Hutchinson
Environmental Sciences Ltd.

Lake of Bays Water Quality Report 2015

Prepared for: Lake of Bays Association
Job #: J100013

March 2016

Final Report

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March 22, 2016 HESL Job #: J100013

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 2015 – final report

I am pleased to submit this final report for the Lake of Bays Water Quality Monitoring Program results from the summer of 2015.

Total phosphorus concentrations were well below applicable Provincial guidelines indicating excellent water quality and were generally lower in 2015 in comparison to previous years. As a result of the lower concentrations, the previously identified increasing trend at Haystack Bay and the two sites downstream (Bigwin East and Fairview) from 2002 to 2014 was no longer statistically significant. Assessment of variability between and within years, and comparison of the summer phosphorus with spring values (District Municipality of Muskoka data), regional precipitation patterns and human phosphorus loading continue to suggest that patterns in summer phosphorus at Lake of Bays is driven by natural variability.

I thank you and the Lake of Bays Association for the continued opportunity to assist with this project and look forward to seeing results for the 2016 monitoring.

Sincerely,
per: Hutchinson Environmental Sciences Ltd.

T. KRR

Tammy Karst-Riddoch, Ph.D.
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Signatures

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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 while fostering community involvement and education.

LOBA's monitoring program began with a pilot study in 2000 to monitor bacteria levels in the lake during summer. This project was successful and LOBA expanded the area of study in the summer of 2001 to include near-shore areas adjacent to developed and undeveloped properties and areas influenced by wetlands and rivers. In 2002, the program was again expanded to include monitoring of phosphorus concentrations in near-shore areas. Over the course of the program, site selection has changed with an ever-increasing understanding of water quality conditions in Lake of Bays and since 2009, sampling has focussed on deep water sites and nearshore undisturbed locations, with reduced sampling effort in enclosed bays (e.g., South Portage Bay, Rat Bay, Little Trading Bay) and river and river-influenced sites (e.g., Narrows, Oxtongue River, Hollow River). This approach continues to allow comparison with other water quality programs, such as the Ministry of the Environment and Climate Change (MOECC) Lake Partner Program and the District Municipality of Muskoka (DMM) Lake System Health monitoring program, which collect data in central, deep offshore areas of the lake during spring overturn.

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, stream and overland flow, and to a lesser degree through groundwater. 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. Beginning in 2016, sampling will 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 shows that Lake of Bays is a clear 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 2015 and discuss them in the context of long-term water quality data collected by the LOBA and the DMM Lake System Health program, human phosphorus loading and local climate records.

2. Methods

Volunteers, coordinated by the LOBA Environment Committee, collected samples for analysis of total phosphorus concentrations on five occasions during the summer of 2015 (June 28, July 20, August 4 and 23, and September 4). The sampling and analytical methods in 2015 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

Total phosphorus was sampled at 20 sites throughout 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. The samples were coarse-filtered using a mesh filter 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).

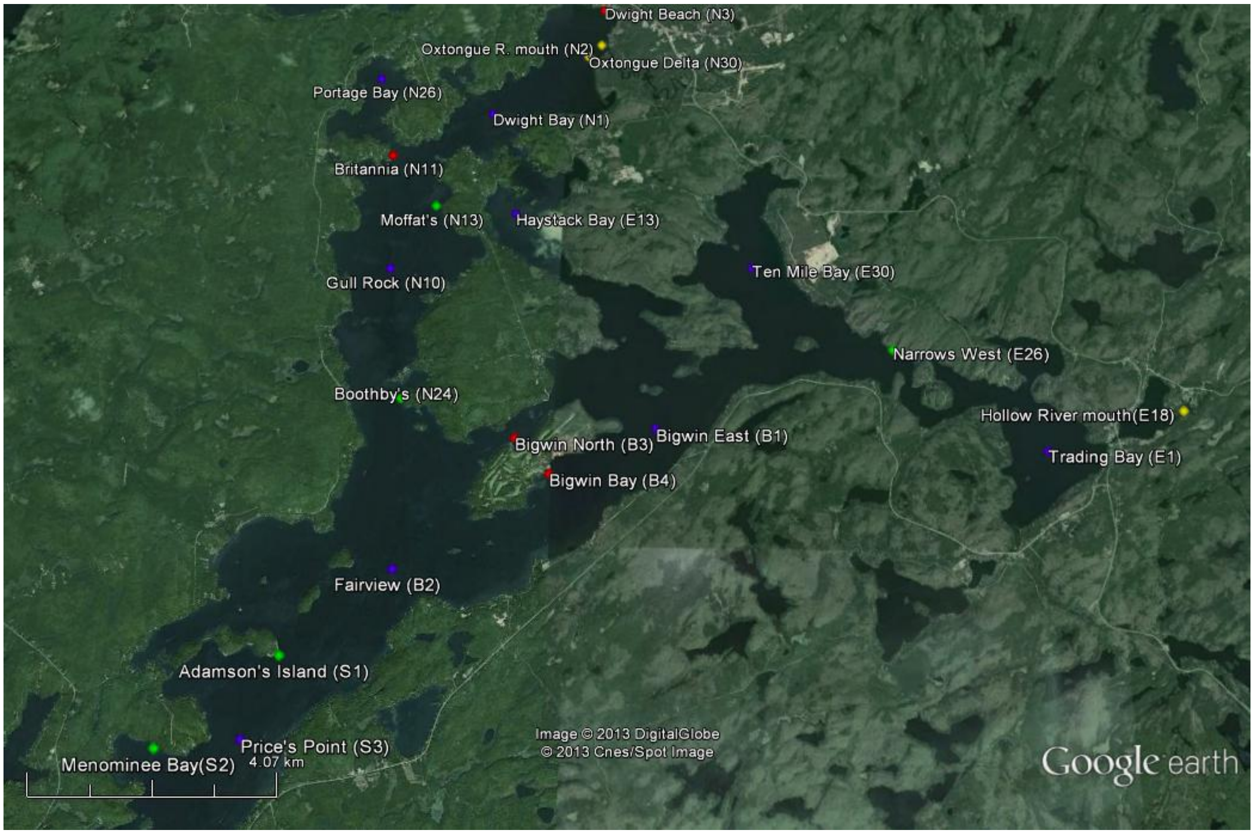
Samples were directly poured into the glass tubes used for phosphorus analysis, stored in a cool place and submitted for analysis to the Trent University laboratory at the MOECC Dorset Environmental Science Centre (DESC).

Table 1. 2015 Sampling Sites and Dates

Site Name	Total Phosphorus Sampling				
	28-Jun	20-Jul	4-Aug	23-Aug	4-Sep
Deep Water Sites					
Bigwin East	1	1	1	1	1
Dwight Bay	1	2	1	1	2
Fairview	1	1	1	2	1
Gull Rock	1	2	2	1	1
Haystack Bay	1	-	1	1	2
Portage Bay	1	1	1	1	1
Price's Point	1	2	1	1	1
Ten Mile Bay	1	1	1	2	1
Trading Bay	1	1	1	1	1
Disturbed Sites					
Bigwin Bay	1	1	1	2	1
Bigwin North	1	1	2	1	2
Britannia	1	1	1	1	2
Nearshore Undisturbed					
Adamson's Island	2	1	1	1	2
Boothby's	1	2	1	2	1
Menominee Bay	1	1	2	1	1
Moffat's	1	2	1	2	1
Narrows West	1	2	1	-	1
River Sites					
Hollow River*	1	1	2	-	1
Oxtongue Delta	2	1	2	2	1
Oxtongue River*	1	1	1	2	1

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

Figure 1. Map of Lake of Bays and LOBA monitoring sites.



Notes: Deep Water sites (blue dots), Disturbed sites (red dots), Nearshore Undisturbed sites (green dots), River sites (yellow dots). Dwight Beach (N3) was not sampled in 2015.

2.2 Quality Control

2.2.1 Field Duplicates

Twenty-two field duplicates for total phosphorus were collected at 16 sites in 2015 to assess the variability of results related to sampling and analytical procedures (Table 1).

Field duplicates analyzed at the DESC laboratory showed excellent agreement between sample pairs with an absolute mean difference of 0.7 μg/L, but a consistent percentage of the samples (5%) had larger than expected differences between field duplicates (i.e., >4 μg/L) (Clark et al. 2010)). Separate experiments excluded sample container cleanliness, lab apparatus, variation in the sub 80μ-sample matrix, and external inputs of phosphorus as sources of contamination that would explain the measured differences and it remains unclear how these samples are contaminated. In almost every case, however, when these samples were reanalyzed, the retested pair of samples agreed with the lower of the original two samples in the bad field split. After testing hundreds of such pairs with sample returns from the Lake Partner Program, sufficient confidence was gained to allow the elimination of the higher of the two samples in cases where there are bad splits (Clark et al. 2010).

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.

2.2.1.1 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. In previous reports, outliers were assessed using the Grubbs' Test (Grubbs, 1969), which is a recommended procedure to screen the DMM's Lake System Health data set for outliers (Gartner Lee Limited, 2008). The Grubbs' Test is designed to identify a single, high value outlier in a dataset. More than one high outlier, however, was often evident in the data set for several of the monitoring sites and so the Grubb's Test was applied multiple times until no outliers were detected. This approach is not statistically strong, but due to the small sample sizes, it was the most suitable approach to identify multiple outliers.

The LOBA dataset has increased in size over the years and more vigorous outlier tests can now be applied to the data. Rosner's ESD Many-Outlier Procedure (Rosner's Test; Rosner, 2011) was therefore selected to assess 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 like the Grubbs' Test.

Outliers were removed from the dataset for further analyses if they were detected as outliers using the Rosner's Test (at $p<0.05$), 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

Mean total phosphorus concentrations were calculated for each site and site type for the 2015 monitoring period following the assessment of bad splits between duplicate samples and outliers.

In previous years, mean total phosphorus concentrations in Lake of Bays were evaluated against the revised Provincial Water Quality Objective (PWQO) for lakes located on the Precambrian Shield (Background + 50%; Province of Ontario, 2010), which were calculated for District Municipality of Muskoka (DMM) lakes using a water quality model developed for the Lake System Health program (Gartner Lee Ltd., 2005). The DMM model used to set the revised PWQO, however, is currently under review. Results were therefore evaluated against the interim PWQO for phosphorus, which states that: "To avoid nuisance concentrations of algae in lakes, average total phosphorus concentrations for the ice-free period should not exceed 20 μg/L. A high level of protection against aesthetic deterioration will be provided by a total phosphorus concentration for the ice-free period of 10 μg/L or less. This should apply to all lakes naturally below this value. Excessive plant growth in rivers and streams should be eliminated at a total phosphorus concentration below 30 μg/L." (MOEE, 1994)

Long-term trends over time (2002-2015) for each site were determined by the Mann-Kendall Trend Test computed using the statistical software, R (R Core Team, 2013). All other descriptive statistics were performed in MS Excel.

3. 2015 Monitoring Results

3.1 Field Duplicates

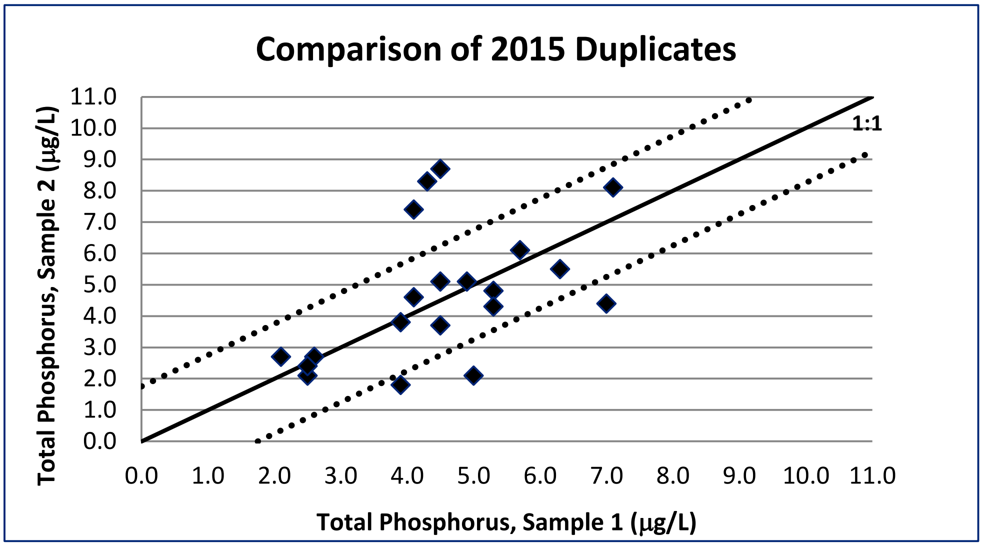
The quality control program continues to provide a high degree of confidence in the sampling protocols and analyses for total phosphorus, although a greater number of bad splits (i.e., 5 µg/L or >35% difference between sample pairs) occurred in 2015 relative to other years. In 2015, 32% of the field duplicate samples were bad splits in comparison to the average of 13% since duplicate sampling began in 2005 (Figure 2, Table 2). The mean difference between field duplicates was 0.8 µg/L in 2015 and 0.6 µg/L in all previous years (2005-2013) after removing the bad splits, which is comparable to the DESC dataset that has a mean difference of 0.7 µg/L between thousands of field duplicate samples.

Table 2. Summary of Bad Splits between Total Phosphorus Field Duplicates in Lake of Bays, 2005-2015

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

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.

Figure 2. Total phosphorus field duplicates in Lake of Bays, 2015.



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

3.2 Outliers

A total of 44 samples were identified as outliers in the LOBA dataset (excluding River sites) using the Rosner's Test, six of which occurred in the 2015 data (Table 3). The change from Grubbs' to Rosner's Test did not significantly alter the detection of outliers. Only two additional outliers were detected by the new method (Ten Mile Bay, TP = 10.3 µg/L on August 21, 2006; Dwight Bay, TP = 0.7 µg/L on July 14, 2003). Outliers were removed from all analyses in this report, but will be reassessed each year as additional data are added to the dataset. Several samples from the River sites were statistical outliers, however, these samples were not removed from the analysis as river-influenced sites are expected to be highly variable between sampling events and the high measured total phosphorus values likely reflects this variability.

Table 3. Outliers in the LOBA Dataset (2002-2015), Rosner's Test (*p* <0.05) (excluding River sites)

Site	Date	Total Phosphorus (µg/L)	Site	Date	Total Phosphorus (µg/L)
Adamson's Island	18-Jul-11	15.1	Haystack Bay	6-Sep-04	74.0
	31-Aug-12	7.9		7-Aug-06	40.3
	18-Aug-13	9.9		1-Sep-06	14.1
Bigwin Bay	15-Jul-02	9.6		6-Aug-07	12.8
	20-Jul-14	10.1		17-Jul-09	57.7
	4-Aug-15	12.0		31-Aug-12	22.4
Bigwin East	28-Jun-15	18.1		28-Jun-15	14.6
Bigwin North	23-Aug-04	27.7		4-Sep-15	18.1
	6-Aug-07	97.7	Menominee Bay	4-Jul-05	11.0
Boothby's	14-Aug-05	10.3	Moffat's	5-Aug-02	36.7
Britannia	1-Sep-03	12.6		6-Aug-07	15.1
	1-Sep-05	9.4		5-Aug-13	11.4
	4-Aug-08	8.4	Narrows West	4-Jul-11	11.4
	18-Aug-13	21.6		1-Aug-11	8.5
	28-Aug-13	13.3		4-Sep-15	8.9
Dwight Bay	14-Jul-03	0.7	Portage Bay	20-Aug-12	61.3
	19-Jul-10	11.7	Price's Point	2-Aug-10	12.7
Fairview	31-Aug-07	12.5		18-Jul-11	12.8
	17-Jul-09	12.3	Ten Mile Bay	21-Aug-06	10.2
Gull Rock	14-Jul-03	16.9		29-Jun-14	10.3
			Trading Bay	19-Aug-02	17.7
				19-Jul-04	12.3
				21-Aug-06	11.0
				28-Jun-15	10.6

3.3 2015 Total Phosphorus Concentrations

Results of the 2015 monitoring continue to demonstrate low phosphorus concentrations in Lake of Bays that are characteristic of low productivity (oligotrophic), clear-water lakes on the Precambrian Shield. The summer total phosphorus concentration of the Deep Water, Disturbed and Nearshore Undisturbed sites ranged from 3.5 to 6.9 µg/L, with an overall mean concentration of 4.5 µg/L (Table 4, Figures 3 to 6). The River sites were more phosphorus-enriched, which is consistent with higher concentrations of phosphorus-rich particulate matter and dissolved organic carbon in rivers (mean TP = 7.0 µg/L). Mean summer total phosphorus concentration at all sites was less than the interim PWQO for phosphorus of <10 µg/L and provided a "high level of protection against aesthetic deterioration" due to nuisance aquatic plant growth (MOE, 1994).

Overall, total phosphorus concentrations were variable at the non-River sampling locations over the 2015 monitoring period, with an average difference of 2.9 µg/L between the minimum and maximum values (range of 1.2 to 5.0 µg/L) measured at each site. This variability represents a 25% difference (Coefficient of Variation, CV; Table 5) from the mean phosphorus concentration observed over the 2015 monitoring, and is typical for lakes on the Precambrian Shield (Clark et al., 2010). In 2014, there was no notable difference in the variability between Deep Water and nearshore (Nearshore Undisturbed and Disturbed) sites due to lower than expected variability at the Nearshore Undisturbed sites (CV = 18% in 2014 versus 23% from 2002-2014). In 2015, however, the nearshore sites were again more variable as in previous years (mean CV = 28%). Higher variability is expected at sites closer to shore as they are more susceptible to local changes in phosphorus from runoff events, uptake by plants in shallow areas and sediment resuspension due to wave action.

Phosphorus concentrations generally declined over the summer with higher values on the June and July sampling events in comparison to the August sampling events (Figure 7). A decline in phosphorus over the summer period is common in deep, stratified, oligotrophic lakes in which particles containing phosphorus settle through the mixed layer of the water column into the hypolimnion and are eventually lost to the sediments. Phosphorus concentrations tend to increase at fall turnover when more phosphorus-rich water contained in the hypolimnion[1] mixes with the surface waters and again in spring due to inputs of phosphorus in runoff from snowmelt.

There was no significant difference (Mann-Witney test; $U = 5$, $p < 0.05$) in phosphorus concentration between the Nearshore Undisturbed (mean TP = 3.7 µg/L) and Disturbed (mean TP = 4.9 µg/L) sites suggesting that shoreline disturbance is having little impact on summer phosphorus concentrations.

In 2012, Portage Bay was added as a monitoring site due to LOBA concerns regarding the potential impact of construction activities. Mean total phosphorus concentration in Portage Bay was 4.6 µg/L in 2015, 6.3 µg/L in 2014 and 5.7 µg/L in 2013, representing a decline from elevated concentrations observed in 2012 (mean TP = 9.6 µg/L) that were coincident with construction activities. The 2015 monitoring results confirm that potential impacts of construction activities at Portage Bay were short term although it is possible that the high concentration in 2012 was spurious and not the result of construction activity.

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[1] *The hypolimnion is the deep, cool layer of water in lakes that is prevented from mixing with warmer, less dense surface waters.*

Table 4. Total Phosphorus Concentrations (µg/L) in Lake of Bays, 2015

Site ID	Site Name	4-Sep	23-Aug	4-Aug	28-Jun	20-Jul	AVG	SD
Deep Water		4.0	3.9	5.1	5.9	5.3	4.8	2.8
B1	Bigwin East	5.5	4.1	3.9	n/d	4.6	4.5	0.6
B2	Fairview	3.3	4.4	3.7	5.9	4.8	4.4	0.9
E1	Trading Bay	4.7	5.0	9.5	n/d	8.2	6.9	2.1
E13	Haystack Bay	n/d	3.3	4.8	n/d	n/d	4.1	0.8
E30	Ten Mile Bay	4.6	4.8	5.8	4.8	5.6	5.1	0.5
N1	Dwight Bay	4.4	3.1	5.1	8.1	4.3	5.0	1.7
N10	Gull Rock	2.5	3.3	3.9	5.7	5.0	4.1	1.1
N26	Portage Bay	3.6	4.5	4.9	5.5	4.8	4.7	0.6
S3	Price's Point	3.0	2.3	4.2	5.4	5.1	4.0	1.2
Disturbed		3.9	4.4	5.5	4.8	6.2	4.9	1.5
B3	Bigwin North	4.5	4.5	4.0	4.2	8.1	5.1	1.5
B4	Bigwin Bay	4.6	2.4	n/d	5.5	6.7	4.8	1.6
N11	Britannia	2.7	6.2	6.9	4.6	3.9	4.9	1.5
Nearshore Undisturbed		2.8	2.4	4.3	4.5	4.7	3.7	1.0
E26	Narrows West	n/d	n/d	4.9	3.4	4.8	4.4	0.7
N13	Moffat's	3.1	2.9	4.1	4.9	5.7	4.1	1.1
N24	Boothby's	2.6	2.1	4.5	5.0	4.1	3.7	1.1
S1	Adamson's Island	2.3	2.6	3.9	4.4	4.5	3.5	0.9
S2	Menominee Bay	3.0	1.9	4.1	4.8	4.5	3.7	1.1
River		7.8	4.2	5.2	10.4	7.7	7.0	2.4
E18	Hollow River Mouth	7.5	n/d	5.9	16.3	8.6	9.6	4.0
N2	Oxtongue Mouth	7.7	5.9	4.6	7.4	7.5	6.6	1.2
N30	Oxtongue Delta	8.1	2.5	5.0	7.6	7.0	6.0	2.1
						All sites:	4.9	1.3
						All sites excluding River sites:	4.5	1.1

Table 5. Coefficient of Variation (CV) in Total Phosphorus for LOBA Monitoring Site Types

Site Type	CV (%)	
	2015	Mean 2002-2015
Deep water	22	21
Disturbed	32	23
Nearshore Undisturbed	25	23
River	31	30
Mean	**26**	**22**
Mean excluding River sites	**25**	**22**

Figure 3. Total phosphorus concentrations in Lake of Bays 2015, Deep Water sites.

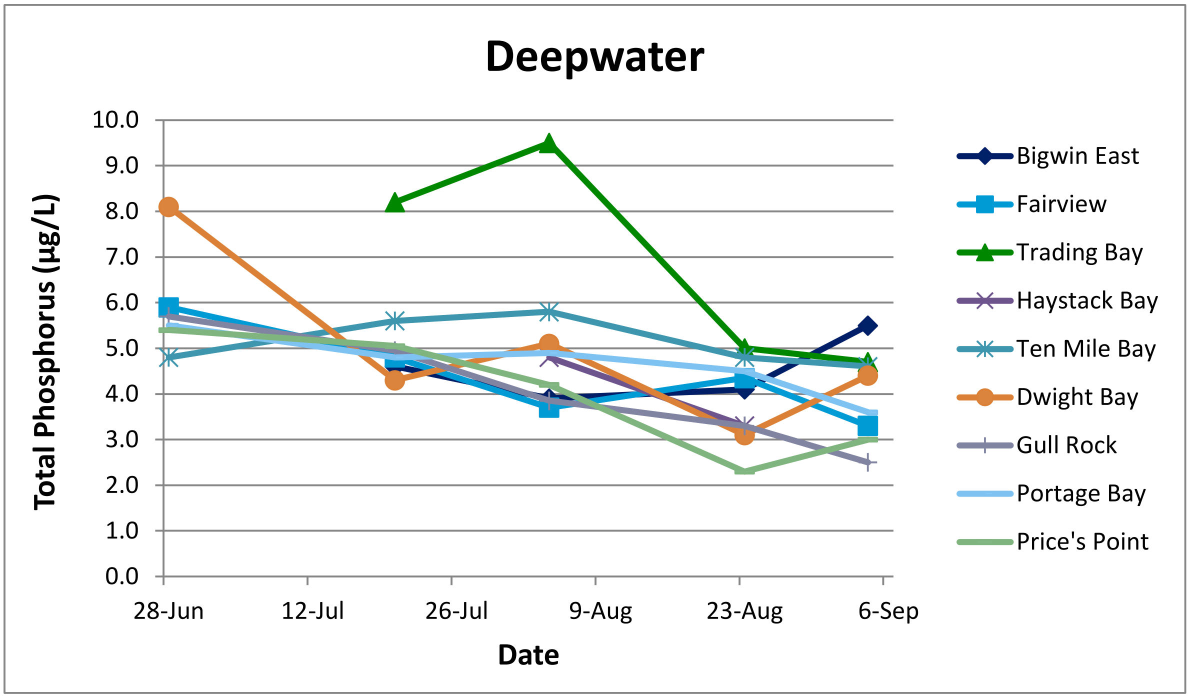


Figure 4. Total phosphorus concentrations in Lake of Bays 2015, Nearshore Undisturbed sites.

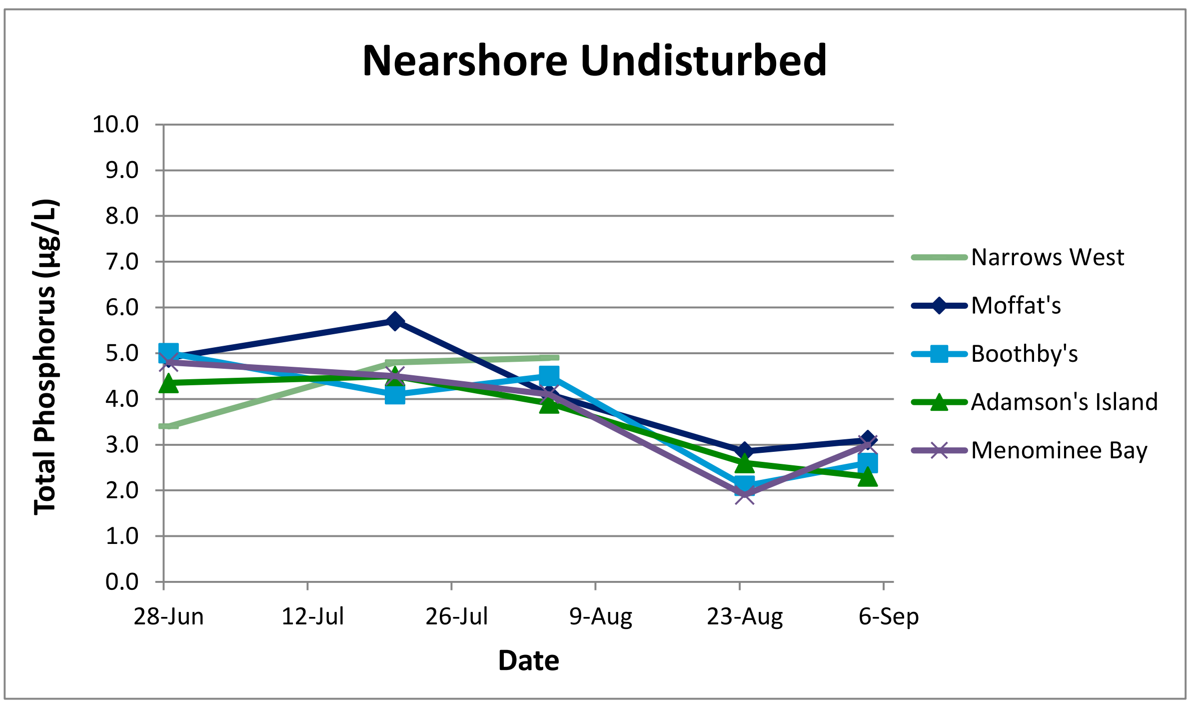


Figure 5. Total phosphorus concentrations in Lake of Bays 2015, Disturbed sites.

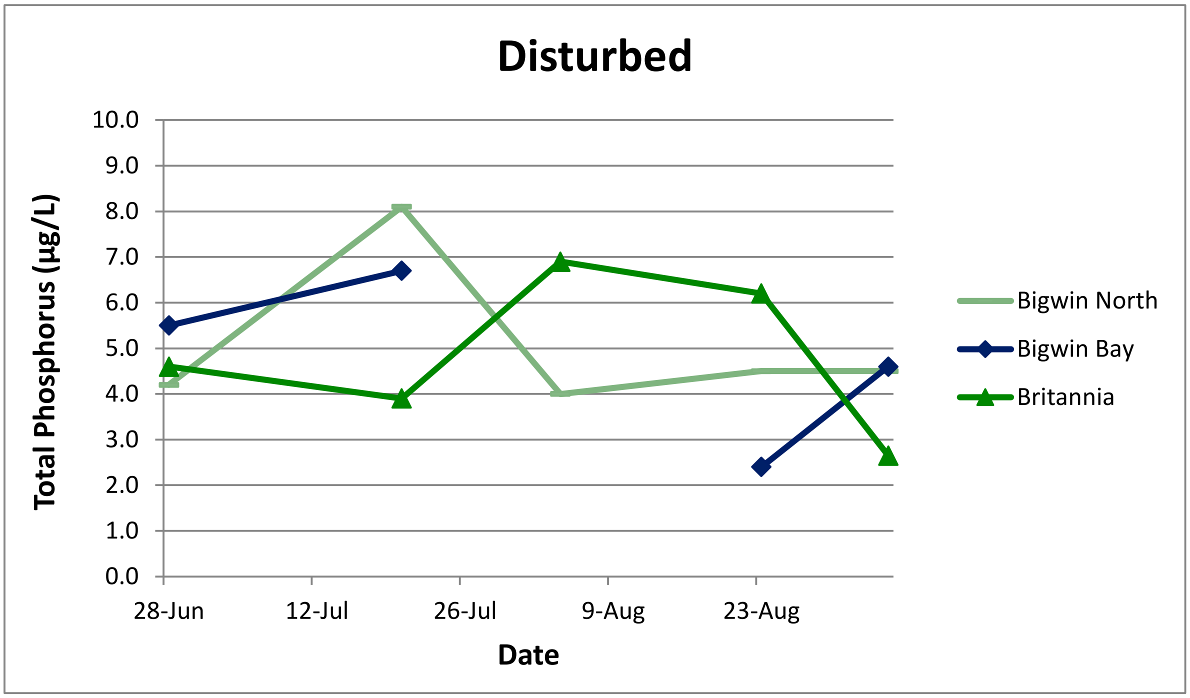


Figure 6. Total phosphorus concentrations in Lake of Bays 2015, River sites.

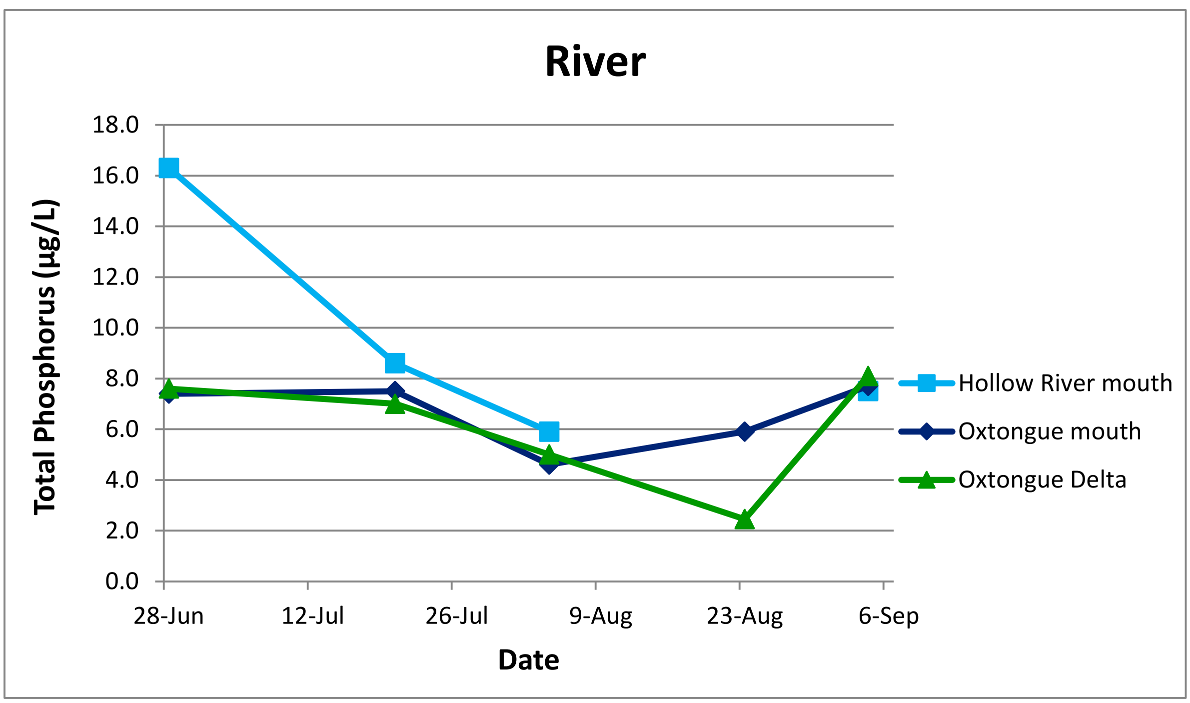
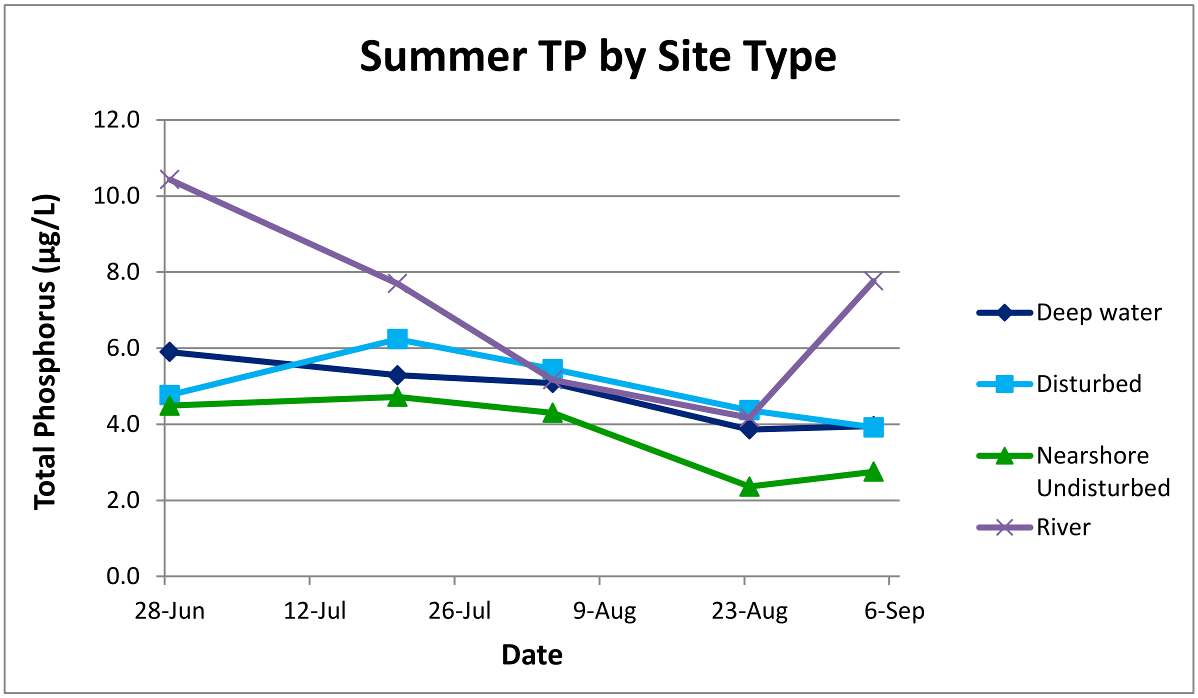


Figure 7. Total phosphorus concentrations in Lake of Bays 2015 by Site Type.



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

4. Long-term Phosphorus Trends

The Lake of Bays Water Quality Monitoring Program has been collecting data over the summer season for over ten years at numerous 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 1,330 samples collected at the end of the 2015 program (Table 6). The large number of sites monitored and samples collected under the program since 2002 provide for an excellent data set to assess long-term trends and variability in total phosphorus concentration in Lake of Bays. All data collected by the LOBA monitoring program since 2002 are provided in Appendix B.

Table 6. Number of Total Phosphorus Samples Collected by the Lake of Bays Monitoring Program (2002-2012)

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
Total # of Samples	631	219	318	162	1,330

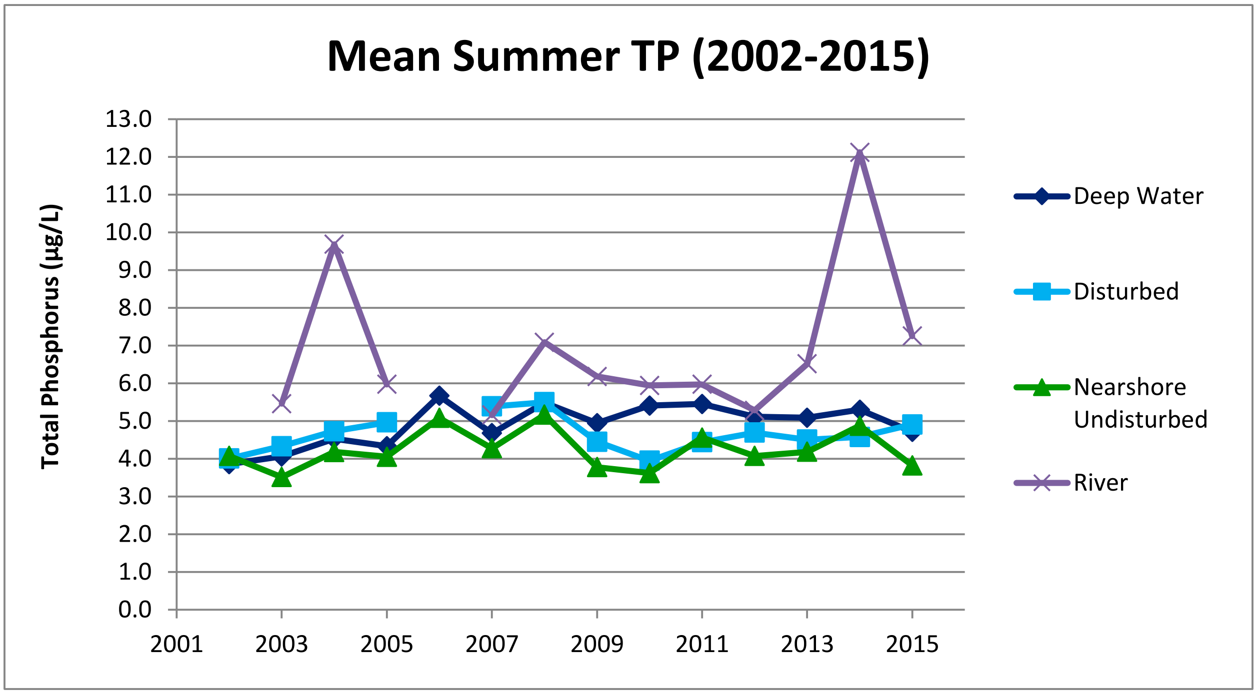
Since 2002, the mean summer total phosphorus concentration has ranged between 3.9 and 6.8 µg/L in the Deep Water (mean TP = 5.0 µg/L), Disturbed (mean TP = 4.7 µg/L) and Nearshore Undisturbed (mean TP = 4.2 µg/L) sites (Table 7, Figure 8). The River sites have been more variable with generally higher concentrations that have ranged from 4.0 to 18.3 µg/L (mean TP = 6.8 µg/L).

Table 7. Mean Summer Total Phosphorus Concentrations in Lake of Bays (2002-2015)

Site	Total Phosphorus (µg/L)														
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	AVG.
Deep Water	**4.0**	**4.1**	**4.7**	**4.5**	**5.9**	**5.0**	**5.8**	**4.9**	**5.2**	**5.4**	**5.7**	**5.0**	**5.4**	**4.7**	**5.0**
Bigwin East	4.2	4.2	4.2	4.0	5.4	4.5	6.2	4.2	5.5	5.0	5.1	5.2	5.9	4.5	4.9
Dwight Bay	4.6	4.2	6.1	4.7	6.0	5.7	6.1	4.6	5.0	5.3	6.5	5.2	6.1	5.0	5.4
Fairview	2.8	3.6	4.0	4.7	5.6	3.9	6.3	4.6	5.0	4.9	4.9	4.3	4.7	4.4	4.5
Gull Rock	4.0	4.2	5.1	4.4	5.6	4.7	5.0	4.1	5.5	5.7	5.1	3.9	5.0	4.2	4.7
Haystack Bay	4.2	4.4	4.6		6.8	5.3	5.3	6.4	5.9	6.2	4.7	6.7	6.2	4.1	5.4
Portage Bay											9.6	5.7	6.3	4.7	6.6
Price's Point				3.4	6.0	4.5	4.6	5.8	5.2	5.3	4.5	5.3	4.5	4.2	4.8
Ten Mile Bay					6.1	5.0	5.5	4.8	5.0	5.1	7.0	5.7	6.5	5.1	5.6
Trading Bay	4.1	4.0	4.9	5.1	4.7	4.5	5.4	5.0	4.9	5.8	5.0	2.5	4.2	6.9	4.8
Disturbed	**4.0**	**4.3**	**4.7**	**4.7**		**5.4**	**5.5**	**4.5**	**3.9**	**4.9**	**4.7**	**5.2**	**4.4**	**4.6**	**4.7**
Bigwin Bay	3.6	4.7	4.9				5.5	4.2	3.6	4.5	4.5	4.5	4.3	4.3	4.4
Bigwin North	5.0	3.9	5.3	5.2		6.3	6.1	5.6	4.5	4.6	4.8	4.9	4.3	5.1	5.0
Britannia	3.3	4.4	4.0	4.2		4.7	4.7	3.6	3.8	4.2	4.8	4.1	4.8	4.5	4.2
Dwight Beach										5.8	4.5	6.8			5.7
Nearshore Undisturbed	**4.1**	**3.5**	**4.2**	**4.1**	**5.1**	**5.5**	**5.3**	**3.8**	**3.5**	**4.5**	**4.0**	**4.3**	**4.8**	**3.9**	**4.2**
Adamson's Island				4.8	4.7	3.3	4.5	3.0	2.8	4.0	3.9	4.0	4.0	3.5	3.9
Boothby's				6.2	5.8	5.2	5.4	4.3	4.3	4.8	3.8	4.1	5.2	3.7	4.8
Menominee Bay				3.1	5.0	3.9	6.0	3.1	2.7	5.2	3.7	4.4	4.6	3.7	4.1
Moffat's	4.1	3.5	4.2	3.7	4.9	3.8	5.2	4.8	3.6	4.3	4.3	3.9	5.5	4.2	4.3
Narrows West						5.4	4.8		4.3	4.0	4.3	4.7	4.9	4.5	4.6
River		**6.2**	**9.7**	**6.0**		**5.2**	**7.9**	**6.2**	**5.9**	**5.9**	**5.2**	**6.3**	**11.5**	**6.8**	**6.8**
Hollow River Lagoon		7.2				5.3	6.3								6.3
Hollow River mouth		5.5	12.7	6.0		5.2	7.1		4.6	5.3	5.1	4.1	5.5	8.8	6.4
Oxtongue Delta							6.9	4.8	4.0	5.0	4.3	5.9	8.5	5.7	5.6
Oxtongue mouth			7.4	5.9			7.3	7.6	9.4	7.8	6.4	8.1	18.3	6.5	8.5

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

Figure 8. Long-term (2002-2015) mean summer euphotic zone total phosphorus (TP) by Site Type.



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

Previous LOBA monitoring reports had noted a statistically significant increasing trend in mean summer total phosphorus concentration of the Deep Water sites[2] since 2002. The trend, however, was not seen at all of the Deep Water sites and was not observed at any of the Nearshore Undisturbed, Disturbed or River sites. While the observed trends were statistically significant, it was noted that the increase in total phosphorus concentrations at these sites was small and well within the range of natural variability (21-23%) that would be expected for lakes on the Precambrian Shield (Clark et al., 2010).

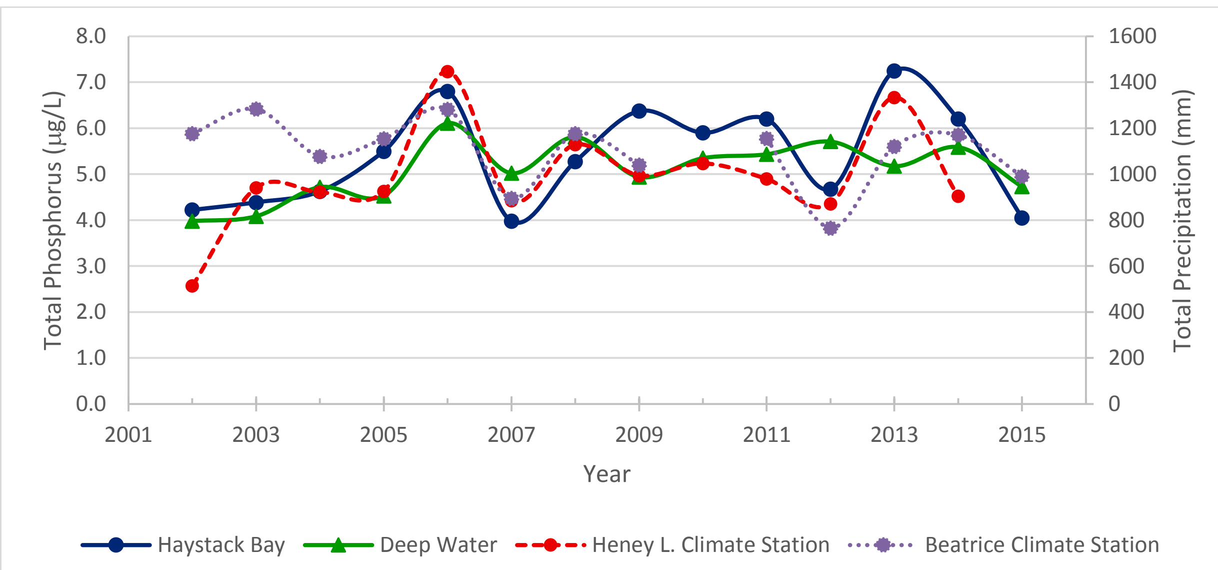
In 2014, it was concluded that the trend in phosphorus concentrations (2002-2014) was restricted to Haystack Bay, Bigwin East and Fairview and most likely reflected localized changes in phosphorus dynamics due to natural variability associated with precipitation patterns. Haystack Bay, which displayed the greatest trend in phosphorus, is a large, relatively isolated bay with no large tributary input. Total phosphorus concentrations at this site were positively correlated to total precipitation records (Pearson rho = 0.73, df = 12, p = 0.003) near Lake of Bays at the Heney Lake climate station operated by the Ontario Ministry of the Environment and Climate Change's DESC (Figure 12). It was hypothesized that precipitation strongly affects phosphorus loads to Haystack Bay given the large surface area (4.94 km^2) of this bay relative to the area of its watershed (8.13 km^2). This means that direct phosphorus loads from precipitation contribute to a large portion of the natural phosphorus load to this bay making the bay especially sensitive to changes in precipitation. 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). The localized changes in phosphorus at Haystack Bay were likely driving the

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

changes at Bigwin East and Fairview sites, as water from Haystack Bay moves past these sites with flow toward the outlet.

With the addition the low total phosphorus concentrations at Haystack Bay, Bigwin East and Fairview in 2015, the previously observed trends at these sites were no longer significant (Mann-Kendall trend test, n_{years}=14, p>0.05). Precipitation data for 2015 were not available for the Heney Lake climate station at the time of report production to assess whether lower precipitation could explain the reduced total phosphorus concentration at Haystack Bay (and the downstream Bigwin East and Fairview sites). Precipitation records at the Environment Canada climate station at Beatrice (Station 6110607) located ~30 km from Lake of Bays, however, suggest that precipitation was lower in 2015 relative to 2014 (Figure 9). Reduced precipitation in 2015 may have resulted in the lower phosphorus concentrations in Haystack Bay and the Deep Water sites overall, and can be confirmed by comparison with the more locally relevant Heney Lake precipitation data, when it comes available.

Figure 9. Mean summer euphotic zone total phosphorus at Haystack Bay and Deep Water sites of Lake of Bays and total annual precipitation at Heney Lake (2002-2014) and at Beatrice (2002-2015) climate stations.



Some increase in total phosphorus concentration over natural conditions is expected in Lake of Bays due to shoreline development. Much of the shoreline area of Lake of Bays is well developed with seasonal cottages, permanent residences and resorts that, in combination with development on upstream lakes, are estimated to potentially increase the phosphorus load. Not all phosphorus from septic systems is likely to reach the lake, however, due to the attenuation of phosphorus by mineral-rich acidic, soils that are characteristic of the Precambrian Shield. Where migration of phosphorus does occur it is slow, averaging ~ 1 m/yr (Robertson et al. 1998) and so may take many years to reach a lake. It is possible that some phosphorus from existing septic systems has only started reaching the lake over the monitoring period, contributing to the previously observed trend at the Haystack Bay, Bigwin East and Fairview sites Nevertheless, Gartner Lee Ltd. (2005) concluded that the potential increase in concentration in Lake of

Bays due to shoreline development ranged from ~ 0.5 µg/L (Main Basin) to 1 µg/L (Haystack and Ten Mile Bay). This is an ~ 20% increase and is well below the revised PWQO for lakes on the Precambrian Shield that allows for a 50% increase in phosphorus concentration over natural conditions to protect water quality from nutrient enrichment (Province of Ontario, 2010).

Spring total phosphorus concentrations collected by the DMM have been more variable between sample years than the summer concentrations collected by LOBA (Figures 10 and 11), most probably related to the varying intensity and timing of spring snowmelt, which would result in varying amounts of phosphorus in the lake during spring that would settle out with stratification and have no effect on summer concentrations. The variability in spring data could therefore mask long-term trends in lake total phosphorus concentration that occur in the summer months. Despite seasonal differences in the two monitoring programs, they provide similar long-term mean phosphorus concentrations for the Deep Water sites monitored by both programs (DMM TP $spring_{02-13}$ = 5.5 µg/L, LOBA TP $summer_{02-15}$ = 5.3 µg/L).

Figure 10. Long-term trends in mean spring overturn (DMM data) and mean summer euphotic zone total phosphorus in Haystack Bay, Dwight Bay, Ten Mile Bay and Trading Bay.

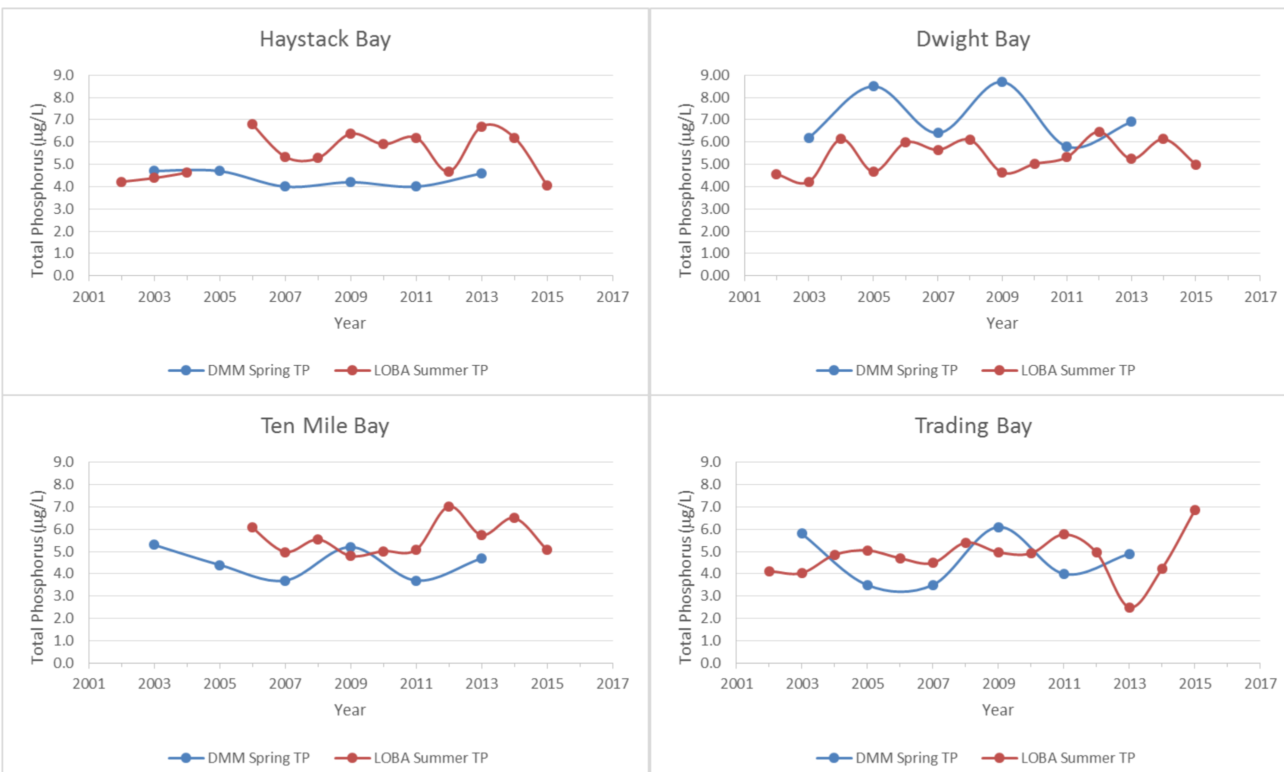
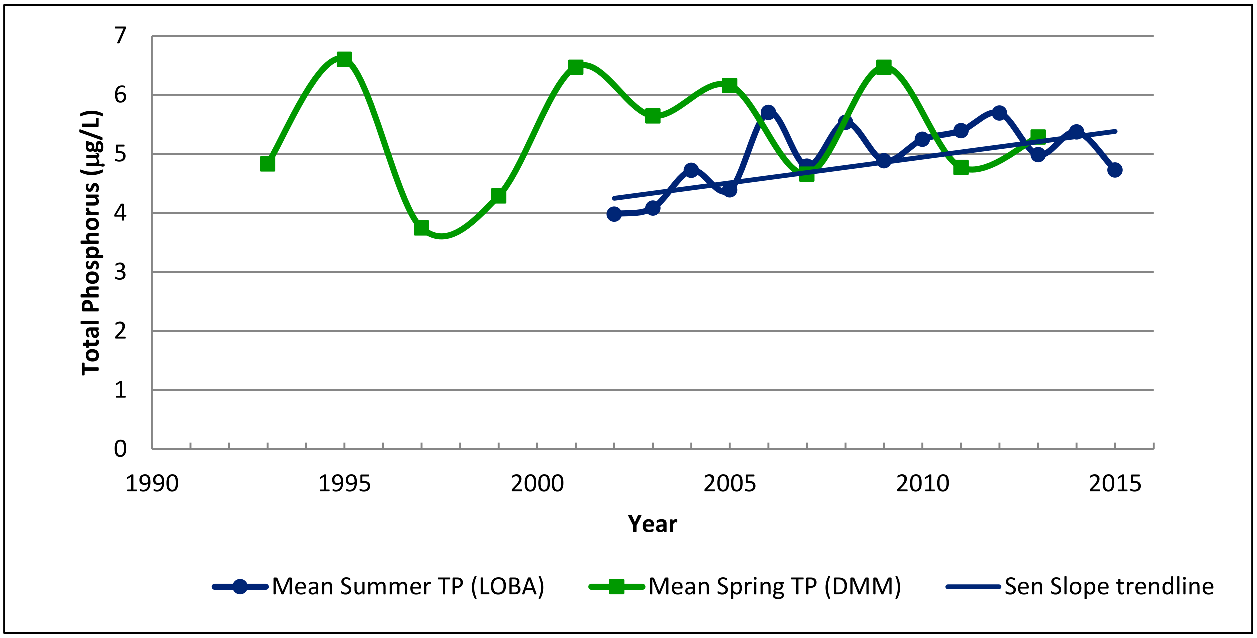


Figure 11. Long-term trends in mean spring overturn (DMM data) and mean summer euphotic zone total phosphorus in Deep Water areas of Lake of Bays.



Note: LOBA sites exclude Little Trading Bay and Portage Bay. DMM sites include Dwight, Haystack, Rat, South Muskoka River, South Portage, Ten Mile and Trading bays.

Natural variability in total phosphorus concentrations occurs due to many factors including differences in weather patterns, localized nutrient uptake by plants and changes in the food chain. Based on long-term monitoring records from Precambrian Shield lakes, the natural variability in total phosphorus concentration between years was 21-23% (Clark et al., 2010), that is, annual total phosphorus concentrations can deviate by +/-21-23% from the long-term mean due to natural causes. Mean total phosphorus concentration at the Deep Water sites has varied by 12-19% (mean CV = 16%), which is within the expected range of natural variability. It is therefore possible that phosphorus concentrations in Lake of Bays will continue to vary over time in this range, and may exhibit trends that are natural like those observed between 2002 and 2014. Trends, however, should not continue over the long term unless directional changes are occurring in the natural environments (e.g., climate change) or due to human influences.

Over the past 10 to 12 years, there have also been increasing trends in total phosphorus concentrations at some of the lakes monitored by the DESC, while other lakes have exhibited decreasing or no trends (Andrew Paterson, MOECC lake scientist, pers. comm.). These changes have occurred in lakes with little to no development in their watersheds and so natural variability or regional or local factors other than development appear to be influencing lakes in the Muskoka area. It is therefore possible that these factors are also contributing to the patterns observed in Lake of Bays. The MOECC are presently investigating the potential causes of differential patterns in phosphorus concentrations in the DESC monitoring lakes and results of this work may help to determine the mechanisms of change in Lake of Bays.

In summary, summer total phosphorus concentration in Lake of Bays is variable from year to year, and evidence suggests that this variability is likely due to natural processes related to precipitation patterns.

Natural variability, in addition to regional or local environmental change (i.e., climate change, acid deposition, invasive species, etc.) and increased phosphorus inputs from human sources can act together as “multiple stressors” resulting in changes in total phosphorus concentrations over time. The Lake of Bays Association water quality monitoring program provides a high-quality long term data set to evaluate these stressors and other emerging issues as they arise.

5. Summary

The total phosphorus data collected by the Lake of Bays Association over the summer of 2015 indicated continued excellent water quality at all sampling sites in the Lake of Bays. The main results of data analyses from 2015 and from previous years are as follows:

1. The LOBA monitoring program continued to provide high quality phosphorus data, although there were a greater number of bad splits and outliers in 2015 than in previous years. Continued vigilance is recommended to reduce the potential of contamination of the phosphorus samples.

2. Total phosphorus concentrations (mean TP = 4.5 μg/L excluding the River sites) were characteristic of lakes with low primary productivity and on average, met the highest Provincial standards for protection of nuisance aquatic plant growth due to phosphorus of 10 μg/L at all sites.

3. Mean total phosphorus concentration in Portage Bay was 4.6 μg/L, 6.3 μg/L in 2014 and 5.7 μg/L in 2013, representing a decline from elevated concentrations observed in 2012 (mean TP = 9.6 μg/L) that were coincident with construction activities. This confirms that potential impacts of construction activities were short term and continued monitoring at this site is no longer required unless other concerns arise.

4. Total phosphorus concentrations varied by 25% over the summer of 2015 and concentrations generally declined over the summer monitoring period. This pattern is typical for oligotrophic, stratified lakes on the Precambrian Shield. There was 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, and were more variable in shallow nearshore areas (Nearshore Undisturbed and Disturbed sites) than Deep Water sites as expected due to natural processes.

5. The previously identified increasing trend in mean summer total phosphorus concentration at Haystack Bay, Bigwin East and Fairview sites from 2002 to 2014 was no longer statistically significant with the addition of lower phosphorus concentrations in 2015. Phosphorus concentrations have varied between years, but this variance has been within the expected range of natural variability for Precambrian Shield lakes in Ontario. This fact, the close relationship between phosphorus concentration and precipitation and the lack of a similar observed trend in spring overturn phosphorus concentrations collected by the DDM suggest that patterns in phosphorus in Lake of Bays is strongly driven by natural fluctuations and not the result of an increase in total phosphorus inputs from human sources.

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

Appendix B. LOBA Total Phosphorus and Bacteria Data