soil/hectares/year) erosion risk represents 35 per cent of the Lake Erie basin; the 12 watersheds with the greatest proportion of high runoff potential soils represents 11 per cent.

There is no pattern among the average quaternary watershed total phosphorus concentrations (see Figure A.2). This is not unexpected because 35 per cent of the watersheds are not currently monitored under the PWQMN. In addition, PWQMN data indicate base flow (low flow) conditions well but do not capture spring/storm runoff events when the contribution of phosphorus from non-point sources would be expected to be greater.

The information used in this characterization are robust, standardized, basin-wide data that allow for within-basin comparisons. However, it would be inaccurate to use the data in figures 5, A.1 and A.2 for interpretations beyond what is stated in this appendix. For example, the phosphorus concentration in a given quaternary watershed (from Figure A.2) cannot be compared with its respective land use/activity categories (from Figure 5) in an attempt to interpret the cause of water quality status in quaternary watersheds in the Lake Erie basin.

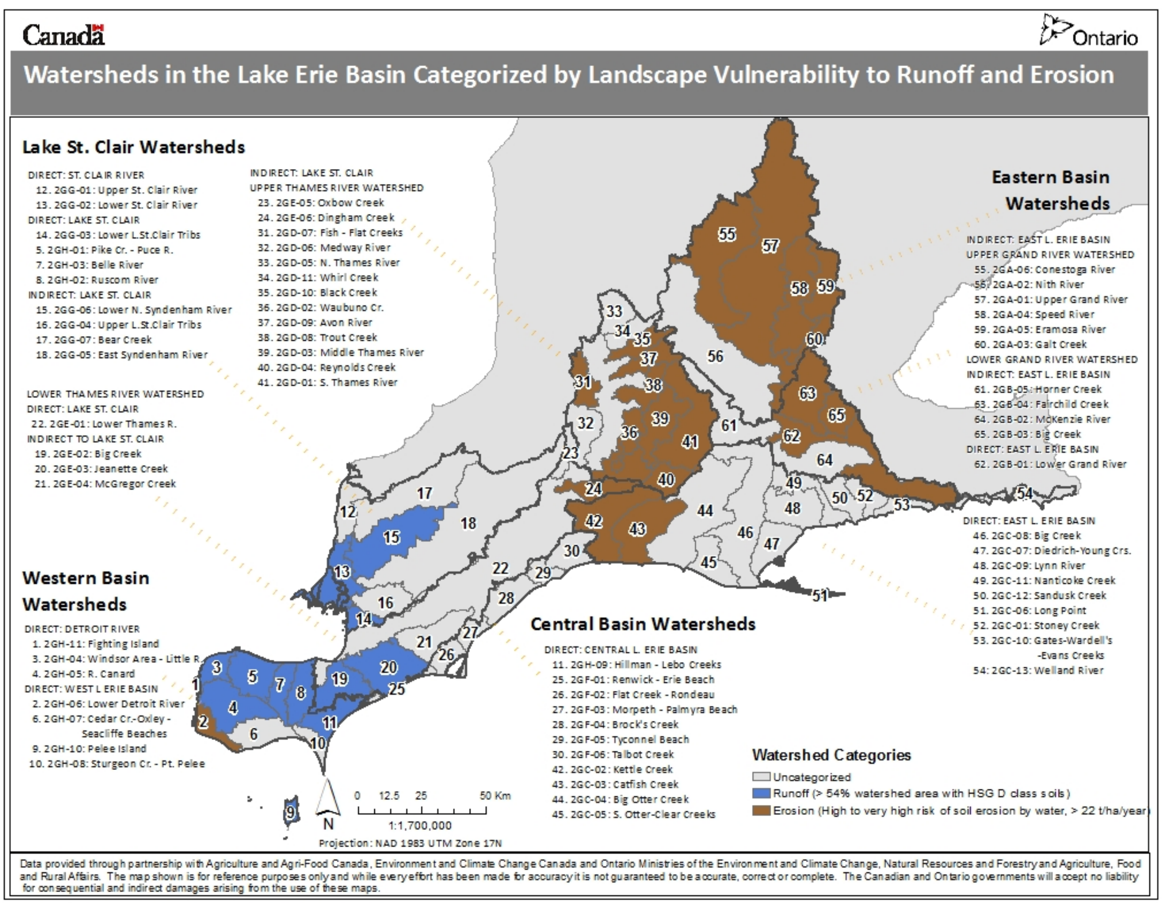

Figure A.1: Quaternary watersheds of the Lake Erie basin categorized by soil and landscape features related to phosphorus transport pathways of runoff and erosion.

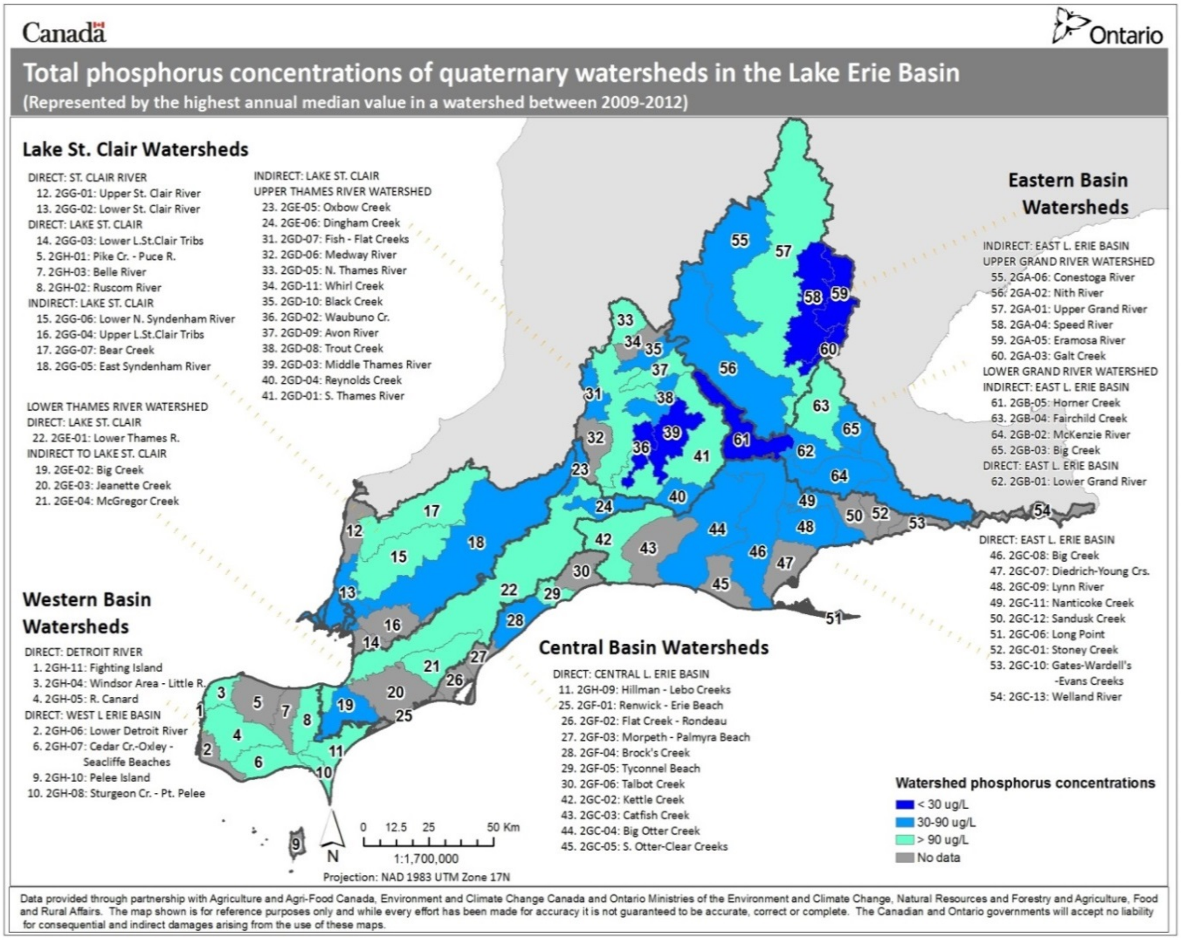

Figure A.2: Quaternary watersheds of the Lake Erie basin categorized by the average quaternary watershed concentration (average of the maximum median over the period of 2009–12) of total phosphorus derived from the Ministry of the Environment and Climate Change Provincial Water Quality Monitoring Network.

People will ask,
What's wrong with Lake Erie?
And what can we do?

What will we tell them?
The more we learn about water
The more obvious it appears
That there is no simple answer
But the right questions make things clear

Balance
What do we mean by Lake? Only water?
Or does it include the beaches and trees?
What about the fish that call this water home
Drawing breath
after breath
after breath?

Connection
We the people who live along its shores
Doesn't the water flow in our veins too?

In our minds we draw dividing lines
Yet in nature there are no frontiers
The Lake is a much larger, living entity
Than our language makes it out to be

Accountability
The people upstream don't hear the waves
In their backyard everyday
The shorebirds and shore are an abstract
Less real than a screen

So let us improve access to water literacy
And empower people to act to protect the Lake,
Its rivers, land, and living communities

Immediacy
Lake Erie is resilient,
But it is also sick
And it doesn't have a voice
We all have the knowledge to be that voice.
Are we speaking for Lake Erie?
Are we speaking with one another?

Gratitude
We all come from our smaller areas
And one person alone cannot approach this
Without feeling powerless.
How can we demonstrate that
Having your moment with your Lake
can shift your perspective and connection to it?

Collective Memory
Do we know how the hidden story of the Experimental Lakes Area and Dr. Seuss's Lorax?
How can we celebrate hyper local success
From around Lake Erie?
Weaving narratives that inspire action.

Agency
How can we explain,

What Lake Erie needs right now

From each one of us,

And from us collectively?

Written on June 25th, by the 2017 AquaHacking Youth Delegation.