Monitoring to Quantify Phosphorous Loadings

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Introduction

The severity of Lake Erie’s current condition has led to programs nationally and bi-nationally including preparing a Canada-Ontario Action plan to target agreed 40% phosphorus reduction by year 2025. Identification and evaluation of possible sources of contaminants could be the first step for any action to be taken toward achieving this objective.

Water quality monitoring along different parts of Thames River is being done through traditional grab sampling methods or discrete data collection systems. It is realized that collected data can only be snapshots of the real situations. In other words, it may potentially miss the major events which can substantially influence the final nutrient loading estimations. This may include major rainfall events along with peak inputs from different contaminant sources.

Various major point and non-point sources affecting river water quality have been identified including wastewater treatment plants, urban storm water and runoff from agricultural lands. Bioavailable phosphorus was studied Maccoux et al. (2016) along with the total phosphorus across Lake Erie’s tributaries including the Thames River from 2009 to 2013 to ascertain the importance of bioavailable phosphorus on Lake Erie’s algal growth. According to this study, the Thames River and Grand River’s contribution of dissolved reactive phosphorus (4% for each) to Lake Erie is among the top four tributaries after Maumee River (20%) and Sandusky River (6%). With the availability of water quality data in Thames River branches (to 2017), a current study was initiated to investigate detail analysis on the spatial variation of DRP and TP, and possible relationships between these parameters.

Other attempts were made to better understand nutrient and sediment loadings, their fate and delivery across the river system. The Thames watershed with an area of 5692 square kilometers is one of the main basins draining to the Lake St. Clair. A recent study (Nürnberg and LaZerte, 2015) analysed 24 years (1986-2012) of river water quality and flow data from 83 sampling points and 26 flow monitoring sites located across the watershed from headwater to the mouth. They assessed 5 water quality parameters; i.e. Total Phosphorus (TP), Dissolved Reactive Phosphorus (DRP), sum of nitrates and nitrites, Total Nitrogen (TN) and Total Suspended Solid (TSS) at the request of Upper Thames River Conservation Authority. The results show a slight decrease in the temporal trend of Total Phosphorus for most of the sampling sites on the three branches of Thames River. No specific trend was found for other water quality parameters. These results do not clearly represent the existing water quality conditions of Lake St. Clair and Lake Erie such as growing algae blooms resulting from nutrient inputs especially of total phosphorus from different sources including Thames River watershed during last two decades. The following uncertainties could be considered to interpret findings of this study.

- “Substantial nutrient and sediment loading may be contributed from extreme high flow events which could not be captured by current monitoring programs. Therefore the collected water quality samples might not be representatives of real condition of the watershed. Types and spatial distribution of flow monitoring stations play an important role on the results. For example, the availability of accurate and consistent long term water quality and flow data close to the mouth can provide more realistic information for the computation of nutrients and sediment loadings.”
- “Decreasing agricultural areas as a result of urbanization during last few decades may have caused less phosphorus discharge to the river. At the same time increasing chloride content of river water may be a result of salted storm water draining from more development of urban areas and highways.”
- “Recent water quality restrictions through the enforcement of government regulations on reduction of phosphorus used in fertilizers and detergents may also be an important factor for decreasing phosphorus content of river flow.”

The City of London has monitored the Thames River water quality since 1963. The monitoring program covers the three branches of the river around the city; i.e. North, South and Main Branches. Water quality parameters measured in the Thames River at 10 locations include: biochemical oxygen demand (BOD), pH, temperature, dissolved oxygen, total phosphorous, ammonia, bacteriological quality, suspended solids, chlorides, nitrates, nitrites, conductivity and some heavy metals. This monitoring program is based on weekly and monthly grab sampling. A more intensive monitoring program including real time continuous monitoring would capture important rainfall events to identify peak loading in the river.

The Great Lakes Nutrient Initiative (GLNI) included tributary loadings using an extensive water quality monitoring program in some of the main tributaries of Lake Erie for three years; i.e. 2012-2014 (Dove et al. 2015). The Thames, Sydenham and Grand Rivers were included in this study. Based on the objectives of the program, monitoring was carried out close to the outlet of each river basin, near reliable flow gauge sites, so that water quality results could be combined with robust stream flow measurements for the computation of loadings. In addition to a weekly grab sampling program, automated ISCO samplers were installed at the outlet of each of these tributaries taking one sample every 8 hour with weekly collection for lab testing. In this way, both low flow and high flow samples were obtained. This has proven to be an efficient method for obtaining information about all stages of the hydrograph and in all seasons. Water quality parameters monitored in this project were total phosphorus (unfiltered), total phosphorus (filtered), soluble reactive phosphorus (filtered), nitrate plus nitrite (filtered), ammonia (filtered), total Kjeldahl nitrogen (filtered), total suspended solids, and major ions (fluoride, chloride and sulphate). The annual loading of nutrients was calculated based on the Beale’s ratio. In this method, loadings are calculated as the product of the total annual stream flow and the ratio of mean daily load and mean daily stream flow, with a correction for statistical bias. Monitoring temporarily ceased at the Thames and Sydenham Rivers, however information was captured about water quality. The study showed that approximately 80% of the phosphorus loading appears to be delivered during runoff events. Sampling efforts should be directed toward capturing runoff events for which continuous monitoring such as automated sampling might be an effective method. This study also showed that water quality monitoring programs with limited grab samples such as Provincial Water Quality Network underestimate nutrient loading.

The Ministry of Environment and Climate Change (MOECC) (2012) in collaboration with a number of partners across Ontario has conducted an intensive water quality monitoring program for over 40 years for physical, chemical and biological water quality parameters such as phosphorus. The comparison of annual average concentrations of total phosphorus (TP) for 30 selected watersheds showed that the highest value of TP occurs in southern Ontario rivers, including the Thames River, with a level of 0.088 mg/l. This exceeds the interim Provincial Water Quality objective of 0.03 mg/L. The purpose of the monitoring program is to determine the nature and causes of water quality impairment of our water resources over the long term. Depending on the specific purpose of monitoring, different samplings methods are adopted. A substantial part of this monitoring program is based on the monthly grab sampling technique during the ice-free period. In some cases the automated ISCO sampling procedure is used in order to overcome the limitation of grab samples to represent extreme rainfall events. Although the long term results shows a general phosphorus reduction in some streams, a recent study on streams in an agricultural watershed in southwestern Ontario found that nutrient levels have not dropped compared to 40 years ago, indicating a need for continued efforts to control sources of phosphorus in these watersheds. Therefore more work needs to be done to collect additional information in support of source protection planning focusing on continuous
monitoring with updated innovative techniques to assess the impact of programs to reduce loadings to Lake Erie.

The total phosphorus loading to the Hamilton Harbour from four different watersheds for the period of July 2010 till May 2012 was studied by Long et al. (2015). They used Teledyne ISCO (Model 6712) automatic water sampler equipped with a water level bubbler module (Model 730) as well as power and telephone connections to permit remote programming of samplers and data downloads from weather instrumentation. In this study 87 24-hour periods during rain events, spring freshet, or base flow were sampled at the four monitoring stations. Water level data were collected in 15-minute intervals and were used for triggering the sampler during an event, as well as for post-event sample processing. For each station and event, 1-L water samples were collected hourly for 24 h which, during rain events, which was generally enough time to capture the rising limbs as well as the peak and falling limbs of the hydrograph. The results of this study show that daily TP loads varied by three orders of magnitude between wet and dry conditions, with storm events driving peak daily loads in the urban watersheds, and spring freshet in the agricultural and wetland influenced watersheds. By increasing the resolution of TP loads estimate from the tributaries, water managers are able to more fully understand the seasonal and event-based loading patterns in each watershed and impacts of action plans to reduce TP.

Standard criteria for design of water quality monitoring programs, including river water monitoring, have been proposed by Carter and Dimple (2015) to ensure that the selected locations and sampling procedure are representative of the conditions in the rivers or streams. For example, the distance between the selected sites from the downstream of a point source should be enough to ensure the complete mixing of river flow. Initially, multiple sampling across the site and different depths might be required to ensure the site is representative. The number of samples and duration vary depending upon the objectives of the program; i.e. baseline, management or project. Continuous monitoring is often an effective means of understanding the processes.

Method

Available water quality and flow data collected by different organizations (Environment Canada, MOECC and UTRCA) across Thames River’s branches during recent years were used. These data were analysed to investigate possible spatial trends between different water quality parameters for better understanding of Thames River water quality processes. The following is a brief description of the data used in this study.
<table>
<thead>
<tr>
<th>Site Name</th>
<th>Location</th>
<th>Data Types</th>
<th>Duration</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorndale</td>
<td>North Branch</td>
<td>TP, DRP &amp; Flow</td>
<td>2003-2015</td>
<td>MOECC &amp; UTRCA</td>
</tr>
<tr>
<td></td>
<td>U/S of Fanshawe Dam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>D/S of Fanshawe Dam</td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

At the Thorndale site located upstream of Fanshawe dam, the Ministry of Environment and Climate Change collected data (47 samples) of TP and DRP for the period of 2003-2015 (13 years) which were analysed in this study. The City of London initiated measurement of Dissolved Reactive Phosphorus across Thames River in August 2015 due to the role of the reactive component of phosphorus on growth.
of algal blooms in The Thames River and Lake Erie. The ratio of DRP and TP has been identified by various studies as an important indicator of characteristics of different sources contributing to water quality of rivers (Maccoux et al. (2016) and Scavia et al. (2014)). Based on Maccoux et al. (2016), since DRP is not routinely reported for point sources, they applied a ratio of DRP to TP to estimate DRP values. Based on data from several Midwestern U.S. municipalities, it has been determined that DRP accounts for approximately 70% of TP in municipal point source effluent; this relatively high ratio is due to the high biological activity of effluents (Dolan and Chapra, 2011, quoted in Maccoux et al. (2016)). This could be a valuable approach to improve water quality monitoring processes. In other words, with an established and reliable ratio of DRP to TP for a specific section of the river system, it will be possible to estimate TP with known values of DRP. This may also be a significant step in advancement of continuous water quality monitoring by employing online measurement technique of DRP which enables indirect estimation of TP. In this study the trends of DRP/TP along Thames River branches have been evaluated. In addition, in spite of data limitation average daily total TP loadings upstream and downstream of Fanshawe dam including very few high flow events have been compared.

**Results and Discussion**

Comparison of the TP concentration and average daily TP loadings of the North branch in Highbury and Thorndale during 2003-2015 are shown in Table 2.

**Table 2: Statistics of TP concentration and average daily TP loading at Highbury and Thorndale sites.**

(2003- 2015)

<table>
<thead>
<tr>
<th>Flow (m³/s)</th>
<th>Highbury - all data for 2003-2015</th>
<th>TP Concentration (mg/L)</th>
<th>TP Loading (kg/d)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Highbury</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thorn-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of Records</td>
<td>47 46</td>
<td>329 329 329 47 46 47 46</td>
<td>43</td>
</tr>
<tr>
<td>Average</td>
<td>39 25</td>
<td>0.115 21 272 0.07 0.11</td>
<td>700 295 123</td>
</tr>
<tr>
<td>Median</td>
<td>7 7</td>
<td>0.09 7 60 0.051 0.10 20</td>
<td>47 19</td>
</tr>
<tr>
<td>Max</td>
<td>391 147</td>
<td>1.26 212 3872 0.371 0.350</td>
<td>12277 2254 1216</td>
</tr>
</tbody>
</table>

* All TP loading data (kg/d) of Highbury and Thorndale which are either at the same date or the closest date to each other

** Selected data (i.e. excluding 4 extreme events at Thorndale site (TP loadings of 12277, 6081, 4940 and 4286 kg/d)
*** TP Concentration (mg/L), all data of Highbury and Thorndale sites which are either at the same date or the closest to each other

**** All TP and corresponding flow data at Highbury site for 2003-2015. The number of available TP data (329) at Highbury are much more than the number of TP data (47) at Thorndale in the same time period

***** Maximum values corresponding to collected water quality data at both sites

NB - Maximum in all flow data (4509 records) for Thorndale and Highbury sites are 766 m³/s and 442 m³/s respectively.

Table 2 shows that average TP concentrations at Highbury and Thorndale sites are 0.11 mg/L and 0.07 mg/L respectively or 57% higher at Highbury. Whereas average daily TP load at Thorndale (700 kg/d) is 137% greater than at Highbury (295 kg/d). TP daily loading is product of concentration and corresponding average daily flow for each site. These two different trends may primarily look to be contradictory. Following analysis will explain more on the discrepancies in this process. Figures 1 and 2 (in Appendix A) illustrate the time series of TP concentrations and TP average daily loadings respectively for these two sites. Based on Figure 1, although the average TP concentration in Highbury is 57% more than Thorndale, distributions of TP concentrations in both sites are fairly uniform. Whereas, Figure 2 shows that very high TP loadings in 4 extreme flow events at Thorndale has dramatically changed TP loading data distribution, leaving the remaining data points at the bottom of the graph. This phenomenon has been shown in Figures 3 to 6, Appendix A, illustrating monthly TP loadings time series and corresponding hydrographs of these 4 extreme events at both sites. In this study the important role of such extreme flow events on TP loading estimates can be realized by finding out that 84% of the TP loading at Thorndale occurred during these four extreme events. Possible reasons for such discrepancies could be related to Fanshawe dam as an impounded area which may change outgoing water quality parameters as a result of particulate deposition. Fanshawe dam’s modifying function also affects the river flow downstream compared with upstream. Maximum average daily flow rates for the sampling dates (47 records) in Thorndale and Highbury sites are 391 m³/s and 147 m³/s respectively, and maximum recorded average daily flow rates during study sampling period; i.e. 2003-2015 (391 records) for Thorndale and Highbury are 766 m³/s and 442 m³/s respectively. Although this may also indicate the general expectation that TP concentrations can be greater in higher river flow rates, however higher average TP concentrations at Highbury with lower peak flows compared with those of Thorndale may be related to the impoundment loading from Fanshawe Dam Lake. According to Nürnberg and LaZerte (2015) different approaches estimated an internal TP load for Fanshawe Lake of 4-16% of the long-term annual load downstream. However, the results of this study showed that for the period of data used, TP loading values in upstream is 137% greater than downstream. This may be partially related to the difference in the average daily flow data of the two sites due to non-simultaneous flow records; i.e. 39 m³/s in Thorndale and 25 m³/s in Highbury, see Table 2. Whereas long record of availability of additional consistent TP concentration data in Thorndale would increase understanding the process of phosphorus transport across this section of Thames River’s North Branch. The number of TP concentration data points at Highbury site for the study period (2003-2015) is 329 or 1 in every 2 weeks and for Thorndale site is 47 or 1 every three months. Only 6 out of 47 have been recorded on the same days at the two locations as indicated in Figures 1 and 2. Non-matching Highbury TP concentration data (47-6=41) on these Figures are the nearest dates for Thorndale TP concentration data dates. In other words the remaining TP concentration data of Highbury site; i.e. 329-46= 283 data have not been included in these Figures.

Spatial variations of the ratio of DRP to TP across Thames River branches as well as upstream and downstream of Fanshawe dam located in the north branch were analyzed. Correlation coefficients of DRP
and TP ratios for monitoring sites of Thames River’s North, South and Main branches for the period of their available data are shown in Table 2 and Figures 7-19, Appendix A.

Table 3: Statistics of water quality parameters (DRP/TP ratios) of three branches of Thames River

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Number of Data</th>
<th>(DRP vs TP)</th>
<th>R² Value</th>
<th>Equation of Best fit Line</th>
<th>Data Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorndale</td>
<td>47</td>
<td>0.52</td>
<td>0.82</td>
<td>y = 0.52x - 0.01</td>
<td>2003-2015</td>
</tr>
<tr>
<td>Highbury</td>
<td>65</td>
<td>0.7</td>
<td>0.94</td>
<td>y = 0.7x - 0.02</td>
<td>Aug 2015- Oct 2017</td>
</tr>
<tr>
<td>Richmond</td>
<td>68</td>
<td>0.63</td>
<td>0.93</td>
<td>y = 0.63x - 0.02</td>
<td>Aug 2015- Oct 2017</td>
</tr>
<tr>
<td>Dundas</td>
<td>58</td>
<td>0.57</td>
<td>0.85</td>
<td>y = 0.57x - 0.01</td>
<td>Aug 2015- Oct 2017</td>
</tr>
<tr>
<td>Whites</td>
<td>61</td>
<td>0.33</td>
<td>0.68</td>
<td>y = 0.33x - 0.002</td>
<td>Aug 2015- Oct 2017</td>
</tr>
<tr>
<td>Adelaide</td>
<td>67</td>
<td>0.37</td>
<td>0.72</td>
<td>y = 0.37x - 0.003</td>
<td>Aug 2015- Oct 2017</td>
</tr>
<tr>
<td>York</td>
<td>70</td>
<td>0.33</td>
<td>0.62</td>
<td>y = 0.33x + 0.001</td>
<td>Aug 2015- Oct 2017</td>
</tr>
<tr>
<td>Wharncliffe</td>
<td>70</td>
<td>0.48</td>
<td>0.72</td>
<td>y = 0.48x - 0.01</td>
<td>Aug 2015- Oct 2017</td>
</tr>
<tr>
<td>Suspension</td>
<td>68</td>
<td>0.57</td>
<td>0.78</td>
<td>y = 0.57x - 0.02</td>
<td>Aug 2015- Oct 2017</td>
</tr>
<tr>
<td>Byron</td>
<td>71</td>
<td>0.51</td>
<td>0.73</td>
<td>y = 0.51x - 0.01</td>
<td>Aug 2015- Oct 2017</td>
</tr>
<tr>
<td>Komoka</td>
<td>57</td>
<td>0.45</td>
<td>0.59</td>
<td>y = 0.45x - 0.01</td>
<td>Aug 2015- Oct 2017</td>
</tr>
</tbody>
</table>

The DRP/TP ratios in the North branch are relatively high (ranging 0.57-0.7) compared with other branches and its values are decreasing as the river enters the city. On the other hand DRP/TP ratios in South branch are lower compared to the North branch (ranging 0.33 – 0.37) and it stays almost unchanged. The ratios of DRP/TP in the Main branch are basically lower than North branch and higher than South branch (ranging 0.45-0.57). Correlation coefficient R² values in this analysis are high in the North branch (0.85 – 0.94) compared with South (0.62 – 0.72) and Main (0.59 – 0.78) branches.

Comparison of recent data of DRP/TP ratios from the two sites in Thames River’s North branch; i.e. Highbury (2015-2017) in downstream and Thorndale (2003-2015) in upstream of Fanshawe dam showed that the DRP/TP ratio for Highbury is about 35% higher than Thorndale (Figures 7 and 8). Although the time periods for the data used for this comparison for these two sites are not the same, they are close enough for the purpose of this study. The increase in the ratio of DRP/TP at Highbury could be related to Fanshawe dam impounded and the presence of zebra mussels contributing to nutrients on the bottom of the reservoir.

The ratio of DRP/TP from Highbury moving downstream to the forks (Dundas) has a decreasing trend.

The cost of a continuous monitoring site and equipment has been estimated at $46,000. The maintenance of the equipment to obtain reliable online data would require personnel able to troubleshoot and repair/replace chemicals in a timely manner and do calibrations and obtain samples for laboratory analysis.
checks. Without the maintenance system, data would not be reliable and not available for the peak flows
to determine loadings and provide feedback on reduction programs.

Conclusions and Recommendations

Long term (2003-1015) water quality data for Thames River’s North Branch collected by different
agencies were analyzed. Average daily TP loading at Thorndale site upstream of Fanshawe dam (700
kg/d) was 137% greater than at the downstream Highbury site (295 kg/d). Based on the used data set
substantial (84%) part of this high TP loading happened during 4 extreme flow events (see Table 2).
Similar results have been reported by Dove et al. (2015). Based on their findings approximately 80% of
the loadings appears to be delivered during runoff events which may not be captured with current grab sampling programs. Therefore, a high percentage of the sampling effort should be directed toward
capturing runoff events which may be accomplished through continuous monitoring programs. Outline of
a continuous monitoring program for Thames River is given in Appendix B.

The comparison of TP concentrations for upstream and downstream of the dam showed an increase of 0.04
mg/L or 57% at the downstream site. This may indicate the effect of impoundment as an additional source of
nutrients affecting the water quality of the river at the downstream site.

Dissolved reactive phosphorus (DRP) component of water quality has been recently focused on as an
important contributor to nuisance algae and cyanobacteria (Scavia et al. (2014). Therefore DRP values
along with TP data of all three branches of Thames River were also analyzed in this study. Using recent
water quality data of 2015-2017, the ratios of these two parameters at various monitoring sites across the
three branches of Thames River were computed. The ratios for the North branch are highest (ranging 0.57-
0.7), the South branch lowest (ranging 0.33-0.37) and main branch in the middle (ranging 0.45-0.57). The
DRP/TP ratio inputs from Adelaide (on the north branch) and Greenway (on the main branch) wastewater
treatment plants are included in this study. High DRP/TP ratio at Adelaide plant (0.77) is close to the higher
end range of incoming ratio (0.7) in the north branch and it may not substantially affect river water quality
considering very low plant flow rate (0.3 m³/s compared with the Thames River’s north branch long term
average flow rate of 20 m³/s) discharging to the river. DRP/TP ratio of Greenway plant (0.59) is slightly
higher than incoming ratio from Wharncliffe site (0.48) which may have minor influence on the water
quality downstream of main branch considering lower plant flow rate (1.5 m³/s compared with the main
branch’s average long term flow rate of 41 m³/s) discharging to the river. Implementation of a continuous
monitoring program would substantially improve the results of this analysis by capturing river water quality
data for runoff events.

The following options could be adopted to design a suitable continuous water quality program
recommended in this study.

- Established DRP/TP ratios combined with the available technology of near real-time monitoring
  of DRP which enable to measure TP concentration and loadings.
- ISCO samplers can also be independently used for short continuous measurement of TP and DRP;
  or
- The monitoring program can be designed to combine both methods if required.
• Do an assessment to ensure a representative sample location is obtained.

• Ensure technical capability/financing for the equipment maintenance and operation for accurate and reliable data.

Considering different practical challenges involved it would be recommended to start continuous monitoring with a pilot site with more controlled conditions for a limited period of time and plan to expand the monitoring network to ensure phosphorous reduction programs are attaining desired results (see Appendix B for costing information).
References


Appendix A

Figure 1: Comparison of temporal distribution of Total Phosphorus (TP) concentration at Highbury and Thorndale sites (2003-2015) –
Highbury (43.038006, -81.224540) and Thorndale (43.096, -81.168)

Note - The circles are the TP concentrations in the same days at the both sites
Figure 2: Comparison of temporal distribution of Total Phosphorus (TP) average daily loading at Highbury and Thorndale sites (2003-2015)

Note - The circles are the TP Loadings in the same days at the both sites.
Figure 3: A selected Thames River high flow hydrograph along with Total Phosphorus (TP) concentration data at Thorndale and Highbury sites (Mar-Apr 2005)
Figure 4: A selected Thames River high flow hydrograph along with Total Phosphorus (TP) concentration data at Thorndale and Highbury sites (March-Apr 2008)
Figure 5: A selected Thames River high flow hydrograph along with Total Phosphorus (TP) concentration data at Thorndale and Highbury sites (March 2013)
Figure 6: A selected Thames River high flow hydrograph along with Total Phosphorus (TP) concentration data at Thorndale and Highbury sites (March-Apr 2014)
Figure 7: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) at Thorndale site (2003-2015)

\[ y = 0.52x - 0.009 \]

\[ R^2 = 0.82 \]
Figure 8: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) in Thames River’s North branch, Highbury site (2015-2017)
Figure 9: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) at the outlet of Adelaide wastewater treatment plant, downstream of Highbury site (2015-2017) – (43.014165, -81.252803)
Figure 10: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) in Thames River’s North branch, Richmond site (2015-2017) - (43.014549, -81.268212)
Figure 11: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) in Thames River’ North branch, Dundas site (2015-2017) – (42.982290, -81.256805)
Figure 12: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) in Thames River’s South branch, Whites site (2015-2017) – (42.968617, -81.150141)
Figure 13: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) in Thames River’s South branch, Adelaide site (2015-2017) – (42.975301, -81.225807)
Figure 14: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) in Thames River’s South branch, York site (2015-2017) – (42.977321, -81.255891)
Figure 15: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) in Thames River’s Main branch, Wharncliffe site (2015-2017) – (42.980802, -81.262528)
Figure 16: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) from the effluent of Greenway wastewater treatment plant, downstream of the Wharncliffe site (2015-2017) – (42.976241, -81.282285)
Figure 17: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) in Thames River’ Main branch, at Suspension Bridge site (2015-2017) – (42.962344, -81.298768)
Figure 18: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) in Thames River’ Main branch, at Byron site (2015-2017) – (42.963030, -81.331907)

\[
y = 0.51x - 0.01
\]

\[
R^2 = 0.73
\]
Figure 19: The relationship between Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) in Thames River’ Main branch, at Komoka site (2015-2017) – (42.934779, -81.421519)
Appendix B - Budget

Based on the primary project requirement estimates, it is predicted that installation of 6 sites (2 for each branch of Thames River) would be sufficient for the purpose of water quality monitoring. The site selection for these sites may be finalized once more detailed information is available. The cost estimation for the project is based on the assumption that each site will be as an independent unit in terms of power needs, telephone connections to permit remote programming and data downloads as well as water level bubbler to collect water level data for triggering the sampler during a wet weather event. The costs used here are partly taken from a few manufacturers as approximates values and may be updated if required. The cost of the construction of a stand-foundation for the equipment housing may vary depending upon the condition of the selected site in terms of the stability of the ground and security considerations. Table 1 shows the detail of the project budget.

Table 4. Details of the project budget

<table>
<thead>
<tr>
<th>Item #</th>
<th>Item Name</th>
<th>Item Description / Model</th>
<th>Unit Price of the Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Foundation-Housing</td>
<td>As a supporting structure</td>
<td>$ 5,000</td>
</tr>
<tr>
<td>2</td>
<td>Power Supply – Solar System</td>
<td>An alternative source of power</td>
<td>$ 4,000</td>
</tr>
<tr>
<td>3</td>
<td>Data Logger HSPALink and accessories</td>
<td>Based on a recent quote from Hoskin Scientific Limited</td>
<td>$ 12,000</td>
</tr>
<tr>
<td>4</td>
<td>Water Level bubbler module (Model 730)</td>
<td>To be updated from the Teledyne</td>
<td>$ 2,000</td>
</tr>
<tr>
<td>5</td>
<td>Sensor YSI EXO or P 700 IQ Analyzer</td>
<td>Approximate estimate from the recent quote for the sensor</td>
<td>$ 15,000</td>
</tr>
<tr>
<td>6</td>
<td>Teledyne ISCO Model 6712 Sampler</td>
<td>To be updated from the Teledyne</td>
<td>$ 5,000</td>
</tr>
<tr>
<td>7</td>
<td>Contingencies</td>
<td>Unpredicted expenses</td>
<td>$ 3,000</td>
</tr>
<tr>
<td>8</td>
<td>Operational costs</td>
<td>Equipment maintenance, Lab testing, data analysis and reporting</td>
<td>TBD – Depending on the period of operation</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>$46,000</td>
</tr>
</tbody>
</table>