Hutchinson

Environmental Sciences Ltd.

Lake of Bays Water Quality Report 2018

Prepared for: Lake of Bays Association
Job #: J100013

March 2019

Final Report

1-5 Chancery Lane, Bracebridge, ON P1L 2E3 │ 705-645-0021
Suite 202 – 501 Krug Street, Kitchener, ON N2B 1L3 │ 519-576-1711

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March, 2018 HESL Job #: J100013

Ms. Deb Cumming
Environment Committee
Lake of Bays Association
PO Box 8
Baysville, ON P0B 1A0

Dear Ms. Cumming:

Re: Lake of Bays Water Quality Report 2018

I am pleased to submit this final report for the Lake of Bays Water Quality Monitoring Program presenting the results of total phosphorus and bacteria sampling from the summer of 2018.

As in previous years, total phosphorus and bacteria levels were well below applicable Provincial guidelines indicating excellent water quality in 2018. Statistically significant trends in total phosphorus were recorded in the Deep Water stations since 2002, however our analysis suggest that these patterns are strongly correlated with natural regional precipitation patterns and in 2018 we have noted an overall decrease in TP concentrations.

I thank you and the Lake of Bays Association for the continued opportunity to assist with this project.

Sincerely,
per: Hutchinson Environmental Sciences Ltd.

Kristopher Hadley, Ph.D.
kris.hadley@environmentalsciences.ca

Signatures

Report prepared by:

Kristopher Hadley, Ph.D.
Aquatic Scientist

Neil Hutchinson, Ph.D.
Principal Aquatic Scientist

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1. Introduction

Since 2001, the Lake of Bays Association (LOBA) has championed a volunteer-based water quality monitoring program in Lake of Bays. The aim of the program is to characterize phosphorus and bacteria levels as an indication of general lake and watershed health and to compare different sites across the lake, while fostering community involvement and education.

Although LOBA had been monitoring spring turnover phosphorus levels as part of the Ministry of Environment's Lake Partnership Program, LOBA's independent monitoring program began with a pilot study in 2000 to monitor bacteria levels in the lake during the summer. This project was successful and deemed valuable and LOBA expanded the area of study in the summer of 2001 to include near-shore sites adjacent to developed and undeveloped properties and areas influenced by wetlands and rivers. In 2002, the program was again expanded to include monitoring of total phosphorus concentrations in near-shore areas and in the Hollow and Oxtongue rivers and river deltas (deep water sites were already being monitored). Site selection has changed as our understanding of water quality conditions in Lake of Bays has increased and, since 2009, sampling has focused on deep water sites, nearshore disturbed and undisturbed locations and our source water rivers.

The LOBA monitoring program continues to focus on total phosphorus concentrations. For recreational lakes on the Precambrian Shield like Lake of Bays, water quality concerns are most often associated with nutrient enrichment due to increased human phosphorus sources. Phosphorus is a natural element in the environment and enters lakes from the atmosphere through precipitation, from streams and overland flow, and to a lesser degree through groundwater. Human sources to recreational lakes include storm water runoff and erosion from altered land uses, fertilizers on manicured lawns and faulty septic systems. Increases in phosphorus loads to lakes from human sources can result in increased growth of aquatic plants and algae, which in turn can lead to a deterioration of water clarity and decrease deep-water oxygen concentrations that affect coldwater fish habitat.

Sampling frequency for bacteria (total coliform and *Escherichia coli*) was reduced to every other year from 2009 to 2013 because earlier monitoring results were very consistent between sites and years and near background levels. Previous monitoring reports have suggested that a reduction in bacteria sampling was warranted; beginning in 2016, it was recommended that sampling be conducted annually at the nearshore sites on one sampling event in mid-summer, and on all sampling events every five years thereafter. The reduced sampling frequency will continue to allow assessment of long-term trends, while increasing resources to expand the program to include other parameters of interest to the Association and maintaining familiarity with bacteria sampling techniques.

The program continues to demonstrate that Lake of Bays is a clear water lake with low phosphorus and bacteria levels and no obvious impact of development on water quality. In this report we present the results of the summer phosphorus monitoring completed by the LOBA in 2018 and discuss them in the context of long-term water quality data collected by the LOBA and local precipitation records.

2. Methods

Volunteers, coordinated by the LOBA Environment Committee, collected samples for analysis of total phosphorus on three occasions during the summer of 2018 (July 2, August 6 and 31) and on the same three dates for bacteria (*E. coli* and total coliforms). The sampling and analytical methods in 2018 were consistent with those used in previous monitoring years and are summarized below. Detailed sampling instructions that are provided to the volunteers are presented in Appendix A.

2.1 Sample Collection

Water samples for bacteria and total phosphorus were collected at 20 sites in Lake of Bays to include deep, open water locations ('Deep Water' sites, n=9), nearshore sites adjacent to developed ('Disturbed' sites, n=3) and undeveloped shorelines ('Nearshore Undisturbed' sites, n=5), and river (Oxtongue and Hollow rivers) and river-influenced (Oxtongue Delta) sites ('River' sites, n=3) (Table 1, Figure 1).

At each Deep Water site, a composite water sample was collected from the euphotic zone, at approximately two times the Secchi depth. At all other sites, the water sample was collected at a depth of ~30 cm. Six field duplicate samples for bacteria and 15 additional duplicates for laboratory analysis were collected in addition, seven field duplicate samples for total phosphorus were collected to assess the variability of results related to sampling and analytical procedures (Table 1).

Phosphorus samples were coarse-filtered using a filtered syringe in order to remove zooplankton (microscopic animals living in the water, such as water fleas) or other large debris that can contaminate the sample and result in non-representative, high phosphorus values (Clark et al. 2010). Samples were then directly poured into sampling containers with acid preservative, stored in a cool place and submitted for analysis to ALS Environmental Laboratory.

Table 1. 2018 Sampling Sites and Dates

Site Name	Total Phosphorus Sampling			Bacteria Sampling		
	2-Jul	6-Aug	31-Aug	2-Jul	6-Aug	31-Aug
Deep Water Sites						
Bigwin East	1	1	1	1	1	**2**
Dwight Bay	1	1	1	1	**2**	
Fairview	1	1	1	**2**	1	**2**
Gull Rock	1	2	2	**2**	2	2
Haystack Bay	1	1	2	1	**2**	3
Portage Bay		1	1	1	1	1
Price's Point	1	1	1	1	1	1
Ten Mile Bay	1	1	1	1	1	1
Trading Bay	1	1	1	1	1	1
Disturbed Sites						
Bigwin Bay		1	2	1	**2**	3
Bigwin North	1	1	1	1	1	1
Britannia	1	1	2	1	**2**	2
Nearshore Undisturbed						
Adamson's Island	1	2	1	1	2	**2**
Boothby's	1	1	1	**2**	1	1
Menominee Bay	1	1	2	1	**2**	3
Moffat's	1		1	1	1	1
Narrows West	1		1	1	1	1
River Sites						
Hollow River mouth*	1	1	1	**2**	1	1
Oxtongue Delta	1		1	1	1	**2**
Oxtongue River mouth*	1	1	1	1	1	1

Notes: 1 = single sample collected, 2 = field duplicate samples collected, **2** = Coliform Lab Duplicate; - = no sample collected; 3 = Lab and Field Duplicates, *Sampled in the mouth of the rivers just upstream of their discharge to the lake.

0 0.5 1 2 3 Kilometers

N

Legend

Rivers

Lakes

Sampling Stations

Project Lead: Kris Hadley
Prepared by: Kris Hadley
Data Source: HESL,Ontario Land
Coordinate System: NAD 1983 UTM Zone 17N

Figure 1:
Lake of Bays
Sampling Stations

Project: Lake of Bays Long-Term Monitoring Program

Project #: J100013

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2.2 Quality Control

2.2.1 Bacteria

Field duplicate bacteria concentrations were compared to assess variability in the results due to sampling and analysis by the Coliplate method.

In previous monitoring years, samples were also submitted to the Central Ontario Analytical Laboratory (COAL), an accredited laboratory in Orillia, Ontario, for membrane filtration analysis of total coliform and *E. coli* for comparison with the Coliplate method. COAL was not able to process the samples since 2017 and therefore membrane filtration analysis of total coliforms and E. coli are now performed by ALS Environmental.

2.2.2 Total Phosphorus

2.2.2.1 Field Duplicates

Duplicate samples were collected for 7 of the 53 samples. Bad splits in the LOBA dataset were identified for duplicate samples that were >35% different or had an absolute difference of >5 μg/L (Hyatt et al., 2012). If a bad split was identified, the higher of the two values was discarded.

2.2.2.2 Outliers

In relatively small datasets like the LOBA data set, the calculation of average total phosphorus concentration is sensitive to outliers, that is, extreme values that are not representative of the site condition. Rosner's ESD Many-Outlier Procedure (Rosner's Test; Rosner, 1983) was performed in the R statistical Software Environment V. 3.3.3, using the "rosnerTest" function of the "EnvStats" package (Millard, 2013), to identify outliers in total phosphorus concentrations collected since 2002 for each LOBA monitoring site. This procedure detects high and low extreme values and is not limited for multiple outliers.

Statistically significant outliers (at $p<0.05$) were removed from the dataset for further analyses (as detailed in Section 3.1.3) but will be re-evaluated each year as additional data are collected, as outliers may, over time, indicate a change to average conditions.

2.3 Data Analysis

2.3.1 Bacteria

Bacteria (*E. coli* and total coliform) levels were compared to the Provincial Water Quality Objectives (PWQO) for recreational water use (MOEE, 1994). The former benchmark for total coliform was 1,000 colony forming units (cfu) per 100 mL, based on a geometric mean for a series of water samples and is intended as a general guideline. Bacterial assessment of water quality should be based on more specific fecal bacteria indicators such as *E. coli*. The PWQO for *E. coli* is 100 cfu per 100 mL, based on a geometric mean of at least five samples taken from one site within one month. Where testing indicates sewage or fecal contamination, a site-specific judgment must be made as to the severity of the problem and the appropriate course of action.

2.3.2 Total Phosphorus

Mean total phosphorus concentrations were calculated for each site and site type for the 2018 monitoring period following the assessment of bad splits between duplicate samples and outliers.

Total phosphorus results were evaluated against the interim PWQO for phosphorus, which suggests average ice-free period TP concentrations should not exceed 20 μg/L in order to avoid nuisance algal growth and that maintaining TP concentrations at or below 10 μg/L provides protection against aesthetic deterioration (MOE 1994). Furthermore, excessive macrophyte growth in rivers and streams should be reduced below 30 μg/L of TP (MOEE, 1994).

Mann Kendall Trend analysis was performed using the “mk.test” and “sens.slope” functions of the “Trend” package in R (Pohlert, 2017) to assess any long-term changes in total phosphorus concentrations over time (2002-2018) for each site.

3. 2018 Monitoring Results

3.1 Quality Control

3.1.1 Bacteria

The quality control program of the Coliplate samples in 2018 provided a high degree of confidence in the sampling protocols and analyses for bacteria (Figure 2). The maximum differences between bacteria duplicates using the Coliplate method was 1 cfu/100 mL for *E. coli* and 30 cfu/100 mL for total coliforms. Pairwise testing of the Coliplate duplicate samples showed no significant difference ($p<0.05$). Lab results, based on the membrane filter technique, for E. coli also showed good agreement with values collected by the Coliplate method (Table 2), however lab data for total coliforms was significantly higher than those gathered using the Coliplate method (Table 2).

Figure 2. Comparison of field duplicate results for total coliform and *E. coli*, 2018

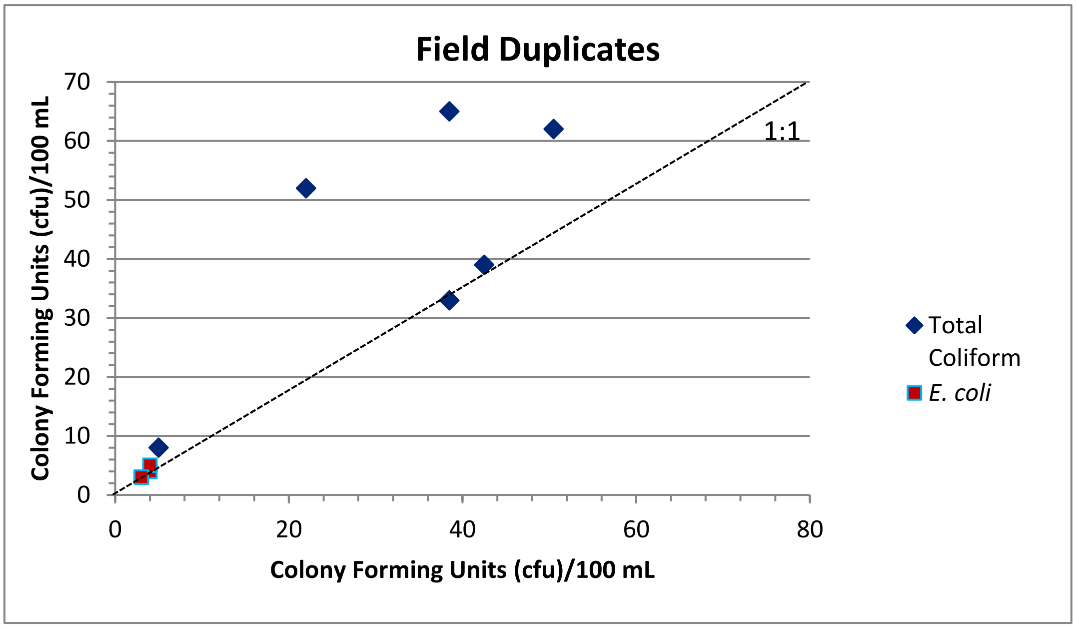


Table 2. Summary of E. coli and Total Coliform QA/QC samples 2018

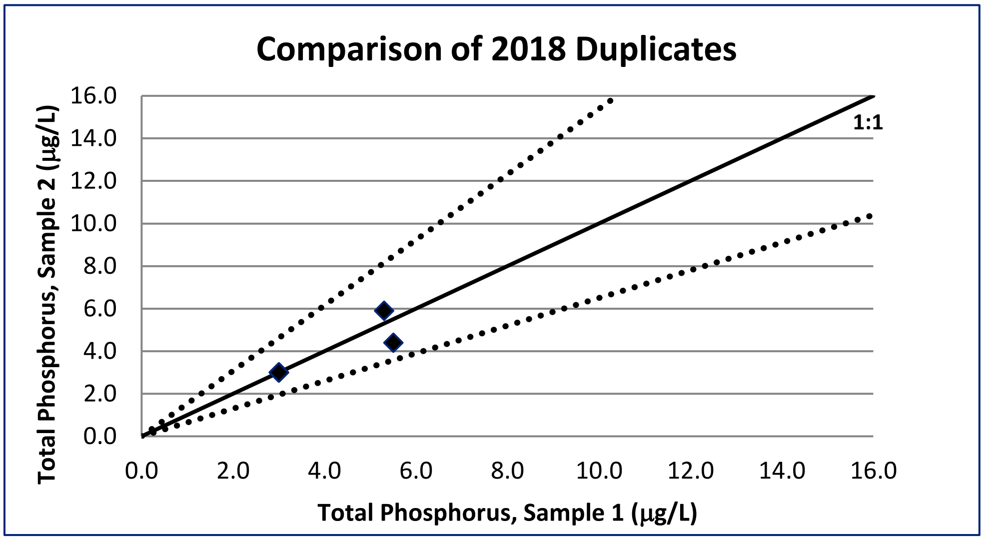
Site	E. coli Coliplate 1	E. coli Coliplate 2	E. coli Lab	Total Coliform Coliplate 1	Total Coliform Coliplate 2	Total Coliform Lab	Heterotrophic Plate Count (HPC)
	cfu/100 mL	cfu/100 mL	cfu/10 0 mL	cfu/100 mL	cfu/100 mL	cfu/100 mL	cfu/100mL
Adamson's Island	3	3		22	52		
Bigwin Bay	4	4	8	38.5	65	201	45
Bigwin East	3		2	43		83	92
Boothby's	5		34	16		201	16
Britannia	4	5	4	38.5	33	201	62
Dwight Bay	5		9	16		201	
Fairview	3		1	8		61	21
Gull Rock	3	3	0	5	8	38	43
Haystack Bay	3	3	3.5	42.5	39	96	64
Hollow River mouth	3	3	1.5	50.5	62	173	463
Menominee Bay	11		15	30		201	117
Oxtongue Delta	28		83	69		201	50

3.1.2 Total Phosphorus

3.1.2.1 Field Duplicates

In 2018, none of the field duplicates collected (n=7) were bad splits (i.e., 5 μg/L or >35% difference between sample pairs), down from 22% in 2017 (Figure 3). By contrast, the average annual proportion of bad splits in samples since 2005, when duplicate sampling began, is 13%. The decreased frequency of bad splits in 2018 is likely a result of a decrease in the overall number of duplicates sampled (7 sites in 2018 vs 22 in 2017) and new sampling protocols which included updated sampling equipment provided by ALS. Continued diligent compliance to and review of sampling protocols are necessary to ensure the integrity of the data.

Figure 3. Total phosphorus field duplicates in Lake of Bays, 2018.



Note: Dotted lines enclose 35% difference from the 1:1 line.

The mean difference between field duplicates after removing the bad splits was 0.2 μg/L in 2018, down from 0.9 μg/L in 2017 and 0.8 μg/L in 2015 and 2016, and 0.6 μg/L in all previous years (2005-2013). The values in 2018 are lower compared to those in the DESC dataset (0.7 μg/L) again this may be due to the change in sampling equipment (i.e., the filtered syringes) used to filter water sampling in the field.

3.1.3 Outliers

A total of 46 samples were identified as outliers in the LOBA dataset (excluding River sites) using the Rosner's Test, two of which occurred in the 2018 monitoring year (Table 4). Fewer outliers and bad splits (Section 3.1.2) in 2018 relative to 2017 suggests some improvement in sampling contamination, likely as a result of new field sampling equipment and techniques instituted as a part of this years change in analytical laboratories.

Table 3. Summary of Bad Splits between Total Phosphorus Field Duplicates in Lake of Bays, 2005-2018

Site	Date	TP1 (µg/L)	TP2 (µg/L)
Adamson's Island	1-Sep-06	7.7	4.1
	1-Sep-17	11.2	4.6
Bigwin East	20-Jul-14	6	9.5
Bigwin North	2-Sep-11	5.9	3.7
	4-Sep-15	4.5	8.7
	4-Aug-15	19.3	4
	14-Aug-16	5.9	3.5
Boothby's	23-Aug-15	5	2.1
	20-Jul-15	4.1	7.4
	1-Jul-16	8.7	3.3
Britannia	1-Aug-16	3.9	5.9
Dwight Bay	1-Sep-06	9.2	31.9
	4-Sep-15	7	4.4
	20-Jul-15	4.3	8.3
	14-Aug-16	11.2	7.3
Fairview	7-Aug-06	4.3	7.5
	14-Aug-16	3.7	10.2
Gull Rock	29-Jun-14	5.5	9
Menominee Bay	1-Sep-06	15.9	8.1
	1-Jul-16	4.8	3.1
Moffat's	4-Jul-05	5.7	4
	7-Sep-10	5.1	3.3
	18-Aug-13	4.1	6.1
	28-Aug-14	4.4	6.9
	23-Aug-15	3.9	1.8
Narrows West	23-Jul-07	8.2	4.1
	18-Jul-16	12.3	5.9
	3-Jul-17	12.7	6.2
	21-Aug-17	29.5	6.1
Price's Point	1-Aug-16	6.2	3.9
	23-Jul-17	8.5	5.4
Ten Mile Bay	14-Jul-08	4.7	6.9
	7-Sep-10	6.1	12.9
Trading Bay	17-Jul-06	7.3	4.5
	21-Aug-17	11.1	6.1

Note: Values in grey shaded cells were considered to be contaminated and were excluded from further analyses. Values in orange shaded cells were unusually low and therefore considered as suspect and excluded from further analyses.

Table 4. Outliers in the LOBA Dataset (2002-2018), Rosner's Test (*p* <0.01)

Row Labels	Date	TP (ug/L)
Adamson's Island	18-Jul-11	15.1
	31-Aug-12	7.9
	18-Aug-13	9.9
	18-Jul-16	8.9
Bigwin Bay	15-Jul-02	9.6
	20-Jul-14	10.1
	4-Aug-15	12.0
Bigwin East	28-Jun-15	18.1
Bigwin North	23-Aug-04	27.7
	6-Aug-07	97.7
Britannia	1-Sep-03	12.6
	1-Sep-05	9.4
	18-Aug-13	21.6
	28-Aug-13	13.3
Dwight Bay	23-Jul-17	14.3
	1-Sep-17	15.4
Fairview	31-Aug-07	12.5
	17-Jul-09	12.3
Gull Rock	14-Jul-03	16.9
Haystack Bay	6-Sep-04	74.0
	7-Aug-06	40.3
	17-Jul-09	57.7
	31-Aug-12	22.4
	28-Jun-15	14.6
	4-Sep-15	18.1
Hollow River mouth	19-Jul-04	25.1
	4-Jul-05	11.0
	14-Jul-08	10.1
	28-Jun-15	16.3
	18-Jul-16	13.3
	14-Aug-16	25.7
	1-Sep-16	18.3
Menominee Bay	4-Jul-05	11.0
	1-Sep-16	12.0
Moffat's	5-Aug-02	36.7
	6-Aug-07	15.1

Row Labels	Date	TP (ug/L)
	5-Aug-13	11.4
	18-Jul-16	17.2
Narrows West	4-Jul-11	11.4
	1-Aug-11	8.5
	4-Sep-15	8.9
	7-Aug-17	8.6
Oxtongue Delta	18-Jul-16	14.2
	3-Jul-17	11.4
Oxtongue mouth	19-Jul-10	13.8
	29-Jun-14	76.8
Portage Bay	20-Aug-12	61.3
Price's Point	2-Aug-10	12.7
	18-Jul-11	12.8
	2-Jul-18	102.0
	6-Aug-18	12.3
Ten Mile Bay	21-Aug-06	10.2
	29-Jun-14	10.3
	18-Jul-16	15.0
Trading Bay	19-Aug-02	17.7
	19-Jul-04	12.3
	1-Sep-16	15.8

With the addition of the 2018 data, three previously identified outliers were no longer considered to be extreme values and were added back to the data set for statistical analyses (Haystack Bay, TP = 14.1 µg/L on September 1, 2006; Fairview, TP = 10.4 µg/L on July 23, 2017; Ten Mile Bay = 9.5 µg/L on July 3, 2017).

Outliers were removed from all analyses in this report but will be reassessed each year as additional data are added to the dataset.

3.2 Bacteria

Bacteria levels in Lake of Bays on July 2, August 6 and August 21, 2018 were low at all deep water sites. Absolute and geomean bacteria counts were below the PWQO of 100 cfu/100 mL for *E. coli* and benchmark value of 1,000 cfu/100 mL for total coliform at all sampling sites (Table 5). Higher bacteria counts observed in the river-influenced and nearshore sites are to be expected given increased exposure to bacteria sources from wildlife and human activity, lower dilution and less time for assimilation or attenuation in comparison to the offshore deep water sites. Elevated concentrations of the heterotrophic plate count (HPC) noted at Hollow River mouth (Table 2) may be the result of an upstream landfill site but were not reflected in E. coli counts which are the primary indicator of water safety for recreational use and consumption (MOECC, 1994). HPC is not a health-based standard, E. coli concentrations remain below PWQO at all sites.

3.3 2018 Total Phosphorus Concentrations

Samples collected during the 2018 monitoring campaign were characterized by low phosphorus concentrations typical in oligotrophic, clear-water lakes on the Precambrian Shield. The summer total phosphorus concentrations of the Deep Water, Disturbed, and Nearshore Undisturbed sites ranged from 3.0 to 9.2 µg/L, with an overall mean concentration of 4.1 µg/L (Table 6). These values compare well with mean spring overturn concentrations of 3.9-6.9 µg/L measured in seven locations in Lake of Bays by the District of Muskoka's Program, which targets only deep-water sites. (http://www.muskokawaterweb.ca/lake-data/muskoka-data/lake-data-sheets/lake-of-bays).

River sampling sites were more phosphorus-enriched (mean TP = 8.9 µg/L), as would be expected given the higher concentrations of particulate matter and dissolved organic carbon typical in rivers. Mean summer total phosphorus concentration was less than the interim PWQO for phosphorus of 10 µg/L for the lake sites and of 30 µg/L for the river sites, suggesting a low risk of aesthetic deterioration due to nuisance aquatic plant growth (MOEE, 1994).

Total phosphorus concentrations consistently peaked at the Deep Water sites on the August 6 sampling event with the exception of Portage Bay and Trading Bay (Figure 4, Figure 8). Nearshore Undisturbed sites produced a similar pattern (Figure 5, Figure 8). We found no consistent pattern in total phosphorus concentrations for Disturbed or River sites (Figure 6, Figure 7, Figure 8). It is likely that variability between sampling events is driven by local factors, e.g., storm events, as has been observed in previous monitoring years (HESL, 2016 and 2018). There was no significant difference (Mann-Whitney test; p >0.173) in phosphorus concentration between the Nearshore Undisturbed (mean TP = 4.7 µg/L) and Disturbed (mean TP = 4.4 µg/L) sites suggesting that shoreline disturbance has had little impact on summer phosphorus concentrations.

Table 5. Average Summer E. coli and Total Coliform Concentration in Surface Water Collected by Coliplate Technique, 2018

Site	*E. coli* (cfu/100 mL)	Total Coliform (cfu/100 mL)
Deep water		
Bigwin East	3	23
Dwight Bay	4	15
Fairview	3	6
Gull Rock	3	8
Haystack Bay	3	39
Price's Point	3	37
Ten Mile Bay	3	11
Trading Bay	3	9
Portage Bay	4	17
Disturbed		
Bigwin Bay	4	33
Bigwin North	3	47
Britannia	4	31
Nearshore Undisturbed		
Adamson's Island	3	61
Boothby's	4	9
Menominee Bay	3	45
Moffat's	3	5
Narrows West	4	12
River		
Oxtongue Delta	10	30
Hollow River	12	97
Oxtongue River	9	25

Table 6. Total Phosphorus Concentrations (µg/L) in Lake of Bays, 2018

Site ID	Site Name	2-Jul	6-Aug	31-Aug	AVG	SD
Deep water		**3.5**	**5.3**	**3.8**	**4.2**	**1.5**
B1	Bigwin East	3.0	6.2	3.0	4.1	1.8
N1	Dwight Bay	3.0	5.0	3.0	3.7	1.2
B2	Fairview	3.0	4.9	3.0	3.6	1.1
N10	Gull Rock	3.0	5.6	3.0	3.9	1.5
E13	Haystack Bay	3.0	4.5	3.0	3.5	0.9
N26	Portage Bay		5.3	9.2	7.3	2.8
S3	Price's Point			3.9	3.9	
E30	Ten Mile Bay	3.3	5.2	3.0	3.8	1.2
E1	Trading Bay	6.2	5.6	3.0	4.9	1.7
Disturbed		**4.9**	**4.4**	**3.0**	**4.1**	**1.2**
B3	Bigwin Bay		3.7	3.0	3.4	0.5
B4	Bigwin North	3.0	5.1	3.0	3.7	1.2
N11	Britannia	6.7	4.5	3.0	4.7	1.9
Nearshore Undisturbed		**3.2**	**5.4**	**3.2**	**3.9**	**1.2**
S1	Adamson's Island	3.0	5.0	3.0	3.7	1.1
N24	Boothby's	3.0	6.1	3.0	4.0	1.8
S2	Menominee Bay	3.0	5.1	3.0	3.7	1.2
N13	Moffat's	3.0		4.2	3.6	0.8
E26	Narrows West	4.1		3.0	3.6	0.8
River		**9.3**	**8.3**	**8.9**	**8.9**	**1.9**
E18	Hollow River	6.4	7.4	11.4	8.4	2.7
N2	Oxtongue River	10.4	9.1	7.7	9.1	1.4
N30	Oxtongue Delta	11.2	8.5	7.7	9.1	1.8
				All sites	4.8	1.4
				All sites excluding River sites	4.1	1.3

An additional site at Portage Bay, initially sampled in 2012 to address concerns over potential water quality degradation following construction activities, has been maintained as a part of the LOBA sampling program. Mean total phosphorus concentration in Portage Bay ranged from 8.1 µg/L to 4.7 µg/L from 2013 to 2018, representing a decline from elevated concentrations observed in 2012 (mean TP = 9.6 µg/L) that were coincident with construction activities. The average value of 8.1 µg/l recorded at Portage Bay in 2017, was attributed to higher than average summer precipitation (442 mm) not long-term construction impacts and is supported by the lower summer precipitation (250mm) and TP concentration (7.3 µg/L) measured in 2018.

Figure 4. Total phosphorus concentrations in Lake of Bays 2018, Deep Water sites.

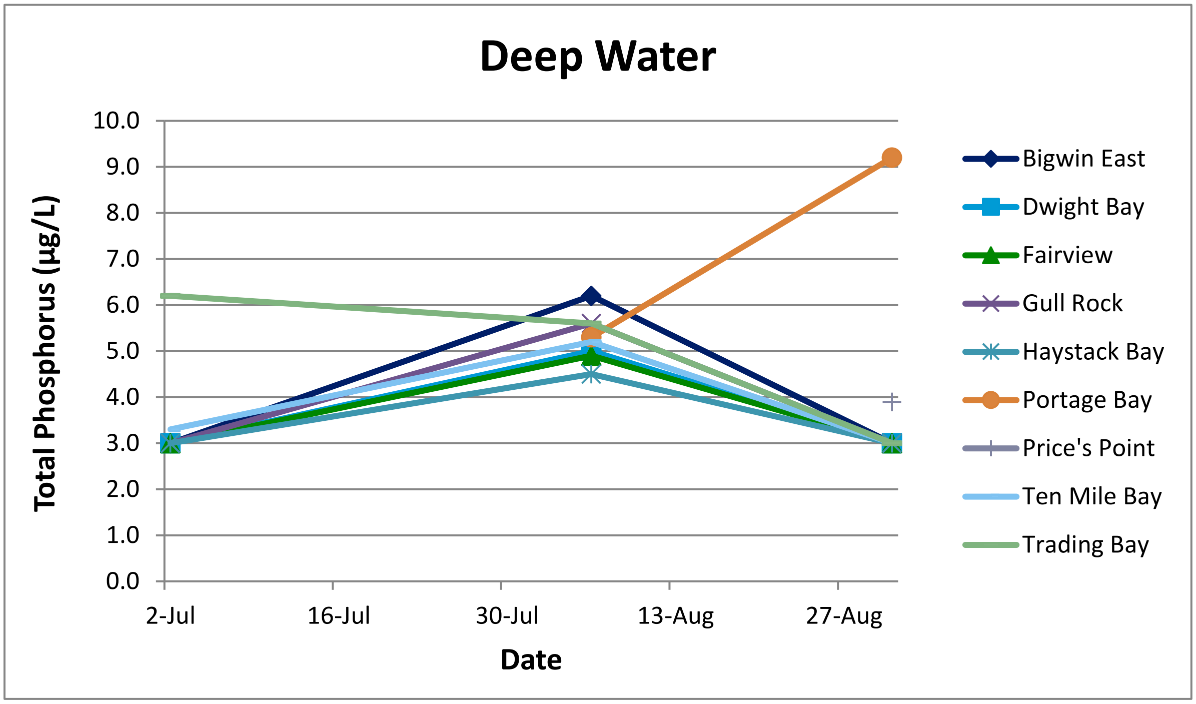


Figure 5. Total phosphorus concentrations in Lake of Bays 2018, Nearshore Undisturbed sites.

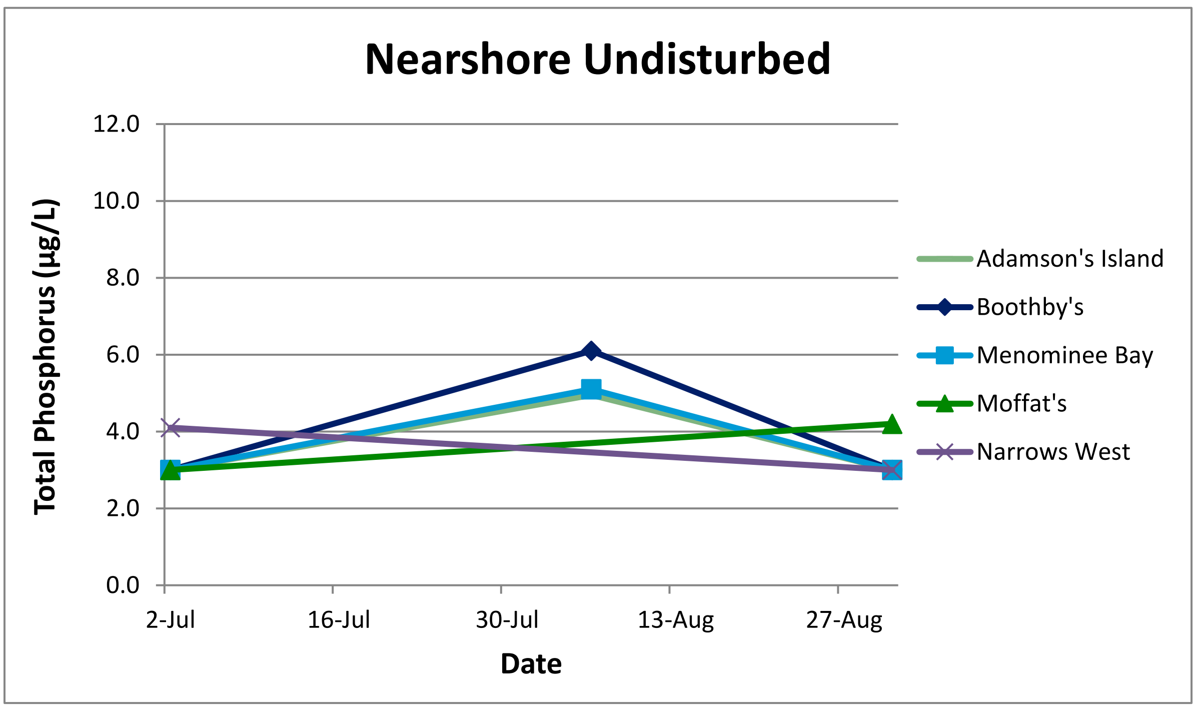


Figure 6. Total phosphorus concentrations in Lake of Bays 2018, Disturbed sites.

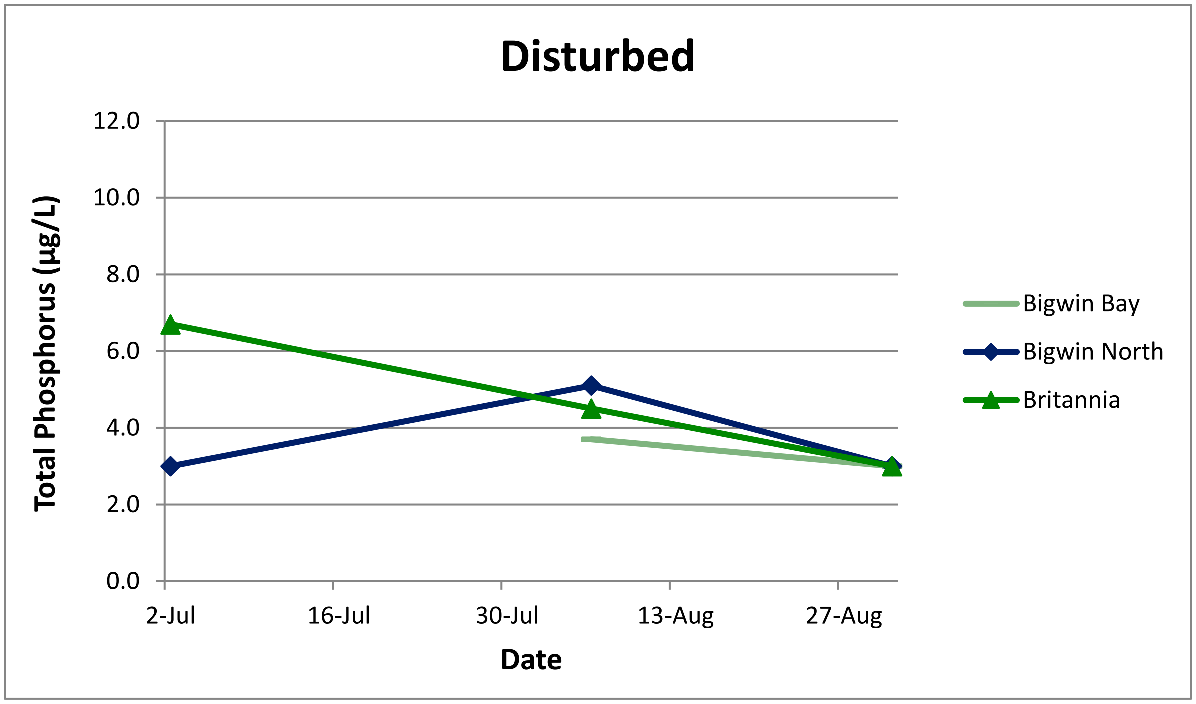


Figure 7. Total phosphorus concentrations in Lake of Bays 2018, River sites.

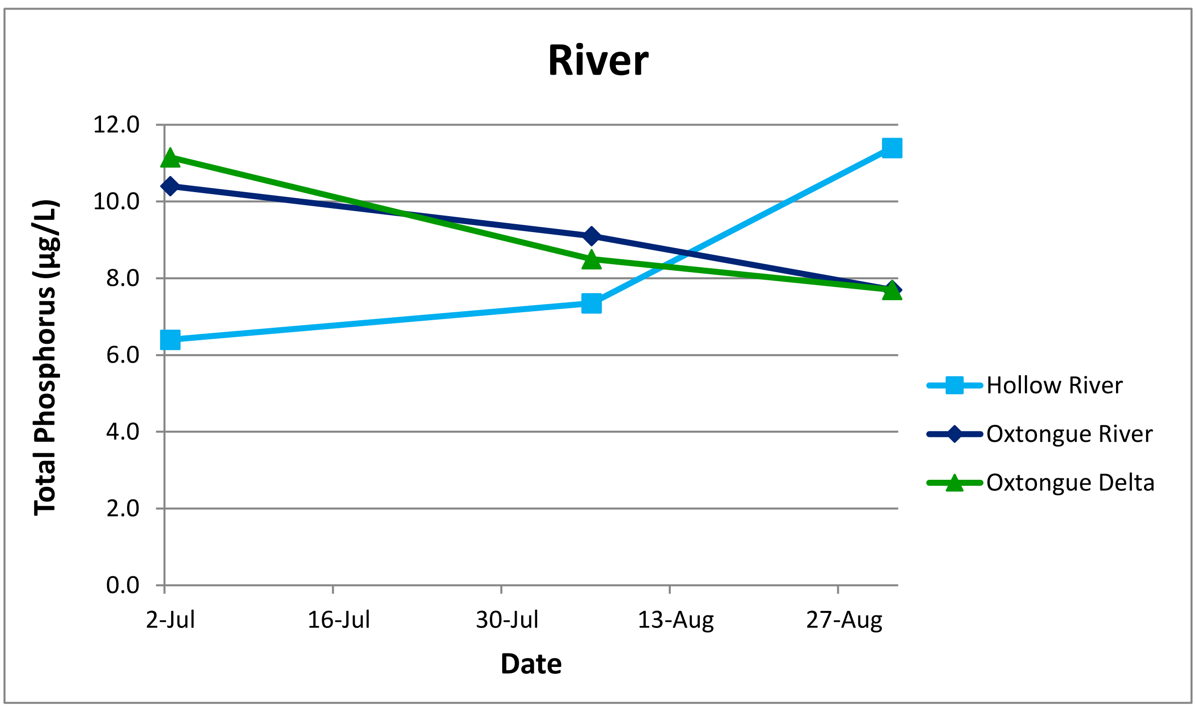
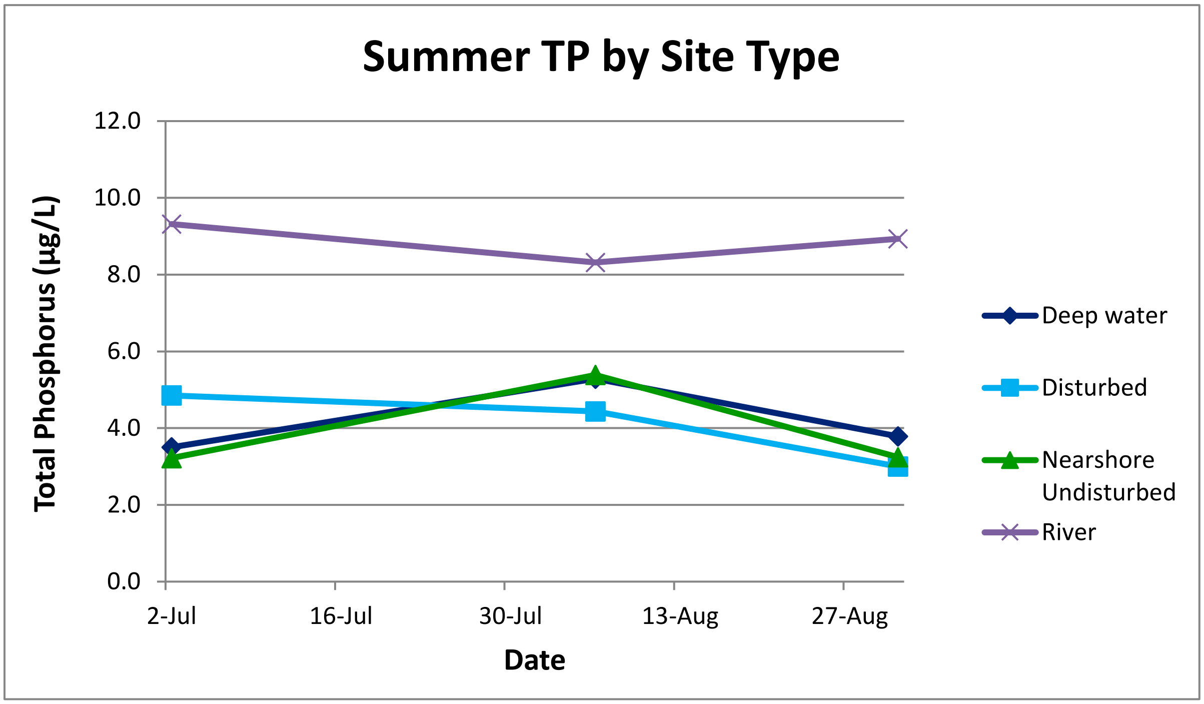


Figure 8. Total phosphorus concentrations in Lake of Bays 2018 by Site Type.



Note: Data points for each date represent mean values of all sites of one type.

4. Long-term Phosphorus Patterns

The Lake of Bays Water Quality Monitoring Program has collected data over the summer season for 17 years at 12-18 locations throughout the lake. The yearly number of samples collected including QA/QC samples ranged from 50 in 2002 to 123 in 2012, with a total of 1,614 samples collected by the end of the 2018 program (Table 7). The large number of sites monitored, and samples collected under the program since 2002 provide for a robust data set for assessing long-term trends and inter-annual variability in total phosphorus concentration in Lake of Bays. The complete LOBA monitoring program data set since 2002 is provided in Appendix B.

Mean summer total phosphorus concentrations decreased in 2018 in the Deep Water (mean TP = 4.2 µg/L), Disturbed (mean TP = 4.0 µg/L) and Nearshore Undisturbed (mean TP = 3.7 µg/L) sites (Table 8, Figure 9) relative to 2017 values. As is typical in the LOBA data set, the River sites have been more variable with generally higher concentrations that have ranged from 3.0 to 21.1 µg/L (mean TP = 10.4 µg/L).

Table 7. Number of Total Phosphorus Samples Collected by the Lake of Bays Monitoring Program (2002-2018)

Year	Deep Water	Disturbed	Nearshore Undisturbed	River	Total # of Samples
2002	30	15	5		50
2003	39	22	7	16	84
2004	28	13	5	7	53
2005	29	8	14	8	59
2006	53		21		74
2007	54	10	36	10	110
2008	48	13	32	15	108
2009	47	15	21	10	93
2010	46	15	29	16	106
2011	44	28	28	13	113
2012	51	26	31	15	123
2013	57	19	25	15	116
2014	53	16	32	18	119
2015	52	19	32	19	122
2016	52	14	30	16	112
2017	54	11	29	19	113
2018	29	7	15	8	59
Total # of Samples	766	251	392	205	1614

Table 8. Mean Summer Total Phosphorus Concentrations in Lake of Bays (2002-2018)

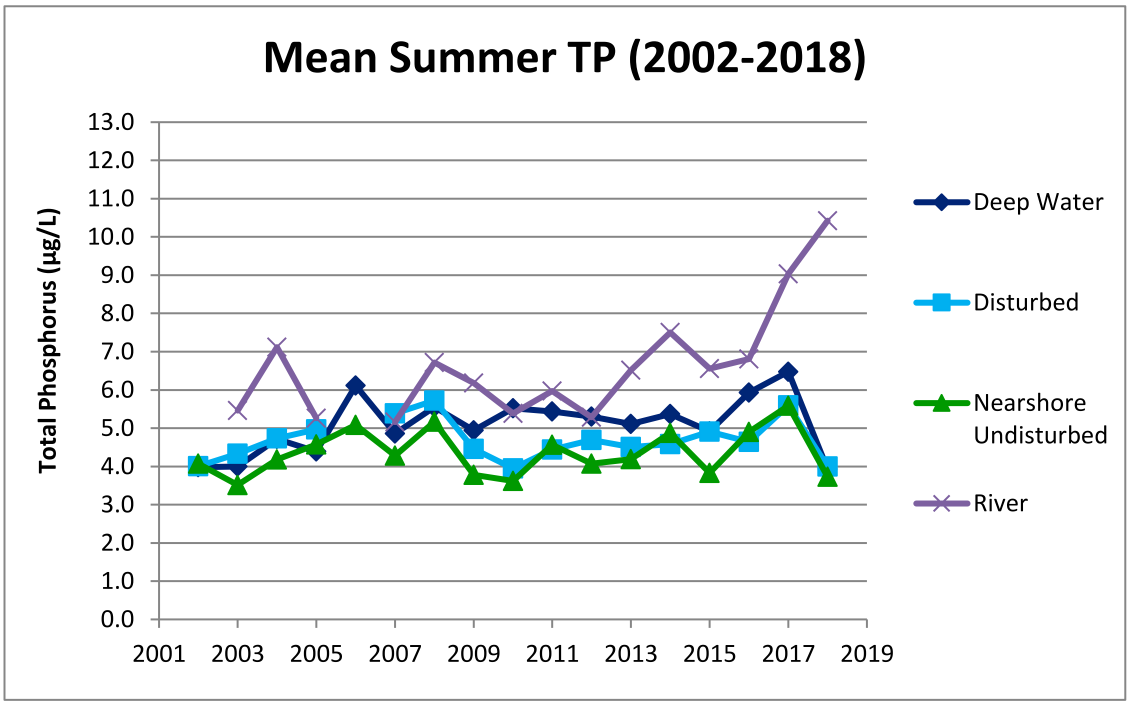
Site	Total Phosphorus (µg/L)																	
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	AVG.
Deep Water	**4.0**	**4.0**	**4.7**	**4.4**	**6.1**	**4.9**	**5.6**	**4.9**	**5.5**	**5.4**	**5.7**	**5.2**	**5.5**	**4.9**	**5.9**	**6.7**	**4.2**	5.1
Bigwin East	4.2	4.2	4.2	4.0	5.5	4.5	6.4	4.1	5.7	4.9	5.0	4.9	6.2	4.5	4.4	6.6	4.1	4.9
Dwight Bay	4.6	3.6	6.1	4.7	6.4	5.9	6.1	4.9	6.2	5.3	6.5	5.3	6.1	5.0	8.9	6.7	3.7	5.7
Fairview	2.8	3.6	4.0	4.7	5.3	3.9	6.1	4.6	5.2	4.9	4.7	4.5	4.8	4.4	4.1	6.7	3.6	4.6
Gull Rock	4.0	4.2	5.1	4.4	5.6	4.7	5.0	4.4	5.5	5.8	5.1	3.9	5.0	4.1	5.2	5.7	3.9	4.8
Haystack Bay	4.2	4.4	4.6		8.6	5.5	5.3	6.4	5.9	6.2	4.7	7.3	6.2	4.1	5.7	8.2	3.5	5.7
Portage Bay											9.6	5.7	6.3	4.7	5.3	8.1	7.3	6.7
Price's Point				3.4	6.0	4.5	4.7	5.7	5.2	5.5	4.5	5.8	4.5	4.0	5.7	5.3	3.9	4.9
Ten Mile Bay					6.1	5.0	5.5	4.8	5.2	5.1	6.8	5.7	6.5	5.1	7.3	6.4	3.8	5.6
Trading Bay	4.1	4.0	4.9	5.1	6.0	4.7	5.4	4.9	5.2	5.8	5.1	2.5	4.2	7.6	6.9	6.3	4.9	5.1
Disturbed	**4.0**	**4.3**	**4.7**	**5.0**		**5.4**	**5.7**	**4.5**	**3.9**	**4.4**	**4.7**	**4.5**	**4.6**	**4.9**	**4.6**	**5.6**	**4.0**	4.7
Bigwin Bay	3.6	4.7	4.9				5.5	4.2	3.6	4.5	4.5	4.5	4.3	4.8	4.3	5.4	3.4	4.4
Bigwin North	5.0	3.9	5.3	5.2		6.3	6.1	5.6	4.5	4.6	4.8	4.8	4.6	5.1	5.1	6.0	3.7	5.0
Britannia	3.3	4.4	4.0	4.6		4.7	5.5	3.6	3.8	4.2	4.8	4.1	4.8	4.9	4.5	5.5	4.7	4.5
Nearshore Undisturbed	**4.1**	**3.5**	**4.2**	**4.6**	**5.1**	**4.3**	**5.2**	**3.8**	**3.6**	**4.6**	**4.1**	**4.2**	**4.9**	**3.8**	**4.9**	**5.6**	**3.7**	4.4
Adamson's Island				4.8	4.7	3.3	4.5	2.9	2.8	4.2	3.9	4.0	4.2	3.5	4.3	4.8	3.7	4.0
Boothby's				8.3	5.8	5.2	5.4	4.3	4.6	4.8	3.9	4.3	5.0	3.7	5.3	6.0	4.0	5.0
Menominee Bay				3.1	5.0	3.9	6.0	3.1	2.9	4.9	3.7	4.3	4.8	3.7	5.7	5.7	3.7	4.3
Moffat's	4.1	3.5	4.2	3.7	4.9	3.8	5.2	4.8	3.6	4.6	4.5	3.9	5.5	4.1	3.8	5.5	3.6	4.3
Narrows West						5.1	4.7		4.3	4.0	4.5	4.5	4.9	4.4	5.4	6.0	3.6	4.6
River		**5.5**	**7.1**	**5.3**		**5.2**	**6.7**	**6.2**	**5.4**	**6.0**	**5.3**	**6.5**	**7.5**	**6.6**	**6.8**	**9.0**	**10.4**	6.6

Site	Total Phosphorus (µg/L)																	
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**AVG.**
Hollow River mouth		5.5	6.6	4.4		5.2	5.7		4.5	5.3	5.1	4.1	5.5	7.3	7.3	9.4	4.7	5.7
Oxtongue Delta							6.9	4.8	4.0	4.9	4.4	6.3	8.5	6.0	6.2	8.8	3.0	5.8
Oxtongue mouth			7.4	5.9			7.3	7.6	8.3	7.8	6.4	8.1	8.7	6.6	7.2	8.9	21.1	8.6

Note: Includes only those sites with at least three years of data collected within the last five years

A statistically significant increasing trend in mean summer total phosphorus concentration of the Deep Water sites[1] since 2002 was identified (Figure 10; Mann Kendall Trend Test: p<0.05, Sen's Slope = 0.098), including significant increasing trends of 0.012 and 0.019 µg/L/year at two individual Deep Water sites (i.e., Fairview and Trading Bay; Figure 11 and Figure 12). Bigwin East, Dwight Bay and Haystack were found to have a significantly positive increase in TP concentration between 2002 and 2017, however the addition of the 2018 data resulted in no significant trend (Figure 13 to Figure 15). Significantly increased TP was also observed at a single Nearshore Disturbed site (Britannia; Figure 16). The average increase in total phosphorus concentration for Deep Water sites was 0.098 µg/yr, representing a total increase of 37% or 1.66 µg/L over 17 years (based on the Sen's Slope of 0.098, p < 0.05). This degree of change exceeds what would be expected due to natural year to year variability for low productivity lakes on the Precambrian Shied, which have been found to vary naturally by an average of 21-23% between years (Clark et al., 2010).

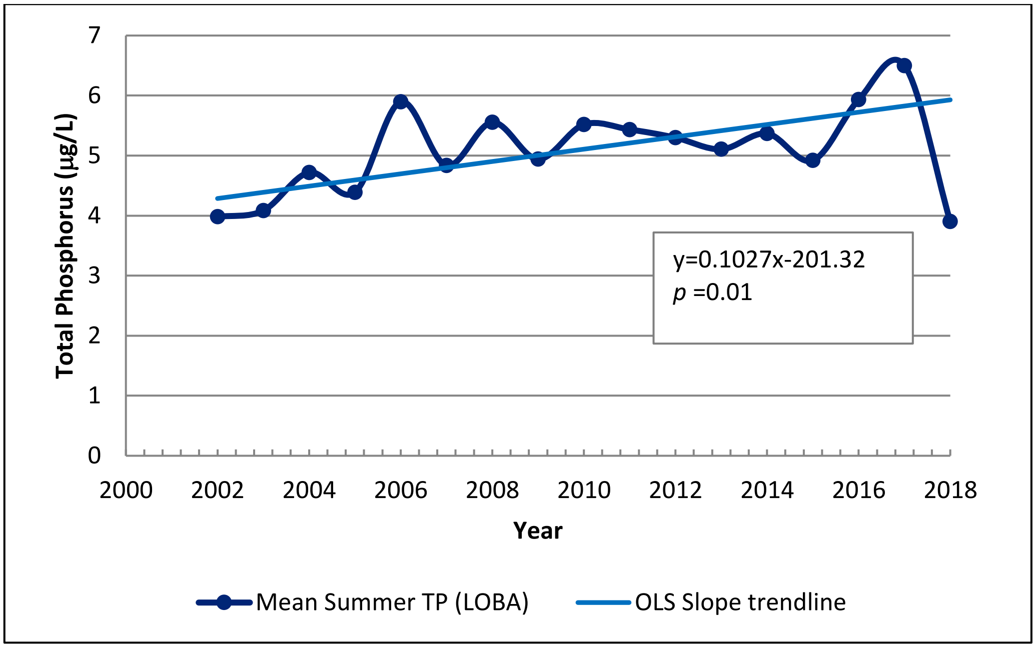
Figure 9. Long-term (2002-2018) mean summer euphotic zone total phosphorus (TP) by Site Type.



Note: Only includes sites with at least five years of data.

[1] *All data combined from eight Deep Water sites with at least five years of data.*

Figure 10. Long-term mean summer total phosphorus in Deep Water areas of Lake of Bays.



Note: LOBA sites exclude Little Trading Bay and Portage Bay.

Figure 11. Long-term Total Phosphorus Concentrations at the Fairview Station

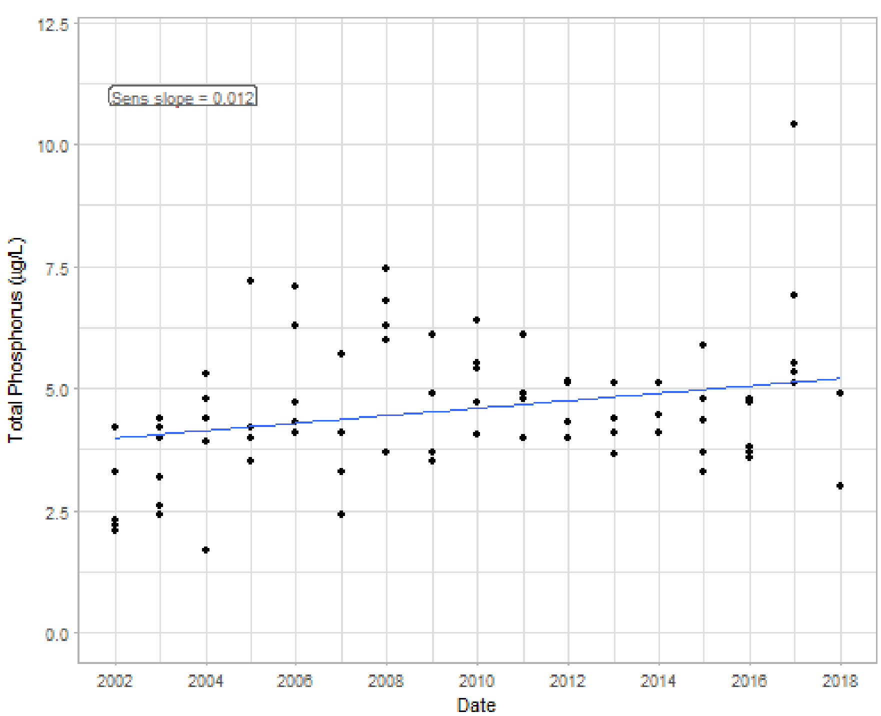


Figure 12. Long-term Total Phosphorus Concentrations at the Trading Bay Station

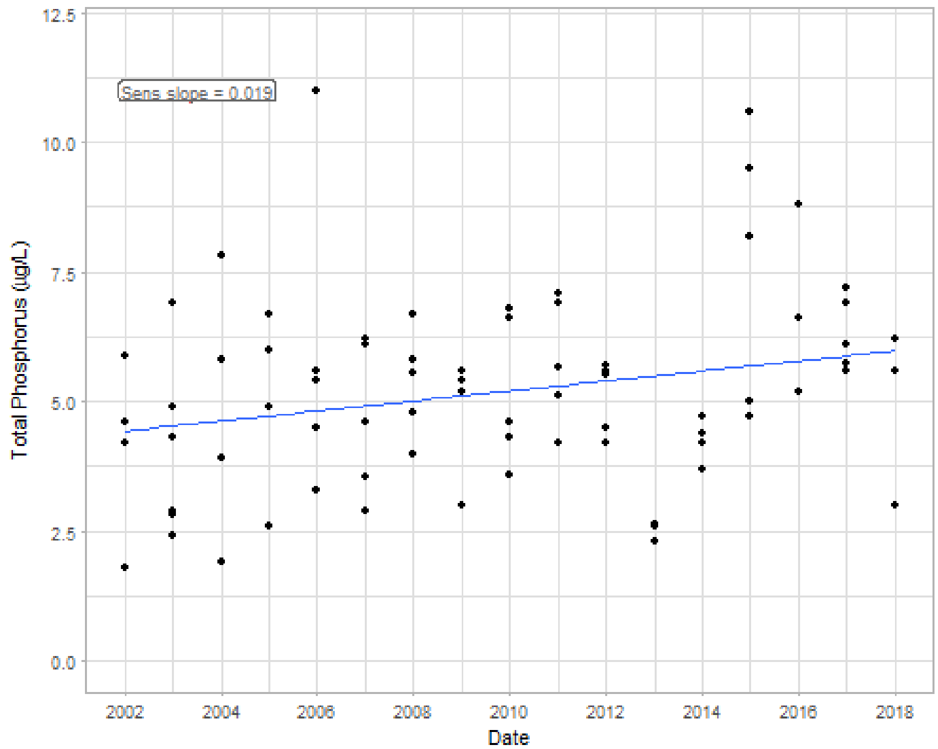


Figure 13. Long-term Total Phosphorus Concentrations at the Bigwin East Station

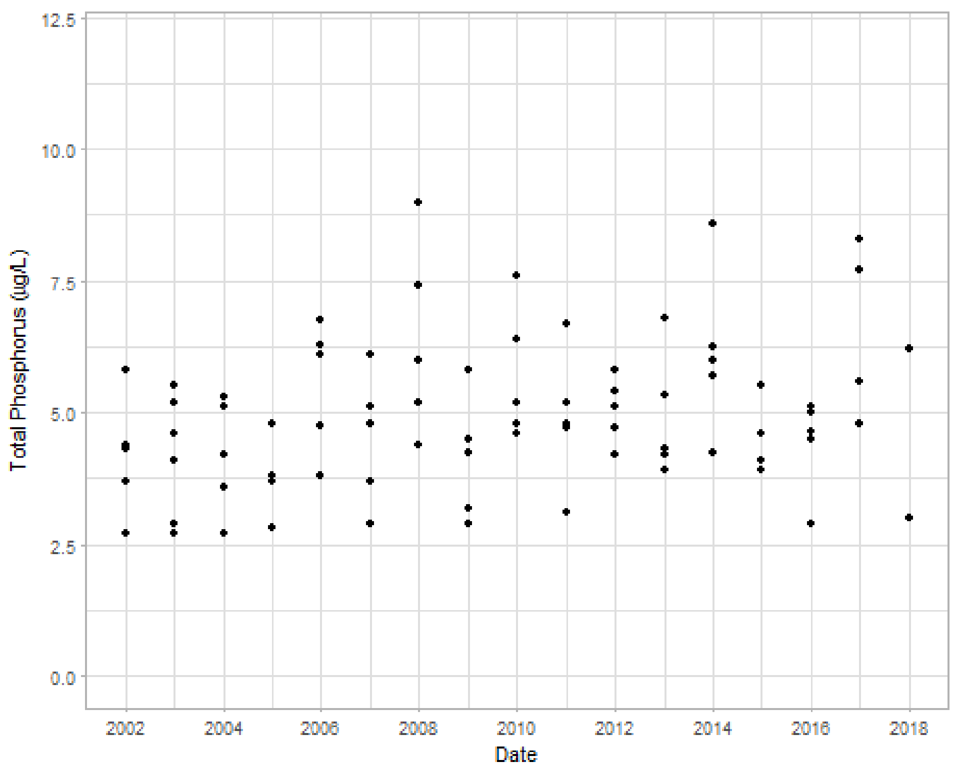


Figure 14. Long-term Total Phosphorus Concentrations at the Dwight Bay Station

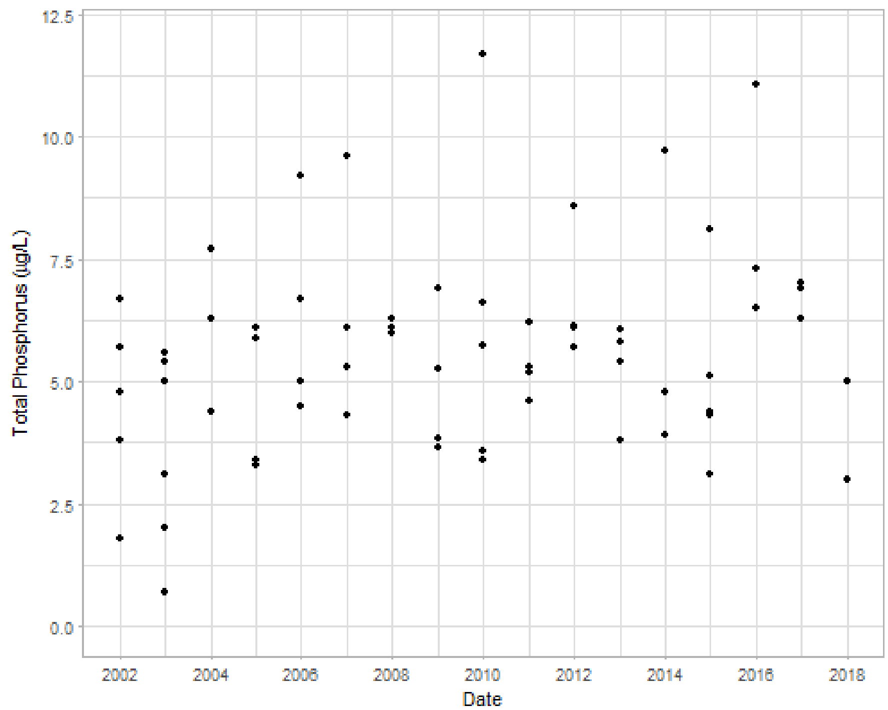


Figure 15. Long-term Total Phosphorus Concentrations at the Haystack Bay Station

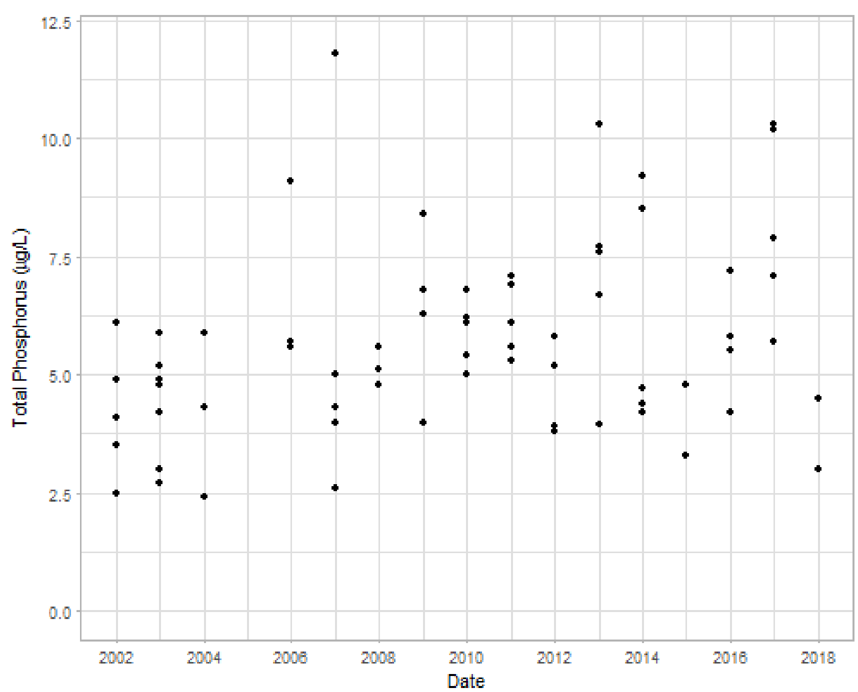
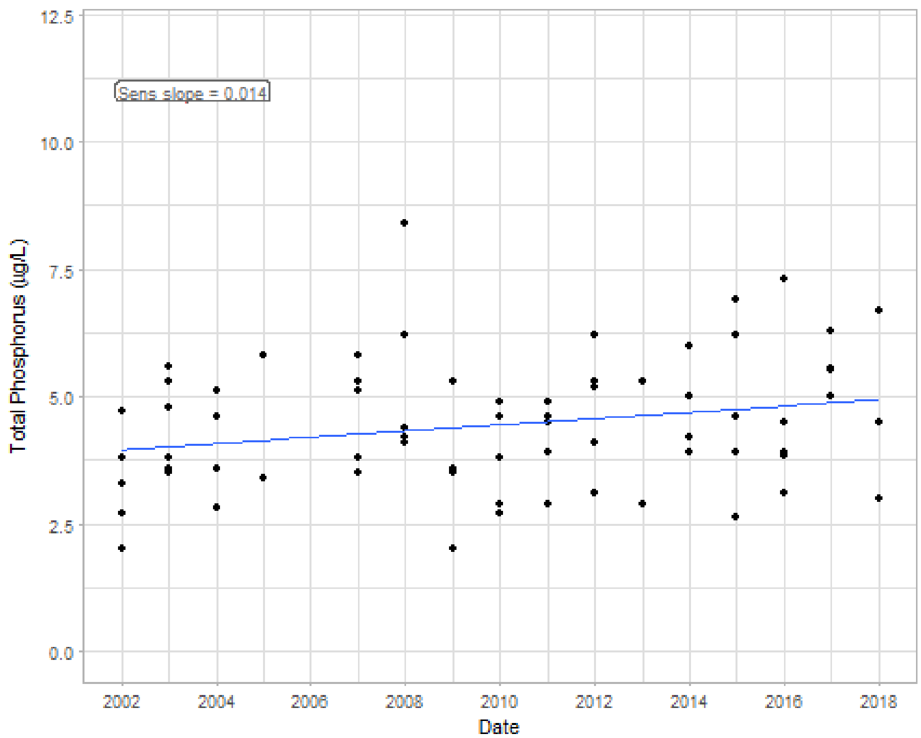


Figure 16. Long-term Total Phosphorus Concentrations at the Brittania Station



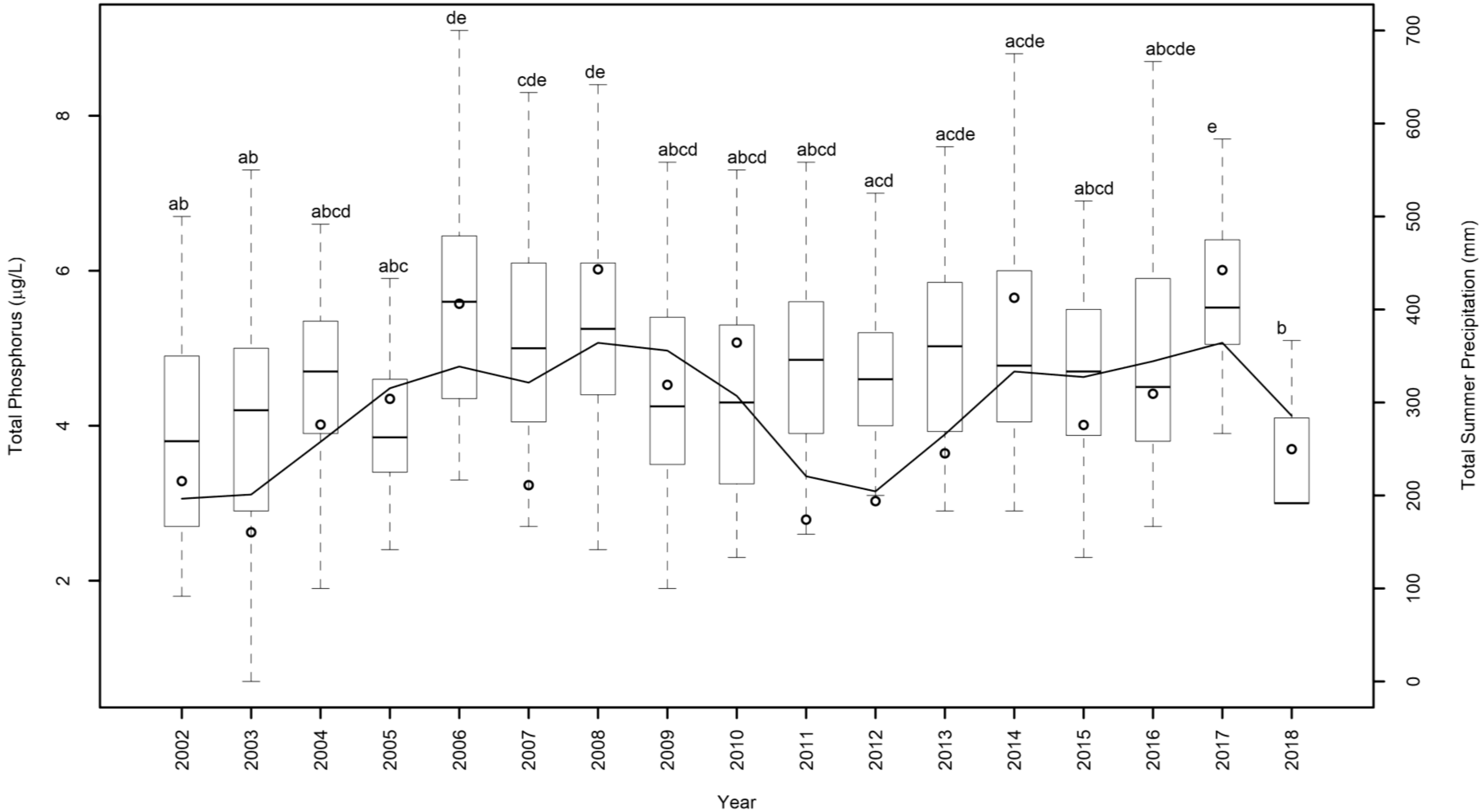
Long-term monitoring has shown increasing trends in total phosphorus have occurred in some Muskoka lakes monitored by the Dorset Environmental Science Centre (DESC), while other lakes exhibited decreasing or no trends (Andrew Paterson, MOECC lake scientist, pers. comm.). These lakes had little to no development in their watersheds and regional (e.g., climate change, long range atmospheric deposition) or local factors other than development, therefore, appear to be influencing lakes in the Muskoka area, including the trends observed for Deep Water sites in Lake of Bays. The District of Muskoka (DMM) has monitored total phosphorus at deep water sites in Lake of Bays since 2001 and has observed no increase, suggesting that the patterns seen in the LOBA data set are related to sampling later in the summer (HESL 2016).

Changes in annual precipitation patterns (amount of precipitation, frequency and duration of storm events) can strongly influence phosphorus loads from atmospheric deposition and also the mobilization and transport of phosphorus from the watershed. Long-term data collected in Lake of Bays, coupled with climate data from Beatrice Climate Station, suggests that inter-annual variability in precipitation may exert a significant influence on the total phosphorus concentration in the lake (Figure 17). In general, total phosphorus concentrations tended to decrease in drier years over the period of record. Lower total phosphorus concentrations in 2018 were statistically similar to those recorded in 2002, 2003, 2004, 2005, 2009, 2010, 2011, 2015, 2016 and significantly lower than all the other years on record (Figure 17, similarity indicated by the letter “b”). The lower TP concentrations in 2018 may also be impacted by the change in detection limits due to a change in laboratories.

The relationship identified by HESL in 2016 between mean annual summer phosphorus concentrations and total summer precipitation at Haystack Bay continues to be apparent when including 2018 data (Pearson rho = 0.60, n = 17, p = 0.01; Figure 18). With the addition of 2018 data, however, the long-term trends in TP reported in 2017 are no longer significant. The isolated bay has a large surface area (4.94 km^2) relative to the area of its watershed (8.13 km^2) and does not receive any significant river or stream discharge and thus direct phosphorus loads from local runoff and direct precipitation likely contribute to a large portion of the natural phosphorus load making it especially sensitive to changes in precipitation volume and storm severity. Phosphorus loading estimates by the DMM indicated that the total load from precipitation constitutes 49% of the natural load to Haystack Bay in comparison to 28% for the main basin of the lake (GLL, 2005).

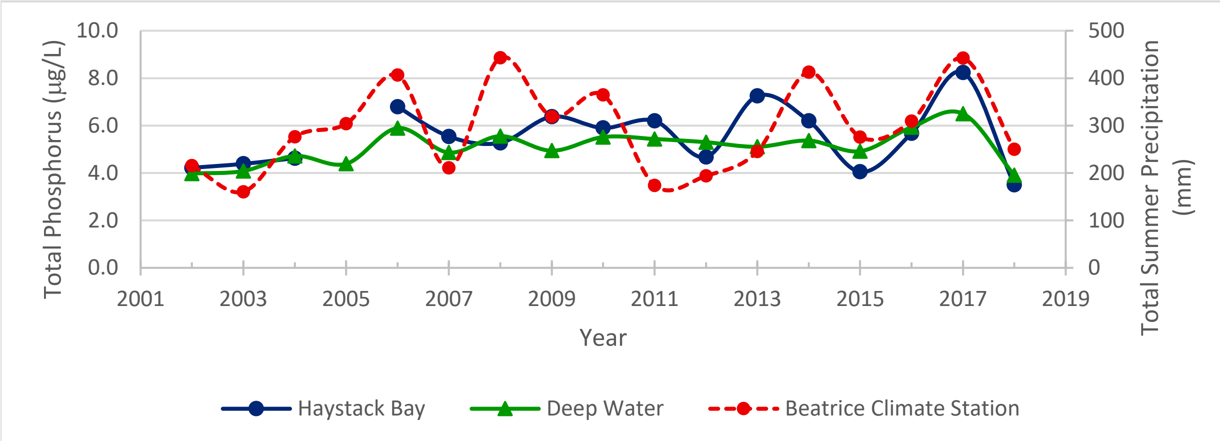
In summary, summer total phosphorus concentration in Lake of Bays exhibits significant inter-annual variability, which based on long-term TP and precipitation data appears to be driven by natural processes related to precipitation. The Lake of Bays Association water quality monitoring program continues to provide a robust long-term data set to evaluate changes over time.

Figure 17. Annual Summary of Summer Total Phosphorus Concentrations and Precipitation at Nearshore Disturbed, Undisturbed and Deep Water Sites in Lake of Bays



Open Circles = Sum of Total Summer Precipitation; Line = Spline Smoothed Precipitation; Boxplots = Total Phosphorus Concentrations. Letters indicate years which are statistically similar

Figure 18. Mean Summer Euphotic Zone Total Phosphorus at Haystack Bay and Deep Water Sites of Lake of Bays and Total Summer precipitation at Beatrice (2002-2018) climate station.



Note: Deep Water sites exclude Little Trading Bay and Portage Bay

5. Summary

The total phosphorus and bacteria data collected by the LOBA in 2018 indicated excellent water quality at all sampling sites in the Lake of Bays. The main results of data analyses from 2018 are as follows:

1. The LOBA monitoring program continued to provide high quality phosphorus data, this year saw a reduction in the frequency of bad splits and outliers.
2. Deep Water sites exhibited a significant increasing trend in total phosphorus concentration from 2002-2018. Natural variability associated with changes in summer precipitation was related to the changes in total phosphorus concentrations observed.
3. Significant long-term trends in total phosphorus were detected in the lake, however several previously identified positive trends at Bigwin East, Dwight Bay and Haystack no longer exhibited positive trends with the addition of 2018 data. Our analysis suggests that changes in total phosphorus concentrations in the lake are the result of regional precipitation and not likely a result of development pressure.
4. Bacteria levels collected by the Coliplate technique were low on all sampling events at all sites, well below the PWQO for recreational use.
5. Laboratory results for Total Coliforms varied significantly from assessments made by the Coliplate technique, however given the consistency in the Coliplate duplicates and the reduced sensitivity of the lab detection limit it is unlikely that this is a cause for concern.
6. Total phosphorus concentrations (mean TP = 4.1 µg/L excluding the River sites) continue to be characteristic of lakes with low primary productivity and meet the highest Provincial standards for protection of nuisance aquatic plant growth due to phosphorus of 10 µg/L at all sites.
7. Mean summer total phosphorus concentration in Portage Bay has been consistently low since 2013, representing a decline from elevated concentrations observed in 2012 that coincided with construction activities. Low TP at Portage Bay in 2018 coinciding with low precipitation supports the conclusions of the 2017 monitoring report that increased TP was a consequence of higher than average precipitation in 2017 and not long-term construction impacts.

8. As in previous monitoring, no significant difference in phosphorus concentration between the Deep Water, Disturbed and Nearshore Undisturbed sites suggesting that shoreline disturbance is having little impact on summer phosphorus concentrations. Concentrations were highest in river sites compared to lake sites as expected due to natural processes.

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Appendix A. Monitoring Protocols for the LOBA Water Quality Monitoring Program

Appendix B. LOBA Total Phosphorus and Bacteria Data