Essex Region Phosphorus Management Plan

March 2022

Updated November 2023

Prepared by:

Essex Region Conservation Authority

sustaining the place for life

This project was undertaken with the financial support of:
Ce projet a été réalisé avec l'appui financier de :

Environment and Climate Change Canada
Environnement et Changement climatique Canada

March 2022 – updated November 2023

Preface

We wish to acknowledge that this land is the traditional territory of the Three Fires Confederacy of First Nations, comprised of the Ojibway, the Odawa, and the Potawatomie Peoples.

We value the significant historical and contemporary contributions of local and regional First Nations and all of the Original Peoples of Turtle Island - North America who have been living and working on the land from time immemorial.

The health and viability of Caldwell First Nation and Walpole Island First Nation, their places of cultural and spiritual significance, and economic opportunities, are inextricably linked to the health of their surrounding traditional lands and waters, which include Lake Erie and Lake St. Clair, and the natural ecosystems of the subwatersheds.

Contributing Authors

Many individuals contributed to the development of this Phosphorus Management Plan for the Essex Region. The following individuals are gratefully acknowledged for their contributions:

Dr. Katie Stammler
Claire Sanders, MSc
Emily Varga, PhD Student, GLIER
Alicia DiCarlo, PhD Student, GLIER
Dr. David Ure, University of Windsor
Tom Dufour, GISP
Alice Grgicak-Mannion, Geospatial Learning Specialist, GLIER
Craig Irwin, MSc
Amy Weinz, MSc
Justin Landry, MSc
Samantha Dundas
Mackenzie Porter

Suggested citation:

ERCA, 2022. Essex Region Phosphorus Management Plan. Available online

Essex Region Conservation Authority
sustaining the place for life

Executive Summary

Algal blooms, nutrient runoff and pollution have been in an issue in the Lake Erie watershed for decades. Following the Great Lakes Water Quality Agreement between the United States and Canada in 1972, there was a reduction in the occurrence of algal blooms during the 1970's and 1980's. However, harmful algal blooms (HABs) have more recently become an annual occurrence in Western Lake Erie and Southern Lake St. Clair, affecting drinking water sources, tourism, recreation, and fisheries, with a direct economic impact in the Essex Region. HABs are often dominated by potential toxin-producing cyanobacteria, mainly *Microcystis*. Among these toxins, the most commonly found in freshwater lakes is microcystin, which poses a threat to our drinking water sources. The increase in frequency and severity of HABs in recent years is attributed to many different factors, including climate change, invasive species, loss of wetlands and nutrient loading from surrounding tributaries and runoff. Phosphorus is considered to be the limiting nutrient to algal growth and is the focus of management actions. Sources of phosphorus include both point-sources and non-point sources, with the latter being more difficult to manage as the direct source is not as identifiable as point-sources.

As harmful algal blooms are an international issue, the Canadian and Ontario governments released a joint Lake Erie Action Plan (LEAP) in 2018 to meet binational 40% phosphorus load reduction targets. The United States federal and state governments released similar documents. The LEAP identifies conservation authorities as key partners in its framework, leading to the creation of the Essex Region Phosphorus Management Plan (PMP) and its coordination by the Essex Region Conservation Authority (ERCA). ERCA received a three-year funding commitment from Environment and Climate Change Canada (ECCC), beginning in July of 2019. The PMP describes the status of phosphorus concentrations in local waterbodies, identifies sources of phosphorus in the Essex Region as well as knowledge gaps, and reduction strategies. The PMP includes a list of Action Items that were developed during the writing of this document. The intent is for this list of Action Items to be a living document, updated as actions are completed and/or new actions identified.

The Essex Region Watershed is a flat clay plain of just under 1700 km^2, consisting of a peninsula surrounded on three sides by the waters of the Great Lakes. There are three major sub watershed areas, which drain into Lake St. Clair, Detroit River and Lake Erie, ultimately, all draining into Lake Erie. The shoreline of the Essex Region extends over 200 km, much of which has been significantly altered by urbanization and shoreline hardening. Nearly 95% of our coastal wetlands, which play an important role in nutrient sequestration, have also been lost or degraded. Land use in the Essex Region is dominated at 80% by agriculture, including over 1100 hectares of fruit, vegetable, and cannabis greenhouses. Maps of the region are shown in Part 2 of the PMP.

ERCA's water quality program includes monitoring a variety of surface and groundwater sites and interpreting the data collected. There are many partners and initiatives involved in

contributing to the research and monitoring of water quality health, described in Part 3 of the PMP. The Provincial Water Quality Objective (PWQO) for phosphorus concentration is 0.03mg/L to prevent eutrophication in streams and rivers. Between 2012 and 2021, phosphorus concentrations in the Essex Region ranged from 0.05mg/L to 75.20mg/L with an average range of 0.18mg/L to 6.17mg/L, putting all of the watersheds in the Essex Region at risk for eutrophication, and adding to nutrient loads to Lake Erie and Lake St.Clair. The highest phosphorus concentrations are observed in the greenhouse influenced streams in Leamington and Kingsville. Sources of phosphorus include row crop agriculture, greenhouses, wastewater treatment facilities, septic systems and urban runoff.

Part 4 of the PMP describes several possible mitigation strategies specifically for the conditions in the Essex Region. The primary source of phosphorus loss in the Essex Region is the agricultural sector because it is both the largest land use and user of nutrient amendments, thus agricultural best management practices, including those for greenhouses, are considered to be of utmost importance. Some of these practices include following the 4R strategy for fertilizer use, cover crops, conservation tillage and managing erosion and runoff. The PMP also discusses municipal and individual actions that can help to mitigate phosphorus loss.

There are many other contributing factors to increased phosphorus loading, including socio-economic factors, drainage transport pathways, climate change and invasive species. These are discussed in Part 5 of the PMP. Climate change in particular is highlighted due to its influence on phosphorus cycling and the ecology of the impacted lakes. Warmer, wetter conditions are adding stress to an already stressed ecosystem, causing an acceleration in cyanobacterial growth rate. The PMP describes future climate projections and their potential impacts, however, a full climate risk assessment is recommended.

The intention of this PMP is to utilize an adaptive management strategy as discussed in Part 6. Local stakeholders of the plan include municipal, county and provincial governments as well as First Nations, industry, wastewater and various farming sectors. These stakeholders will be included in consultation and encouraged to comment on the feasibility of the Action Items, provide insight into progress already made towards phosphorus reduction, identify additional knowledge and/or management gaps, or provide any other feedback that will strengthen the PMP. It is important that this work be considered ongoing and continuous as the results of our efforts may take several years to observe. Key to this will be a commitment to ongoing monitoring in the Essex Region watersheds.

Part 7 of this report briefly discusses the next steps for Education and Outreach, which will begin with stakeholder consultation and ultimately result in web content and incorporation into ERCA's many education programs. Part 8 of this report acknowledges that ongoing reporting will be necessary to ensure the PMP is executed; however, this will be dependent on available funding.

Draft Phosphorus Management Plan Action Items 2022

Stakeholder Engagement		
Action	**Lead**	**Supporting**
Circulate the draft phosphorus management plan to stakeholder groups for comment	ERCA	
Invite participants of Research Roundtable to provide an update on their work; Circulation table of Research Actions	ERCA	
Develop and establish a regular reporting schedule to provide updates on the PMP implementation; Adaptive Management	ERCA	

Outreach & Education		
Action	**Lead**	**Supporting**
Identify engagement and outreach strategies that will increase the adoption of BMPs (agricultural, individual, industry, etc)	ERCA	
Continue and enhance engagement with the agricultural sector to showcase BMPs and encourage adoption	ERCA	
Create a social media campaign targeted at encouraging proper maintenance of septic systems		
Continue to advocate for stormwater pond design to consider both water quantity and quality concerns		
Promote education on stormwater and urban runoff (e.g. Yellow Fish Road or Adopt a Drain)		
Encourage the implementation of Low Impact Design and green infrastructure projects, including monitoring		
Continue to incorporate information of individual actions in Education and Outreach Programs and through social media	ERCA	Municipalities
Share information about successful tactics/technologies/BMPs with relevant sectors to encourage uptake		

Stewardship		
Action	**Lead**	**Supporting**
Seek funds to provide grants for BMP implementation	ERCA	
Work with OGVG/OMAFRA/municipalities to hold fertigation optimization workshops for greenhouse growers	ERCA	OGVG
Coordinate optimization workshops with MECP and local WWTP operators		
Continue to seek funds where available to control P. australis on ERCA properties	ERCA	
Seek out grant funds to provide opportunities for restoration projects like tree and prairie meadow planting, and wetland creation		

Municipal		
Action	**Lead**	**Supporting**
Work with municipalities to catalogue the methods and innovations used to further reduce phosphorus in wastewater treatment plant effluent	ERCA	Municipalities
Support municipal efforts to implement new technologies in WWTPs	Municipalities	ERCA
Include exceedances and/or lack of exceedances from WWTPs in future phosphorus update reports and encourage transparency in reporting annual nutrient loads from WWTPs	ERCA	Municipalities
Encourage the use of regulatory tools for septic systems where necessary	Municipalities	
Support municipal efforts to create more connections to sanitary sewers where possible	Municipalities	ERCA
Review and report on local municipal bylaws that could prevent storm water sewage from private property being discharged into a sanitary sewer, including downspout disconnections and incentives	ERCA	Municipalities

Agriculture		
Action	**Lead**	**Supporting**
Implement BMPs that are appropriate for each farming scenario (e.g. cover crops, 4R nutrient strategy, buffers, controlled drainage, conservation tillage, etc.)	Ag partners	ERCA, OSCIA, EFAO, IFAO, etc.
Continue to demonstrate and promote innovative practices	Ag partners	ERCA
Utilize ERCA's Demo Farm to demonstrate and promote innovative practices	ERCA	
Ensure new greenhouse builds are built to high standards that prevent all accidental discharge to the environment	Greenhouse operators	OGVG
Repair known breaks or leaks in greenhouses that result in accidental discharge to the environment	Greenhouse operators	OGVG
Encourage optimization of greenhouse stormwater ponds		
Follow guidelines to reduce per acreage loss of nutrients by greenhouses – optimize inputs, manage outputs	Greenhouse operators	OGVG

Existing Data & Monitoring Programs		
Action	**Lead**	**Supporting**
Identification of microcystin-LR as a drinking water issue in Lake St. Clair	ERCA	
Continue to refine the data management plan	ERCA	
Complete 2022 watershed report card	ERCA	
Establish a regular monitoring report template for ERCA's water quality data beyond watershed report card	ERCA	
Continue to refine nutrient load calculations for Wigle Creek	ERCA	
Complete analysis of Wigle Creek data and create a regular cycle for analysis updates	ERCA	
Complete greenhouse mapping project and update census of agriculture data when available		
Re-analyze KLN data and create a regular cycle for analysis		
Calculate nutrient loads in greenhouse influenced streams (Sturgeon Creek, Lane Drain, and Mill Creek)		
Continue monitoring greenhouse influenced streams		
Complete data analysis for Puce River sampling and prepare a details report; continue collaboration across agencies, develop research and/or ongoing monitoring projects		
Continue to work with municipal partners to update drainage network and create a reporting tool for notifications of changes	ERCA	
Continue to seek grant funds and partnerships to ensure that important long term monitoring programs continue	ERCA	
Continue to participate and seek out partnerships to conduct edge of field monitoring	ERCA	
Ensuring compatibility of data and load calculation methods between labs and research projects		

March 2022 – updated November 2023

New Research		
Action	**Lead**	**Supporting**
Inform knowledge on source/sink potential of in-stream sediment	GLIER	
Identify mitigation actions that reduce both phosphorus and nitrogen load		
Continue to identify areas of research and innovation to mitigate phosphorus loss		
Complete Thames mesocosm project identifying conditions of algal growth	GLIER	
Collaborate with researcher to conduct a more fulsome analysis of available water quality data	ERCA	GLIER
Determine the phosphorus contribution from WWTPs, lagoons and other water treatment facilities		
Determine the phosphorus contributions from septic systems in the Essex Region		
Create a comprehensive list of all known point sources, other than WWTPs, in each watershed; determine phosphorus contributions		
Support further research to better understand how stormwater pond design can be optimized to reduce nutrient loss, particularly in the greenhouse sector		
Determine the extent of spread of P. australis and identify appropriate mitigation measures		
Undertake a Climate Change Risk Analysis; Ensure that Climate Change scenarios are considered in modelling efforts and projections for future nutrient loads		
Source tracking with isotopes	UWindsor	ERCA
Specific greenhouse-related research discussions included exploring available MECP datasets from storm water ponds and expanding dye testing. Further research is also needed on the microbiological processes in greenhouse stormwater ponds (phosphorus-cycling)		
Improve the understanding of the sources, fate, and delivery of phosphorus throughout the Essex watershed		
Sequential extractions to obtain more information about what form phosphorus is in and legacy phosphorus in sediments		
Additional monitoring in Lake St Clair watersheds		
Investigating the impact of agricultural drain clean outs to determine the impact to P and erosion		

Table of Contents

List of Appendices

List of Tables

List of Figures

1.0 Introduction

The Phosphorus Management Plan (PMP)has been developed to identify phosphorus sources and develop phosphorus reduction management strategies for selected tributaries in the Lake Erie watershed (Action A1.3). This will help to fulfill a part of Environment and Climate Change Canada's commitment under the Canada-Ontario Lake Erie Action Plan (Action A1.3) by contributing to the identification of critical nutrient source areas and implementation of load targets for this priority region. The PMP will be used as a guide in mitigating phosphorus loading in the Lake Erie watershed and contribute to healthy fish and wildlife populations, clean drinking water, and essential recreation and tourism opportunities.

1.1 Background

Harmful Algal Blooms

Harmful algal blooms (HABs) have become an annual occurrence in the western basin of Lake Erie as well as the southern shores of Lake St. Clair, impacting the shores and beaches of the Essex Region. HABs are composed of cyanobacteria, also known as blue-green algae, which are capable of producing toxins. The dominant genus of cyanobacteria found in this region is Microcystis, known to produce the hepatotoxin microcystin, which may cause serious health effects in many living organisms (Carmichael & Boyer, 2016). The presence of these toxins can make water dangerous for human consumption, recreation, and wildlife. Once ingested, microcystins can be distributed to, and affect, many organs in humans, particularly the liver (Massey et al., 2018). Lake Erie HABs also effect local tourism, recreation activities, and sport and commercial fisheries, directly impacting the economy in the area. HABs in Lake Erie have increased in size and severity in recent years and have resulted in the closure of beaches throughout the western basin, as well as water treatment plants on Pelee Island and in Ohio. In response to the growing concerns related to HABs, the Essex Region Source Protection Committee identified microcystin-LR (a specific congener of microcystin) as a drinking water issue for Lake Erie intakes.

There are many factors that have led to the increase in severity of HABs in recent years, including climate change, invasive species, loss of wetlands, and nutrient contributions from the surrounding watersheds and runoff. However, the primary driver of the rapid increase in HABs of Lake Erie is thought to be nutrient loading from upstream tributaries (Choquette et al., 2019). Phosphorus is considered to be the limiting nutrient to algal growth in freshwater environments and recent increases in phosphorus loading, mainly soluble reactive phosphorus (SRP), have occurred due to changes in agricultural management as well as climate (Kalcic et al., 2019). An excess amount of phosphorus can result in eutrophication, leading to increased algal growth, hypoxic (low oxygen) conditions and fish kills. Phosphorus is found in animal and human waste and commercial fertilizer, and is necessary for the survival of both animals and plants. It is introduced to the environment by point and non-point sources. Point source pollution originates from identifiable single sources such as discharge pipes at factories or sewage treatment plants and is generally easier to manage. Non-point source pollution is the result of many dispersed sources over a large area (e.g., surface water runoff of fertilizer and manure in rural areas, and runoff from lawns, parks and parking lots in urban areas) making it more difficult to manage. Many areas in the Great Lakes region experience issues with an oversupply of nutrients, but Lake Erie's large population, booming agricultural industry and shallow, warm water have resulted in the most severe algal bloom problems.

Algal blooms, nutrient runoff and pollution have been an issue in the Lake Erie Watershed for decades. In 1972, the United States and Canada signed the Great Lakes Water Quality Agreement (GLWQA) in order to address issues like nutrient loadings in the Great Lakes. The binational effort led to significant improvements in the overall health of the Great Lakes in the 1970s and 1980's. An annual phosphorus load target of 11,000 metric tons was set, and was achieved by targeting reductions from point sources (Bertani et al., 2016; Maccoux et al, 2016). This resulted in a reduction in the frequency and severity of algal blooms in Lake Erie (Bertani et al., 2016; Maccoux et al, 2016). However, increased population, industrial activities, agricultural development and complex environmental issues like climate change and invasive species lead to the recurrence of algal blooms in Lake Erie beginning in the mid-1990s (Dolan & Chapra, 2012; Stumpf et al, 2012). Based on evidence that spring phosphorus loads are positively correlated to bloom severity (Stumpf et al., 2012) and that biologically available phosphorus has been increasing since the mid 1990's (Baker et al., 2014; Stow et al., 2015), along with numerous watershed models that have since been developed, a new phosphorus load target has been set. The United States and Canada updated the GLWQA in 2012 and in 2016, and set the new target to achieve a further 40% reduction of phosphorus loadings (from 2008 levels) to Lake Erie, particularly from identified priority watersheds in the U.S. and Canada. The Canadian priority tributaries are the Leamington Area tributaries in the Essex Region and the Thames River. The Maumee River watershed is the single largest contributor of phosphorus loading to Lake Erie, with all Canadian sources together accounting for approximately 16% of the total phosphorus load (Maccoux et al., 2016). While the contribution may be less, it is still essential that phosphorus reduction targets be met. In addition, there has been substantially less work completed to identify sources of phosphorus to Lake St. Clair, which may be more strongly influenced by Canadian sources.

HABs are an international issue and in 2018 the Canadian and Ontario governments released a joint Lake Erie Action Plan (LEAP) and the United States federal and state governments released similar documents. The Canada-Ontario Lake Erie Action Plan identifies over 120 actions by Canada, Ontario and other partners, to meet binational 40% phosphorus load reduction targets. It identifies Conservation Authorities as key implementation partners in its framework and led to the creation of the Essex Region Phosphorus Management Plan (PMP) and its coordination by the Essex Region Conservation Authority (ERCA).

Phosphorus

Phosphorus is measured in water samples as a concentration, the mass present in a given volume of water (usually measured in mg/L). Concentration data are combined with water quantity data (volume of water, usually measured in L) to determine the load, or total mass, of phosphorus over a given time period (usually reported in kg or metric ton per year). Calculating load requires several years' worth of concentration and volume data collected over multiple water years, capturing seasonal changes, and most importantly, capturing different flow conditions. ERCA is working towards calculating nutrient loads for four Lake Erie watersheds (Sturgeon Creek, Lane Drain, Mill Creek and Wigle Creek). However, at this time, most of the data presented in this report will reflect nutrient concentrations.

Phosphorus occurs in different forms in the environment. Dissolved reactive phosphorus (DRP), also known as soluble reactive phosphorus (SRP), is phosphorus that remains in water after filtration. Phosphorus attached to the sediment that remains on the filter is called particulate phosphorus. Together these two forms of phosphorus make up the total phosphorus (TP) concentration in a water sample. The most bioavailable form of phosphorus is DRP, which is dominated by orthophosphate (Machesky et *al*., 2010). As such, water samples are typically analyzed for TP and DRP, and particulate phosphorus is calculated by subtracting dissolved phosphorus from total phosphorus.

Phosphorus is removed from soil by crop/plant uptake, runoff and erosion, and leaching. Runoff is the major pathway for phosphorus loss (P loss) and carries both DRP and particulate phosphorus from soil surface. Leaching is the loss of DRP from sub-surface soil as water percolates vertically down the soil profile. The pathways for P loss are dependent on land use and soil characteristics. While particulate phosphorus makes up the largest portion of phosphorus loads into Lake Erie, it tends to settle to the lake bottom, whereas DRP remains in the water column and is bioavailable to algae. Legacy phosphorus is phosphorus that has accumulated in soils from past fertilization.

Within the watersheds leading to Lake Erie there exists a mechanism to store and utilize phosphorus by bed and suspended sediments, as well as their associated microbes, invertebrates, and plants to mitigate changes in DRP (Weigelhofer et *al*., 2018). Orthophosphate has a high affinity for adsorption and is strongly absorbed to Essex County's common sediment types (Machesky et *al*., 2010). These concentrations remain in a dynamic equilibrium between the sediment and the water column. Research funded by an NSERC Strategic Partnership Grant is currently underway at the University of Windsor to better understand equilibrium phosphorus in Ontario's streams. Legacy phosphorus has accumulated within the land-water continuum and can delay the onset of notable improvements in water quality, despite the inherent reduction in phosphorus loading (Lannergard et *al*. 2020). Along with reducing external phosphorus loadings into these tributaries, governing authorities are also faced with internal phosphorus loading. It has been shown that regeneration of phosphorus does occur in the sediment of Lake

Erie, contributing to the total concentration in the water column and slowing efforts of recovery (Wang et al., 2021).

Action Item: University of Windsor to complete ongoing research projects to inform knowledge on the source/sink potential of in-stream sediment

Nitrogen

It is important to note other factors that may be affecting the growth of HABs as previous research has shown that in addition to high concentrations of phosphorus, a low nitrogen to phosphorus ratio as well as temperatures in the range of 16 to 26 degrees Celsius can promote the growth of CyanoHABs (Havens et al., 2002). More recent whole-lake experiments have shown that there is a stronger response of HAB formation when there is a combined enrichment of phosphorus *and* nitrogen and that the reduction of phosphorus alone has not been successful in reducing HAB occurrence in small lakes (Paerl et al., 2016). Studies have shown that in Lake Erie during late summer, phytoplankton growth demonstrates co-limitation with nitrogen and phosphorus (Salk et al., 2018). It has also been shown that the concentration, as well as speciation of nitrogen present has an effect on the quantity of toxins produced by HABs (Davis et al., 2015,Newell et al. 2019) found an increase in non-nitrate N (or TKN) load in the Maumee River that is also significantly correlated to HAB biomass. Many of the actions identified to mitigate phosphorus loss will also help to reduce nitrogen, however, specific actions to reduce nitrogen should also be considered.

Action Item: Identify mitigation actions that reduce phosphorus and nitrogen load

Climate Change

Climate change and its associated hydrologic changes strongly influence not only the physio-chemical environment but also biotic processes, which for HABs is most notably metabolism, growth rates, and bloom formations (Paerl and Paul, 2012). Since CyanoHABs are prokaryotes with optimal growth rates at higher temperatures, warming surface waters become advantageous especially under nutrient-enriched conditions (Butterwick et al., 2004). Further, the warming of surface waters increases vertical stratification which is uniquely exploited by CyanoHABs (Paerl and Paul 2012). It has also been shown that buoyant cyanobacteria may locally increase water temperatures at the surface, creating a positive feedback mechanism and further promoting growth and competitive dominance over eukaryotes (Kahru et al. 1993, Paerl and Paul 2012). Climate Change is discussed in greater detail in Section 4.0.

1.2 Threat to Sources of Drinking Water

The re-occurrence of HABs in our freshwater resources is an important issue concerning public health and is potentially the greatest threat to our drinking water. HABs produce hepatotoxins, which cause damage to liver tissue (Backer, 2002). There have been many studies conducted which outline the necessity to manage phosphorus loadings into our freshwater rivers and lakes and to implement nutrient restrictions to mitigate eutrophication (Smith & Schindler, 2009).

Microcystin

Among the known hepatotoxins, microcystin is the most commonly found in freshwater lakes during eutrophic and hyper-eutrophic conditions and are produced by a wide variety of cyanobacteria (Brittain et al., 2000; Christiansen et al., 2003). There are over 60 isoforms of microcystin, with the most common and most toxic being microcystin-LR. Various studies have shown that many environmental factors, including temperature, light intensity and nutrient concentration affect the dominance of toxigenic strains and the quantity of microcystin production (María et al., 2016). The most abundant microcystin-producing genera of CyanoHABs in Lakes Erie and St. Clair include *Microcystis, Planktothrix* and *Anabaena*, though not all species of these genera will produce toxins and those that can produce toxins do not do so continuously (Davis et al., 2014; Francy et al., 2016). It is not yet fully understood how the environmental factors contribute to the quantity and variant of microcystin which is produced. Of the 3 genera listed, *Microcystis* is thought to be the primary producer of microcystin in these lakes, as concentrations above the recommended limit of 1 µg/L in drinking water are often observed during *Microcystis* bloom events (Rinta-Kanto et al., 2009). It has been shown that an increase in light intensity causes some strains to produce more microcystin until a maximum growth rate is reached (Wiedner et al., 2003). *Planktothrix agardhii* also exhibits a correlation between light intensity and microcystin production, but unlike *Microcystis*, the quantity of microcystin remains constant, while the toxicity increases with light intensity (Tonk et al., 2005). *Anabaena* also exhibits changes in the microcystin variants produced dependent on light intensity, as well as temperature. In the optimal temperature range, this genus produces more toxic variants, whereas at sub-optimal temperatures and high temperatures coupled with high light intensity, the toxicity is reduced (Rapala et al., 1997).

Under the *Clean Water* Act, a drinking water issue can be identified if there is a contaminant present in the source water that negatively impacts drinking water treatment. Microcystin-LR is a parameter listed on Schedule 2 of the Ontario Drinking Water Quality Standards and has a maximum allowable limit in drinking water of 1.5 ug/L. In 2014, the Essex Region Source Protection Committee (SPC) reviewed total microcystin concentration data for the raw water at the intakes of Lake Erie water treatment plants and determined that microcystin-LR should be identified as a drinking water issue pursuant to rule 115.1 in the Technical Rules associated with the *Clean Water Act*. Total microcystin concentration is used because the analysis to determine specific congeners (e.g., Microcystin-LR) is cost prohibitive and only conducted when it is deemed necessary. However, microcystin-LR tends to be the dominant congener of microcystins in the lower Great Lakes (Palagam et al. 2020; Dyble et al. 2008); therefore, we can assume that total microcystins are an appropriate estimate of microcystin-LR. In 2021, the SPC reviewed total microcystin data for Lake St.Clair drinking water intakes and is in the process of formally identifying microcystin-LR as an issue for these intakes. In order for microcystin-LR to be identified as a drinking water issue the following evidence was noted:

- Concentration of total microcystin has been noted on several occasions at or above half maximum allowable concentration (1/2 MAC)
- Concentration of total microcystin have been noted on several occasions at or above maximum allowable concentration (MAC)
- Concentration of total microcystin are not declining over time, but are variable depending on annual conditions
- Elevated concentration of total microcystin occurs annually and persists throughout the summer months
- Support from Water Treatment Operators who identify HABs as an issue that results in the need for enhanced or altered treatment to ensure that the contaminant does not reach treated water

The Essex Region Source Protection Plan includes a policy to continue monitoring for phosphorus and microcystin as well as a regional education and outreach policy related to phosphorus, microcystin as a drinking water issue, and algae blooms in general. ERCA continues to be a leader in phosphorus monitoring and research, and has integrated HABs into all of our educational programs directed at a variety of target audiences including youth, special interest groups and the agricultural community.

Action Items:
Complete data analysis from Thames mesocosm project; prepare a detailed report
Complete the process of identification of microcystin-LR as a drinking water issue in Lake St.Clair – this was completed in September 2023

Phycocyanin

Phycocyanin (PC) is a blue-light absorbing, photosynthetic accessory pigment from the phycobiliprotein family found in cyanobacteria. Previous studies using fluorescence have found a positive correlation between PC concentration and algal biomass as well as some correlation between PC and microcystin concentration (Izydorczyk et al., 2005). As such, there has been an increasing interest in the use of phycocyanin in fluorescence for the quantification of cyanobacterial biomass (Eriksen, 2008). Methods which utilize fluorescence provide benefits over traditional methods, such as microscopy and qPCR. A considerable limit to microscopy is that it cannot identify whether a particular strain has the ability to produce toxins, though it may be a strain which has been identified as having the potential to produce toxins. qPCR has been effective in the past for quantifying cyanobacteria which have the necessary gene cluster needed for microcystin production (mcy gene), however these analyses are complex and take considerable time, during which there may have already been public exposure to toxins. Alternatively, methods which employ fluorescence as an indicator of PC, as well as chlorophyll, can provide much quicker results and early warnings of cyanobacterial biomass and increasing concentrations of microcystin in freshwater sources (Francy et al., 2016).

1.3 Developing a Phosphorus Management Plan

In July 2019, ERCA received a three-year funding commitment from Environment and Climate Change Canada (ECCC) to develop a regional phosphorus management plan (PMP) in part to fulfill ECCC's commitment under the Canada-Ontario Lake Erie Action Plan to identify phosphorus sources and develop phosphorus reduction management strategies for selected tributaries in the Lake Erie watershed (Action A1.3). The objectives of the PMP are:

- Develop a clear strategy for how to address phosphorus sources in the Essex watershed.
- Identify Action Items to address knowledge gaps
- Create a short-term and long-term plan to complete the identified Action Items
- Where possible, establish priorities for the application of phosphorus reduction measures, including the most appropriate best management practices for this region

Scope

The scope of the PMP will be limited to the ERCA boundaries and its sub-watersheds (**Appendix I, Map 1**) in order to enact on-the-ground efforts to reduce phosphorus loadings to local water bodies and, ultimately, Lake Erie. This region is unique among Conservation Authorities in that it is made up of several hydrologically separate watersheds, rather than the nested watersheds common in other areas. While the PMP is specific to the Essex Region, the outcomes will be applicable to the clay plains of the Lower Thames area that are physiographically similar.

Methodology

The PMP was intended to be developed with a wide range of local stakeholder and community input including representation from municipal, county, provincial and federal governments, First Nations, industry (e.g., wastewater, greenhouse, and agricultural sectors), academia and community members. A Project Charter was developed along with a mandate for a Steering Committee. However, as discussed below, this approach was severely impacted by Covid-19.

To guide decision-making and identify strategies to address phosphorus sources in the Essex watershed, the PMP summarizes the soils, land uses, natural heritage features, known water quality data and nutrient sources in the Essex watershed. It also identify gaps in information and knowledge that limit understanding of phosphorus movement in the Essex watershed and Action Items to address those gaps.

Action Items:
Circulate the Draft Phosphorus Management Plan to Stakeholder groups for comment
Identify engagement and outreach strategies that will increase the adoption of BMPs

Implications of COVID-19

In January, 2020, an in-person Phosphorus Research Round Table was held at the Great Lakes Institute of Environmental Research (GLIER). This was intended to be the first of several in person stakeholder engagement sessions to share and gather information from local resources (e.g., agricultural, municipal, government). With a shift to working from home beginning in March 2020, this approach was put on hold, assuming that in-person meetings would resume in due course. ERCA presented the phosphorus management plan approach to GLIER's Farm Advisory Board in the fall of 2020. However, with the virtual meeting space crowded and the acknowledgement of virtual meeting fatigue, ERCA opted to change the approach of ongoing stakeholder meetings. Instead, this draft PMP has been prepared by ERCA staff with input from graduate students conducting phosphorus and/or HAB related research locally.

2.0 Description and maps of the Essex Region

2.1 Watersheds

The Essex Region Watershed consists of a peninsula in the extreme south-western corner of Ontario, bounded on three sides by the waters of the Great Lakes; as well as Pelee Island (Township of Pelee) in Lake Erie, and several smaller islands. The Essex Region Watershed is composed of three major sub-watershed areas consisting of land areas that drain to Lake St. Clair, Detroit River and Lake Erie. These major drainage areas may further be divided into approximately 28 sub-watersheds watersheds (**Appendix I, Map 1**). The Lower Thames Valley Conservation Authority shares the eastern boundary of the Essex Region Watershed.

While Lake Erie's HABs have long received international attention, practitioners have also been sounding the alarm on annual severe HABs in Lake St. Clair over the last decade. Lake St. Clair is a shallow basin that connects Lake Huron to the north by the St. Clair River and drains into Lake Erie to the south via the Detroit River. The lake is 42 km long and 39 km wide with a surface area of 1100km^2. The average depth is around 3.4m with a dredged navigational channel of maximum depth of 8.2m (Derecki 1984). The lake drains about 12,400km^2 in Canada and the US. At the northeastern end of the lake is Walpole Island, the largest delta of the Great Lakes and one of the largest freshwater deltas in the world. The delta is home to the Bkejwanong, Walpole Island, First Nation.

The Detroit River is a 51km-long connecting channel linking Lake St. Clair to the western basin of Lake Erie. It carries water and nutrients from the upper Great Lakes, Lake St Clair and the St Clair River watersheds, delivering approximately 80% of the flow that enters Lake Erie (Scavia et al., 2020). The Detroit River was designated as an Area of Concern (AOC) under the Great Lakes Water Quality Agreement in 1987. Eutrophication (or undesirable algae) is one of 14 potential impaired beneficial uses by which the status of AOCs is assessed. The eutrophication beneficial use has been considered 'not impaired' since 1991. HABs do not occur in the river and there are no other indications of cultural eutrophication (e.g., low dissolved oxygen), due in large part to the water current and the average water retention time in the Detroit River (approximately 19 to

21 hours) (Green et al. 2010). However, the watersheds draining into the Detroit River become a source of phosphorus for Lake Erie and recent estimates suggest that Lake Huron contributes more than half of the Detroit River TP load to Lake Erie, even taking into account retention in Lake St. Clair (Scavia et al., 2020).

Ultimately, all watersheds in the Essex Region drain into the western basin of Lake Erie. Lake Erie is the fourth-largest lake (by surface area) of the five Great Lakes, and smallest by volume of the Great Lakes, and therefore has a short average water residence time. Lake Erie's fish populations are the most abundant of the Great Lakes, partially because of the lake's relatively mild temperatures and plentiful supply of plankton. The Lake Erie watershed drains over 58,000 km^2 and is the most densely populated Great Lake with 11 million people in the US and Canada living in the basin.

The region has over 200 km of shoreline on Lake St. Clair, the Detroit River, and Lake Erie, much of which has been significantly altered by intensive urbanization and industrial development over the last century. Hard shorelines, characterized by concrete breakwaters or steel sheet piling, were commonly engineered in the early 20th century to protect from erosion, flooding, and to accommodate industry and ship navigation. Upwards of 95% of coastal wetlands, which play an important role in nutrient management, have also been lost and/or degraded. Historically, wetlands consisted of a diverse community of emergent marsh but now non-native *Phragmites* dominates most wetlands and shorelines. The shoreline is mostly privately owned and developed, primarily for residential use, and includes numerous marinas, beaches and other water-based recreational activities. In the City of Windsor, the shoreline includes a mixture of residential, industrial/commercial uses, as well as an extensive waterfront park system.

2.2 Hydrological Processes

Most of the streams/rivers/creeks in this region flow through the flat terrains of the clay or sand plains of the watershed region. Surface drainage in much of the region is influenced by a ridge, which extends roughly from the south part of Windsor, in a southeasterly direction through the central part of the Region. This ridge defines a drainage divide, north of which water flows mainly into Lake St. Clair, while south of the divide streams flow westward into the Detroit River or southward into Lake Erie. Surface drainage of the till plain is predominately northward to Lake St. Clair (Chapman and Putnam, 1984). Many of the streams have extensive marsh areas at the mouth, which fluctuate in size with the lake levels. Many have headwaters that periodically dry up in the summer due to extensive artificial drainage and historical clearing/removal of wetlands. Throughout most of the Essex Region, dredged ditches and tile drains were installed in order to improve drainage and provide satisfactory conditions for crop growth and tillage (Chapman and Putnam, 1984). Several watersheds have been substantially altered by major diversions of parts of their watershed areas. In several parts of the region, lands have been artificially created and drained by a series of dykes and pumping schemes – this includes much of Pelee Island, the south-east part of Leamington, and in the east part of Windsor near Lake St. Clair.

Highly Vulnerable Aquifers (HVAs) are aquifers on which external sources have or are likely to have a significant adverse impact and include the land above the aquifer. A number of factors such as how close the aquifers are to the ground surface, what types of soil or rock are covering the aquifers, and the characteristics of the soil or rock surrounding them, determine the vulnerability of an aquifer to contamination. In the Essex Region, these HVAs are generally located in the sandy soil areas in the southern part of the region, including most of Pelee Island.

Groundwater recharge occurs where rain or snowmelt percolates into the ground and flows to an aquifer. The greatest recharge usually occurs in areas that have loose or permeable soil such as sand or gravel that allows the water to seep easily into the aquifer. Most of the Significant Groundwater Recharge Areas (SGRAs) are located in the sandy soil areas of the southern part of the Essex Region, in the Harrow area, parts of Leamington and Kingsville, and limited parts of the Turkey Creek and Pelee Island subwatersheds.

2.3 Soil and topography

The Essex Region Watershed is approximately 1,681km^2 in size and predominantly consists of a relatively flat clay plain with the exception of some sandy areas, primarily in the southern portion of the Region (**Appendix I, Map 2**). The predominant land use in the watershed is agriculture, due to the region's excellent farmland and growing conditions. The remainder of the area is roughly 18–19% urban land use and 8.5% natural cover. Although most of the urban land use is in the northwestern area, in and around the City of Windsor, there are numerous smaller urban centers and settlement areas in other parts of the watershed (**Appendix II, Map 3**).

The Essex Region Watershed generally varies in elevation from approximately 173 – 196m above sea level, with the exception of the moraine in Leamington, near County Road 31, which climbs to 227m above sea level (**Appendix I, Map 4**). In addition to the moraine near Leamington, there are a few other areas of concentrated relief. Near Harrow, there is a sandy extrusion which reaches 195m above sea level, while a low gravel ridge through the centre of the region also rises to 19m above sea level. Point Pelee, at the south-eastern tip of the mainland of the Essex Region Watershed, is a spit of land extending out into Lake Erie. Pelee Island is also part of the Essex Region Watershed, lying some 13km south of Point Pelee. It covers around 42km^2 and is about 8km from north to south, and 5km east to west. With a relief of 175 – 182m above sea level, the island is only 10m above Lake Erie's mean water level at its apex, and substantial portions of the island are below lake level and protected by dykes.

2.4 Land use

Agriculture

The Essex Region is home to a thriving agricultural industry. Located in the southern tip of Ontario, the climate allows for one of the longest growing seasons in Canada. With around 80% of the region's land use belonging to the agriculture sector, the Essex Region leads Ontario in gross domestic product (GDP) generated by agriculture at $1.2 billion (McRae et al., 2015). According to the 2016 Census of Agriculture, land use for crops in the Essex Region covers approximately 132,750 hectares. Much of this acreage consists of soybeans (74,000 hectares), followed by corn (25,000 hectares) and winter wheat (23,000 hectares) (Statistics Canada, 2016abc). The climate in the Essex Region also allows for diverse fruit production, including apples, grapes, peaches and strawberries (ECFA, 2015).

Between the 2011 and 2016 Census, fruit acreage declined the greatest with all varieties decreasing between 10-40%, while tomato acreage decreased by approximately 10% (Statistics Canada, 2016bc). In contrast, soybean acreage increased by approximately 14% as well as corn and oats for grain by 16% and 180% respectively (Statistics Canada, 2016a). These changes may be attributed to increasing temperatures throughout the region as corn and soybean varieties are able to withstand higher soil temperature, while high air temperatures can prevent flowering crops from producing fruit. It is important to note that these changes may also be attributed to the 2014 closure of the Leamington Heinz factory. As the decreased demand for field tomatoes in the region likely caused farmers to change crops.

Greenhouse Sector

The Essex Region also has the most intensive greenhouse growing area in Canada. In 2019, the floor area of greenhouses in Essex County was 11,200,000m^2 (1,120 hectares), comprised primarily of vegetables and fruit (96%), flowers and potted plants (3%), and greenhouse cannabis (1%) (Essex County Regional Energy Plan, 2021). The sector continues to grow at an accelerated rate, with growth estimates predicting 13,600,000m^2 (1,360 hectares) by 2041.

The Ontario Greenhouse Vegetable Growers (OGVG), an important partner in the Phosphorus Management Plan, represents 200 members responsible for greenhouse tomatoes, peppers and cucumbers across the province. The sector experiences over $946M in farm gate sales and contributes $1.6B economy each year with a 5% compounded growth rate over the past 20 years. OGVG has been supporting its members for over a decade and are committed to addressing phosphorus loadings through education and mitigation.

Cities and Towns

The region consists of two single tier municipalities, the City of Windsor and the Township of Pelee Island, and an upper tier municipality, the County of Essex. The County of Essex has a population of 191,000 in seven lower tier municipalities with populations ranging from 19,600 to 34,546. The 2011 population of the City of Windsor was reported to be 210,891 and the 2011 population for the Township of Pelee was reported to be 171.

The Windsor Essex region is currently booming with ongoing construction activity and new development. In addition to the Gordie Howe International Bridge and the proposed new regional hospital for urgent and acute care, the region's commercial, industrial, and residential developments continue to grow in the area. Recent provincial government projections suggest that the region’s population could grow by close to 35% by 2046 (Windsor Star).

Industry

Windsor-Essex is home to a wide range of industry. The City of Windsor has a long history of advanced manufacturing, including automation and automotive, and is home to more than 1,000 manufacturers. Industry sector growth includes other areas of advanced manufacturing, agriculture and agri-tech (including greenhouse technology and cannabis), information and communication technologies, health and life sciences (including pharmaceuticals and nutraceuticals), and transportation and logistics, such as warehousing and cross-border technology (Invest Windsor Essex, 2021). While these industries are not a significant source of phosphorus, any loading contribution would be identified through Ontario Ministry of Environment, Conservation and Parks (MECP) approvals for wastewater treatment facilities under the Ontario Water Resources Act (see section 3.5)

Natural Heritage

Due to its southerly location and moderate climate, the Essex region supports a unique and diverse ecosystem. As part of the Carolinian forest zone, which is quite small in comparison with other vegetation zones, it hosts a greater number of floral and faunal species than any other ecosystem in Canada (Carolinian Canada, 2006). It is estimated that approximately 2,200 species of herbaceous plants (seventy different species of trees alone) are found within the Carolinian forest zone (ERNHSS, 2013). With respect to the Essex Region, due to its extreme southerly latitude, no other region in the province or country has higher biodiversity, a greater number of significant (rare) species, or a greater diversity of habitat types. For example, the Essex Region alone is home to more than 270 rare species of plants alone; 37 of which are Species at Risk.

Since the time of European settlement in the 1830's, much of the original natural resources of the Essex Region have either been removed from the landscape or have become degraded as a direct or indirect result of clearing and drainage for timber, agriculture, and urban development. Currently, it is estimated that the total natural cover within the Essex Region is approximately 8.5% of the landscape (5.8% terrestrial, 2.7% wetland/aquatic), and consists of small, isolated remnants of forest, wetland, prairie, savanna, alvar, and riparian habitat. The remaining 91.5% of the region consists of agricultural or urban land uses. While highly significant ecologically, the current natural heritage ecosystem is generally characterized by a lack of riparian habitat, wetland area, forest cover, and few green linkages between natural features. This paucity of natural features contributes to poor water quality and aquatic habitat. The cumulative loss and alteration of the region's original natural heritage since European settlement has had profound consequences on the region’s ecological sustainability and health, necessitating the need to significantly increase the extent and quality of remaining natural habitats (ERCA, 2013).

3.0 Phosphorus in the Essex Region

Like all Conservation Authorities in Ontario, ERCA prepares a Watershed Report Card every 5 years. The last watershed report card was released in 2023. These report cards are prepared using standardized methods across the province, resulting in a letter grade for water quality of A through F based on phosphorus concentrations, *E.coli* and benthic macroinvertebrates. In the last three watershed report cards, ERCA's watersheds scored an average score of 'D', which is largely driven by high phosphorus concentrations. In fact, phosphorus concentrations in watercourses in the Essex Region are, on average, amongst the highest in Ontario. The greenhouse influenced streams in Leamington and Kingsville boast the highest concentrations, often orders of magnitude higher than other watercourses in Essex and exceeding the Provincial Water Quality Object of 0.03mg/L by up to 300x (Maguire et al., 2018).

3.1 Water quality monitoring programs in the Essex Region

ERCA monitors surface water quality at sites throughout the Essex Region. The ERCA water quality program strives to improve our understanding of potential land use impacts and prioritize areas for restoration improvements. It also helps us to track the success of habitat enhancement and best management practices along watercourses. ERCA monitors all watersheds in the region under different sample programs depending on availability of external grant funding.

ERCA's monitoring programs are largely supported by external grants and/or partnerships with other agencies (e.g., federal or provincial government; academia). The monitoring programs described below were relatively long-term, but many of them have been affected by the loss of external funding support that occurred in 2023. All monitoring programs, including historical monitoring programs for which funding has ceased are described in **Appendix II** along with site locations, start and end year, and parameters measured. **Appendix I, Map 5** displays the location of ERCA's water monitoring stations in their respective watersheds.

Action Item: Continue to seek grant funds and partnerships to ensure that important long-term monitoring programs continue

---

Kingsville Leamington Nutrient Project

The Kingsville Leamington Nutrient (KLN) project is in partnership with the Ontario Ministry of Environment, Conservation and Parks (MECP), with funding provided by the Canada-Ontario Agreement (COA). The goal was to examine greenhouse influenced and non-greenhouse influenced streams in the Leamington and Kingsville area identified as a priority watershed in Annex 4 of the Great Lakes Water Quality Agreement. There are 16 monitoring sites; six of which are not situated downstream of a greenhouse. The stations were visited bi-weekly year-round. This program was created in 2012 and monitoring continued in this manner until March 2023. Due to funding constraints, monitored has continued with reduced frequency at a subset of sites (please see ERCA, 2023 for more detailed information on this program). Beginning in 2017, most sites were equipped with HOBO or Solinst water level loggers, and certain sites were equipped with ISCO autosamplers to begin collecting data suitable for calculating nutrient loads. As the greenhouse sector continues to grow, new sites were added in 2020 in the Ruscom River watershed that was previously unaffected by greenhouse effluent. See also the greenhouse section above.

Wigle Creek Monitoring Programs – GLASI/ONFARM/Living Lab Ontario

Wigle Creek became the focus of enhanced water quality monitoring in 2015 beginning with the Great Lakes Agricultural Stewardship Initiative Priority Subwatershed Project (GLASI-PSP), which ended in 2018 and was replaced with the ONFARM program from 2019-March 2023. The Wigle Creek watershed is also a study location for the Living Lab Ontario project, which ran from 2020-2023. These projects were focused on the west branch of Wigle Creek, located in Kingsville, Ontario, which spans a total area of 14km^2. Wigle Creek has a total watershed area of ~35km^2, the dominant land use is row crop agriculture (90% agricultural land), and the dominant soil type is Brookston Clay. On average, the total phosphorus concentration in Wigle Creek is 4-7 times greater than the Provincial Water Quality Objective, and the drainage network is largely man-made. These characteristics are typical of watersheds in the Essex Region making it an ideal study location. Wigle Creek empties directly into the Western Basin of Lake Erie.

The goal of the GLASI-PSP was to evaluate the effectiveness of a focused stewardship approach through highly targeted Best Management Practice (BMP) implementation to reduce edge-of-field losses of soil nutrients, with an emphasis on phosphorus. Seven water quality stations (WRd 6, Wigle 1, WE9, WKLN 13, WKD, WCD, and WDD) were monitored biweekly and during events using grab samples and ISCO automated samplers at Wigle 1 and WRd 6. Routine sample collection was conducted year-round. Additionally, Solinst water level loggers were deployed at WRd6, Wigle 1, WKLN 13 and WE9. The devices collected water level data in order to determine nutrient loadings and assess the effectiveness of the BMPs in reducing phosphorus load. Data were provided to modellers as part of a larger synthesis from several sites in southwestern Ontario. This program ran from September 2015 – March 2018.

On-farm Applied Research and Monitoring (ONFARM) is a continuation of the work established under the GLASI-PSP and research priorities identified by Ontario's Soil Health and Conservation Strategy. The program was a four-year research initiative with a focus on water quality and soil health. One important criterion focused on engagement; an opportunity to enhance engagement opportunities with stakeholders and farmers to foster a network of demonstration farms. Along with continued monitoring and modelling established in the Priority Subwatersheds, established in-field paired trials were used to identify soil health indicators and test the effectiveness of BMPs. During the ONFARM program, two water quality stations (Wigle 1 and WRd6) were monitored biweekly and during rain/snowmelt events year-round using grab samples and ISCO automated samplers at Wigle 1. Additionally, water level measurements are recorded every 15 minutes using Solinst Water level loggers in order to determine nutrient loadings and assess the effectiveness of BMPs in reducing phosphorous load. One edge of field site has also been established where water is collected from three locations as it leaves the field in order to test the effectiveness of certain BMPs. This project began in the fall of 2019 and ran until March 31, 2023. Both GLASI and ONFARM were developed by OMAFRA (Ontario Ministry of Agriculture, Food, and Rural Affair) and delivered by OSCIA (Ontario Soil and Crop Improvement Association).

The Living Lab – Ontario initiative, funded by Agriculture and Agri-Food Canada, is a new approach to agricultural innovation in Canada that brings farmers, scientists, and other collaborators together to co-develop and test innovative practices and technologies. Living Lab supported agricultural discovery science and innovation, with a focus on climate change, soil and water conservation, and biodiversity. Collaborators include farmers, scientists from Agriculture and Agri-Food Canada and other federal departments, three Conservation Authorities (Essex Region, Lower Thames Valley, and Upper Thames River CAs), Ecological Farmers Association of Ontario, Innovative Farmers Association of Ontario (IFAO), the Ontario Soil Network (OSN), and the Ontario Soil and Crop Improvement Association (OSCIA). Research focused on reducing the soil and nutrient runoff from agricultural land into Lake Erie, improving water quality, conserving soil health, and increasing biodiversity on agricultural lands in Ontario. The data collected from Wigle 1 for the ONFARM program were also used for the Living Lab project. Living Lab also included additional data collected from edge of field sites by federal scientists. Both ONFARM and Living Lab have watershed modelling components that will help us to better understand phosphorus movement in our unique landscape and eventually to help identify the agricultural Best Management Practices (BMPs) that are most likely to work here. This project also began in the fall of 2019 and ran until March 31, 2023.

Surface Water/PWQMN

The Surface Water/PWQMN (Provincial Water Quality Monitoring Network) involves sampling streams and ditches in Essex County to monitor water quality parameters including nutrients (nitrate, nitrite, total phosphorus, orthophosphate, total Kjeldahl nitrogen, ammonia), E. coli, chloride, total dissolved solids (TSS) and metals. There are 19 sampling sites in total; 11 E sites (ERCA Surface Water project) and 8 M sites (PWQMN). PWQMN sites are monitored once a month from April through November with the exception of M1, M2 and M5 which began year-round monitoring in 2016. E sites are monitored monthly throughout the year. PWQMN sites originated in various years, some dating back as early as 1966. Sampling at E sites began as early as 2010. Water temperature, pH, dissolved oxygen (DO), specific conductivity, ambient conductivity and turbidity (FNU) are measured using an YSI multiparameter water quality sonde at all sites. Rain/snowmelt event samples are not collected at these sites. Water chemistry analysis is an in-kind contribution from the MECP (Ontario Ministry of Environment, Conservation and Parks) for PWQMN sites; all other costs are currently captured under ERCA's municipal Past Monitoring Programs

Table 2 - Summary of ERCA water quality monitoring programs including both current and historical programs

Program	Start Date	End date	Parameters measured	Frequency
KLN	1. 2012 2. April 2023	March 2023 Present	Nutrients, metals, TSS, water temp, pH, DO, conductivity, FNU.	1. Biweekly, events 2. Monthly at some stations
Wigle Creek	Sept 2015 April 2023	March 2023 Present	Nutrients, TSS, water temp, pH, DO, conductivity, FNU.	Biweekly, events Monthly
Surface Water / PWQMN	Various (E-sites ~2010; PWQMN Sites early as 1966)	Ongoing	Nutrients, E. coli, chloride, TSS, metals, water temp, pH, DO, conductivity, FNU.	E-sites (monthly); M-sites (monthly April – Nov.)
Sturgeon Creek	March 2018	November 2019	Nutrients, TSS, water temp, pH, DO, conductivity, FNU.	Biweekly
Wet Weather	2011	2015	Nitrates, total suspended solids, total-phosphorus, E.coli and chloride	Events
Historical E Sites	2008	2011	E.coli, nitrates, total phosphorus and total suspended solids	Unknown
Optical Probe	2014	2017	Temperature, specific conductivity, chlorophyll, and BGA-PC	Weekly May – October; stationary probes sampled every 30 minutes June - October

3.2 Data Management Plan

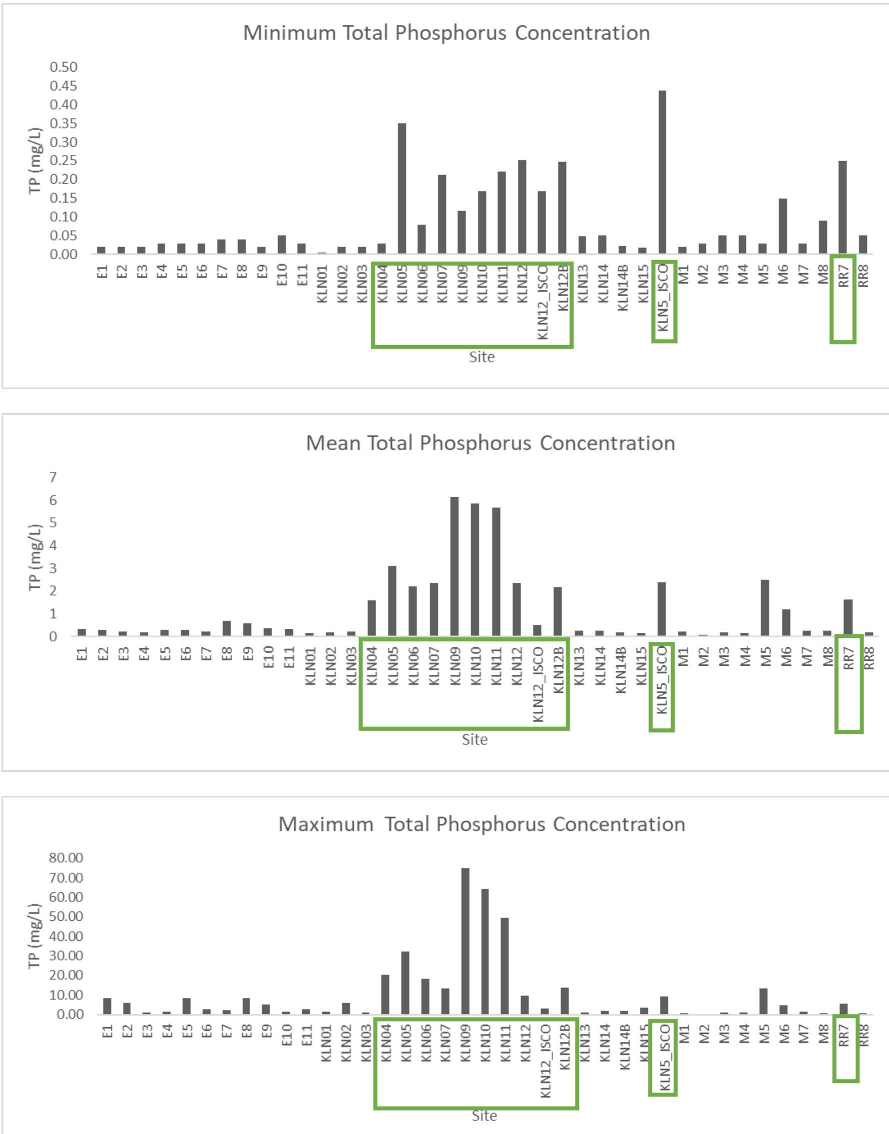
In recent years, ERCA has made substantial effort to modernize the electronic management of water quality and quantity data. Due to the large volume of data collected and variety of electronic tools used, ERCA has developed a Data Management Plan (**Appendix III**). This plan outlines the steps from data collection, receipt of laboratory results, file storage and ultimately import to WISKI (Water Information Systems Kisters) database for long term data storage. The data management plan is an evolving document that is regularly refined as efficiencies are developed and/or issues corrected. The data management plan is also an essential training tool for new water quality staff at ERCA.

Action Item: Continue to refine the data management plan

3.3 Local Phosphorus Concentrations

ERCA has a robust data record spanning more than a decade for most monitoring stations. Presented here are some preliminary basic statistics; however, it is strongly recommended that these data be explored for a more fulsome analysis of temporal and spatial trends. Using data from 2012 to 2021, the minimum total phosphorus concentration in watercourses in the Essex Region ranges from 0.05mg/L to 0.44mg/L, with an average of 0.09mg/L. These minimum values are all above the PWQO of 0.03mg/L. Average total phosphorus concentration ranges from 0.18mg/L to 6.17mg/L, with an average of 1.19mg/L. The maximum total phosphorus ranges from 0.82mg/L in an agriculture dominated watershed to 75.20mg/L in a greenhouse influenced watershed, with an average of 10.38mg/L, which is 346x the PWQO (**Figure 1; Appendix II, Table 4**). Note that data from Wigle Creek are not presented here at this time as these data are part of an ongoing special study.

Figure 1 – From top to bottom, the graphs show the minimum, mean and maximum concentration of total phosphorus for each of ERCA's current water quality monitoring stations. Sites within the green boxes are in greenhouse influenced watercourses. Note that the Provincial Water Quality Objective is 0.03mg/L.



Action Items:

Complete 2022 Watershed Report Card – This item was completed in 2023

Collaborate with researchers to conduct a more fulsome analysis of available water quality data – KLN report completed in 2023

Establish a regular monitoring report template

3.4 Status of Nutrient Loading Calculations

There are currently four watersheds in the Essex Region equipped with ISCO automated samplers and continuous water level loggers which will provide sufficient data for the calculation of nutrient loads. These include three greenhouse influenced streams (Sturgeon Creek, Lane Drain and Mill Creek) and Wigle Creek. Both water quality and quantity data are used to calculate nutrient loadings. Water quantity is collected by measuring continuous instream water levels, as well as taking regular flow measurements. These data are used to develop a rating curve for the watercourse, which is necessary to calculate continuous discharge. Then, using the rating curves developed, water quantity data is combined with water quality data within WISKI to create nutrient loading estimates for watercourses, which can then be analyzed for temporal and spatial patterns. Nutrient loadings will be estimated using both the feature within the WISKI software and the Erie Loading Tool. Decision analysis will select the most relevant methods to use based on the data assumptions of each method. A baseline load estimate will be created from routine sampling while event sampling will provide data for large loading events, as that is when the majority of nutrients enter waterways.

Preliminary phosphorous loads were calculated for Wigle Creek using the WISKI tool, however, these data are being re-analyzed by Environment and Climate Change Canada (ECCC) using the Erie Loading Tool. All results will be compared to determine the most accurate measure of nutrient loads. Data from the remaining three sites are also being analyzed by ECCC. Results of these analyses will be published at a later date.

Action item: Calculate nutrient loads for Wigle, Sturgeon, Lane and Mill watersheds

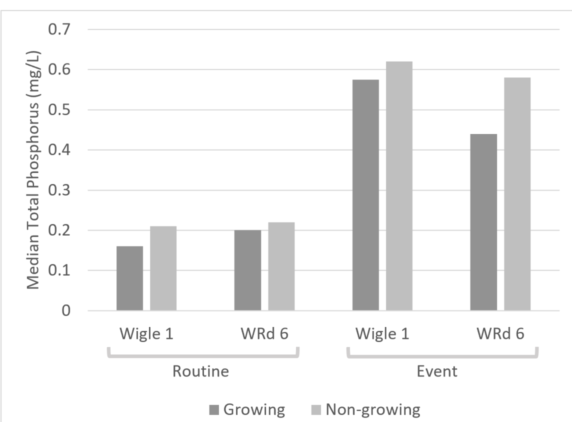
3.5 Known Sources of Phosphorus

Agriculture

Agriculture is the dominant land use in the Lake Erie – Lake St. Clair drainage basin, particularly in the western Lake Erie basin (Myers et al., 2016). Data collected since the mid-1990s have shown that the recurrence and increasing frequency of HABs directly correlate to an increase of dissolved reactive phosphorus (DRP) (D.B. Baker et al., 2014; Stow et al., 2015), which is linked to agricultural non-point sources (Guo et al., 2020; Williams et al., 2018; Wolf et al., 2017). Nutrient mobilization is influenced by many factors, such as the mechanisms of surface runoff, the intensity of precipitation events and agricultural management practices (Dean et al., 2008.) Because up to 90% of the agricultural phosphorus is lost as total phosphorus attached to sediment particles, it has been recommended that agricultural operations adopt conservation practices such as the use of no-till and reduced till to meet reduction targets (Strickland et al., 2010). Despite efforts to reduce agricultural phosphorus loss, improvement of Lake Erie water quality has been limited, partially due to a shift towards increases in soluble phosphorus and the release of legacy phosphorus (Matisoff et al., 2016; Jarvie et al., 2013). Phosphorus in soils accumulates from past applications of fertilizer and manure and can continue to contribute to phosphorus loss from fields for many years (Sharpley et al., 2013). Legacy phosphorus also reduces the buffering capacity of the soil in agricultural fields, meaning additional applications of phosphorus will be more vulnerable to surface runoff (Stackpoole et al., 2019).

The quantification and understanding of phosphorus loss from agricultural fields is widely studied, with new results published frequently. Importantly, the way that phosphorus is lost from agricultural fields (e.g. via surface and/or tile flow) differs depending on agricultural practices, physiography and soil characteristics (Plach et al., 2017; Plach et al., 2018; Grant et al., 2019) and this also influences the best mitigation options (Macrae et al., 2021). Researchers in Ohio and Ontario conduct edge of field research to understand how and when phosphorus leaves agricultural fields under a variety of best management and conventional practices, the results of these studies can vary depending on a variety of factors (e.g. Plach et al., 2019; Smith et al., 2014). Most research finds that phosphorus concentrations in agricultural streams tend to be highest during rainfall or snowmelt events in the non-growing season when the ground is bare, as was also seen in ERCA's data collected in Wigle Creek (**Figure 2**). ERCA and ECCC monitored edge of field sites in Wigle Creek as part of ONFARM and Living Lab, respectively, but weather conditions and timing of the funding hindered our ability to obtain meaningful results from these sites at this time. ERCA has also partnered with the University of Waterloo in the past to conduct edge of field research. Because of our unique landscape, it is essential that this type of research continue to be conducted locally through partnerships.

Figure 2 – Median total phosphorus concentrations at two sites in Wigle Creek (Wigle 1 is downstream of W Rd6). Results show that total phosphorus is highest during rainfall or snowmelt events during the non-growing season when the ground is bare.



Action Items: Complete analysis of Wigle Creek data (this was completed in 2023) **and create a regular cycle for analysis updates**
Continue to participate and seek out partnerships to conduct edge of field monitoring

Greenhouses

The Essex Region is home to the one of the largest concentrations of greenhouse agriculture in Canada. The warm climate with ample sunlight makes the setting ideal for greenhouse use, as well as existing and expanding infrastructure to provide energy and water (see the Essex County Regional Energy Plan for more information https://www.countyofessex.ca/en/essex-county-regional-energy-plan.aspx). Greenhouse agriculture has been common in Leamington and Kingsville for many decades mainly for growing tomatoes, cucumbers, peppers and flowers. However, there has been unprecedented growth in the greenhouse sector with less need for field tomatoes and the advent of legalized cannabis. According to data collected by Statistics Canada for the Census of Agriculture, the total area in greenhouse production was six times higher in 2016 than it was in 1991, with the steady growth throughout that time. There are fewer greenhouses, suggesting that each greenhouse is now larger. The majority of greenhouses in the Essex Region are in Leamington and Kingsville, with the greatest growth occurring in Kingsville from 2011 to 2021 (**Table 2 and 3**). New greenhouses continue to be built, while existing greenhouses continue to expand, many to accommodate cannabis. In recent years, the greenhouse sector has expanded northward along Highway 77 in Leamington. These new greenhouses are within the Ruscom River or Big Creek watersheds, which drain to Lake St.Clair, whereas most of the existing greenhouses are in Lake Erie watersheds. Of note, it is uncertain at this time whether or how cannabis greenhouses are captured in the Census of Agriculture. Additionally, the census data does not provide watershed scale data.

Table 2 – The number of greenhouses and total area in greenhouse production in Essex County from 1991 to 2021 based on Statics Canada's Census of Agriculture. Statistics Canada. Table 32-10-0159-01 Greenhouses and mushrooms, Census of Agriculture historical data

Essex County	# of Greenhouses	Area (m^2)
1991	183	1,267,176
1996	200	1,776,842
2001	213	3,954,176
2006	209	5,475,246
2011	182	6,166,783
2016	170	7,814,527
2021	141	10,590,342

Table 3 - The number of greenhouses and total area in greenhouse production in municipalities where greenhouses are common and/or where growth in the sector was expected from 2011 and 2021 based on Statics Canada's Census of Agriculture. Statistics Canada. Table 32-10-0159-01 Greenhouses and mushrooms, Census of Agriculture historical data*

Municipality	Year	Number of Greenhouses	Flowers	Vegetables	Mushrooms	Other	Total Area (m^2)
Leamington	2011	107	12	93	1	5	3,725,665
	2016	93	9	84	1	4	3,844,240
	2021	75	9	65	1	4	6,044,899
Kingsville	2011	54	7	46	1	2	2,397,010
	2016	60	7	52	1	4	3,927,489
	2021	45	3	41	3	4	3,687,691
Lakeshore	2011	2	2	1	0	1	x
	2016	4	2	1	0	2	11,612
	2021	3	0	2	0	1	763,844
Amherstburg	2011	4	4	0	1	0	44,260
	2016	3	3	0	0	1	x
	2021	1	0	0	0	1	x
Essex	2011	5	2	2	0	1	13,318
	2016	2	1	1	0	0	x
	2021	7	1	5	0	3	x

*Note that cannabis operations are not captured in these tables. 'x' indicates that data are suppressed to meet the confidentiality requirements of the Statistics Act

To further address greenhouse growth, specifically in terms of spatial distribution over time, ERCA and students from the University of Windsor's Geographic Information Science (GISc.) Certificate program have partnered to develop a new geodatabase and map layer of greenhouse footprints within the region (ERCA, 2023). Most of the work utilizes spatial software (ESRI's ArcPro 2.8™) and digital orthophotography from the years 2000 to 2021 to delineate and digitize greenhouse footprints, via polygon topology (**Figure 3**). Greenhouse characteristics such as year built, building status, areal measurement, greenhouse type, etc. will also be identified, classified, and calculated for each polygon. Results from these classifications will also be input into the layer's geodatabase framework, making it an ideal structure for multi-disciplinary queries, especially those related to spatial distribution and nutrient loadings, as well as economic impact to the greenhouse industry (i.e., loss of flower-based greenhouses to cannabis greenhouses). In addition, a quality assurance and quality control document will be written to outline the standardization procedures used to construct these features and to provide a guide on how to maintain these data in the future. Metadata will also be included and will identify necessary supplemental information about this layer (i.e., abstract, projection and coordinate systems used, data maintenance schedule, etc.). Lastly, the overall project and its procedures will be shared with the public via an online ESRI's StoryMap™ application. This platform allows the team to share their spatial data generation workflow by combining text, interactive maps, and other multimedia content in a captivating story-telling template.

Figure 3 – Yellow polygons show where previous greenhouse building footprints were located compared to a recent air photo, which shows building expansion and contraction.

Fruit and vegetable crops are grown using a hydroponic system in inert media slabs which sit on top of graded troughs and are fertigated (irrigation + fertilizer) using drip irrigation. Excess nutrient feed water is captured in a trough, treated, balanced and recirculated. Historically, growers grew directly on the ground in greenhouses and the excess nutrient feed water went in the ground where it would be carried by tile drainage to a surface drain or stormwater pond. As the sector grew, technology advanced and the current process of growing plants was developed. While there is a large investment in recirculation systems, there is an overall savings of 30%-40% to do so. Today, 92%-94% of members recirculate, including all newly built greenhouse operations. Current phosphorus losses may be due to historical effects and leaks in the trough system that allows spilled nutrient feed water to be absorbed through the ground to tile drainage.

Water quality sampling conducted by the Ministry of Environment and Climate Change (MOECC) from 2010 and 2011 demonstrated phosphorous levels in greenhouse effluents/discharges in the Leamington area to be approaching 100 times that of normal background surface water quality for the area (MOECC, 2011). In 2011, the total phosphorus concentrations in two watercourses that drain to Lake Erie (Sturgeon Creek in Leamington and Mill Creek in Kingsville) were 130 times higher than the Provincial Water Quality Objective (PWQO) of 0.03mg/L for phosphorus in streams and rivers. The PWQO for phosphorus is a benchmark for the nuisance growth of plants such as algae. As well, long-term data for Sturgeon Creek collected for the Provincial Water Quality Monitoring Program (PWQMN) shows a sharp increase in phosphorus concentrations between 1996 and 2002, when major expansions to greenhouse operations began (**Figure 4**).

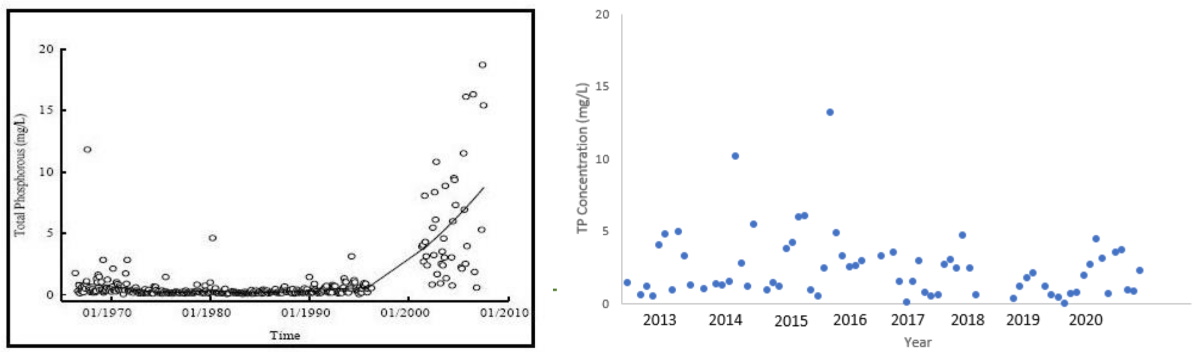


Figure 4 – On the left, total phosphorus concentration in Sturgeon Creek from 1996 to 2010, showing the sharp rise in concentration which coincides with the expansion of the greenhouse sector. On the right, total phosphorus concentration in Sturgeon Creek from 2013 to 2021. Data are taken from the MECP PWQMN program where streams are sampled once a month from April to November.

Beginning in 2012, ERCA, in partnership with the MECP, began a long-term monitoring program (see KLN program description) in watercourses in the municipalities of Leamington and Kingsville that discharge directly into Lake Erie. The purpose of the monitoring was to compare greenhouse influenced to non-greenhouse influenced streams and to track changes in nutrient concentration over time. Beginning in 2016, additional data have been collected that will allow for the calculation of nutrient loads for some watersheds. Additional sites were added to the program in 2020 in the Ruscom River to monitor changes in water quality with the expansion of greenhouses in this watershed.

Total phosphorus (TP) and phosphate (PO_4) concentrations between 2012 and 2016 were significantly higher (TP was 20x higher and PO_4 was 28x higher) in watercourses influenced by greenhouses than those that were not, suggesting that greenhouses are a source of elevated nutrient concentrations in downstream riverine systems (Maguire et al., 2018). In typical row crop agricultural systems, TP concentrations tend to be highest in the non-growing season (November-April) during rain/snow melt events. We have observed the opposite trend with TP concentrations highest during the typical growing season (May-October), with concentrations often diluting during rain events (Maguire et al 2018). This suggests that greenhouse influenced streams may differ from non-greenhouse influenced streams in the timing of TP delivery as well as the concentration, but requires further investigation. These findings highlight the importance in including greenhouse operations in water quality management planning.

Also of note, the cannabis industry introduces a great deal of uncertainty with very little known about nutrient inputs or exports. There is no governing body equivalent to the Ontario Greenhouse Vegetable Growers (OGVG) for this sector, which makes it challenging to obtain this information. The cannabis greenhouses observed in Leamington are very large and require more water than a typical vegetable greenhouse. This led to a moratorium on new large non-residential service water applications for up to 12 months beginning March 2021 due to strain on the local water treatment plant's treatment capacity with a 32% increase in demand from 2015 to 2020. New greenhouse builds are now seeking alternative options such has using groundwater to provide feedwater for greenhouse plants. It is therefore important that monitoring continue in watersheds where growth of this sector continues. Please see notes on mitigation in the greenhouse sector in Section 4.0.

Action Items:
Complete greenhouse mapping project; update Census of Agriculture data when available
Re-analyze KLN data – this was completed in 2023 - **and create a regular cycle for analysis updates**
Calculate nutrient loads in greenhouse influenced streams
Continue monitoring greenhouse influenced streams

Municipal Wastewater Treatment
In 2019, over 103 million m^3 of municipal wastewater was treated in facilities in the region. Municipal wastewater is used water from homes, businesses, industries and institutions that drain into sewers. It includes sanitary sewage and may be mixed with stormwater in areas where stormwater and sanitary sewers are combined. Phosphorus in municipal wastewater comes from human waste, food and some soaps and detergents. The Essex Region has 19 municipal wastewater facilities: 9 lagoons and 10 sewage treatment plants (**Table 4; Appendix I, Map 6**).

Phosphorus removal during mechanical treatment of wastewater can be achieved through chemical removal, advanced biological treatment, or a combination of both. Chemical removal typically involves precipitating influent phosphorus with an iron or aluminum salt. While removal rate is high, it results in large amounts of chemical sludge that requires haulage and disposal. A biological phosphorus removal process removes biosolids and associated phosphorus from the liquid stream processes via the waste activated sludge using an anaerobic-aerobic sequence to select for polyphosphate accumulating organisms (PAOs). PAOs absorb dissolved phosphorus from wastewater and store it in granules within their cells, doubling the phosphorus content of the solids. Additional information on wastewater phosphorus removal can be found in **Appendix IV**. In addition, there are many new companies doing ground-breaking work on phosphorus capture and reuse as fertilizer pellets – e.g., Ostara.

The Ontario Ministry of Environment, Conservation and Parks (MECP) is responsible for providing discretionary provincial approvals for wastewater treatment facilities under the Ontario Water Resources Act. As a significant point source, wastewater treatment plants are relatively easy for the province to regulate and monitor. Therefore, over the last several decades, wastewater plants have been the focal point of provincial phosphorus regulations and municipalities have made great strides in improving infrastructure and level of treatment, and P removal methods. All municipal and institutional sewage treatment works discharging into the Lake Erie Basin (including the St. Clair River - Lake St. Clair - Detroit River system), regardless of nominal design capacity, are required to have effluents not exceeding a monthly average total phosphorus concentration of 1.0 mg/L, which is achievable through secondary treatment. Any exceedances have to be reported MECP and are publicly released online.

The 2018 Canada-Ontario Lake Erie Action Plan established that Ontario would work with municipal partners to achieve an effluent discharge limit of 0.5 mg/L of total phosphorus for municipal wastewater treatment plants in the Lake Erie basin that have an average daily flow capacity of 3.78 million litres or more. In the Essex Region, that includes seven wastewater treatment plants (Denis St. Pierre WPCP, Lakeshore West WPCP, Essex WPCP, Leamington WPCP, Amherstburg WPCP, Little River WPCP, and Lou Romano Water Reclamation Plan). In 2019, the total phosphorus load from municipal treatment plants in the region was 26,754kg.

Action Item:
Work with municipalities to catalogue the methods and innovations used to further reduce phosphorus in wastewater treatment plant effluent
Support municipal efforts to implement new technologies
Include exceedances and/or lack of exceedances in future phosphorus update reports; Encourage transparency in reporting annual nutrient loads from WWTPs

Essex North East Lagoons and the Puce River:
In November of 2017, ERCA's Water Quality department was alerted to an issue in the Puce River by Conservation Area staff working in Maidstone Conservation Area. They reported that the Puce River in this naturalized area was flowing fluorescent green, which was later determined to be due to an overgrowth of green algae. In response, ERCA reported this to the MECP Spills Action Centre and mobilized to take photos and samples. In April of 2018, the Puce River was once again reported to be fluorescent green. The MECP Spills Action Centre and Compliance Officers were again notified and ERCA's Water Quality team was dispatched to collect water samples and take photos throughout the length of the Puce River. At that time, it was determined that the green colour occurred downstream of the Essex NE lagoons all the way to the mouth of the Puce River where it meets Lake St.Clair. The green colour did not occur upstream of the lagoon nor in the eastern branch of the headwaters of the Puce River. It was also confirmed that the Essex NE Lagoon was discharging from its cells during each of the observed occurrence of green colouration in the Puce River, thus indicating that the lagoon effluent is the source of this contamination. Algal samples indicated that the green colour was due to an abundance of green algae or chlorophytes, likely *Scenedesmus* and/or *Closterium,* which are non-toxic algae. The algal contamination and green colouration dissipated following the completion of discharge from the lagoon.

Table 4 Municipal wastewater treatment facilities in the Essex Region

WWS Name	Municipality	Level of Treatment	Population Served	Design Rated Capacity (m3/day)	2019 Total Annual flow (m3)	Estimated TP annual load (kg)	TP Concentration Objective monthly average (mg/L)	TP Final Effluent Compliance Limits (mg/L)
Essex N. E. Lagoon	Essex Town	Secondary Equivalent	2,985	2910	507,455	Not available	0.8	1.0
Comber Lagoon	Lakeshore	Secondary Equivalent	1,050	430	150,014	2.02		
Cottam Lagoon	Kingsville	Tertiary	1,700	833	239,675	2.02	0.5	1.0
The Denis St.Pierre Wpcp	Lakeshore	Secondary		14500	4,882,528	911.26	0.5	0.8
Mcgregor Lagoon	Amherstburg	Tertiary		1127	277,864	20.83	0.3 mg/L (May 1 - Nov. 30); 0.5 mg/L (Dec. 1 - Apr. 30)	0.5 mg/L (May 1 - Nov. 30); 1.0 mg/L (Dec. 1 - Apr. 30)
Harrow Lagoon	Essex Town	Tertiary	3,000	2106	331,953	28.44	0.3	0.5
Stoney Point P.V. Lagoon	Lakeshore	Secondary Equivalent	1,450	959	522,779	6.64		
Edgewater Beach Lagoon	Amherstburg	Secondary Equivalent		1614	318,619	105.94	N/A	1.0
Colchester South Lagoon	Essex Town	Secondary Equivalent	2,229	1816	422,886	29.47	0.8	1.0
Lakeshore West Wpcp	Kingsville	Secondary	14,690	5400	2,002,047	600.58	0.8	1.0
Mcleod Wpcp	Amherstburg	Tertiary		1015	231,599	15.96	0.5	
Essex Wpcp	Essex Town	Tertiary	3,364	4590	714,816	109.74	0.3	0.5
Big Creek Marsh Stp	Amherstburg	Tertiary	292	195	3,538	2.59	0.3	0.5
Boblo Island Wpcp	Amherstburg	Secondary		258.50	40,498	5.39		
South Woodslee Wpcp	Lakeshore	Tertiary		210	14,329	0.98	0.2	0.3
Leamington Wpcp	Leamington	Secondary	28,000	35000	7,551,737	936.35	0.8	
Kingsville Lagoon	Kingsville	Secondary Equivalent	6,000	2760	276,135	Not available		1.0
Amherstburg Wpcp	Amherstburg	Secondary		9500	246,740	490.81	0.6	0.8
Little River Wpcp	Windsor	Secondary	89,329	72800	16,736,056	4116.91	0.5	1.0
Lou Romano Water Reclamation Plant	Windsor	Secondary	179,209	218000	65,607,276	19367.90	0.4	0.5
Woodslee Estates Sewage Treatment Plant	Lakeshore	Tertiary	59	330	Not available	Not available	0.2	0.3

In April 2020, ERCA's Water Quality staff once again reported a green colour when conducting their routine monitoring in the Puce River. It is worth noting that ERCA's Water Quality staff visit watercourses all around the region, year-round, over many years and are valuable and reliable sources for reporting unusual circumstances. The MECP Spills Action Centre and Compliance Officers were informed of this issue and confirmed that the lagoon was discharging, but that effluent was clear and met all limits in their environmental compliance approval (ECA). ERCA Water Quality staff again visited sites from upstream of the lagoon to the mouth of the Puce River, confirming that the lagoon effluent was the source of the algal contamination affecting the full length of the river. Following another report of algae in May 2020, the MECP indicated that they would be working with the municipality on a long-term plan to mitigate this issue.

The lagoon is operated by the Ontario Clean Water Agency (OCWA) for the Town of Essex. Following direction from the MECP that the issue of algal contamination must be mitigated during discharge events, in consultation with the Town of Essex and CanDetec Inc, it was determined that a Sonic Solutions LLC Quattro DB ultrasound unit would be installed to control blue-green and green algal growth in the lagoon cells. The Quattro DB ultrasound technology emits over 2000 frequencies in pulses. The ultrasonic frequencies result in the rupture of tiny gas vacuoles within the cyanobacteria (or blue-green algae) which inhibits their ability to move within the water column to feed which limits their ability to reproduce resulting in the decrease in population over a period of weeks. Ultrasound disrupts internal fluid flow in green algae again interfering with algal reproductive cycles and ultimately expediting algal cell death. Importantly, the technology does not break the cell wall of cyanobacteria so toxins are not released from the dead cells. Ultrasound causes algae populations to decrease generally in 3-4 weeks. The time for control of a population within a system depends on the starting population count and the species makeup of the algae as some algae, such as filamentous species, are not controlled with ultrasound. The Quattro DB ultrasound is effective within a 150m radius of the device for green algae and 400m for cyanobacteria, making it ideal to treat these contained lagoon cells. In addition, there is no contamination to the environment, and it is safe for aquatic and terrestrial flora and fauna as it only affects algal growth. While this technology is effective at killing algal cells, it does not specifically address the issue of nutrient loading.

OCWA installed the Quattro DB ultrasound unit on March 31, 2021 and continued monitoring for algal growth. The Town of Essex was granted an extension of the spring discharge period from April 30 to May 15 to allow for treatment prior to release to the environment. Prior to the lagoon discharge, ERCA, OCWA and the MECP developed a sampling protocol in the Puce River with samples taken 100m upstream of the effluent pipe and at several downstream locations before, during and after the lagoon discharge period **(Figure 5**). Sampling began on May 3, 2021 and concluded May 12, 2021. All water quality samples were analyzed for nutrients (total phosphorous, soluble reactive phosphorous, nitrate, nitrite, total Kjeldahl nitrogen, ammonia, unionized ammonia), total suspended sediment and E.coli (beginning May 5, 2021). In addition, samples were collected for algal identification at a downstream site and all sites were photographed. Water flow measurements were taken at one upstream and one downstream site before, during and after the lagoon discharge. A similar sampling regime was followed during the fall lagoon discharge from October 4, 2021 to October 27, 2021 and in the spring of 2022 from March 17, 2022 to March 28, 2022. Algal samples were not collected during the fall 2021 sampling. The spring 2022 lagoon discharge occurred earlier due to high water levels that were in danger of breaching the lagoon's berms. Unfortunately, there was insufficient time between ice melt and lagoon discharge to deploy the ultrasonic unit, however this provided an opportunity to observe downstream conditions without the ultrasonic treatment.

Figure 5 – Map showing the location of sampling locations in the Puce River

In 2021, neither the spring nor fall lagoon discharge events resulted in an overgrowth of algae in the Puce River nor were there reports throughout the year of green colouration in the river, suggesting that the ultrasonic technology was successful in killing the algae prior to discharge to the environment. Only filamentous algae were observed in algal samples collected in the spring of 2021 with no algal toxins detected. Preliminary data analysis from spring 2021 do not suggest that the lagoon discharge resulted in increased total phosphorus, however the results do indicate that there is a source of both phosphorus and E.coli between Puce 3 and Puce 5 that should be investigated (**Figure 6**). The MECP has been alerted to this. During both lagoon discharge periods, water flow and volume were higher at the downstream site compared to the upstream site. Additionally, the sediment at the downstream site was muckier than at the upstream site, with a noticeable fecal smell during the lagoon discharge event. During the spring discharge event in 2022, without ultrasonic treatment, the Puce River was confirmed to have green colouration downstream of the lagoon effluent and, microcystins, the toxin produced by the cyanobacteria *Microcystis* was observed in low concentration at a down stream site (Puce 3; 0.16 ug/L). The Town of Essex has been granted an extension for the spring discharge period to allow time for the ultrasonic treatment to work prior to any further lagoon discharge to the environment. It is recommended that more fulsome data analysis be conducted and that the Puce River continue to be monitored during lagoon discharge events.

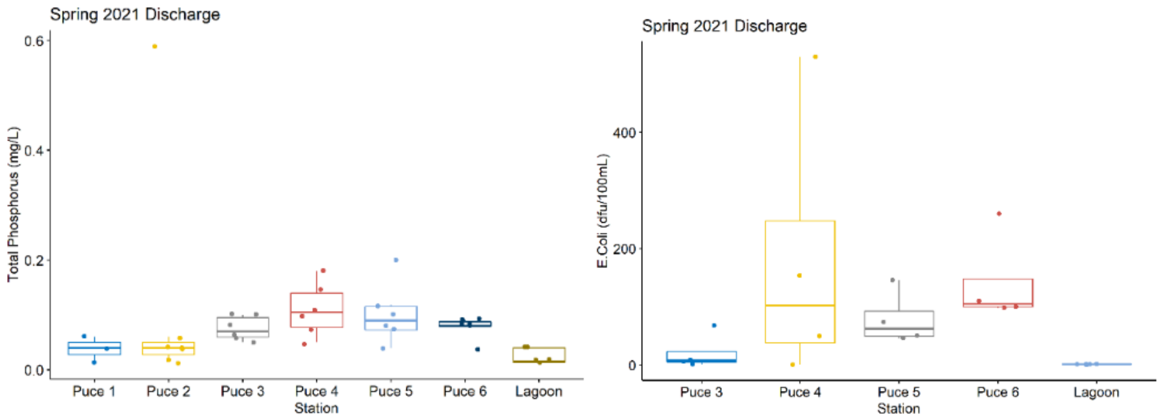


Figure 6 – Total Phosphours concentation (right) and E.coli counts (left) for monitoring sites in the Puce River during discharge of the NE Sewage Lagoon in Essex, ON

This is considered to be a success and shows the importance of collaboration with local agencies. The MECP, OCWA, Town of Essex and ERCA now have an established method of communication of lagoon discharge events as well as a treatment to minimize the effect on the environment and a sampling protocol to ensure success of this program. The results of this effort should be shared with other municipalities and water operating authorities with similar algal issues. However, as noted, there continue to be concerns with both phosphorus and E.coli additions to the Puce River during lagoon discharge events. Additionally, funding for continued downstream monitoring during lagoon discharge events is not currently available.

Action Items: Complete data analysis for Puce River sampling; prepare a detailed report; continue collaboration across agencies; develop research and/or ongoing monitoring projects

Other Facilities with Environmental Compliance Approvals (ECAs):

There are likely other types of facilities with ECAs for phosphorus in the Essex Region, however, it was not in the scope of this project to catalogue each of these. The MECP maintains a record of all ECAs with a searchable database. Working with the MECP, the ECAs with phosphorus effluent limits could be obtained for facilities in the Essex Region and mapped to the watershed of the receiving water body. This would provide a comprehensive list of all known point sources of phosphorus in each watershed.

Action Item: Create a comprehensive list of all known point sources, other than WWTP in each watershed

---

March 2022 – updated November 2023

Septic Systems

Septic systems, or on-site treatment facilities, are common across the region in rural areas not serviced by municipal wastewater treatment facilities. Septic systems use large tanks to hold and partially treat effluent before releasing it into a tile drain bed. In a properly functioning septic system, effluent flows from the tile beds, into the groundwater where it is eventually transported to a nearby tributary or waterbody. Under these circumstances, a small proportion of nutrients, including phosphorus, is expected to be lost to the environment. However, there are also several ways in which a septic system can fail, resulting in increased contamination of nearby surface water:

1. A poorly designed septic system, lack of maintenance or overloading the system can result in increased nutrient loss if the system becomes clogged or saturated, resulting in leakage or seepage with effluent reaching tributaries via overload flow. This is estimated to occur in up to 20% of all septic systems.
2. Illegal misconnections where the effluent of a septic system is delivered directly to a tributary or agricultural drain (i.e. 'hot pipes'). This practice is frequency observed in the Essex Region.
3. In agricultural areas, the subsurface drainage of the septic system may be interrupted by a tile drain or field ditch.

Maintenance of septic systems are the responsibility of the landowner and improperly maintained systems result in nutrient and fecal contamination of nearby tributaries. Routine maintenance is recommended every 3-5 years. In Ontario, on-site sewage systems are regulated by the Building Code Act, 1992 and the Ontario Building Code (O. Reg. 332/12). Enforcement is carried out by designated Principal Authorities (municipalities). The location of septic systems is also important to prevent discharge to the environment in high water or rain events. For example, in certain areas of the Essex Region, high lake levels in 2019 and 2020 meant some septic systems were subject to high wave action and/or were completely under lake water for periods of the season.

Recent research in the Canadian Lake Erie subwatersheds suggest that, overall, septic systems may contribute between 1.7% and 7% of the total phosphorus load to Lake Erie from Canadian tributaries, depending on the modelled scenario (Oldfield et al. 2020). This research also showed that the Essex Region (referred to as Cedar watershed) has the highest density of septic systems per square kilometer in the study area of southwestern Ontario. Given this, the Essex Region also has the highest phosphorus load per square kilometer with septic systems possibly contributing 8-20% of the phosphorus load from our local tributaries to Lake Erie. This estimate does not account for failing septic systems nor hot pipes. Further localized quantification of the contribution of septic systems is warranted, however the results of this study suggest that septic systems may be contributing to high nutrient concentrations in the Essex Region watersheds.

Action Items:
Determine the phosphorus contribution from septic systems in the Essex Region
Create a social media campaign to encourage proper maintenance of septic systems
Support municipal efforts to create more connections to sanitary sewers
Encourage the use of regulatory tools where necessary

Urban Runoff

Lake Erie eutrophication is closely tied to human behaviour and anthropogenic inputs, and as such, another major contributor of phosphorus loading to the western basin of Lake Erie is urban stormwater runoff (Environment and Climate Change Canada, 2020). The Essex Region is undergoing rapid urbanization with a steady increase in new housing developments replacing formerly agricultural land. Similar to agricultural inputs, urban runoff enters storm drains, urban creeks and rivers from many unregulated and diverse non-point sources, contributing biologically available phosphate to downstream waters (Wurtsbaugh et al., 2019).

A continued increase in urbanization has lead to an increase in nutrient loading through wastewater and runoff from impermeable surfaces due to rainfall and snowmelt. These processes mobilize road salt, animal excrement, decaying vegetation and phosphorus from lawn fertilizers (R. B. Smith et al., 2019). In order to accommodate increased urbanization, changes in infrastructure have created a shift in the permeability of drainage surfaces, including an increase in paved surfaces, buildings and structures, and a decrease in green space. Although there is less green space with urbanization, some, such as lawns, golf courses and parks, remain a significant source of phosphorus pollution due to the use of fertilizers (Hobbie et al., 2017).

Stormwater Ponds

Stormwater retention ponds (SWPs) have been shown to be an effective best management practice for controlling the rate of stormwater flow and improving stormwater quality through several biological, chemical and physical processes (Marsalek et al., 2002). The increased retention time afforded through the use of SWPs promotes passive sedimentation of the pollutants which can be carried by stormwater, as well as the microbial transformation of excess nutrient loads prior to reaching downstream waters (Blaszczak et al., 2018). However, as they are designed to control runoff by retaining water, nutrients can accumulate and algal blooms are often detected within these waters, posing concern to the downstream tributaries and lakes, particularly as urbanization is increasing around the Great Lakes region (Brooks et al., 2016). As a result, the City of Windsor has identified an "increase in rainfall and temperature causing increased algae growth in our water bodies" as an impact in their Degrees of Change: Climate Change Adaptation Plan (2019) due to increased blooms in urban stormwater ponds.

Action Items:
Continue to advocate for stormwater pond design to consider both water quantity and quality concerns;
Support further research to better understand how stormwater pond design can be optimized to reduce nutrient loss, particularly in the greenhouse sector

3.6 State of the Knowledge - Research Roundtable

On January 31, 2020, ERCA hosted a research roundtable at the University of Windsor to discuss the state of local knowledge specific to the clay plains of the Essex Region and Lower Thames Valley. Workshop participants were primarily from the University of Windsor, as well other academic institutions, and federal and private agencies. All participants had expertise in, or responsibility for, monitoring, modeling, or research activities related to HABs and/or phosphorus in Lake Erie and/or the Essex Region. **Appendix V** (available on request) provides a summary of the informational presentations as well as ideas and recommendations that were collected for research opportunities with existing data, and needs for new or enhanced monitoring.

Discussions highlighted the need for existing data to be available to researchers, the need to monitor the success of BMPs at a watershed scale, and the creation of hydrogeological models. Potential ideas for new research to fill gaps included:

- Source tracking with isotopes;
- Increasing monitoring along each tributary reach using nested sites and extensive sampling to find critical source areas;
- Deploying real time sensors for continuous phosphorus monitoring;
- Adding carbon analysis to monitoring programs;
- Sediment monitoring to determine sediment phosphorus sources;
- Sequential extractions to obtain more information about what form phosphorus is in and legacy phosphorus in sediments;
- Additional monitoring in Lake St Clair watersheds;
- Investigating the impact of agricultural drain clean outs to determine the impact to P and erosion;
- Ensuring compatibility of data and load calculation methods between labs and research projects.
- Specific greenhouse-related research discussions included exploring available MECP datasets from storm water ponds and expanding dye testing. Further research is also needed on the microbiological processes in greenhouse stormwater ponds (phosphorus-cycling)
- Improve the understanding of the sources, fate, and delivery of phosphorus throughout the Essex watershed

Other recommendations discussed at the workshop included collaborating with municipalities to determine what they are monitoring for point source phosphorus loadings; examining where the city has built low impact design (LID) features and establishing a monitoring plan for those features; and exploring educational resources and remediation for septic tank and sewer line leaks.

Discussions also highlighted the importance of raising the profile of local champion farmers, agencies, and researchers, using the long-term data to show success and communicate progress, and the need to use trusted specialists to translate and share knowledge. Undertaking additional stakeholder engagement was considered, including working with farmers to understand use of fertilizers and BMPs in the region, as well as to build relationships to improve onsite monitoring. Opportunities for citizen science projects were also discussed.

Action Items:
Invite participants of Research Roundtable to provide an update on their work;
Circulate table of Research Actions

4.0 Mitigation

Many mitigation techniques exist for all types of wastewater discharge, but the efficacy of these techniques varies greatly depending on the type of discharge. In general, urban, and industrial wastewater discharge occurs as point sources. This allows for the centralized collection and treatment of these discharges which also tend to have higher phosphorus concentrations. In contrast, agricultural discharges are non-point sources that occur over a wide geographic range with relatively low P concentrations. The nature of the wastewater being treated determine the type(s) of mitigation techniques that can be used to effectively prevent phosphorus loadings.

In Windsor-Essex County, the primary source of phosphorus is from agricultural fields as this is the largest land use. The following review of current mitigation techniques focuses on agricultural best management practices (BMPs) for the mitigation of phosphorus leaching. Further, experimental methodologies are discussed in **Appendix IV** including their applicability to agricultural and urban/industrial wastewater treatment.

4.1 Field Agriculture

There are numerous Best Management Practices available to help mitigate phosphorus loss from agricultural fields. Watershed models conducted for the Maumee River and St.Clair/Detroit River system include analysis of the effectiveness of different BMP scenarios with most models concluding that using multiple BMPs and choosing BMPs that are appropriate for the land and agricultural practices are most effective (Martin et al., 2020; Scavia et al., 2019). The Upper Thames Conservation Authority has a comprehensive guide to BMPs commonly used in southwestern Ontario, as well as resources available through Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) and various farm groups like Ecological Farmers of Ontario and Innovative Farmers of Ontario and Ontario Soil and Crop.

As previously discussed, there are many factors that influence phosphorus loss from agricultural fields. Practices that mitigate or reduce phosphorus loss vary depending on these factors. A recent collaboration by Macrae et al. (2021) showed that subtle differences in microclimate, soils and topography should be considered when recommending appropriate conservation practices to reduce phosphorus loss from agricultural landscapes. The study identified four management regions within the Lake Erie watershed: Northeast, Transition North, Transition South and Southwest (**Figure 7**). Most of the Essex region is located within the Southwest, which more similar to watersheds in Michigan and Ohio than elsewhere in Ontario. Moderate winter and hot summer climate coupled with flat clay soils and intensive land drainage result in high phosphorus loss from agricultural fields in the southwestern region. Both surface and subsurface phosphorus loss occurs year-round, although phosphorus loss is highest in the non-growing season. Thus, conservation practices that reduce dissolved or colloidal phosphorus in tile drainage year-round should be prioritized. The efficacy of no-till or conservation till at mitigating P loss may vary across the geographic regions of the Lake Erie watershed (e.g. Baker et al., 2017). In the southwestern region, an alternative, preferred practice is the coupling of subsurface placement with no-till, which work synergistically to manage phosphorus losses in the surface and subsurface (Macrae et al., 2021).

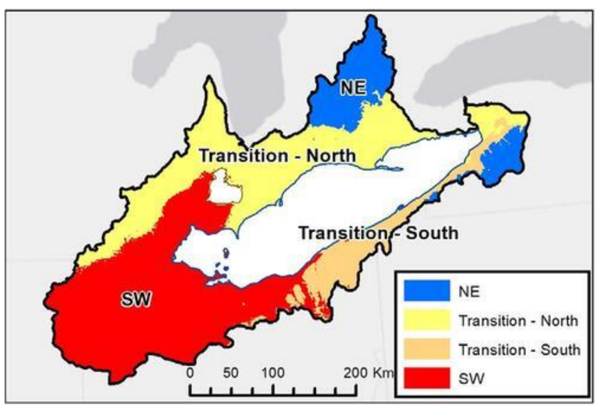


Figure 7: Differing phosphorus management regions within the Lake Erie watershed from Macrae et al., 2021

Since the 1970's, ERCA has worked with local agencies, organizations and residents to promote conservation activities and deliver programs and projects aimed at improving and protecting watershed health, including agricultural Best Management Practices (BMPs). ERCA's Clean Water~Green Spaces programs have provided technical assistance and financial incentives to improve and protect water quality and reduce erosion. Collectively, these programs have offered grants to help cover the cost of best management practices; including conservation farm practices, erosion control, buffer strips, rock chutes, tree planting, wetland creation, well decommissioning, septic improvements, cover crops and more (**Appendix I, Map 7**). We have long understood the importance of these stewardship programs not just as it relates to phosphorus and water quality, but for overall watershed health, water quantity, soil health, erosion, natural heritage, and more recently, addressing impacts of climate change. The types of BMPs offered through these programs varies depending on available funding, as well as the current state of knowledge regarding their effectiveness, particularly in the Essex Region.

Transport treatment BMPs focus on reducing the transport of phosphorus off agricultural land through a variety of approaches. The primary routes of loss are soil erosion which results in the loss of soil-bound phosphorus while surface runoff and subsurface runoff result in the loss of soluble phosphorus. Therefore, all transport treatment BMPs rely on minimizing erosion, surface runoff, or subsurface drainage. Cover crops or perennial plants are used to prevent soil erosion and surface runoff reducing phosphorus losses (Liu et al, 2019). Conservation tillage practices are also widely used to maintain soil stability and prevent erosion/surface runoff (Daryanto et al, 2017). These methods are highly effective at preventing the erosion of topsoil and the loss of P through surface runoff. However, they are associated with enhanced loss of phosphorus through subsurface flow especially in cold weather environments with repetitive freeze-thaw cycles (Liu et al, 2019). Other approaches include strip cropping, riparian zones, and livestock management (Sharpley et al, 2006).

The nutrient removal efficiency of vegetated buffer strips is initially quite high. However, over time they become saturated with phosphorus and may change from nutrient sinks to sources (Stutter et al, 2019). This can be mitigated through the harvesting of phosphorus from the buffer strips. Hille et al (2019) studied methods to fix a phosphorus -saturated buffer strip (Hille et al, 2019). They harvested either topsoil or plant matter from buffer strips. They found that topsoil harvesting, a labor-intensive process, did not enhance phosphorus sorption by the buffer strip. However, harvesting the plant matter from the buffer strip resulted in a 2.3 % reduction in phosphorus content per annum. They suggest that the annual harvesting of plant matter can extend the functional lifespan of buffer strips.

Reducing phosphorus losses at the field edge is an essential part of reaching phosphorus loading targets. There are numerous technologies currently available and many in development. The primary challenges associated with the treatment of runoff at the field edge are the relatively low phosphorus concentrations and the diffuse nature of the discharges. The low concentrations make certain techniques ineffective while the non-point source nature of the discharges makes centralized collection and treatment difficult, if not impossible. Therefore, mitigation techniques must be effective at the concentrations found in agricultural wastewater and be applicable in a decentralized manner.
Appendix IV provides a detailed explanation and review of these techniques.

Action Items: ERCA to continue to seek out funds to provide grants for BMP implementation

4.2 Greenhouses

The Ontario Greenhouse Vegetable Growers (OGVG) and its members are working to reduce the per acreage loss of phosphorus by minimizing inputs (precise fertigation), maximizing reuse of outputs (recirculation) and managing excess. There are three options for managing excess feedwater: transportation to a water treatment plant via truck; discharge to sanitary sewer; or land application. Currently, the ability to discharge to sanitary sewers is geographically limited and land application must meet specific circumstances to be allowable, making transportation to a water treatment plant the most likely permissible option. In 2016, the MECP changed the process for obtaining approval for greenhouse stormwater ponds, which now includes ongoing monitoring to ensure nutrient limits are not exceeded (MECP, 2016).

In addition, there are several ongoing research studies at the University of Windsor that will further our knowledge and understanding of these systems, including the functioning of greenhouse stormwater ponds. As well, ECCC has been working with ESSA Technologies to create conceptual models of complex pathways affecting phosphorus loads, including greenhouse management, in Lake Erie and uncertainties about the actions managers can take to reduce phosphorus loads. This report will be invaluable to supporting the Essex Region Phosphorus Management Plan.

Action Item:
Work with OGVG / OMAFRA/municipalities to hold fertigation optimization workshops for greenhouse growers
Continue to identify areas of research and innovation to mitigate phosphorus loss

4.3 Municipalities

An Environmental Commissioner of Ontario report published in May 2017, Every Drop Counts, notes that even though non-point sources typically represent the majority of phosphorus loadings to Ontario's lakes, point sources receive more attention, highlighting a disproportionate cost-to-environment benefit equation (Saxe, 2017). The report notes that further efforts to increase phosphorus removal from municipal wastewater facilities should be balanced against the other options such as investing in non-point source BMPs and other community environmental priorities, including greenhouse gas reductions. That said, additional improvements can be made through operational optimization.

For example, in 2021, OCWA and the Town of Kingsville collaborated on an experimental phosphorus removal technique using a rare earth-based chemical composed of lanthanum and cerium called RE300. Unlike iron- and aluminum-based phosphorus removal chemicals, RE300 requires a lower dose, does not produce as much chemical sludge, improves sludge dewatering, and it does not consume alkalinity or lower pH like other coagulants. Results of this project are pending (OCWA, 2021)

Action Items:
Coordinate optimization workshops with MECP and local WWTP operators
Review and report on local municipal bylaws that could prevent storm water sewage from private property being discharged into a sanitary sewer, including downspout disconnections and incentives
Promote education on stormwater and urban runoff (e.g. Yellow Fish Road or Adopt a Drain)
Encourage the implementation of Low Impact Design and green infrastructure projects, including monitoring

4.4 Individual

While the burden of reductions in phosphorus load will largely be carried by municipalities and agriculture in the Essex Region, it is important to highlight the actions that individuals can take as well. These small actions can add up to big changes, and they show support for our farmers and municipal leaders by demonstrating that individuals are willing to make changes too.

These actions include, but are not limited to:

- Reduce the use of fertilizer in urban settings; follow the 4R (right source, right rate, right place, right time) strategy
- Keep leaves and organic matter out of street and storm drains
- Perform regular septic system maintenance; repair failing septic systems
- Disconnect downspouts
- Plant raingardens; use native plants
- Pick up after pets

Action Item: ERCA and municipalities to continue to incorporate information on individual actions in Education and Outreach programs and through social media

5.0 Other contributing Factors/Stressors

There are many other contributing factors and/or stressors affecting the occurrence and severity of harmful algal blooms as well as the degree of phosphorus loss from the landscape. The information below highlights some of these factors that are most relevant to the Essex Region.

5.1 Socio-economic Factors

Socioeconomic factors, such as crop prices and demand, play a significant role in the region's agricultural production and ability to adopt agricultural BMPs. Of note, there are several ongoing studies in Ontario that are working on better understanding the socioeconomic influences and impacts of implementing agricultural BMPs. The results of these studies will help us to deliver meaningful and effective cost-share programs to implement BMPs.

5.2 Land use and Drainage Changes

Prior to European Settlement, the Essex Region was dominated by lush natural areas including Carolinian woodlands, wetlands and tallgrass prairies (ERCA, 2013). Since this time of settlement in the 1830's, much of the original natural resources of the Essex Region have either been removed from the landscape or have become extremely degraded as a direct or indirect result of clearing and drainage for timber, agriculture, and urban development (ERCA, 1986; Oldham, 1983). This also included extensive changes to the drainage network including straightening, relocation and/or burial of existing channels, and creation of new channels. Because of the extremely flat topography and the need to move water off of the land, there are some drains that create a linkage between what should be hydrologically distinct watersheds, making it challenging to create and execute accurate watershed models. ERCA is aware of this challenge and is in the process of working with municipalities to create a current drainage network layer as well as a mechanism that will allow for notification of changes to the network.

Within the region, there has been an overall loss of approximately 97% of the original wetland area (Snell, 1989) and 95% of the original forest area (Vandall, 1979). This has resulted in a degraded ecosystem characterized by a lack of riparian habitat, wetland area and appropriate buffers, forest cover and core natural areas, few green linkages between natural features, and poor water quality and aquatic habitat.

Constructed wetlands are built downhill of sloped fields (Vymazal 2011). The phosphorus leaches from these fields as particulate and dissolved phosphorus during soil erosion and subsurface drainage. These wetlands act as a sink for excess sediment in runoff and sequester it before it enters downstream aquatic ecosystems. Also, plants and microorganisms in the wetland feed on phosphorus, reducing it before it enters downstream aquatic ecosystems. For example, a floating wetland system composed of pickerelweed (*Pontederia cordata*) decreased phosphorus content by 90% (Spangler et al., 2019). One challenge with this approach is the sensitivity of wetlands to high flow events induced by precipitation which can reduce their effectiveness at phosphorus remediation (Lavrnić et al., 2020).

In addition, other methods of phosphorus remediation can be incorporated into wetlands (Ballantine et al. 2010, Vohla et al 2011, Saeed et al, 2011). This includes the incorporation of phosphorus sorbent materials such as limestone. For example, a review that scored materials based on effectiveness as soil amendments or filtration materials in constructed wetlands found that limestone was effective at both functions while alum was useful as a soil amendment, and tree bark, slag, and seashells served better as filtration materials (Ballantine et al, 2010). A comparative study of different substrates used for plant growth showed that organic mulch was more effective than gravel at removing total phosphorus (Saeed et al, 2011).

The primary disadvantage to constructed wetlands is the land required to achieve effective phosphorus mitigation. Larger wetlands will achieve higher and longer-lasting removal efficiency but may take up space that could be used for other activities.

In addition, the Essex Region is amongst the fastest growing development area. With more affordable land prices and warmer climate, the Essex Region is ideal for residential growth. There is also a strong history of industrial use with important transportation linkages to the United States. The growth in these sectors results in the loss of highly productive agricultural land, increased imperviousness and increased stress on our local waterways.

For many decades, ERCA has offered restoration programs through our landowner grant programs that have resulted in the planting of well over 6 million trees. Since 2002, ERCA has created at least 40 small wetlands (0.25 – 5 acres each), including some with multiple wetland features, which total approximately 45 acres of new wetland area. There are two new large coastal wetland areas currently being restored that bring the total area to well over 100 acres. The Collavino wetland is near the mouth of River Canard, and the Caldwell First Nation is restoring the wetland at mouth of Sturgeon Creek, which was formerly a marina. In addition, ERCA now also offers the option of prairie meadow plantings for restoration projects. Increasing the footprint of natural features will play a key role in reducing nutrient loads by reducing erosion, improving the natural filtration and cycling of nutrients and reducing the need for fertilizer input on these lands. ERCA typically funds these programs through external grants.

Action Item: ERCA to continue working with municipal partners to update drainage network and create a reporting tool for notification of changes; ERCA to continue to seek out grant funds to provide opportunities for restoration projects like tree and prairie meadow planting, and wetland creation

5.3 Invasive Species

Great Lakes ecosystems and contributing watersheds have been dramatically impacted over the last several decades by invasive species. Non-native *phragmites* and dreissenid mussels (Zebra and Quagga species.) have irrevocably changed both the landscape of the watersheds and the ecology of the lake itself.

Zebra mussels were first found in the Great Lakes ecosystem in the late 1980s and have rapidly reproduced and outcompeted native mussels. Quagga mussels, which have a greater depth tolerance than zebra mussels and do not require a hard surface to attach to, have now replaced zebra mussels as the primary invader. Dreissenid mussels feed on phytoplankton but selectively avoid *Microcystis* when feeding, which may facilitate HABs. Furthermore, mussel populations and phosphorus availability are now inextricably linked. Since they transiently store large quantities of phosphorus in their biomass, recent research has shown that phosphorus availability in the lower four Great Lakes is now regulated by quagga mussels (Li et al., 2021). Mussel biomass can fluctuate in Lake Erie dramatically and mortality can quickly increase TP concentrations in the water column. This relationship is important to understand since the response of the lake to inputs from the watershed will change over time based on mussel biomass, making predictions and phosphorus management much more difficult. However, Li et al. (2021) notes that, because of Lake Erie's short hydrological residence time, reducing external phosphorus inputs is more likely to limit mussel growth over a reasonably short time scale of several years than in the other lakes.

In the watersheds, wetland plants and changing plant communities may also impact phosphorus availability and nutrient cycling. Invasive *Phragmites australis*, with its high net primary production, spreads quickly and out-competes native species for water and nutrients. While it prefers areas of standing water, its roots can grow to extreme lengths, allowing it to survive in relatively dry areas. This can result in areas with dense monocultures and decreased biodiversity. Areas with stands of invasive *P. australis* may also have lowered water levels because water is transpired at a faster rate than it would be in an area of native vegetation leading to the drying of wetlands and the loss of hydrological functions. However, the literature is conflicted as to whether *P. australis*-invaded wetlands increase or decrease nutrient stocks. Recent research has show that in areas where *P. australis* dominates previous meadow marsh, nutrient storage may actually be increased. However, Yuckin and Rooney (2019) note that any increase in nutrient storage is insufficient to make a meaningful contribution to Lake Erie phosphorus load reduction targets. Whereas, in areas where *P. australis* dominates previous cattail marsh (*C. canadensis*) nutrient storage is unchanged. As biocontrols become available for *P. australis,* it may be necessary to further control phosphorus inputs into the watershed. Anecdotally, it has been noted that *P. australis* in the Essex Region is particularly dense and widespread in our coastal wetlands and inland watercourses. ERCA has successfully implemented prescribed burns to control *P. australis* in Hilman Marsh and has completed the first phase of control in a wetland at the mouth of River Canard.

Action Items:
ERCA to continue to seek funds where available to control *P. australis* on its lands
Determine the extent of spread of *P. australis* and identify appropriate mitigation measures

5.4 Impacts of Climate Change

Climate change is influencing both the phosphorus-cycling and ecology of Lakes Erie and St Clair, as well as the phosphorus loadings from the watersheds. The impacts to lake ecology are too numerous to cite but it is well understood that warmer, wetter weather is adding stress to an already stressed system and cyanobacteria growth rate is accelerated at higher temperatures, while more extreme rainfall could lead to more pulses of phosphorus throughout the spring, summer and fall. Air temperatures in the region have risen in every season (Maher and Channell, 2020) and with wind speeds projected to decrease, we can expect increased stratification in the lakes, exacerbating the HABs. Under business-as-usual scenarios, we can expect blooms to intensify earlier in the summer, with a longer bloom window (up to two additional weeks), in Lake Erie and Lake St Clair.

The interactions between phosphorus loadings and climate change projections are complex and primarily driven by the projected change in precipitation patterns. To predict the future response of watersheds to phosphorus loading, researchers use hydrological models, such as SWAT (Soil and Water Assessment Tool) or EPIC (Environmental Policy Integrated Climate) with inputs that include a range of downscaled global and regional climate models. These hydrological models simulate DRP loss from surface runoff and subsurface drainage under future climate scenarios. EPIC can also be used to simulate physiological crop growth and phosphorus uptake by crops. **Table 5** summarizes climate projections and some possible impacts and vulnerabilities to phosphorus pathways. A complete Climate Change Risk Analysis is recommended to determine the likelihood of possible impacts in general and in the Essex Region in particular, their affect on phosphorus load, and possible mitigation opportunities.

The interactions between climate variables, crop growth, phosphorus availability and crop uptake, surface runoff and subsurface drainage are complex. Several studies suggest a warming climate may counteract the increase in average amount of rainfall throughout the year leading to lower phosphorus loadings across Great Lakes watersheds (Wang et al, 2021; Kalcic et al. 2019). However, both studies used averages in precipitation across months and seasons and do not consider the increase frequency in extreme events. Projections for the Essex Region suggest that total precipitation will slightly increase but large changes are expected in the extremes, with summer rains becoming concentrated in fewer events of higher intensity, interspersed with prolonged dry periods. It is generally understood that these extreme precipitation events will lead to pulse loading. In situations where summer drought was followed by an intense rainfall, Sol Lisboa et al. (2020) found significant transfer of phosphorus and sediment from the landscape to the tributaries. This study also notes that the mechanisms and biogeochemical processes for how nutrients are released into streams following dry periods is not well understood. However, there is also evidence to suggest that non-point sources of phosphorus and point sources of phosphorus behave differently during periods of drought. Watershed models using data collected in Wigle Creek, Sturgeon Creek, Lane Drain and Mill Creek will have the ability to include these climate change scenarios to help us better understand how our watercourses will respond to these circumstances.

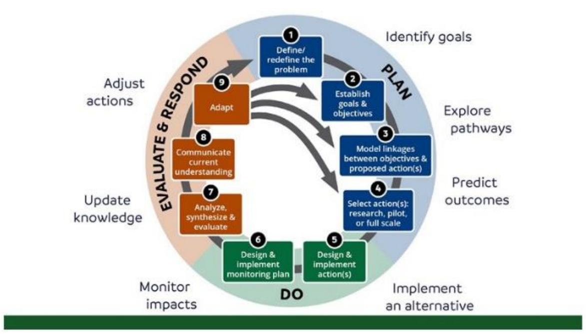
Action Item: Undertake a Climate Change Risk Analysis; Include Climate Change scenarios in modelling efforts and projections of future nutrient loads.

6.0 Cooperative, Adaptive Management Plan

Adaptive Management is a systematic approach for improving natural resource management by learning from the outcomes of our actions and adjusting them to achieve the goal to improve the environment (**Figure 8**). The concept of adaptive management explicitly links learning with policy and implementation. This approach is necessary because natural systems are inherently variable and the effects of management actions are difficult to predict (Gunderson, 1999). Climate change and the ecosystem changes caused by invasive species further increase uncertainty and variability.

An adaptive management plan has three phases – planning, doing, and evaluating and responding. This PMP is the first part of the first phase of the process. Proposed Action Items in this PMP will be reviewed by stakeholders to determine priority actions as well as the appropriate implementing body to achieve the objective of the action. It will be important to identify performance measures against which to measure success. Implementation of an adaptive management plan will require ongoing collaboration between ERCA, government agencies, research scientists and local stakeholders. Essential to this is the continuation of long-term monitoring coupled with regular reporting of results.

Figure 8 – An example of a multi-phase adaptive management approach



Source: Delta Stewardship Council.
https://deltacouncil.ca.gov/pdf/science-program/2019-09-06-iamit-strategy-april-2019.pdf

Table 5 – Climate change projections for Essex County, ON and their potential outcomes. A complete Climate Risk Assessment is recommended to determine the possible impact on phosphorus loading.

Projections	Possible Outcomes
Increased temperature all year round. Average, maximum, and minimum temperatures are expected to increase Average increases between 1.69 for minimum temperature and 1.60 for maximum temperature. **Increased number of days over 30 degrees in the summer**.	• Increased soil desiccation cracking and shrinkage, leading to increased susceptibility to intense precipitation and runoff due to increased permeability • Drought leading to hardening of soil and decreased infiltration for groundwater • Increased temperatures leading to greater plant potential evapotranspiration (PET) or evapotranspiration (ET) • Increased soil temperature • Non-growing season decline in evapotranspiration, resulting in increases in surface runoff and subsurface drainage water discharge
	• Increase in urban stormwater pond temperatures leading to increase frequency of HABs* • Drought leading to increased residential fertilizer use and lawn watering
Increased precipitation all year round. The largest increases in precipitation are expected to occur December - April. Precipitation in March is expected to increase by as much as 13% (8 mm) by 2050. Fall and summer months are expected to see small increases in precipitation.	• Changes in hydro-period and increased runoff, decreased infiltration • Changes in nutrient transport process; groundwater – picks up current & legacy nutrients • Changes in runoff timing
Timing, intensity, frequency and duration of precipitation events. In general storms are projected to become more intense and extreme. Precipitation will fall at a faster rate; shorter storms will have an increasingly high intensity; shorter return periods of heavy storms	• Increased intense rainfall events leading to increased runoff • Changes in flood frequency • Change in nutrient transport process; groundwater – picks up current & legacy nutrients • Changed hydrological regime “flashy” flows • Increased flow in watercourses leading to increased erosion and subsequent sediment & particulate P deposition
	• Increased waste water treatment plant bypasses • Increased failure of septic systems, particularly those at risk of being submerged • Change in timing of WWTP discharge and/or bypass
Decrease in frost and ice days. In the recent past (1976-2005), the Essex Region experienced 117 frost days and 45 ice days. By 2050, that is expected to be 95 frost days and 16 ice days. **Increased Winter temperature** by as much as 2.3°C by 2050.Summer temperatures are projected to increase in temperature as much as 2.1°C by 2050.	• Changes in snowpack/ice duration • Increased runoff/tile flow during non-growing season • Reduced soil moisture retention • Longer growing season • Potential to change crop types or varieties
Wind: Annual average wind speed projections varied from a decrease of 4% to an increase of 1%	• Decreased wind speeds result in lower PET and ET thereby eventually increased surface runoff and subsurface drainage • Leading to less wind-transported sediment and deposition
Short wave radiation modeling varies from a decrease of 3% to an increase of 2%	• Potentially increases PET and ET leading to lower surface runoff and subsurface drainage.
Atmospheric carbon dioxide is projected to increase	• Leading to increased P uptake by crops and vegetation • May lead to slight decrease in PET and ET due to reduction of stomatal conductance leading to increased surface runoff and subsurface drainage; leading to DRP loss in surface runoff but DRP loss in subsurface drainage decreased by 11%.
Relative humidity is likely to decrease up to 5% in the future	• May lead to minimal increase in PET and ET leading to lower surface runoff, subsurface drainage, and DRP loss.
Fluctuating lake Levels	• Shoreline septic systems underwater • Shoreline erosion, flooding leading to increase in legacy nutrients

Climate data under RCP 8.5 for the Essex Region was accessed from Climate Atlas; Precipitation event data from *A Comparison of Future IDF Curves for Southern Ontario: Technical Report.* *Due to a recent increase in algal blooms in urban stormwater ponds, the City of Windsor identified an “increase in rainfall and temperature causing increased algae growth in our water bodies” as an impact in the Degrees of Change: Climate Change Adaptation Plan (2019).

7.0 Outreach and Engagement

Pending review by contributing partners and authors, the Essex Region Phosphorus Management Plan will be circulated to stakeholders for comment. This will include municipalities, agriculture and greenhouse representatives, academia and government scientists. Suggested edits will be reviewed and incorporated into the final PMP which will be posted on ERCA's website and distributed electronically to interested stakeholders. ERCA will use the information in the PMP to further inform its Education and Outreach programs targeted at a variety of audiences.

8.0 Reporting on the Management Plan

Pending available funding, ERCA will regularly report on the progress made towards implementing the identified Action Items in the plan. The frequency of reporting will be determined during the consultation period for this draft version of the PMP and will be in line with the Adaptive Management Plan developed.

9.0 References

Backer, L. C. (2002). Cyanobacterial Harmful Algal Blooms (CyanoHABs): Developing a Public Health Response, Lake and Reservoir Management. 18(1), 20–31. https://doi.org/10.1080/07438140209353926

Ballantine, D. J.; Tanner, C. C. (2010) Substrate and filter materials to enhance phosphorus removal in constructed wetlands treating diffuse farm runoff: a review. New Zealand Journal of Agricultural Research 2010, 53 (1), 71-95.

Baker, D.B., Confesor, R., Ewing, D. E., Johnson, L. T., Kramer, J. W., & Merryfield, B. J. (2014). Phosphorus loading to Lake Erie from the Maumee, Sandusky and Cuyahoga rivers: The importance of bioavailability. Journal of Great Lakes Research, 40(3), 502–517. https://doi.org/10.1016/j.jglr.2014.05.001

Baker, David B., Johnson, L. T., Confesor, R. B., & Crumrine, J. P. (2017). Vertical Stratification of Soil Phosphorus as a Concern for Dissolved Phosphorus Runoff in the Lake Erie Basin. Journal of Environmental Quality, 46(6), 1287–1295. https://doi.org/10.2134/JEQ2016.09.0337

Blaszczak, J. R., Steele, M. K., Badgley, B. D., Heffernan, J. B., Hobbie, S. E., Morse, J. L., Rivers, E. N., Hall, S. J., Neill, C., Pataki, D. E., Groffman, P. M., & Bernhardt, E. S. (2018). Sediment chemistry of urban stormwater ponds and controls on denitrification. Ecosphere, 9(6), e02318. https://doi.org/10.1002/ecs2.2318

Brittain, S. M., Wang, J., Babcock-Jackson, L., Carmichael, W. W., Rinehart, K. L., & Culver, D. A. (2000). Isolation and characterization of microcystins, cyclic heptapeptide hepatotoxins from a Lake Erie strain of microcystis aeruginosa. Journal of Great Lakes Research, 26(3), 241–249. https://doi.org/10.1016/S0380-1330(00)70690-3

Brooks, B. W., Lazorchak, J. M., Howard, M. D. A., Johnson, M.-V. v., Morton, S. L., Perkins, D. A. K., Reavie, E. D., Scott, G. I., Smith, S. A., & Steevens, J. A. (2016). Are harmful algal blooms becoming the greatest inland water quality threat to public health and aquatic ecosystems? Environmental Toxicology and Chemistry, 35(1), 6–13. https://doi.org/10.1002/etc.3220

Butterwick, C., Heaney, S. I., Talling, J. F. (2004) Diversity in the influence of temperature on the growth rates of freshwater algae, and its ecological relevance. Journal of Freshwater Biology, v.50, p.291.

Chapman and Putnam, 1984 (ref from SWP plan)

Christiansen, G., Fastner, J., Erhard, M., Börner, T., & Dittmann, E. (2003). Microcystin Biosynthesis in Planktothrix: Genes, Evolution, and Manipulation. JOURNAL OF BACTERIOLOGY, 185(2), 564–572. https://doi.org/10.1128/JB.185.2.564-572.2003

A.F. Choquette, R.M. Hirsch, J.C. Murphy, L.T. Johnson, R.B. Confesor (2019) Tracking changes in nutrient delivery to western Lake Erie: Approaches to compensate for variability and trends in streamflow. Journal of Great Lakes Research. Volume 45, Issue 1,

Daryanto, S.; Wang, L.; Jacinthe, P. A. (2019) Meta-Analysis of Phosphorus Loss from No-Till Soils. J Environ Qual 2017, 46 (5), 1028-1037.

Davis, T. W., Watson, S. B., Rozmarynowycz, M. J., Ciborowski, J. J. H., McKay, R. M., & Bullerjahn, G. S. (2014). Phylogenies of Microcystin-Producing Cyanobacteria in the Lower Laurentian Great Lakes Suggest Extensive Genetic Connectivity. PLoS ONE, 9(9), e106093. https://doi.org/10.1371/journal.pone.0106093

Dean, S., Freer, J., Beven, K., Wade, A., & Butterfield, D. (2008). Uncertainty assessment of a process-based integrated catchment model of phosphorus. Stoch. Environ. Res. Risk Assess, 2009(23), 991–1010.

Derecki, J.A. 1984. Detroit River, physical and hydraulic characteristics. National Oceanographic Atmospheric Administration, Great Lakes Environment Research Lab, GLERL Contribution NO. 417. Ann Arbor. 11pp.

Dolan, D. M., & Chapra, S. C. (2012). Great Lakes total phosphorus revisited: 1. Loading analysis and update (1994–2008). Journal of Great Lakes Research, 38(4), 730–740.

Dyble, Julianne & Fahnenstiel, Gary & Litaker, Richard & Millie, David & Tester, Patricia. (2008). Microcystin concentrations and genetic diversity of Microcystis in the Lower Great Lakes. Environmental toxicology. 23. 507-16. 10.1002/tox.20370.

Environment and Climate Change Canada. (2020). Canadian Environmental Sustainability Indicators: Phosphorus loading to Lake Erie.

ERCA, 2023. Expanding greenhouse sector in Essex County, ON and downstream water quality degradation. Kingsville Leamington Nutrient Project 2012-2022. Available online: https://essexregionconservation.ca/watershed-health/water-quality/

Eriksen, N. T. (2008). Production of phycocyanin - A pigment with applications in biology, biotechnology, foods and medicine. In Applied Microbiology and Biotechnology (Vol. 80, Issue 1, pp. 1–14). Springer. https://doi.org/10.1007/s00253-008-1542-y

Francy, D. S., Brady, A. M. G., Ecker, C. D., Graham, J. L., Stelzer, E. A., Struffolino, P., Dwyer, D. F., & Loftin, K. A. (2016). Estimating microcystin levels at recreational sites in western Lake Erie and Ohio. Harmful Algae, 58, 23–34. https://doi.org/10.1016/j.hal.2016.07.003

Grant, K. N., Macrae, M. L., Rezanezhad, F., & Lam, W. V. (2019). Nutrient Leaching in Soil Affected by Fertilizer Application and Frozen Ground. Vadose Zone Journal, 18(1), 1–13. https://doi.org/10.2136/VZJ2018.08.0150

Green et al. (2010) DRCC Stage 2

Gunderson, L. 1999. Resilience, flexibility and adaptvie management—antidotes for spurious certitude? Conservation Ecology 3(1): 7. [online] URL: http://www.consecol.org/vol3/iss1/art7/.

Guo, T., Confesor, R., Saleh, A., & King, K. (2020). Crop growth, hydrology, and water quality dynamics in agricultural fields across the Western Lake Erie Basin: Multi-site verification of the Nutrient Tracking Tool (NTT). Science of the Total Environment, 726, 138485. https://doi.org/10.1016/j.scitotenv.2020.138485

Havens, K. E., James, R. T., East, T. L., & Smith, V. H. (2002). N:P ratios, light limitation, and cyanobacterial dominance in a subtropical lake impacted by non-point source nutrient pollution. www.elsevier.com/locate/envpol

Hille, S.; Graeber, D.; Kronvang, B.; Rubaek, G. H.; Onnen, N.; Molina-Navarro, E.; Baattrup-Pedersen, A.; Heckrath, G. J.; Stutter, M. I. (2019) Management Options to Reduce Phosphorus Leaching from Vegetated Buffer Strips. J Environ Qual 2019, 48 (2), 322-329.

Hobbie, S. E., Finlay, J. C., Janke, B. D., Nidzgorski, D. A., Millet, D. B., & Baker, L. A. (2017). Contrasting nitrogen and phosphorus budgets in urban watersheds and implications for managing urban water pollution. Proceedings of the National Academy of Sciences of the United States of America, 114(16), 4177–4182. https://doi.org/10.1073/pnas.1618536114

Izydorczyk, K., Tarczynska, M., Jurczak, T., Mrowczynski, J., & Zalewski, M. (2005). Measurement of phycocyanin fluorescence as an online early warning system for cyanobacteria in reservoir intake water. Environmental Toxicology, 20(4), 425–430. https://doi.org/10.1002/tox.20128

Jarvie, H. P., Sharpley, A. N., Spears, B., Buda, A. R., May, L., Kleinman, P. J. A., Building, M., & Gifford, C. (2013). 8997−8998 Downloaded via 98.143.66.91 on April 15. Environ. Sci. Technol, 47, 26. https://doi.org/10.1021/es403160a

Kahru, M., Leppanen, J., Rud, O. (1993) Cyanobacterial blooms cause heating of the sea surface. Marine Ecology Progress Series, v.101, p.1-7

Kalcic M, Rebecca Logsdon Muenich, Samantha Basile, Allison L. Steiner, Christine Kirchhoff,Donald Scavia (2019) Environmental Science & Technology 2019 53 (13), 7543-7550

Lannergård, E. E., Agstam-Norlin, O., Huser, B. J., Sandström, S., Rakovic, J., & Futter, M. N. (2020). New insights into legacy phosphorus from fractionation of streambed sediment. Journal of Geophysical Research: Biogeosciences, 125(9) , e2020JG005763

Lavrnić, S.; Nan, X.; Blasioli, S.; Braschi, I.; Anconelli, S.; Toscano, A. (2020) Performance of a full scale constructed wetland as ecological practice for agricultural drainage water treatment in Northern Italy. Ecological Engineering 2020, 154.

Li, J., Ianaiev, V., Huff, A., Zalusky, J., Ozersky, T., Katsev, S. (2021). Benthic invaders control the phosphorus cycle in the world's largest freshwater ecosystem. PNAS, 118, 6. https://doi.org/10.1073/pnas.2008223118

Liu, J.; Macrae, M. L.; Elliott, J. A.; Baulch, H. M.; Wilson, H. F.; Kleinman, P. J. A. (2019) Impacts of Cover Crops and Crop Residues on Phosphorus Losses in Cold Climates: A Review. J Environ Qual 2019, 48 (4), 850-868.

Maccoux, M. J., Dove, A., Backus, S. M., & Dolan, D. M. (2016). Total and soluble reactive phosphorus loadings to Lake Erie: A detailed accounting by year, basin, country, and tributary. Journal of Great Lakes Research, 42(6), 1151–1165. https://doi.org/10.1016/J.JGLR.2016.08.005

Machesky, M. L., Holm, T. R., & Slowikowski, J. A. (2010). Phosphorus Speciation in Stream Bed Sediments from an Agricultural Watershed: Solid-Phase Associations and Sorption Behavior. Aquatic Geochemistry, 16(4), 639–662.

Macrae, M., Jarvie, H., Brouwer, R., Gunn, G., Reid, K., Joosse, P., … Zwonitzer, M. (2021). One size does not fit all: Toward regional conservation practice guidance to reduce phosphorus loss risk in the Lake Erie watershed. Journal of Environmental Quality, 50(3), 529–546. https://doi.org/10.1002/jeq2.20218

Maguire, T. J., Wellen, C., Stammler, K. L., & Mundle, S. O. C. (2018). Increased nutrient concentrations in Lake Erie tributaries influenced by greenhouse agriculture. Science of the Total Environment, 633. https://doi.org/10.1016/j.scitotenv.2018.03.188

Maher, E. & Channell, K. 2020. Atmospheric temperature changes in the Western Lake Erie Climate Division. *In* Checkup: Assessing Ecosystem Health of the Detroit River and Western Lake Erie. *Edited by:* Hartig, J., Francoeur, S.N., Ciborowski, J.H., Gannon, J.E., Sanders, C.E., Galvao-Ferreira, P., Knauss, C.R., Gell, G. & Berk, K. Great Lakes Institute for Environmental Research Occasional Publication No. 11, University of Windsor, Ontario, Canada

María, R., Zú, P.-M. G., Fernando Martínez-Jerónimo, I., Pineda-Mendoza, R. M., & Zúñiga, Á. G. (2016). Microcystin production in Microcystis aeruginosa: effect of type of strain, environmental factors, nutrient concentrations, and N:P ratio on mcyA gene expression. Aquatic Ecology, 50, 103–119. https://doi.org/10.1007/s10452-015-9559-7

Marsalek, J., Rochfort, Q., Grapentine, L., & Brownlee, B. (2002). Assessment of stormwater impacts on an urban stream with a detention pond. https://iwaponline.com/wst/article-pdf/45/3/255/425108/255.pdf

Martin, J. F., Kalcic, M. M., Aloysius, N., Apostel, A. M., Brooker, M. R., Evenson, G., … Wang, Y.-C. (2020). Evaluating management options to reduce Lake Erie algal blooms using an ensemble of watershed models. Journal of Environmental Management. https://doi.org/10.1016/j.jenvman.2020.111710

Matisoff, G., Kaltenberg, E. M., Steely, R. L., Hummel, S. K., Seo, J., Gibbons, K. J., … Chaffin, J. D. (2016). Internal loading of phosphorus in western Lake Erie. Journal of Great Lakes Research, 42(4), 775–788. https://doi.org/10.1016/j.jglr.2016.04.004

MECP (Ministry of the Environment Conservation and Parks). (2106). Guide: Obtaining Approval for a Greenhouse Stormwater Management Facility. Available online: https://www.flowerscanadagrowers.com/uploads/2017/03/seca%20guidance%20document%20final.pdf

Ministry of the Environment. (2011). Technical Memorandum: An Analysis of Nutrients and Select Metals Within Wastewater (Pond Discharges). https://www.ontario.ca/page/technical-memorandum-analysis-nutrients-and-select-metals-within-wastewater-pond-discharges

Myers, D. N., Thomas, M. A., Frey, J. W., Rheaume, S. J., & Button, D. T. (2016). USGS - NAWQA - Water Quality in the Lake Erie-Lake Saint Clair Drainages - Introduction. Retrieved March 9, 2021, from https://pubs.water.usgs.gov/circ1203/

Newell, S. E., Davis, T. W., Johengen, T. H., Gossiaux, D., Burtner, A., Palladino, D., & McCarthy, M. J. (2019). Reduced forms of nitrogen are a driver of non-nitrogen-fixing harmful cyanobacterial blooms and toxicity in Lake Erie. Harmful Algae, 81, 86–93. https://doi.org/10.1016/J.HAL.2018.11.003

Oldfield, Sabina Rakhimbekova, James W. Roy, Clare E. Robinson (2020) Estimation of phosphorus loads from septic systems to tributaries in the Canadian Lake Erie Basin. Journal of Great Lakes Research. Volume 46, Issue 6.

Oldham, M. 1983. Environmentally Significant Areas of the Essex Region. Essex Region Conservation Authority Publication. Essex, ON. 426pp.

Paerl, H. W., & Paul, V. J. (2012). Climate change: Links to global expansion of harmful cyanobacteria. Water Research, 46(5), 1349–1363.

Palagama, David Baliu-Rodriguez, Brenda K. Snyder, Jennifer A. Thornburg, Thomas B. Bridgeman, Dragan Isailovic (2020) Identification and quantification of microcystins in western Lake Erie during 2016 and 2017 harmful algal blooms, Journal of Great Lakes Research, Volume 46, Issue 2

Plach, J. M., Macrae, M. L., Ali, G. A., Brunke, R. R., English, M. C., Ferguson, G., … Van Esbroeck, C. J. (2017). Supply and Transport Limitations on Phosphorus Losses from Agricultural Fields in the Lower Great Lakes Region, Canada. Journal of Environment Quality, 47(1), 96. https://doi.org/10.2134/jeq2017.06.0234

Plach, J. M., Macrae, M. L., Williams, M. R., Lee, B. D., & King, K. W. (2018). Dominant glacial landforms of the lower Great Lakes region exhibit different soil phosphorus chemistry and potential risk for phosphorus loss. Journal of Great Lakes Research, 44(5), 1057–1067. https://doi.org/10.1016/j.jglr.2018.07.005

Plach, J., Pluer, W., Macrae, M., Kompanizare, M., McKague, K., Carlow, R., & Brunke, R. (2019). Agricultural Edge-of-Field Phosphorus Losses in Ontario, Canada: Importance of the

Nongrowing Season in Cold Regions. Journal of Environment Quality, 0(0), 0. https://doi.org/10.2134/jeq2018.11.0418

OCWA (Ontario Clean Water Agency). (2021). OCWA piloting technology to reduce phosphorus in wastewater effluent. Available online: https://www.ocwa.com/news/ocwa-piloting-technology-reduce-phosphorus-wastewater-effluent

Rapala, J., Sivonen, K., Lyra, C., & Niemelä, S. I. (1997). Variation of microcystins, cyanobacterial hepatotoxins, in Anabaena spp. as a function of growth stimuli. Applied and Environmental Microbiology, 63(6).

Rinta-Kanto, J. M., Konopko, E. A., DeBruyn, J. M., Bourbonniere, R. A., Boyer, G. L., & Wilhelm, S. W. (2009). Lake Erie Microcystis: Relationship between microcystin production, dynamics of genotypes and environmental parameters in a large lake. Harmful Algae, 8(5), 665–673. https://doi.org/10.1016/j.hal.2008.12.004

Saeed, T.; Sun, G., A comparative study on the removal of nutrients and organic matter in wetland reactors employing organic media. Chemical Engineering Journal 2011, 171 (2), 439-447.

Salk, K. R., Bullerjahn, G. S., McKay, R. M. L., Chaffin, J. D., and Ostrom, N. E. (2018) Nitrogen cycling in Sandusky Bay, Lake Erie: oscillations between strong and weak export and implications for harmful algal blooms, Biogeosciences, 15, 2891–2907, https://doi.org/10.5194/bg-15-2891-2018

Saxe, D. 2017. Evaluating the costs of cutting phosphorus in Ontario. Water Canada website. https://www.watercanada.net/feature/evaluating-costs-cutting-phosphorus/

Scavia, D., Bocaniov, S. A., Dagnew, A., Hu, Y., Kerkez, B., Long, C. M., Wang, Y.C. (2019). Detroit River phosphorus loads: Anatomy of a binational watershed. https://doi.org/10.1016/j.jglr.2019.09.008

Scavia, D., Long, C.M, & Vaccaro, L. 2020. Detroit River phosphorus loads to Lake Erie *In* Checkup: Assessing Ecosystem Health of the Detroit River and Western Lake Erie. *Edited by:* Hartig, J., Francoeur, S.N., Ciborowski, J.H., Gannon, J.E., Sanders, C.E., Galvao-Ferreira, P., Knauss, C.R., Gell, G. & Berk, K. Great Lakes Institute for Environmental Research Occasional Publication No. 11, University of Windsor, Ontario, Canada

Sharpley, A.; Daniel, T.; Gibson, G.; Bundy, L.; Cabrera, M.; Sims, T.; Stevens, R.; Lemunyon, J.; Kleinman, P.; Parry, R. (2006) Best management practices to minimize agricultural phosphorus impacts on water quality. Agriculture, U. S. D. o., Ed. ARS: 2006; Vol. 163.

Sharpley, A., Jarvie, H. P., Buda, A., May, L., Spears, B., & Kleinman, P. (2013). Phosphorus Legacy: Overcoming the Effects of Past Management Practices to Mitigate Future Water Quality Impairment. Journal of Environmental Quality, 42(5), 1308–1326. https://doi.org/10.2134/jeq2013.03.0098

Smith, V. H., & Schindler, D. W. (2009). Eutrophication science: where do we go from here? In Trends in Ecology and Evolution (Vol. 24, Issue 4, pp. 201–207). Elsevier Current Trends. https://doi.org/10.1016/j.tree.2008.11.009

Smith, D. R., King, K. W., Johnson, L., Francesconi, W., Richards, P., Baker, D., & Sharpley, A. N. (2014). Surface Runoff and Tile Drainage Transport of Phosphorus in the Midwestern United States. Journal of Environment Quality, 0. https://doi.org/10.2134/jeq2014.04.0176

Smith, R. B., Bass, B., Sawyer, D., Depew, D., & Watson, S. B. (2019). Estimating the economic costs of algal blooms in the Canadian Lake Erie Basin. Harmful Algae, 87, 101624. https://doi.org/10.1016/j.hal.2019.101624

Snell, E.A. 1989. Recent wetland loss trends in southern Ontario. In Proceedings of the Conference of Wetlands: Inertia or Momentum. Edited by M.J. Bardecki and N. Patterson. Federation of Ontario Naturalists and Ryerson Polytechnical Institute. Toronto, ON. Pp. 183-197.

Sol Lisboa, Rebecca L. Schneider, Patrick J. Sullivan, M. Todd Walter (2020) Drought and post-drought rain effect on stream phosphorus and other nutrient losses in the Northeastern USA, Journal of Hydrology: Regional Studies, Volume 28.

Spangler, J. T.; Sample, D. J.; Fox, L. J.; Owen, J. S.; White, S. A.(2019) Floating treatment wetland aided nutrient removal from agricultural runoff using two wetland species. Ecological Engineering 2019, 127, 468-479.

Stackpoole, S. M., Stets, E. G., & Sprague, L. A. (2019). Variable impacts of contemporary versus legacy agricultural phosphorus on US river water quality. Proceedings of the National Academy of Sciences of the United States of America, 116(41), 20562–20567. https://doi.org/10.1073/pnas.1903226116

Stow, C. A., Cha, Y., Johnson, L. T., Confesor, R., & Richards, R. P. (2015). Long-term and seasonal trend decomposition of Maumee River nutrient inputs to western Lake Erie. Environmental Science & Technology, 49(6), 3392–3400. https://doi.org/10.1021/es5062648

Strickland, T., Fisher, L., Korleski, C., Kramer, J., Richards, R. P., & Kessler, J. (2010). Ohio Lake Erie Phosphorus Task Force Final Report Acknowledgements Conservation Action Project and Henry County SWCD-Todd Hesterman Northeast Ohio Regional Sewer District-Seth Hothem Ohio Department of Natural Resources, Soil and. www.epa.ohio.gov/dsw/lakeerie/ptaskforce/index.aspx.

Stumpf, R. P., Wynne, T. T., Baker, D. B., & Fahnenstiel, G. L. (2012). Interannual variability of cyanobacterial blooms in Lake Erie. PloS One, 7(8), e42444. https://doi.org/10.1371/journal.pone.0042444

Stutter, M., Kronvang, B.; D, O. h., Rozemeijer, J. (2019) Current Insights into the Effectiveness of Riparian Management, Attainment of Multiple Benefits, and Potential Technical Enhancements. J Environ Qual 2019, 48 (2), 236-247.

Tonk, L., Visser, P. M., Christiansen, G., Dittmann, E., Snelder, E. O. F. M., Wiedner, C., Luuc, ‡, Mur, R., & Huisman, J. (2005). The Microcystin Composition of the Cyanobacterium *Planktothrix agardhii* Changes toward a More Toxic Variant with Increasing Light Intensity. APPLIED AND ENVIRONMENTAL MICROBIOLOGY, 71(9), 5177–5181. https://doi.org/10.1128/AEM.71.9.5177-5181.2005

Vandall, P.E. 1979. A brief history of Essex County. *In* Field Studies in the Detroit-Windsor-Essex County Region. Department of Geography, University of Windsor Publication. Windsor, ON.

Wiedner, C., Visser, P. M., Fastner, J., Metcalf, J. S., Codd, G. A., & Mur, L. R. (2003). Effects of Light on the Microcystin Content of Microcystis Strain PCC 7806. APPLIED AND ENVIRONMENTAL MICROBIOLOGY, 69(3), 1475–1481. https://doi.org/10.1128/AEM.69.3.1475-1481.2003

Vohla, C.; Kõiv, M.; Bavor, H. J.; Chazarenc, F.; Mander, Ü. (2011) Filter materials for phosphorus removal from wastewater in treatment wetlands—A review. Ecological Engineering 2011, 37 (1), 70-89.

Vymazal, J. (2011) Constructed wetlands for wastewater treatment; five decades of experience. Environ Sci Technol 2011, 45, 61-69.

Wang, Z., Zhang, T. Q., Tan, C. S., Wang, X., Taylor, R. A. J., Qi, Z. M., Yang, J. W. (2019). Modeling the Impacts of Manure on Phosphorus Loss in Surface Runoff and Subsurface Drainage. Journal of Environmental Quality 48(1), 39-46.

Weigelhofer, G., Ramião, J. P., Pitzl, B., Bondar-Kunze, E., & O'Keeffe, J. (2018). Decoupled water-sediment interactions restrict the phosphorus buffer mechanism in agricultural streams. Science of The Total Environment, 628–629, 44–52.

Williams, M. R., Livingston, S. J., Penn, C. J., Smith, D. R., King, K. W., & Huang, C. hua. (2018). Controls of event-based nutrient transport within nested headwater agricultural watersheds of the western Lake Erie basin. Journal of Hydrology, 559, 749–761. https://doi.org/10.1016/j.jhydrol.2018.02.079

Wolf, D., Georgic, W., & Klaiber, H. A. (2017). Reeling in the damages: Harmful algal blooms' impact on Lake Erie's recreational fishing industry. Journal of Environmental Management, 199, 148–157. https://doi.org/10.1016/j.jenvman.2017.05.031

Wurtsbaugh, W. A., Paerl, H. W., & Dodds, W. K. (2019). Nutrients, eutrophication and harmful algal blooms along the freshwater to marine continuum. Wiley Interdisciplinary Reviews: Water, 6(5), e1373. https://doi.org/10.1002/wat2.1373

March 2022 – updated November 2023

Yuckin Sarah, Rooney Rebecca (2019) Significant Increase in Nutrient Stocks Following *Phragmites australis* Invasion of Freshwater Meadow Marsh but Not of Cattail Marsh. Frontiers in Environmental Science. 7 PAGES=112
URL=https://www.frontiersin.org/article/10.3389/fenvs.2019.00112