Expanding greenhouse sector in Essex County, ON and downstream water quality degradation

Kingsville Leamington Nutrient Project
2012-2022

Prepared by:

Essex Region Conservation Authority
sustaining the place for life

August 2023

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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 Report. The following individuals are gratefully acknowledged for their contributions:

Dr. Katie Stammler
Amy Weinz, MSc
Justin Landry, MSc
Jamie Lilly
Alice Grgicak-Mannion, Geospatial Learning Specialist, GLIER
Deana Duong
Cooper O'Rouke
Sarika Sharma
Breanna Stamcoff
Charlotte Wills
Tom Dufour, GISP
Samantha Dundas
Mackenzie Porter

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Executive Summary

The Great Lakes Water Quality Agreement named the Leamington Tributaries as a priority watershed for phosphorus load reduction to mitigate Harmful Algal Blooms in Lake Erie (Annex 4 Objectives and Targets Task Team, 2015). These tributaries are actually several relatively small, hydrologically distinct watersheds that lie mostly in the municipalities of Leamington and Kingsville in Essex County, Ontario, and they are heavily influenced by greenhouse agriculture. Average total phosphorus concentrations from 2017 – 2021 in agriculturally dominated watersheds in the Essex Region ranged from 0.12mg/L to 0.30mg/L, whereas average total phosphorus concentrations in the Leamington tributaries in the same time period ranged from 2.9mg/L to 6.0 mg/L, which is 100-200 times higher than the Provincial Water Quality Objective of 0.03mg/L for streams to prevent nuisance algal growth.

In 2012, the Essex Region Conservation Authority began monitoring these watersheds biweekly year-round and in 2016 began event sampling with ISCO autosamplers in three watersheds. Now, with a decade of data, we have explored long term trends and comparisons in nutrient concentration and load between greenhouse and non-greenhouse influenced streams. In addition, students at the University of Windsor digitized the footprint of greenhouses from aerial photography between 2000 and 2021. In total, the greenhouse footprint has more than doubled over this 20-year period, with many more greenhouses installed after our analysis. In the study watersheds, the greenhouse footprint increased between 4 and 20%.

Year over year, nutrient concentrations continue to be significantly and strikingly higher in greenhouse streams than non-greenhouse streams, with most individual sites showing no trend over time. In typical agricultural streams, the highest nutrient concentrations and loads are observed during rain or snow melt events in the non-growing season, due to surface runoff over bare fields. However, in greenhouse watersheds, the highest concentrations and loads are observed during baseflow conditions in the growing season, with rain events causing a dilution effect. This tells us that these streams behave as though they have point sources.

Further action is needed to determine the means by which nutrients are escaping from what should be closed-loop operations. This may require compliance monitoring and/or oversight during construction to ensure that losses to the environment are prevented. Perhaps most telling is the increase in nutrient concentration in a watershed where the greenhouse footprint changed from 0% to >20% where all structures are newly built. With greenhouse agriculture continuing to expand in this area, and elsewhere in the Great Lakes Basin, it is essential that we take heed of this canary in the coal mine. Next steps include refining the nutrient load calculations for inclusion in bi-national reporting and continued monitoring if and when funds become available.

August 2023

Kingsville Leamington Nutrient Project – 2012-2022

Introduction

Algal blooms have historically been a common occurrence in Lake Erie and the nearshore areas of Lake St. Clair. In the 1960's the algal blooms were so dense that Lake Erie was declared dead. Whole lake experiments conducted by David Schindler in the Experimental Lakes Area tested and confirmed the theory that phosphorus is the key nutrient that drives eutrophication (high nutrient concentrations that lead to overgrowth of algal biomass) (Schindler, 1977). Under the 1972 Great Lakes Water Quality Agreement (GLWQA, 2012), the U.S. and Canada reduced phosphorus inputs to the Great Lakes, including Lake Erie. Between the late 1960s and early 1980s there was an approximate 60% reduction in the phosphorus loading to Lake Erie and a subsequent reduction in algal blooms. Despite continuing to meet targets for phosphorus loads, however, Lake Erie began to experience algal blooms again in the late 1990's, with 2011 and 2015 as the largest blooms on record (ECCC & MECP, 2018).

The algal blooms experienced since the 1990's are considered to be Harmful Algal Blooms (HABs) because the organisms creating the bloom, called cyanobacteria or blue-green algae (e.g. *microcystis*), are capable of making and releasing toxins that are dangerous to human health (e.g. microcystins). 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, and of Water Treatment Plants (WTPs) on Pelee Island and in Ohio.

HABs are an international issue, and in 2016, the Great Lakes Water Quality Agreement was amended to include the requirement of a further 40% reduction in phosphorus loads to Lake Erie. At that time, several watersheds were identified as being a priority for phosphorus reduction, two of which are in Canada – the Thames River and the Leamington Tributaries (Annex 4 Objectives and Targets Task Team, 2015) (**Figure 1**). In 2018, the Canadian and Ontario governments, and the United States federal and state governments released Domestic Action Plans that will lead to the target of 40% reduction of phosphorus to Lake Erie (ECCC & MECP, 2018).

The Leamington Tributaries are several relatively small, hydrologically distinct watersheds that lie mostly in the municipalities of Leamington and Kingsville in Essex County, Ontario, and they are heavily influenced by greenhouse agriculture (**Figure 1**). 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, increased viability of growing other fruit and vegetable crops, and the advent of legalized cannabis.

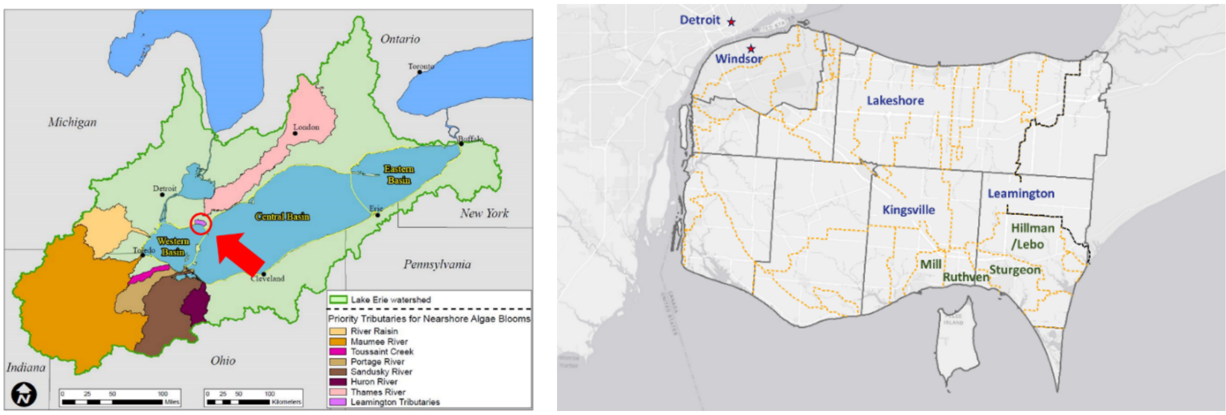
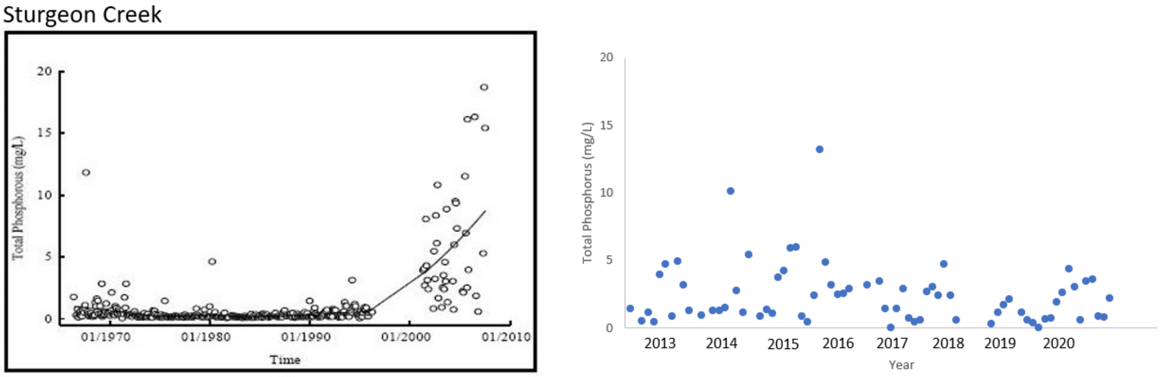


Figure 1 – Located in the southeast corner of Essex County, Ontario, the Leamington tributaries are several hydrologically distinct watersheds in the municipalities of Leamington and Kingsville. These include Lebo Creek, Sturgeon Creek, Mill Creek and the Ruthven Area drainage, which consists of six small watersheds.

High concentrations of nutrients originally came to light several years ago when data from a long-term monitoring station in Sturgeon Creek were reviewed. Prior to 1996, total phosphorus concentrations were typical of similar agricultural streams. Following a gap in the record until 2002, total phosphorus concentrations were substantially and consistently higher than the previous record (**Figure 2**). Following this observation, the Ministry of Environment, Conservation and Parks (MECP) conducted a study in 2010 and 2011 demonstrating that phosphorous levels in greenhouse effluents/discharges approached 100 times that of normal background surface water quality for the area (MECP, 2012). Maguire et al (2017) documented that total phosphorus and soluble reactive phosphorus concentrations were 20 and 28 times higher in greenhouse influenced streams than non-greenhouse influenced streams.


Sturgeon Creek

Source MOE: Provincial Water Quality Monitoring Network
station number 16002700102

Figure 2 – Total phosphorus concentrations in Sturgeon Creek at a long-term monitoring station from 1965-2022

In 2012, the Southwest Regional office of the Ministry of Environment and the Essex Region Conservation Authority began a study to assess the water quality and quantify the nutrient loading from constructed drains and natural watercourses in and around the municipalities of Leamington and Kingsville that discharge directly into Lake Erie. Sites were selected to represent both greenhouse and non-greenhouse influenced streams in the same geographic area. This work was funded through Canada-Ontario Agreements with the MECP through December 31, 2022.

Now, with a decade of data, we have explored long term trends and comparisons in nutrient concentration between greenhouse and non-greenhouse influenced streams. From 2017-2021, average total phosphorus concentrations in agriculturally dominated watersheds in the Essex Region ranged from 0.12mg/L to 0.30mg/L, whereas average total phosphorus in the Leamington tributaries in the same time period ranged from 2.9mg/L to 6.0mg/L, which is 100-200 times higher than the Provincial Water Quality Objective of 0.03mg/L for streams to prevent nuisance algal growth.

This report explores annual and seasonal trends in phosphorus concentrations. In addition, students at the University of Windsor digitized the footprint of greenhouses from aerial photography between 2000 and 2020. Data have been provided to Environment and Climate Change Canada (ECCC) to provide load calculations using a standardized tool for Lake Erie watersheds.

Growth of the Greenhouse Sector

According to data collected by Statistics Canada for the Census of Agriculture, the total area in greenhouse production was eight times higher in 2021 than it was in 1991, with 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 Leamington from 2011 to 2021 (**Table 1 and 2**). 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 1 – The number of greenhouses and total area in greenhouse production in Essex County from 1991 to 2021 based on Statistics Canada's Census of Agriculture. 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 2 – The number of greenhouses and total area in greenhouse production from 2011 and 2021 in municipalities where greenhouses are common and/or where growth in the sector is expected based on Statistics Canada's Census of Agriculture. Table 32-10-0159-01 Greenhouses and mushrooms, Census of Agriculture historical data*

	Leamington		Kingsville	
Year	# GH	Area (m^2)	# GH	Area (m^2)
2011	107	3,725,665	54	2,397,010
2016	93	3,844,240	60	3,927,489
2021	75	6,044,899	45	3,687,691

*Note that cannabis operations may not be captured in these tables.

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 (referred to as the Glasshouse Geospatial Group – GGG) partnered to develop a new geodatabase and map layer of greenhouse footprints within the region. The GGG consists of Deana Duong, Cooper O'Rouke, Sarika Sharma, Breanna Stamcoff and Charlotte Wills, under the supervision of Alice Grgicak-Mannion, Geospatial Learning Specialist at the University of Windsor. The section of the report regarding this work was prepared by the GGG.

The creation of the geodatabase was undertaken by utilizing GIS software (ESRI's ArcPro 3.0™) and digital orthophotography from the years 2000 to 2021 to delineate and digitize greenhouse footprints, via polygon topology (**Figure 3**). Please see Appendix I for a detailed description of the methodology, including steps for QA/QC, used for this exercise.

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

In parallel to the digitization procedure, attribute data for each polygon was added into a geodatabase framework using supplemental data/information from ERCA, Agricultural and Agri-food Canada and Google Maps. These data helped to further validate the location of current greenhouses and provided insight on greenhouse characteristics such as: greenhouse type, areal measurements, presence or absence of holding tanks, when the greenhouse was built, etc. for each polygon. These classifications and calculations were inputted into the layer's geodatabase attribute table. Overall, the total number of greenhouse polygons within the geodatabase now stands at 2,033.

Greenhouse structures have grown in the Windsor-Essex region in terms of areal measurement and land usage over a 20-year period by 148% (**Table 3**). These figures align well with the data obtained from Statistics Canada for Essex County. The benefit of this new geodatabase is that each greenhouse footprint is georeferenced and attributed. **Figure 4** depicts a map highlighting the expansion of greenhouse structures spatially over a 20-year period and specifically for the Kingsville-Leamington area.

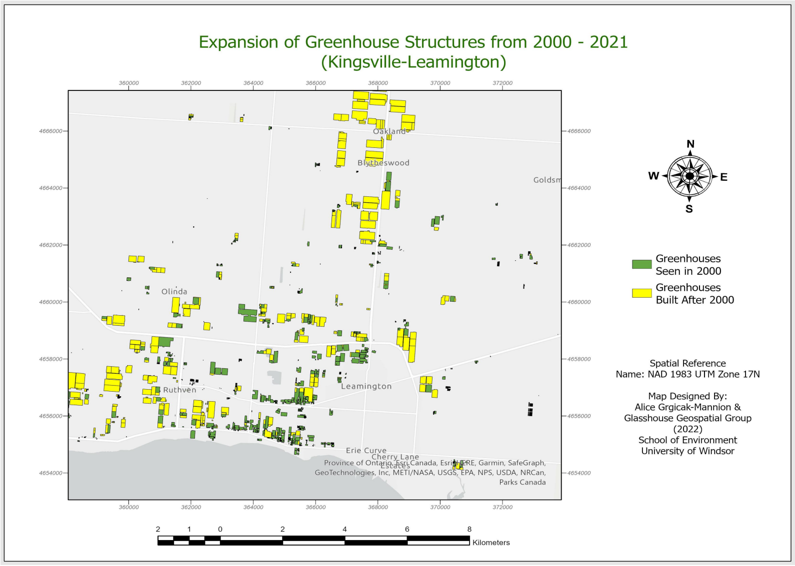


Figure 4 – Map showing greenhouse expansion over a 20-year period

Table 3 – Through a simple SQL query, calculations on total areal measurements of greenhouses were obtained for 2000 and 2021 and shows a significant increase in greenhouse land usage for the Windsor-Essex Region

Area of Greenhouse Structures in 2000 (m^2)	Area of Greenhouse Structures in 2021 (m^2)	Areal Percent Difference
4,210,895.8	10,458,415.2	148% increase

Using the data obtained from the GGG project, the percent areal greenhouse coverage for each of the study watersheds was calculated for the years 2000 and 2021, which are the earliest and latest years for which these data are available. In the future we will calculate the percent areal coverage for all available years to show the change over time. Watersheds classified as greenhouse influenced experienced an increase in areal coverage between 2.3 and 20.6% with an average of 9% increase in greenhouse coverage (**Table 4, Figure 5**).

Table 4 – The areal percentage of greenhouse coverage for each study watershed in the years 2000 and 2021

Site	% Greenhouse 2000	% Greenhouse 2021	Difference
KLN 01	0.0	0.0	0
KLN 02	0.0	0.0	0
KLN 03	0.0	0.0	0
KLN 04*	1.4	5.9	+4.5
KLN 05_ISCO*	8.5	12.8	+4.3
KLN 06*	18.2	20.8	+2.6
KLN 07*	20.7	23.0	+2.3
KLN 09*	7.0	19.2	+12.2
KLN 10*	7.3	19.0	+11.7
KLN 11*	4.6	18.2	+13.6
KLN 12_ISCO*	1.5	10.6	+9.1
KLN 12B*	4.4	25.0	+20.6
KLN 13	0.0	0.8	+0.8
KLN 14B^	0.0	0.0	0
KLN 15	0.1	0.2	+0.1
RR 07*	0.0	20.1	+20.1
RR 08^	0.4	0.7	+0.3

*Indicates greenhouse influence

^KLN 14B and RR 08 do contain some small greenhouses. However, because of the larger size of these watersheds, the percent areal coverage is negligible.

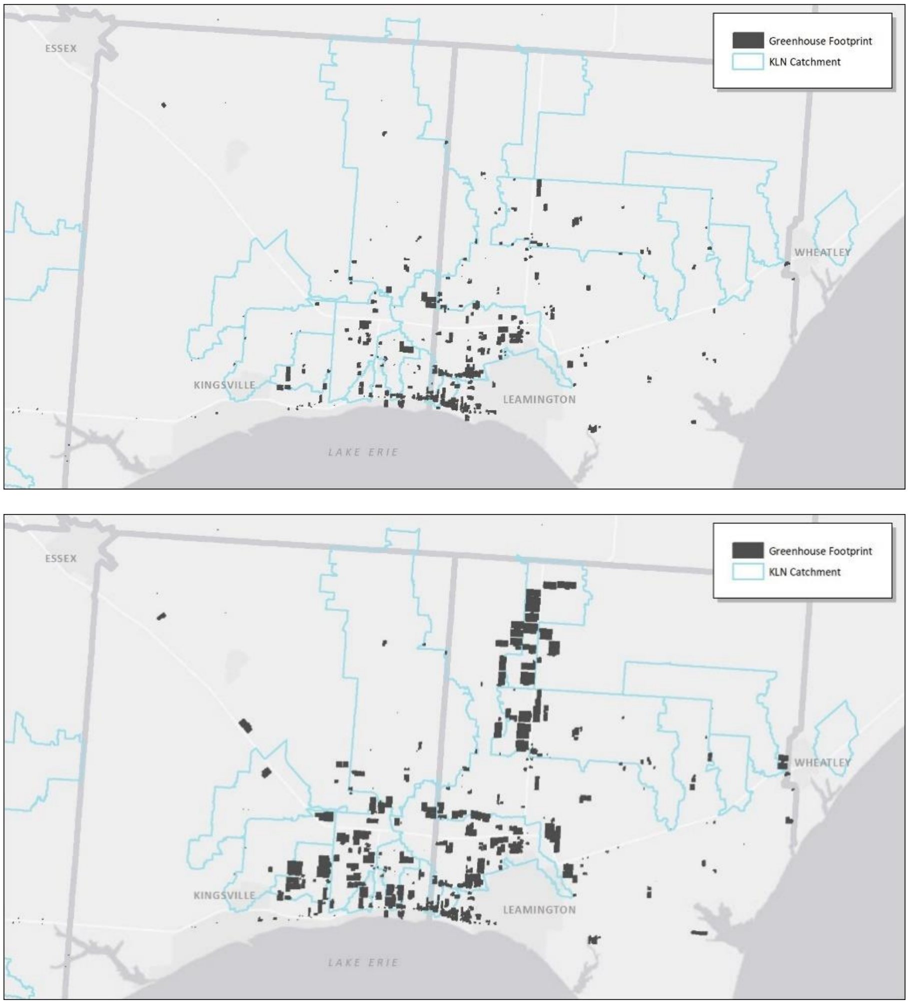


Figure 5 – Areal greenhouse coverage in study watersheds in Leamington and Kingsville in 2000 (top) and 2021 (bottom)

Overall, this partnership yielded a new and improved greenhouse footprint layer and geodatabase for ERCA, along with QA/QC digitization procedures for maintenance consistency and efficiency. The geodatabase also can be used for multi-disciplinary analyses related to spatial expansion of greenhouses in the regions and understanding greenhouse industry changes by type. The GGG group has also recommended that other features, such as holding tanks, parking lots and stormwater ponds should be digitized to account for greenhouse land disturbance and whether these should be part of what are deemed greenhouse “footprints.” The GGG will be addressing this in the second phase of this project, which is part of their GISc. Certificate capstone course.

Site Locations

The project began in 2012 with 14 sites (n=6 non-greenhouse and n=8 greenhouse influenced streams). Over the course of the project, some new sites have been added and while most site locations have remained unchanged, others were relocated or paused for various reasons. Additional sites have been added to capture areas with rapid greenhouse expansion (**Table 5** and **Figure 6**). Please see Appendix I for a detailed description of watershed characteristics and specific circumstances regarding when sites were paused or relocated.

Table 5 – Site locations, number of samples (routine only), start and end year

Station	Watershed	Latitude	Longitude	#Samples	Start Year	End Year
KLN 01	Mervin Drain	42.095092	-82.446772	193	2012	2022
KLN 02	West Two Creek	42.092435	-82.473688	181	2012	2022
KLN 03	Muddy Creek	42.080446	-82.489164	179	2012	2022
KLN 04*	Lebo Creek	42.071608	-82.523613	190	2012	present
KLN 05*	Sturgeon Creek	42.032514	-82.564948	109	2012	2018
KLN 05_ISCO*	Sturgeon Creek	42.045504	-82.574625	107	2017	present
KLN 06*	Judson Morse Drain	42.038079	-82.641753	149	2012	2022
KLN 07*	Rawley Drain	42.038931	-82.645158	151	2012	2022
KLN 09*	Esseltine Drain	42.039714	-82.661404	138	2012	2022
KLN 10*	Albert Gunning Drain	42.039860	-82.676776	191	2012	2022
KLN 11*	Lane Drain	42.037910	-82.694859	199	2012	present
KLN 12*	Mill Creek	42.027854	-82.742094	115	2012	2018
KLN 12_ISCO*	Mill Creek	42.039706	-82.744155	105	2017	present
KLN 12B*	Mill Creek	42.0473855	-82.723295	97	2016	present
KLN 13	Wigle Creek	42.053238	-82.759530	190	2012	present
KLN 14	Cedar Creek	42.053721	-82.855395	85	2012	2016
KLN 14B^	Cedar Creek	42.054331	-82.867234	119	2016	2022
KLN 15	Dolson Creek	42.005525	-82.840386	188	2012	2022
RR 07*	Ruscom River	42.172077	-82.604717	37	2020	present
RR 08^	Ruscom River	42.181312	-82.653625	39	2020	present

*Indicates greenhouse influence

^ KLN 14B and RR 08 do contain some small greenhouses. However, because of the larger size of these watersheds, the percent areal coverage is negligible.

This report includes data collected up to September 30, 2022 (at the end of water year 2021/2022). As of March 2023, sampling has ceased at nine locations due to a loss of funding. Two of these sites are also PWQMN sites so they will continue once a month (KLN14B and KLN 03), four of the sites would likely be discontinued anyway (KLN 01 and KLN 02 are non-greenhouse sites with no observable trends in 10 years of data; KLN 06 and KLN 07 are sites with very small watersheds), leaving three sites that we would like to sample but aren't able to at this time (KLN 15, KLN 09 and KLN 10).

Figure 6 – Upstream watershed delineations for current sampling locations

Sampling Methodology

Beginning in 2012, grab samples were collected at all sites every two weeks (biweekly) year-round, unless the streams were dry, frozen, or otherwise inaccessible. Sampling was reduced from biweekly to monthly in October 2018 due to reduction in available funding. At that time, the frequency of sampling at KLN 06 and KLN 07 was reduced to every other month. These sites were determined to be lower priority because they tend to have similar phosphorus concentrations year-round, have small contributing watersheds and minimal flow. Routine sampling was restored to biweekly frequency in January 2020, with KLN 06 and KLN 07 sampled monthly.

Estimating nutrient loads requires three key pieces of data. Continuous water level (i.e. stage), instantaneous discharge measurements to develop rating curves and nutrient concentrations taken at all points of a hydrograph. In 2016, additional sampling began in order to be able to quantify the nutrient loading in three of the study watersheds – Sturgeon Creek (KLN 05_ISCO), Lane Drain (KLN 11) and Mill Creek (KLN 12_ISCO). These sites were equipped with ISCO autosamplers that had bubbler modules to measure water level every 15 minutes and modems that allowed staff to access data and control the autosampler remotely. The ISCOs were programmed to turn on during precipitation events once water levels rose between 5 and 8cm above pre-event levels and then collect stream samples once every 4 hours. The ISCOs were manually stopped once water levels returned to near base-flow conditions. Using the water level data, discrete samples were chosen for laboratory analysis targeting the rising limb, peak and falling limb of the hydrograph. All attempts were made to capture as many events as possible throughout the year including both small and large rain events with varying duration as well as rain on snow and snow melt events.

To ensure consistent water quality data, the protocols for the PWQMN program were used. Samples for general chemical, nutrient, total suspended solids and metal analysis were collected at each monitoring site using clean, polyethylene bottles. During the Covid-19 pandemic when there was a period of time when the MECP lab was closed or had limited capacity, as well as when samples were collected during precipitation events, samples were analyzed for nutrients and total suspended solids only. All metal samples are preserved with approximately 15 drops of nitric acid to achieve a pH below two. The standard methods recommended by the American Water Works Association (AWWA) and the Water Environment Federation (WEF) for preservation and storage of samples for specific parameters are followed during the entire sampling period (Standard Methods, 2023). Most laboratory analyses were conducted by the MECP certified laboratory in Etobicoke. During the Covid-19 pandemic when this lab was shut down, samples were analyzed by Caduceon, a private lab. Once the MECP lab re-opened, lab load was reduced so only routine samples were sent to the MECP and event-based samples were sent to Caduceon. A handheld multiparameter meter, the YSI ProDSS, was used to measure pH, dissolved oxygen, water temperature, turbidity, and conductivity of surface water when collecting biweekly water samples.

Level loggers were installed in September 2017 at all KLN sites except KLN 06, 07, 12B, and 15. These sites do not have level loggers for a variety of reasons (e.g. consistently low water levels and/or flow; inability to secure loggers due to accessibility and/or poor substrate). Data from the loggers is uploaded at least quarterly and the loggers are winterized to protect against freezing. The logger at KLN 09 broke in July 2018, and the logger at KLN 02 broke in December 2018. Because of funding constraints, these loggers could not be replaced at that time. A new level logger was deployed at KLN 02 in June 2020. However, drain construction at KLN 09 commenced in early Spring of 2020, and the stream underwent significant changes to the channel and it was determined not to redeploy a level logger at this site.

Instantaneous discharge is measured using a handheld flow meter following USGS protocols. ERCA makes every effort to measure flow at all points on the hydrograph, however it is difficult to measure high flows due to safety as well as timing, with the highest flows often occurring overnight. Together these data points are used to plot stage (i.e. water level) vs discharge pairs and a develop a relationship called a rating curve. Accurate rating curves require numerous discharge measurements at all ranges of stage and streamflow. Since each stream channel is different, each rating curve is unique to that site and can change over time if there is a significant alteration in geomorphology (i.e., the shape, size, slope, and roughness of the channel at the stream gage).

Environment and Climate Change Canada have been provided the data necessary to calculate nutrient loads for Sturgeon Creek (KLN 05_ISCO), Lane Drain (KLN 11) and Mill Creek (KLN 12_ISCO). They will use Version 1.4 of the Erie Loading Tool (ECCC, 2020) which estimates annual loads from tributaries (monitored and unmonitored), point sources, and atmospheric deposition. The methodology implemented in the tool is based on the Dolan approach as described in

Maccoux et al., 2016. Annual loads are calculated on a water year basis (October 1-September 30) for each basin and total area for Lake Erie.

Beginning in April 2023, a reduced number of sites (see **Table 5**) are now sampled monthly and there is currently no event-based sampling.

Water Quality Analyses

For the purposes of this report, we are focusing on concentrations of total phosphorus (TP) and dissolved phosphorus, measured as soluble reactive phosphorus (SRP). Additional parameters may be considered in future reporting. Data collected between 1 October 2012 and 30 September 2022 were used for these analyses. Because the concentrations are generally high at the study locations sites in all years, we did not observe any non-detect data and therefore did not have to use any special statistics. When investigating annual trends, we used water years (1 October – 30 September). For general statistics, trend analysis, and seasonal comparisons, only routine data collected every two weeks were used. Event data are only collected at three stations and these data would not be comparable across all sites. Event data are used elsewhere in our statistical analyses and for load calculation. TP and SRP concentration data from routine samples for all sites across all years are shown in **Figure 7.** These graphs also distinguishes greenhouse influenced streams (in blue) from non-greenhouse influenced streams (in orange).

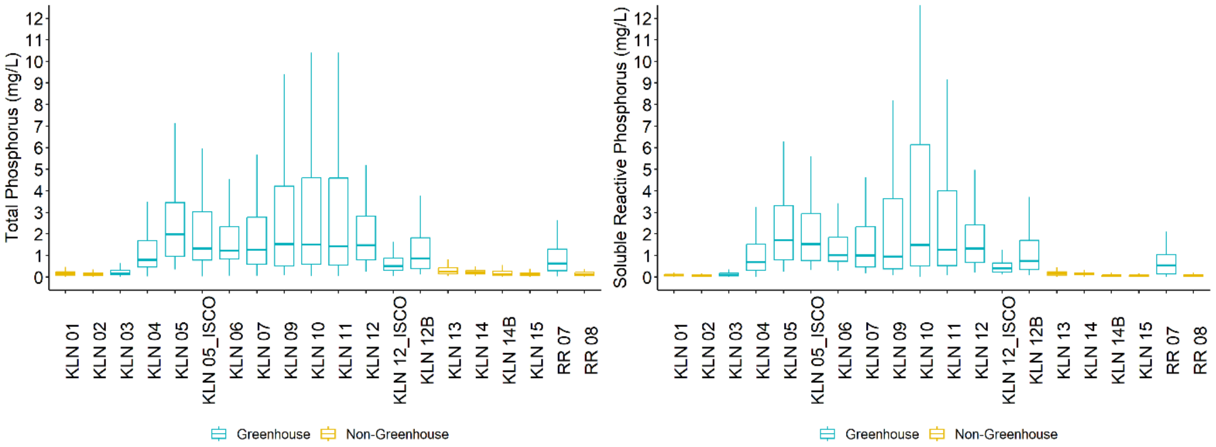


Figure 7 – Box and whisker plot showing the distribution of TP concentration (left) and SRP concentration (right) for each site using routine data collected from 2012-2022

Trends in annual median concentration

To determine trends in the concentrations for TP and SRP over the period of interest (water years 2012/13 to 2021/22), we first calculated annual median concentrations for each site. Median values were used to minimize the influence of extreme high or low concentration values because grab samples are collected on a set schedule (every two weeks) and may occur at any point on the hydrograph. Mann-Kendall trend tests, performed in RStudio using the 'trend' package, were used to determine whether significant monotonic trends occurred in annual median concentrations for each parameter during the period of interest at each of the selected sites. Note that Mann-Kendall tests can be run with as few as four samples, but it is recommended to have at least 8 data points. There are some stations that have insufficient data for this trend analysis because they have different start and end dates, resulting in fewer data points than recommended.

Of the stations with sufficient data for trend analysis, two have increasing trends in TP concentration, four have decreasing trends and the remaining five have no significant trend. Of interest, the sites with declining TP concentration are all identified as greenhouse influenced, while those with increasing trends are identified as non-greenhouse. It is important to note, however, that the greenhouse influenced streams begin and end with higher concentrations than the non-greenhouse influenced streams. Five stations show declining trends in SRP concentration and the remaining six stations show no trend. Further investigation into these trends is warranted. Please see Appendix I for detailed results of this analysis.

Comparison between watershed type

To determine whether TP and SRP concentrations in routine samples varied between watershed types (greenhouse influenced vs non-greenhouse influenced), Wilcoxon Rank Sum tests were performed in R. This test was used because the data do not meet the assumptions of normality nor equal variance. In summary, TP and SRP concentrations are both significantly higher in greenhouse influenced streams than in non-greenhouse influenced streams ($p<0.001$) (**Figure 8**). Note that the Provincial Water Quality Objective (PWQO) is 0.03mg/L. Given that we do see some significant trends through time, future analyses could tease apart differences in particular years, or individual sites.

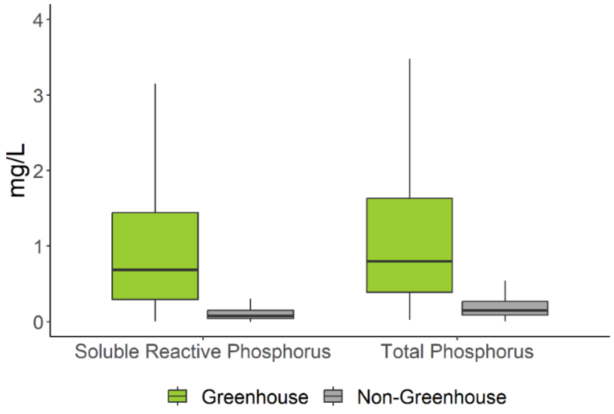


Figure 8 – Box and whisker plot showing the distribution of SRP and TP concentration in greenhouse (green) and non-greenhouse (grey) influenced streams

Seasonal differences

We also looked at whether TP and SRP concentration in routine samples differed in greenhouse and non-greenhouse influenced streams across seasons, where winter was defined as December-March, spring as April-June, summer as July-August, and fall as September-November. We chose these definitions to work towards addressing the Great Lakes Water Quality Agreement's Annex 4 direction to reduce phosphorus loads during the spring months in order to minimize harmful algal blooms in Lake Erie (Annex 4 Objectives and Targets Task Team, 2015). Future analysis could examine additional or different seasonality, as well as individual sites. We used Kruskal-Wallis rank tests performed in R. This test was used because the data do not meet the assumptions of normality nor equal variance. If Kruskal-Wallis tests detected a significant difference among groups, Dunn's post-hoc tests, which are recommended for comparing groups with unequal sizes, were used to determine pair-wise differences between watershed types. Data used for this analysis were from January 2013 to August 2022.

In greenhouse influenced streams for both TP and SRP concentrations, the Kruskal-Wallis test determined that there were significant differences amongst the seasons ($p<0.001$). Dunn's tests showed that summer concentrations were significantly higher than all other seasons ($p<0.001$) and winter concentrations were lower than all other seasons ($p>0.001$). There was no difference in either TP or SRP concentrations between spring and fall.

In non-greenhouse influenced streams for both TP and SRP concentrations, the Kruskal-Wallis test determined that there were significant differences amongst the seasons ($p<0.001$). However, Dunn's tests between seasons are not as easy to interpret. TP and SRP concentrations are higher in the summer than in winter or spring ($p<0.001$). Fall differs significantly from spring and winter ($p<0.001$), but neither fall and summer, nor spring and winter differ significantly (**Figure 9**).

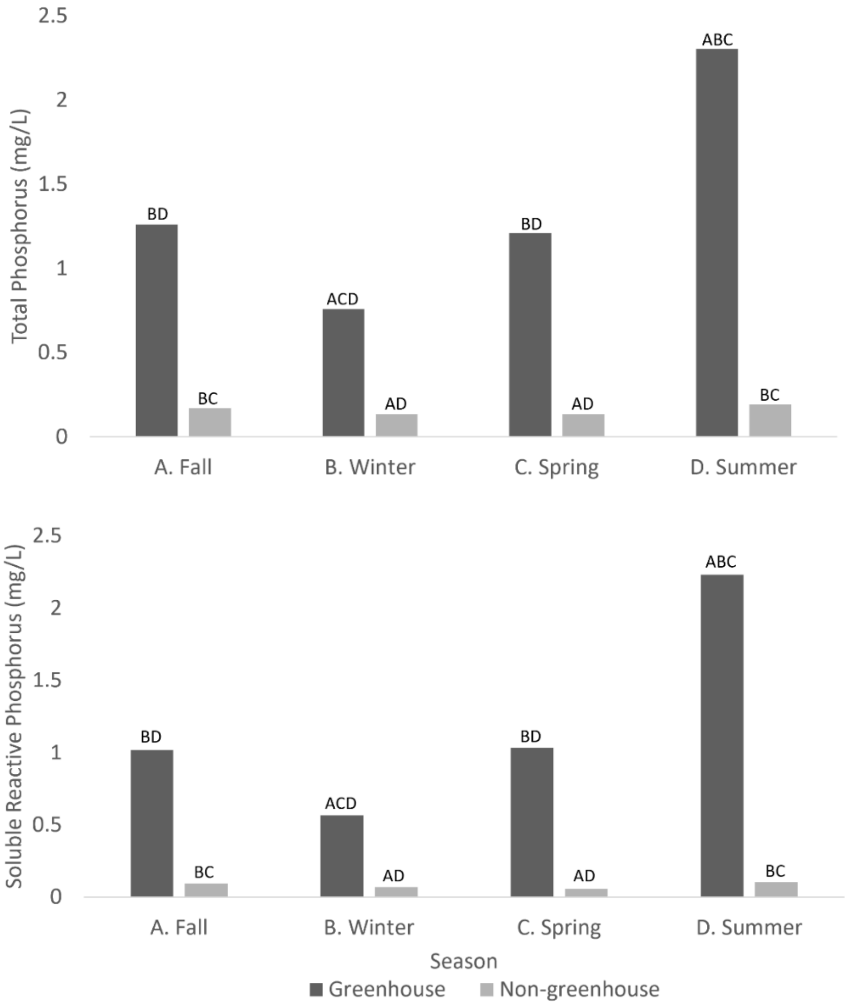


Figure 9 – Bar charts showing median TP concentration (top) and SRP concentration (bottom) in greenhouse and non-greenhouse influenced streams across seasons. The letters above each bar indicate significant ($p < 0.001$) seasonal differences.

<u>Comparison of nutrient concentrations in the growing and non-growing season during routine and event sampling</u>

In a typical agricultural stream, TP and SRP concentrations tend to be highest during precipitation events in the non-growing season (November to March). This is because rain or snow melt picks up sediment bound TP from bare fields in surface runoff and SRP through tile drainage. It is for this reason that measuring concentration and flow during precipitation events at various points on the hydrograph is critical to calculating nutrient loads. Capturing concentration and flow at the peak (highest point) of a hydrograph is especially critical and the most challenging as the streams are typically unsafe to enter at these times.

We have sampled two sites along a nearby agricultural stream with no greenhouses (Wigle Creek) in a similar manner to those presented in this study, as part of the GLASI and ONFARM program. Wigle Creek is consistent with our expectations with the highest TP and SRP concentrations occurring during precipitation events in the non-growing season (**Figure 10**). We examined whether the same pattern exists in greenhouse streams using the same criteria for growing season (April to October) and non-growing season (November to March) as we use for agricultural streams, however, we recognize that plants may be grown in a greenhouse year-round. Future analysis will include discussion with the greenhouse sector to include what they would consider a more appropriate definition of growing season (when plants are receiving nutrients through fertigation) and non-growing season (when irrigation no longer includes the addition of nutrients).

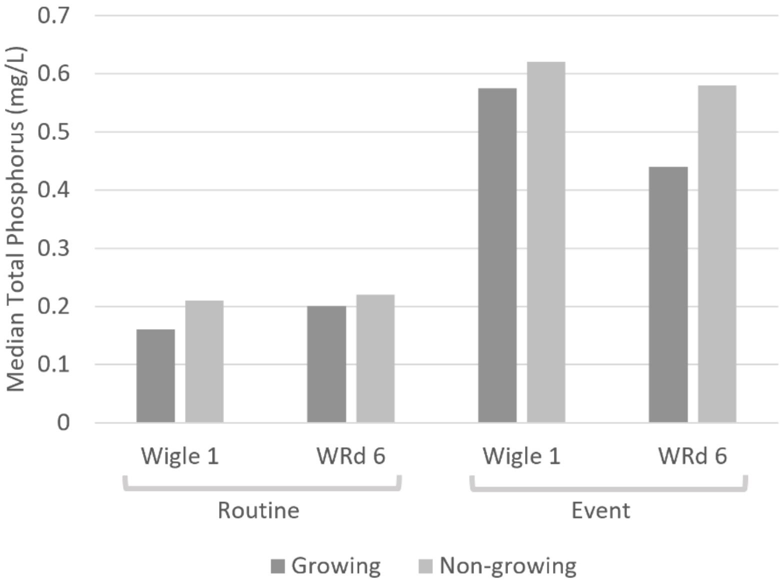


Figure 10 – Median TP concentrations at two locations within an agricultural watercourse in the Essex Region showing that TP concentrations are highest during weather events in the non-growing season.

To determine whether TP and SRP concentrations varied between samples collected during routine sampling (every two weeks) and event samples (rain and snow melt events) during the growing and non-growing season, a series of one-way Kruskal-Wallis rank tests were performed in R. This test was used because the data do not meet the assumptions of normality nor equal variance. In the future, we will consider multivariate or two-way ANOVAs to analyze these data, but we do not expect any change in the result. This analysis was conducted for the three stations equipped to monitor during events using ISCO autosamplers (KLN 05_ISCO, KLN 11 and KLN 12_ISCO).

In summary, the highest concentrations of TP and SRP are observed in routine samples taken during the growing season, which is in contrast to a typical agricultural stream (**Tables 6** and **7** and **Figures 11** and **12**). This indicates that precipitation events act to dilute nutrient concentrations in these streams, giving further evidence to the effect of greenhouses behaving as point sources of nutrients to the downstream receiving waters. This pattern is most evident in Sturgeon Creek (KLN 05_ISCO) and Lane Drain (KLN 11). TP concentrations in Mill Creek (KLN 12_ISCO) do not exhibit a difference in concentration in the growing vs non-growing season, but routine TP concentrations are higher than event TP concentrations. SRP concentrations in Mill

Creek do not exhibit a difference in concentration in event vs routine samples, but growing season SRP concentrations are higher than non-growing season SRP concentrations**.**

Table 6 – Results of Kruskal-Wallis paired tests for TP concentration using data from 2013-2022

Test	Chi-Squared	p-value	Result
Growing vs non-growing season: Routine	7.71	0.005	TP concentrations during routine sampling in the growing season are significantly higher than TP concentrations in the non-growing season
Growing vs non-growing season: Event	36.70	<0.001	TP concentrations during event sampling in the growing season are significantly higher than TP concentrations in the non-growing season
Routine vs Event: All data	9.82	0.002	TP concentrations during routine sampling are significantly higher than TP concentrations during events regardless of season
Routine vs Event: Growing Season	5.5	0.019	TP concentrations during routine sampling are significantly higher than TP concentrations taken during events during the growing season
Routine vs Event: Non-growing season	5.05	0.025	TP concentrations during routine sampling are significantly higher than TP concentrations taken during events during the non-growing season

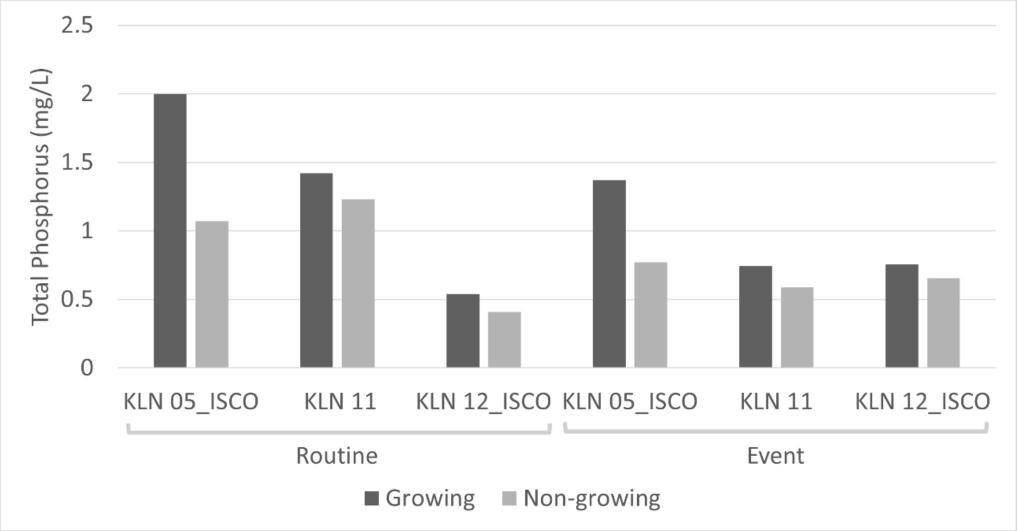


Figure 11 – Bar graph showing median TP concentration at each of the three sites equipped with ISCO autosamplers during event and routine sampling in the growing and non-growing season.

Table 7 – Results of Kruskal-Wallis paired tests for SRP concentration using data from 2013-2022

Test	Chi-Squared	p-value	Result
Growing vs non-growing season: Routine	35.20	<0.001	SRP concentrations during routine sampling in the growing season are significantly higher than TP concentrations in the non-growing season
Growing vs non-growing season: Event	89.55	<0.001	SRP concentrations during event sampling in the growing season are significantly higher than TP concentrations in the non-growing season
Routine vs Event: All data	96.59	<0.001	SRP concentrations during routine sampling are significantly higher than TP concentrations during events regardless of season
Routine vs Event: Growing Season	32.59	<0.001	SRP concentrations during routine sampling are significantly higher than TP concentrations during events during the growing season
Routine vs Event: Non-growing season	66.26	<0.001	SRP concentrations during routine sampling are significantly higher than TP concentrations during events during the non-growing season

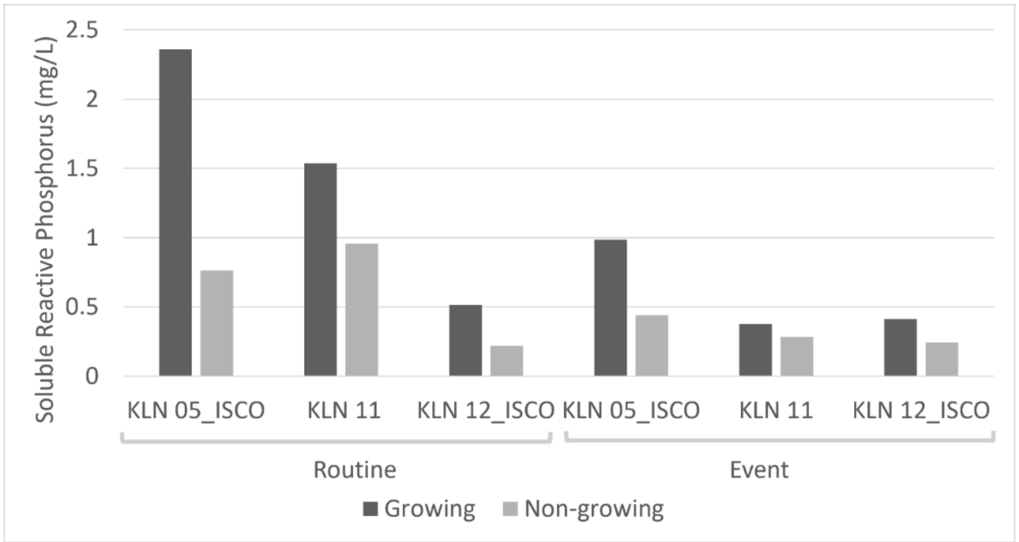


Figure 12 – Bar graph showing median SRP concentration at each of the three sites equipped with ISCO autosamplers during event and routine sampling in the growing and non-growing season

Ruscom River

The greenhouse sector continues to expand in the northern part of Leamington, along the highway 77 corridor as is evidenced by the digitization of the greenhouse footprint done by the GGG group (see **Table 4** and **Figure 5**). This area of expansion is in the headwaters of the eastern branch of the Ruscom River, which flows south into the municipality of Lakeshore and eventually to Lake St. Clair. In October 2020, additional sampling locations in the Ruscom watershed were added to routine monitoring to capture this growth of the greenhouse sector.

The site RR 07 is located in the east branch of the Ruscom River where expansion of the greenhouse sector is growing at a fast rate. The greenhouse footprint in this watershed was 0% in 2000 and 20% in 2021, with more greenhouses built in the years since this analysis. The site RR 08 is located in the west branch of the Ruscom River where the land use remains largely field agriculture. These sites are sampled every two weeks, and there is a level logger at RR 07. There is also a long-term monitoring station in the Ruscom River (M1) that is part of the Provincial Water Quality Monitoring Program where sampling began in 2001 (**Figure 13**).

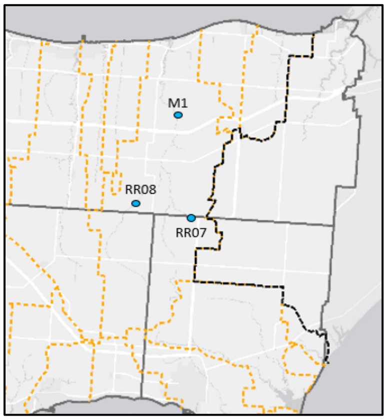


Figure 13 – Map showing the location of the long-term monitoring station (M1) in the Ruscom River relative to RR 07 and RR 08

We examined the trend in annual median TP and SRP concentration at M1 for 2001-2022 using Mann-Kendall non-parametric tests in RStudio with the 'trend' package. Both TP concentration (p=0.024) and SRP concentration (p=0.017) are increasing significantly at this site, driven largely by higher concentrations from 2019 onward (**Figure 14**). Similar data from Sturgeon Creek raised the initial concern that nutrient concentrations in the Leamington area were increasing.

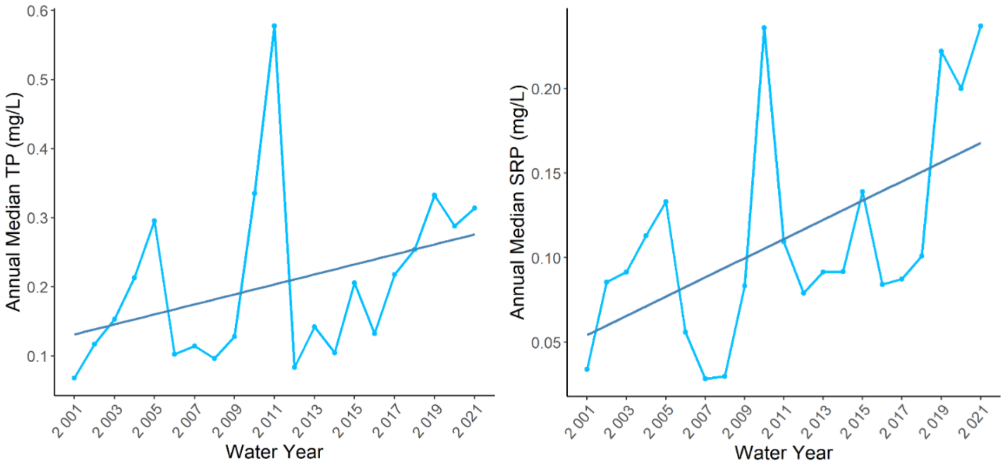


Figure 14 – Trend in annual median Total Phosphorus (left) and Soluble Reactive Phosphorus (right) at site M1 in the Ruscom RiverWe also used Mann-Kendall trend analysis to examine whether there were trends in TP and SRP concentration at RR 07 and RR 08 using all the data collected from 11 September 2020 to 8 November 2022. The Mann-Kendall analysis doesn't account for seasonality, however, there is insufficient data to examine annual trends. TP

concentration (p=0.039) is increasing significantly at RR 07 (greenhouse) while SRP (p=0.139) is not (**Figure 15**). There is no significant trend in either TP or SRP at RR 08 (non-greenhouse) (**Figure 16**). The difference in the scale of the y-axis between RR 07 and RR 08 should also be noted. Once more data are collected at these sites, seasonality should be considered in analyses.

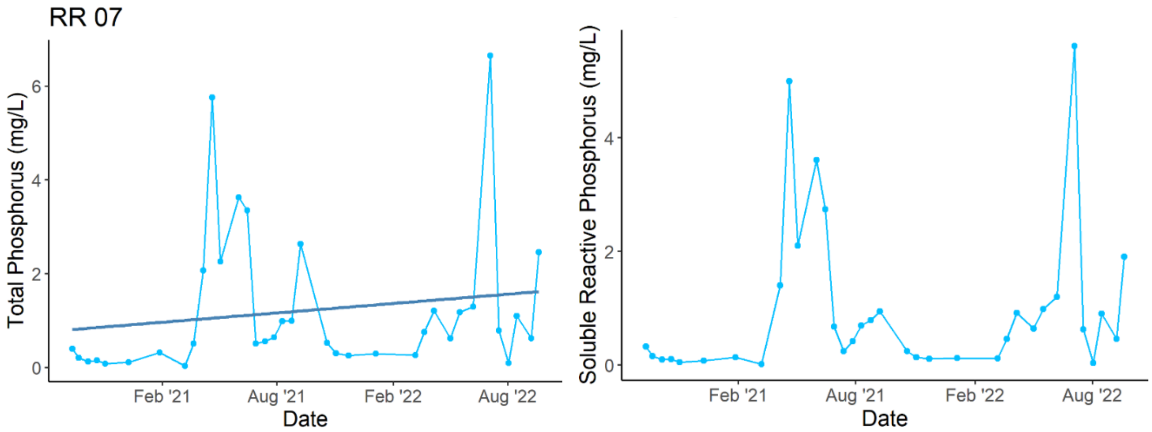


Figure 15 – Scatter plot and trend line for TP concentration (left) and SRP concentration (right) at RR 07 in the Ruscom River

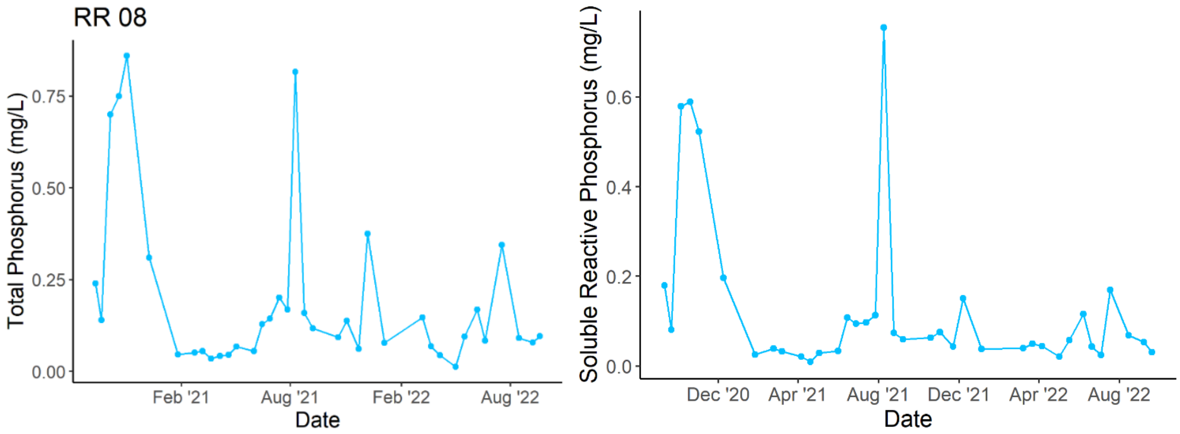


Figure 16 – Scatter plot for TP concentration (left) and SRP concentration (right) at RR 08 in the Ruscom River

Summary and Next Steps

Following 10 years of data collection in greenhouse and non-greenhouse influenced streams in Leamington and Kingsville, Ontario, some clear and strong patterns have emerged. Both total phosphorus and soluble reactive phosphorus concentrations are significantly, and drastically, higher in greenhouse than non-greenhouse influenced streams. Using data from 2012 to 2016, Maguire et al. 2017 showed that concentrations in greenhouse influenced streams were more than 20 times higher than non-greenhouse influenced streams. Despite communication of these findings and a decreasing trend at some sites, high nutrient concentrations in greenhouse influenced streams continue to persist. This pattern remains in all seasons, with the greatest difference between greenhouse and non-greenhouse influenced streams in summer months and least difference in winter months. This aligns with fertilizer practices where greenhouse plants are provided with nutrient rich water throughout their growing season and nutrients are tapered off as the plants reach senescence. This is in contrast to row-crop agriculture where fertilizer is applied at specific points in time.

In most watersheds, nutrient concentrations and loads are highest during precipitation events in the non-growing season when run-off occurs over bare soil. Our findings show that the greenhouse influenced streams display the opposite pattern with the highest nutrient concentrations occurring during baseflow conditions in the growing season. Rather than nutrients increasing as a result of additions from run-off, there is a dilution effect. This suggests that there are point sources in these watersheds with a consistent input of nutrients.

Finally, there are now two long term datasets in Sturgeon Creek and the Ruscom River that clearly show an increase in downstream nutrient concentrations following the installation of greenhouse infrastructure. The evidence presented here should be taken as a warning that even newly built greenhouses are losing nutrients to the environment. These new greenhouses should have been built to the highest standards which should include managing their losses to the environment. The Ruscom River flows into Lake St. Clair, which experiences a persistent, toxic harmful algal bloom each summer. It is imperative that nutrient contributions to these receiving waters be reduced.

These lines of evidence show clearly that nutrients from greenhouse agriculture are ending up in the downstream environment, whether accidentally or through purposeful discharge. The Canada-Ontario Lake Erie Action Plan identified several actions that should be taken by the greenhouse sector to lessen their downstream impact. Future work should include the continued monitoring of these streams, which is currently unfunded, to track progress towards these goals. Further studies are also warranted to pinpoint hotspots within watersheds and also to determine the pathways through which nutrients are being discharged to the environment so that corrective actions can be taken. There is also an opportunity at this point to ensure that all newly built greenhouses meet the highest standards. Dye tests should be required to find and repair leaks prior to operations beginning and throughout the life cycle of a greenhouse. At a time when food scarcity is a growing issue, it is essential that we take the time to make corrective actions to ensure that our efforts to grow food do not result in further environmental degradation.

Effect of Covid-19 on execution of the project

In March 2020, the ERCA offices were closed and staff began working remotely. At that time, water quality sampling was determined to be an essential service and ERCA initiated, and continued to modify, protocols to ensure the health and safety of our Water Quality Technicians such that there was no disruption in our ability to deliver our monitoring programs. For example:

- Each Technician was assigned their own vehicle and sampling equipment
- Each Technician was provided with PPE (e.g. gloves, masks, face shields)
- Staff were encouraged to maintain physical distance while sampling

Shortly after the pandemic was announced, the MECP lab was closed to routine monitoring programs like KLN. During this closure, a private laboratory, Caduceon in Windsor, ON was used where they implemented protocols to ensure the health and safety of their staff and those dropping off samples. Submissions could be done electronically, and sample drop off was contact-less. Because there were no funds specifically allotted for laboratory analysis, which is typically done through in-kind support from MECP, we reduced the number of analytes to keep costs down. Samples were analyzed for total phosphorus, soluble reactive phosphorus, nitrate, nitrite, ammonia, total Kjeldahl nitrogen and total suspended solids only. A benefit to using this private lab is that results are received more quickly and in a format that is easier to integrate into our databases than the MECP lab.

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