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Integrated Science 3002A: Phosphorus Loading in London's Fresh-Water

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A Critical Analysis of Past and Present Phosphorus Levels in London’s Waterways, and Prospective Consequences

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PHOSPHORUS LOADING IN LONDON’S FRESH-WATER

INTRODUCTION

The state of Lake Erie and its surrounding rivers has been long impacted by anthropogenic nutrient loading. Leading up the 1970s the waterways surrounding Lake Erie had reached an all-time high in frequency and potency of toxic algae bloom, due to phosphate heavy fertilizers. Following the establishment of the 1972 Great Lakes Water Quality Agreement, an international multi-billion dollar lake clean up, and legislation banning phosphate fertilizers, toxic algae bloom decreased over the next decade. Moving into the 1990s and 2000s, hypoxia and nuisance algae started to return to Lake Erie (Scavia et al., 2014). Given that illegal fertilizer cannot be the primary driver of the re-emergence of high phosphorus content in Lake Erie, this report focuses primarily on urban sources of phosphorus, and specific target areas across the City of London.

Understanding the source of phosphorus in City waterways is of utmost importance as it directly impacts the citizens in the London area. London’s primary source of freshwater for drinking comes from the Great Lakes, Huron and Erie (City of London, 2017). Furthermore, Lake Erie itself is the primary supply of drinking water for more than 11 million people and brings in more than $50 billion annually from recreational services (Watson et al., 2016). Not only this, First Nations communities too depend on the Erie feeder waterways such as the Thames River for water for more than just drinking water, but also a crucial connection to their Creator. Although the City already funds cleanup projects, the effectiveness of their efforts is unknown; that is, there is debate regarding if resources are being allocated in the most efficient way. Should the state of Lake Erie continue to worsen the City may have greater economic and
cultural concerns than now, thus it is crucial to find the root of phosphorus spikes throughout London.

Although the ultimate cause of the recent increase in phosphorus loading is unknown, spatial sampling data can be used to determine if there is more phosphorus coming into the City via the entry points, or if there is more leaving the City via the exit points. This would be indicative of whether the source of phosphorus loading is a result of rural contributions or urban contributions, respectively. A review of the literature gives somewhat mixed results as to whether urban or rural sources are most significant. However, a particularly relevant study published this year in the *Canadian Water Resources Journal* examined the effect of land-use on phosphorus and nitrogen input into the Canadian watersheds surrounding Lake Erie and Lake Huron. This study compared the impacts of multiple land use categories for data collected in 2012 and found that in general, despite high phosphorus regulations on sewage treatment plants, urban contributions – in particular wastewater treatment facilities and impervious surface area – were generally the most significant factor in accounting for phosphorus variability. Their results across southern Ontario showed that 95% of sites downstream of a wastewater treatment plant exceeded the Canadian Environmental Quality Guidelines meso-eutrophic target of 0.035 mg/L total phosphorus. This number was only 63% for sites downstream of agricultural regions. (Thomas, Lazor, Chambers, & Yates, 2018)

To best assess the current phosphorus trends within London, secondary data such as previously extracted samples and records were gathered two main focuses: the Thames waterway and wastewater treatment plants (WWTPs). This study aims to establish the primary driver of phosphorus loading in the London area by analyzing spatial trends in phosphorus across the City.
Using data collection from waterway entry and exit branches and WWTP influent and effluent of phosphorus, this report aims to (1) investigate difference in raw phosphorus concentrations in inner-City waterways; (2) investigate difference in phosphorus effluent between WWTPs, expecting the Oxford location to have a significantly larger amount of phosphorus leaving the plant in 2017; (3) determine trends in phosphorus concentrations over time and determine the most significant ‘trouble spots’ for phosphorus concentration across the City of London region, and (4) analyze data for phosphorus concentrations throughout the Thames River as well as the Detroit River, predicting whether or not the concentrations within these tributaries will remain relatively similar to the concentrations of the Thames as it exits London.

METHODS

WWTPs

Total phosphorus effluent data were acquired from annual City of London wastewater treatment plant (WWTP) reports. Using a significance level of 0.05, correlation test between year and WWTP phosphorus influent is determined through a parametric correlation Pearson test, and a one-way ANOVA was used to determine any significant difference in phosphorus effluent between Greenway, Pottersburg, Oxford, and WWTPs in 2017. Analyses were followed up with Tukey’s post-hoc to determine where significance originates. Parametric correlation, ANOVA, and Tukey’s HSD analyses were performed using RStudio Team 1.1.453 (2016).

Thames River

Total phosphorus data were acquired from the City of London at 20 sampling points around London, including three sites on the North branch, three sites on the South
branch, five sites on the Main branch, and various additional sites at points along smaller streams in the London area (City of London, 2018). These data spanned from 1977 to 2017. Though regular estimates were given throughout the year for most sites, only yearly averages were considered in producing this particular set of results. First, graphs and bar charts were produced describing trends over time and comparing total phosphorus concentration as well as difference in total phosphorus from the North and South inflows to the Main branch outflow. Secondly, total phosphorus values and sampling site map was used to create a map layer in Esri’s ArcGIS 10.6 (2017) which stored the total phosphorus values at their associated locations from the years 2010 to 2017. An additional layer was added showing the rough location of the six London WWTPs for reference. Three additional City of London ArcGIS files were used with City permission: London boundary, major roads, and water shape polygons. Inverse-Distance Weighted (IDW) interpolations were calculated for each year from 2010 to 2017 using the sampling point data. Finally, the sampling point file was exported as a KML and loaded into Google Earth to give a better idea of surrounding land use.

Dams and Outflows

A report produced for the City of London by CH2M in 2017 examined total phosphorus in the region of the Springbank dam and compared them against locations upstream (Wharncliffe) and downstream from the dam (Byron). This report compared data from when the dam was operational to when it was not, as well as comparing total phosphorus concentration in wet and dry weather. (CH2M Hill Canada Limited, 2017)

Tributaries of Erie
Nutrient concentrations present in the key waterways flowing into Lake St. Clair, and eventually Lake Erie were acquired from the Government of Canada dataset on nutrient concentration records for tributaries of the Great Lakes (Government of Canada, 2018). These data were used to isolate nutrient sampling sites along the length of the Thames River which serves as the main tributary that flows away from the City of London. The Thames River will be the particular tributary in focus within the context of this report, as London’s interaction with it is far more prominent than any other major tributaries that eventually feed into Lake Erie. While the Thames River opens into Lake St. Clair, it will be assumed that any effects or patterns of phosphorus concentrations affecting Lake St. Clair will be mirrored by Lake Erie (As Lake St. Clair is the only major body of water from Canada that flows into Lake Erie). Six particular marker sites were considered for the Thames River with all sites being Lake St. Clair Tributary (LSCT) stations. The six LSCT stations arranged in order from London to the mouth of the Thames are as follows:

- LSCT1 - Located in Byron
- LSCT2 - Located in Muncey
- LSCT3 - Located near Dutton on Currie Rd.
- LSCT4 - Located in Thamesville
- LSCT5 - Located in Chatham
- LSCT6 - Located at the mouth of the Thames River

Two of the sites (LSCT1 and LSCT2) along the Thames River were analyzed using an unpaired t-test with unequal variances three times (for the years of 2016, 2017, and
Additionally, all available data from 2016, 2017, and 2018 were compared on a scatter plot to better observe overall trends occurring in phosphorus concentration moving towards Lake St. Clair from London.

**RESULTS/DISCUSSION**

*Thames River*

Figures 3 through 5 show that total phosphorus in the Thames tends to be highly variable over time, but that there has been a significant decrease since the 1980s. A number of sources indicate that phosphorus concentrations in Lake Erie as a whole are once again rising (Scavia et al., 2014; Lake Erie Nutrient Science Task Group, 2009), however with the high variability of the Thames River data, this trend could not be demonstrated on the scale of the City of London.

The bar charts in Figures 6 and 7 show how total phosphorus concentration changes between each sampling location. The first plot shows from the North branch input to the Main branch output, and the second plot shows from the South branch input to the Main branch output (Main branch values are included on both graphs for comparison). The SEM for these plots gives a relatively wide interval since values were calculated by taking the 5-year mean of the yearly averages. These could likely be controlled better by calculating the 5-year average straight from the original regular sample data (rather than the average) but due to time constraints only the yearly averages were used for this analysis. Even so, there are a few significant relationships that appear.

Firstly, over the last few years, the stretch from Richmond to Dundas has significantly decreased the amount of total phosphorus in the Thames. Similarly, the
stretch from Adelaide to York decreases total phosphorus at best and adds roughly 0 mg/L total phosphorus at worst. The original hypothesis was that these effects may be the result of a lower proportion of impermeable surface along these stretches, however Figure 19 does not show a significantly increased proportion of parkland in these areas as compared to others. In fact, it is the Whites to Adelaide and Highbury to Richmond stretches which appear to have the greatest proportion of surrounding greenspace. Alternatively, another potential explanation can be found by examining the locations of the WWTPs in Figures 11-18. Unlike many of the other stretches, the Richmond to Dundas and Adelaide to York stretches do not contain WWTPs. Whether this is a direct cause of the decreased phosphorus input or merely a coincidence has not been determined.

The Whites to Adelaide, York to Wharncliffe, Wharncliffe to Springbank, and Springbank to Byron stretches show significant increases in total phosphorus from year to year. This demonstrates that these stretches of the Thames are the most critical in minimizing total phosphorus input in London. Looking at the graphs comparing absolute concentration at each location, it can be inferred that the Whites to Adelaide jump occurs likely because Whites has the lowest overall total phosphorus average concentration, indicating that the water coming in via the South branch generally has a better water quality in regard to total phosphorus. On the other hand, both Byron and Springbank show significant increases from both the North and South branch total phosphorus values near the forks. Therefore it is the stretches from Wharncliffe to Springbank and Springbank to Byron that have the potential to make the most difference in overall total
phosphorus concentration in the water leaving London. This is further emphasized by the maps in Figures 11 to 18. The outgoing water in the Main branch is generally higher than either of its North or South inflows and tends to show an increase between Wharncliffe and Springbank.

The last point of interest highlighted by Figures 11-18 is the high levels of variability in phosphorus input from rural sources from year to year. The Old Victoria and Highbury Ave sampling points are prime examples of this. As seen in Figure 19, they are located on the outskirts of the city and have greater influence from agricultural land. Figures 11, 13 and 16 show a very high input of phosphorus from Old Victoria in 2010, 2012 and 2015, while the same location shows one of the lowest concentrations of the map in both 2014 and 2017 (Figures 15 and 18). Similar examples can be found for Highbury Ave, though variation generally tends to be less extreme. It is not immediately clear what causes these fluctuations, though perhaps analyzing data on fertilizer use for those years might offer some explanation. The fate of these streams, and how much they impact the Thames and Lake Erie has not been explored, however as they are in the London City bounds, these results may be worth further analysis.

WWTPs

A Pearson Correlation test concluded that there is likely a significant, positive linear relationship between year and raw phosphorus content flowing into WWTPs (Pearson, \( r=0.70; p<0.01, \) Fig. 1). This supports the first hypothesis – there is difference in raw phosphorus concentrations throughout the City over the years, and WWTPs phosphorus influent has been steadily increasing. Though this has not yet impacted
effluent phosphorus levels, it is important to determine the cause of this increase before these levels do become great enough to cause a problem. In support of the hundreds of other publications that contribute to the global awareness of nutrient loading and algae bloom (Watson et al., 2016), these data illustrate the need to recognize and reduce the anthropogenic impact on freshwater. The Canada-Ontario Lake Erie Action Plan (2018) provides cost-effective and high impact actions to pursue the reduction of phosphorus levels in Lake Erie; however, the health of freshwater cannot depend on just government cleanup plans such as this. The only way to ensure perpetual health of freshwater source is if there is a communal effort, and if the majority of citizens are aware of the threats posed to this source of water.

A One-way ANOVA determined there is at least one significant difference in phosphorus outflow between Greenway, Pottersburg, Oxford, and Adelaide WWTPs (ANOVA, \( F=21.97; p<0.05 \), Fig. 2). Tukey’s post-hoc test concluded that the Oxford branch has a phosphorus effluent with a significantly lower amount of phosphorus outflow than Greenway and Pottersburg (Tukey, \( p<0.01 \), Fig. 2). Looking at Figures 15 through 18, it made sense that Oxford WWTP would have a significantly higher phosphorus output than other plants due to its spatial location; it sits relatively close to the exit point of City water, where the higher concentrations of phosphorus have generally been observed. However, this assumption was not supported by the data in this experiment – Oxford WWTP does not have a significant increase in phosphorus effluent when compared to other WWTPs in 2017 – it instead favours the exact opposite. This makes sense, since the Oxford WWTP uses a membrane bioreactor (MBR) process rather
than the typical secondary settling used by every other WWTP in London. It is expected that effluent water quality would be positively impacted, otherwise the additional cost of the MBR process would not be supported. This also implies that the spike in phosphorus concentration around the Oxford area must come from another source. Although this is not very helpful as to where the phosphorus loading point source is, it is reassuring to know that London’s WWTPs are efficiently doing their job to keep phosphorus effluent limited. It would be interesting to further study other possible sources of re-emerging severe eutrophication, as these data support that the urban center of London is not a major contributor.

\textit{Dams and Outflows}

Figures 9 and 10, referenced from the CH2M report, reveal that the total phosphorus concentrations in the summer during both wet and dry weather are significantly higher with the dam versus without the dam. In dry weather, the average concentration of phosphorus is almost twice as high with the dam versus without it. These concentrations tend to increase further downstream, with lowest concentrations generally found at Wharncliffe. Drier weather already decreases the flow of the river, minimizing water turnover rates and providing an environment highly conducive to algal growth. The additional phosphorus associated with the Springbank dam serves to further modify the environment in favor of algal growth, thus adding to the problem.

\textit{Tributaries of Erie}

While there may be some form of concrete pattern for data within the London area, it seems evident that the Thames River tributary in its entirety has a greater level of
complexity in its mechanisms for phosphorus onloading and offloading. While some demonstrated a strong disparity of phosphorus concentrations between the mouth of the river and the region where it exits London, other years were far more ambiguous in their connection to London’s phosphorous contributions, as seen in Figure 8. It may be possible that precipitation levels or erosion along the river varied from 2016 to 2018, resulting in many additional factors that may have had a role in skewing any correlation between London’s contribution of phosphorous and the end concentration that pours into Lake St. Clair. Figure 20 also illustrates the variability of phosphorus concentrations along the Thames tributary between the years of 2016 and 2018, seen over the various LSCT stations present along the river. A larger dataset over a greater number of years would be much more effective in better establishing a firm relationship between London’s nutrient pollution and the eutrophication that plagues Lake St. Clair and Lake Erie.

Regardless of the validity of the correlation between London’s phosphorus contributions and the Thames River, there is little uncertainty regarding the notion that phosphorus levels have been prone to fluctuation as the Thames moves through and exits London (see Figures 12, 16, and 18). Years associated with more significant algae blooms, such as 2015, have generally correlated with higher concentrations of phosphorus exiting London, though these trends do not hold within the city itself. While this may be a coincidental relationship, there are still mitigation strategies that can be considered for urban centers such as London in order to reduce phosphorus eutrophication. One such example is a more careful approach in construction projects.
Construction sites have been shown to have a disproportionately large contribution to urban runoff by way of the erosion induced in the process. These contributions result in erosion rates that are 12 to 50 times greater than agricultural practices - allowing for the flow of substantial levels of nutrients to be taken along as well (Carpenter et. al, 1998). Addressing the negative impact of construction in urban environments can at the very least be alleviated by incorporating fewer impervious surfaces such as pavement, a material adept at increasing runoff. More general mitigation strategies can be seen through various forms of diverting stormwater and wastewater. London’s storm and wastewater effluent both pour directly into the Thames River, which isolates the flow of nutrients to one body of water. The integration of retention ponds, wetlands, rain gardens, and greenways can serve as nutrient sinks to minimize phosphorus concentration in the Thames, a major tributary to Lake Erie.

CONCLUSION

Though it cannot be explained with certainty what causes phosphorus contamination in the City of London, this report highlights a number of areas of interest. If the problem is truly urban, as the study by Thomas et al. (2018) concluded, it is not immediately clear that the issue can be linked specifically to the London wastewater treatment plants as might have been expected. The graphs and maps provided indicate that there is something impacting phosphorus roughly southwest of the Wharncliffe sampling station, since total phosphorus concentration tends to increase significantly past this point. The stretch between Richmond and Dundas is also of interest due to its tendency to reduce phosphorus concentration in the region. Next steps would be to further investigate these ‘hotspots’ in an effort to determine the exact causes of these
patterns. London’s six wastewater treatment plants are highly controlled and regulated, and do not appear to be the main cause of the problem. As such, it is necessary to consider potential non-point sources such as impermeable surface area, construction erosion, and runoff from urban fertilizers. By paying attention to these regions of interest the City of London can make better decisions about what mitigation strategies to implement and where those strategies would have the most impact on resulting phosphorus concentrations.
REFERENCES


APPENDIX

Figure 1. Correlation between average annual raw (influent) phosphorus (mg/L ± SE) of wastewater treatment plants in London, ON and year. It is likely that a linear significant relationship exists (Pearson, \( r = 0.70; p < 0.01 \)).
**Figure 2.** Total effluent phosphorus (mg/L ± SEM) of wastewater treatment plants in London, ON. Different letters denote significant differences.

![Graph showing total effluent phosphorus](image1.jpg)

**Figure 3.** North, South, and Main branch of the Thames total phosphorus means (mg/L) from 1978 to 2017, graphed with Linear fit.

![Graph showing total phosphorus means](image2.jpg)

**Figure 4.** Mean total phosphorus (mg/L) across all Thames sampling points from 1978 to 2017, graphed with Linear fit.
Figure 5. Comparison of total phosphorus (mg/L ± SEM) for North, South, and Main branches of the Thames in 1980 versus 2017, showing significant reduction of total phosphorus over time in every case.

Figure 6. Average difference in total phosphorus (mg/L ± SEM) for the North branch route, calculated by subtracting downstream sites from upstream sites. Ordered from left to right with left being upstream inflow from the North branch and right being downstream outflow through the Main branch. Negative values indicate net reduction in total phosphorus between sampling locations, while positive values indicate net addition of total phosphorus.

Figure 7. Average difference in total phosphorus (mg/L ± SEM) for the South branch route, calculated by subtracting downstream sites from upstream sites. Ordered from left to right with left being upstream inflow from the South branch and right being downstream outflow through the Main branch. Negative values indicate net reduction in total phosphorus between sampling locations, while positive values indicate net addition of total phosphorus.
Figure 8. Average annual phosphorus concentrations (mg/L ± SD) in along the Thames tributary for the most recent 3 years. Red bars represent concentrations acquired at the Byron site (near London) and blue bars represent concentrations acquired from the mouth of the Thames River.

Figure 9. Boxplots showing total phosphorus concentrations during summer dry-weather period. B indicates Byron, S indicates Springbank, W indicates Wharncliffe. Group 1 samples were collected with the dam, while Group 2 were collected without the dam. (CH2M Hill Canada Limited, 2017)
Figure 10. Boxplots showing total phosphorus concentrations during summer wet-weather period. B indicates Byron, S indicates Springbank, W indicates Wharncliffe. Group 1 samples were collected with the dam, while Group 2 were collected without the dam. (CH2M Hill Canada Limited, 2017)

*Figures 11-18. IDW interpolations of total phosphorus concentration produced according to the Methods section above. These interpolations DO NOT SHOW change in true total phosphorus concentrations across an area. Realistically, the interpolation can only be applied to the extent of the river boundaries and would also need to consider direction of flow. However, these maps allow for easy visualization of relative TP concentrations by area, and easy comparison of concentrations and trouble-spots across years since the concentration classes are constant. It is also worth noting that, due to the quality of the reference maps and addresses used to produce the Sampling Point and WWTP point files, these points may have a relatively high spatial error.
*Figure 11.* Total phosphorus interpolation for 2010, interpreted according to section above.
*Figure 12.* Total phosphorus interpolation for 2011, interpreted according to section above.
Figure 13. Total phosphorus interpolation for 2012, interpreted according to section above.
*Figure 14. Total phosphorus interpolation for 2013, interpreted according to section above.
*Figure 15. Total phosphorus interpolation for 2014, interpreted according to section above.
*Figure 16.* Total phosphorus interpolation for 2015, interpreted according to section above.
*Figure 17. Total phosphorus interpolation for 2016, interpreted according to section above.
*Figure 18.* Total phosphorus interpolation for 2017, interpreted according to section above.
Figure 19. Sampling points projected onto Google Earth image of London, showing land use surrounding each location.

Figure 20. Average total phosphorus (mg/L) for Lake St. Clair Tributary stations 1-6 for past 3 years.