Hutchinson
Environmental Sciences Ltd.

Lake of Bays Water Quality Report 2012

Prepared By: **Hutchinson Environmental Sciences Ltd.**
Prepared For: **Lake of Bays Association**

Project #: J100013
Date: October, 2013

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Project #: J100013

October 18, 2013

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

Dear Ms. Cumming:

Re: HESL J100013 - Lake of Bays Water Quality Report 2012

I am pleased to submit this final report to the Lake of Bays Association on behalf of Hutchinson Environmental Sciences Ltd. (HESL). The report summarizes the results of the 2012 monitoring program, and discusses long-term total phosphorus concentrations that have been observed since the onset of the program in 2002.

As in previous years, total phosphorus concentrations in Lake of Bays were indicative of excellent water quality. Over the past 11 years, there has been a significant increasing trend in mean summer concentrations at the deepwater sites. We have described several potential causes for the increasing trend in summer total phosphorus concentration in Lake of Bays including natural variability, regional or local environmental change (i.e., climate change, acid deposition, invasive species, etc.), and increased phosphorus inputs from human sources. While it is not possible at present to determine the exact mechanisms behind the change, it is likely that several factors are acting together as “multiple stressors” to elicit the observed trend.

It has been a pleasure to continue assisting the Association with their monitoring program and I look forward to working with you again to plan the 2013 field season.

Sincerely,

Tammy Karst-Riddoch, Ph.D.
Senior 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 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 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 sites (e.g., Narrows, Hollow River). This approach continues to allow comparison with other water quality programs, such as the Ministry of the Environment's Lake Partner Program and the District Municipality of Muskoka (DMM) 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 since 2009 because results were very consistent over the course of the monitoring program. Biannual sampling 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. Bacteria was not sampled in 2012, but will be sampled in 2013, and every other year thereafter.

Lake of Bays has so far been 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 2012 and discuss them in the context of long-term water quality data collected by the LOBA, the MOE Lake Partner Program and the District Municipality of Muskoka.

2. Methods

Volunteers, coordinated by the LOBA Environment Committee, collected samples for analysis of total phosphorus concentrations on five occasions during the summer of 2012 (July 1 and 23, August 4, 20, and 31). The sampling and analytical methods in 2012 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

2.1.1. Total Phosphorus

Total phosphorus was sampled at 22 locations throughout Lake of Bays to include deep, open water locations ('Deepwater' sites, n=9), nearshore sites adjacent to developed ('Disturbed' sites, n=5) and undeveloped shorelines ('Nearshore Undisturbed' sites, n=6), and other areas of interest, e.g., areas influenced by discharge from the Oxtongue and Hollow rivers ('River' sites, n=2). Sites monitored in 2012 are presented in Table 1, and illustrated on Figure 1.

At each deepwater site, a water sample was collected from the euphotic zone, at approximately two times the Secchi depth. At each nearshore site, a 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) that can contaminate the sample and result in non-representative, high phosphorus values.

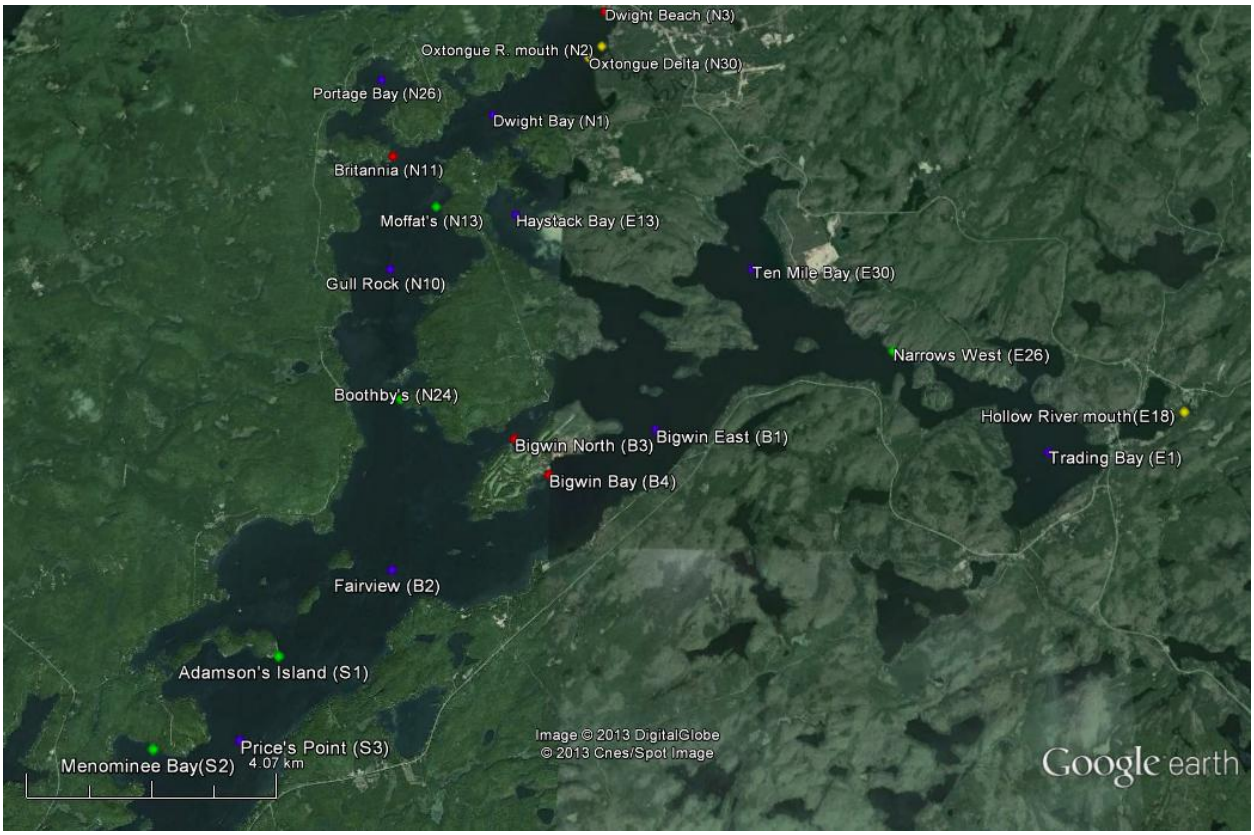
Samples were directly poured into the glass tubes used for phosphorus analysis, stored in a cool place and submitted for analysis to the Trent University laboratory at the Ministry of the Environment (MOE)'s Dorset Environmental Science Centre (DESC).

Table 1. 2012 Sampling Sites and Dates

Sites	Sampling Dates				
	Jul 1	Jul 23	Aug 4	Aug 20	Aug 31
Deepwater					
Bigwin East	✓	✓	✓	✓	★
Dwight Bay	✓	★	✓	✓	✓
Fairview	✓	✓	★	★	✓
Gull Rock	★	✓	✓	✓	✓
Haystack Bay	✓	✓	✓	✓	✓
Portage Bay	✓	✓	✓	✓	✓
Price's Point	✓	✓	✓	✓	✓
Ten Mile Bay	✓	✓	★	✓	
Trading Bay	✓	★	✓	✓	✓
Disturbed					
Bigwin Bay	✓	✓	★	✓	✓
Bigwin North	✓	✓	✓	★	✓
Britannia	✓	✓	✓	✓	✓
Dwight Beach	✓	★	✓	✓	✓
Port Cunnington	✓	✓	✓	✓	✓
Nearshore Undisturbed					
Adamson's Island	★	✓	✓	✓	✓
Boothby's	✓	★	★	✓	✓
Menominee Bay	★	✓	✓	✓	✓
Moffat's	✓	★	✓	✓	★
Narrows West	✓	✓		★	✓
Oxtongue Delta	✓	✓	✓	★	✓
River					
Hollow River mouth	✓	✓		✓	✓
Oxtongue River mouth	✓	✓	✓	✓	✓

Notes: Bad splits have been removed, ★ indicates sites where duplicate samples were collected

Figure 1. Map of Lake of Bays and Sites Sampled by the LOBA in 2012.



Notes: Deepwater sites (blue dots), Disturbed sites (red dots), Nearshore Undisturbed sites (green dots), River sites (yellow dots)

2.2 Quality Control

2.2.1. Total Phosphorus

2.2.1.1 Field Duplicates

Field duplicates for total phosphorus were collected at 17 sites in 2012 to assess the variability of results related to sampling and analytical procedures.

Field duplicates analyzed at the DESC laboratory show excellent agreement between sample pairs with an absolute mean difference of 0.7 μg/L, but a consistent percentage of the samples (5%) have larger than expected differences between field duplicates (i.e., >4 μg/L). Much investigation has failed to identify the cause for these measured differences. Separate experiments have excluded sample container cleanliness, lab apparatus, variation in the sub 80μ-sample matrix, and external inputs of phosphorus as sources of contamination. It remains unclear how these samples are contaminated. In almost every case, however, when these samples are reanalyzed, the retested pair of samples agrees 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 (Bev Clark, HESL, pers. comm.) Following the DESC approach, bad splits were identified in the LOBA dataset (>4 μg/L difference between duplicates) and the higher value was removed from further analysis.

2.2.1.2 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. Outliers are assessed statistically using the Grubb's Test (Grubbs 1969), which is a recommended procedure to screen the DMM's Lake System Health data set for outliers (Gartner Lee Limited, 2008). To perform the Grubb's Test, the ratio 'Z' is calculated as the difference between the suspect sample and the mean divided by the standard deviation (SD). Note that the mean and SD are calculated from all values, including the outlier. If Z is higher than the critical value of Z for a given sample size (N) (Table 2), the sample is considered to be an outlier at $p<0.05$.

For each sampling site, all total phosphorus values collected since 2002 were screened for outliers using the Grubb's test. Outliers were removed from the dataset for further analyses.

Table 2. Grubb's Critical Values of Z (p <0.05)

N	Critical Z	N	Critical Z
3	1.15	27	2.86
4	1.48	28	2.88
5	1.71	29	2.89
6	1.89	30	2.91
7	2.02	31	2.92
8	2.13	32	2.94
9	2.21	33	2.95
10	2.29	34	2.97
11	2.34	35	2.98
12	2.41	36	2.99
13	2.46	37	3.00
14	2.51	38	3.01
15	2.55	39	3.03
16	2.59	40	3.04
17	2.62	50	3.13
18	2.65	60	3.2
19	2.68	70	3.26
20	2.71	80	3.31
21	2.73	90	3.35
22	2.76	100	3.38
23	2.78	110	3.42
24	2.8	120	3.44
25	2.82	130	3.47
26	2.84	140	3.49

2.3 Data Analysis

2.3.1. Total Phosphorus

Total phosphorus concentrations were compared by site and site type for the 2012 monitoring period and long-term annual trends were evaluated by site type and compared to DMM spring monitoring data.

Mean total phosphorus concentrations in Lake of Bays were evaluated against a) the MOE's interim Provincial Water Quality Objectives (PWQO; MOE 1994), and the revised PWQO (MOE et al., 2010). The interim PWQO for the protection of aquatic life states that:

1. Average total phosphorus concentrations for the ice-free period should not exceed 20 µg/L to avoid nuisance concentrations of algae in lakes.

2. 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.
3. Excessive plant growth in rivers and streams should be eliminated at a total phosphorus concentration below 30 µg/L.

The revised PWQO allows phosphorus concentration to be increased by 50% over background concentration (i.e., the concentration of phosphorus that would occur if all human development was removed from the watershed) to a maximum cap of 20 µg/L to protect water quality (MOE et al., 2010). Background +50% thresholds have been set for individual basins of Lake of Bays by the DMM for the Lake System Health Program using a whole watershed scale water quality model that can predict phosphorus concentrations in Muskoka lakes (Table 3; Gartner Lee Ltd., 2005). Thresholds range from 5.9 µg/L in Trading Bay to 8.0 µg/L in Ten Mile Bay. The LOBA total phosphorus concentrations are derived from euphotic zone composite samples collected over the summer months, whereas DMM's thresholds are based on spring overturn values. As such, the LOBA phosphorus concentrations may differ (higher) from the DMM thresholds for the same lake, as they do not include the effect of dilution from the bottom layers and do not include the same months of measurement.

Table 3. Background Total Phosphorus Concentration +50% Thresholds for Individual Basins of Lake of Bays (Gartner Lee Ltd., 2005)

Basin	Background TP +50% (µg/L)
Dwight Bay	7.5
Haystack Bay	6.8
Rat Bay	7.7
South Muskoka River Bay	7.9
South Portage Bay	6.3
Ten Mile Bay	8.0
Trading Bay	5.9

3. 2012 Monitoring Results

3.1 Quality Control

3.1.1. Total Phosphorus

3.1.1.1 Field Duplicates

The quality control program continues to provide a high degree of confidence in the sampling protocols and analyses for total phosphorus with no bad splits (i.e., >0.4 µg/L difference between sample pairs) between field duplicates in 2012. Since 2002, bad splits occurred in 4 of 55 (7.3%) field duplicate samples (Figure 2, Table 4). The mean difference between field duplicates was 0.6 µg/L in 2012 and 0.8 µg/L in all previous years (2002-2011) after removing

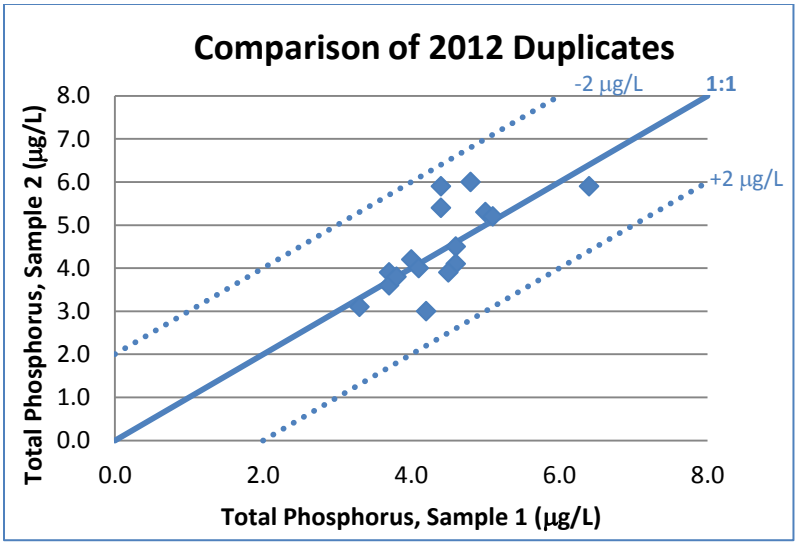
the bad splits, which is comparable to the DESC dataset that has a mean difference of 0.7 µg/L between thousands of field duplicate samples.

Table 4. Summary of Bad Splits between Total Phosphorus Field Duplicates in Lake of Bays, 2002-2012

Date	Site	TP1 (µg/L)	TP2 (µg/L)	Difference (µg/L)
01-Sep-06	Dwight Bay	9.2	*31.9*	22.7
01-Sep-06	Menominee Bay	*15.9*	8.1	7.8
23-Jul-07	Narrows West	*8.2*	4.1	4.1
7-Sep-10	Ten Mile Bay	6.1	*12.9*	6.8

Note: Sample values in italics are considered to be contaminated and are removed from the dataset for further analysis.

Figure 2. Total Phosphorus Field Duplicates in Lake of Bays, 2012.



3.1.1.2 Outliers

A total of 33 samples were identified as outliers in the LOBA dataset using the Grubb's test, two of which occurred in the 2012 data (Table 5). These outlier samples were removed from all analyses in this report, but should be reassessed each year as additional data are added to the dataset. Several samples from the River sites are statistical outliers based on the Grubb's test, 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 reflect this variability.

Table 5. Summary of Outliers in the LOBA 2002-2012 Dataset Based on Grubb's Test (p <0.5) Excluding River Sites.

Site	Date of Outlier	Outlier TP (µg/L)
Adamson's Island	18-Jul-11	15.1
Bigwin Bay	15-Jul-02	9.6
Bigwin North	23-Aug-04	27.7
	6-Aug-07	97.7
Boothby's	14-Aug-05	10.3
Britannia	1-Sep-03	12.6
	1-Sep-05	9.4
	4-Aug-08	8.4
Dwight Bay	19-Jul-10	11.7
Dwight Beach	4-Jul-11	9.5
	18-Jul-11	7.4
Fairview	31-Aug-07	12.5
	17-Jul-09	12.3
Gull Rock	14-Jul-03	16.9
Haystack Bay	6-Sep-04	74
	7-Aug-06	40.3
	1-Sep-06	14.1
	6-Aug-07	11.8
	17-Jul-09	57.7
	31-Aug-12	22.4
Little Trading Bay	3-Jul-06	11.9
Menominee Bay	4-Jul-05	11
Moffat's	5-Aug-02	36.7
	6-Aug-07	15.1
Narrows West	4-Jul-11	11.4
	1-Aug-11	8.5
Portage Bay	20-Aug-12	61.3
Price's Point	2-Aug-10	12.7
	18-Jul-11	12.8
Ten Mile Bay	21-Aug-06	10.2
Trading Bay	19-Aug-02	17.7
	19-Jul-04	12.3
	21-Aug-06	11

3.2 Total Phosphorus

The 2012 summer total phosphorus concentration of sites monitored in Lake of Bays ranged from 3.1 to 12.9 µg/L, with a mean concentration of 5.1 µg/L (Table 6). Mean summer total phosphorus concentrations at all sites were <10 µg/L and are indicative of oligotrophic conditions with low algal productivity, and provide a "high level of protection against aesthetic deterioration" due to nuisance aquatic plant growth in accordance with the interim PWQO (MOE, 1994).

Mean summer total phosphorus concentrations in Dwight (7.5 µg/L), Haystack (6.8 µg/L), Ten Mile (8.0 µg/L) and Trading (5.9 µg/L) bays were below the revised PWQO (background plus 50% threshold values) for these basins (see Table 2) and as such, existing human development has not adversely impaired water quality in Lake of Bays. For Portage Bay, however, the average total phosphorus concentration of 9.6 µg/L exceeded the revised PWQO threshold value of 6.3 µg/L for South Portage Bay[1]. This site was sampled in 2012 in response to concerns about shoreline development that was occurring that summer. The last monitoring in Portage Bay by LOBA was in 2007 and included a nearshore undisturbed site and a deepwater site near Wee Island, with an average total phosphorus concentration of 6.5 µg/L and 5.6 µg/L, respectively. Monitoring of Portage Bay should continue to assess whether the higher total phosphorus concentrations observed in 2012 relative to 2007 were due to construction activities, or natural variability in the bay.

At other lake sites without DDM thresholds, total phosphorus concentrations were below the lowest Lake of Bays threshold of 5.9 µg/L, further indicating excellent water quality with respect to phosphorus.

For each type of site (e.g. deepwater, disturbed, nearshore undisturbed) total phosphorus concentrations varied little over the summer growing season, showing no significant increasing or decreasing trends (Figure 3). The variability observed at nearshore sites in previous years (e.g., 2011), was not evident in the 2012 data. Average concentrations were similar between nearshore disturbed and undisturbed sites (Figure 3), supporting previous conclusions that shoreline disturbance is having little impact on phosphorus concentrations. On average, these sites had lower phosphorus concentrations than the deepwater sites likely due to uptake by aquatic plants and attached algae that are more abundant in shallower water. The average total phosphorus concentration measured at the River sites was similar to that measured at the deep the deep water sites. The division between river and deepwater concentrations was not observed in 2012.

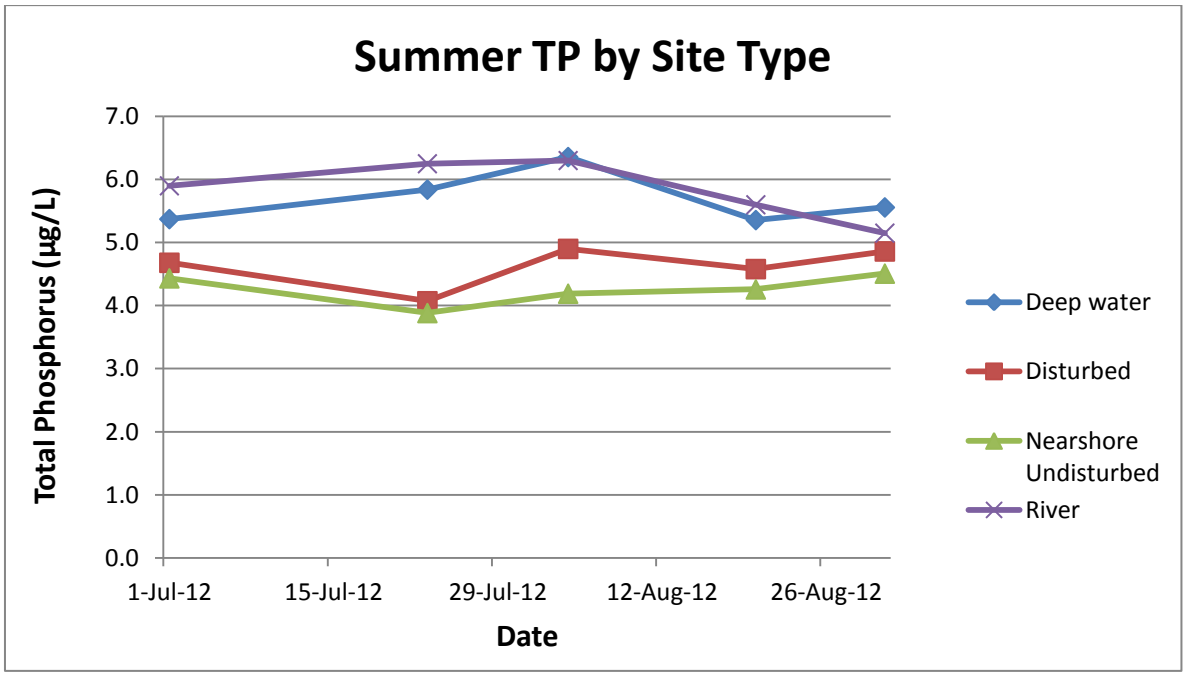
[1] *This PWQO may not be appropriate to evaluate the LOBA data for Portage Bay due to differences between the LOBA and DMM monitoring sites/times (i.e., spring overturn versus summer euphotic zone concentrations and Portage Bay versus South Portage Bay sampling locations).*

[2] *The LPP Secchi depth data collected after 2002 were only available from Little Trading Bay and south of Britania Bay. The*

Table 6. Total Phosphorus Concentrations (µg/L) in Lake of Bays, 2012

Site ID	Site Name	1-Jul	23-Jul	4-Aug	20-Aug	31-Aug	Mean
Deep Water							**5.7**
B1	Bigwin East	5.8	5.1	4.2	4.7	5.4	5.0
B2	Fairview	4.3	5.1	5.2	5.2	4	4.7
E1	Trading Bay	4.5	4.2	5.6	5.5	5.7	5.1
E13	Haystack Bay	5.2	3.8	5.8	3.9		4.7
E30	Ten Mile Bay	6.7	6.0	7.9	6.7		6.8
N1	Dwight Bay	6.1	6.2	6.1	8.6	5.7	6.5
N10	Gull Rock	5.15	4.8	6.3	4.1	5.3	5.1
N26	Portage Bay	6.3	*12.9*	*11.6*		*7.7*	*9.6*
S3	Price's Point	4.3	4.5	4.6	4.2	5.1	4.5
Disturbed							**4.6**
B3	Bigwin North	4.4	4.3	6.2	4.9	4.2	4.8
B4	Bigwin Bay	3.4	3.3		4.1	7	4.5
B6	Port Cunnington	4.7	5.1	3.9	4.5	4	4.4
N11	Britannia	6.2	3.1	5.2	4.1	5.3	4.8
N3	Dwight Beach	4.7	4.6	4.3	5.3	3.8	4.5
Nearshore Undisturbed							**4.3**
E26	Narrows West	4.6	4.9		3.8	4.5	4.5
N13	Moffat's	4.9	3.2	5.7	4.2	4.4	4.5
N24	Boothby's	3.4	3.8	3.7	5.2	3.2	3.9
N30	Oxtongue Delta	6.0	3.8	4.5	4.1	3.5	4.4
S1	Adamson's Island	4.1	3.7	3.7	4.1	7.9	4.7
S2	Menominee Bay	3.6	3.9	3.4	4.2	3.6	3.7
River							**5.8**
E18	Hollow River mouth	5.5	5		4.8	4.9	5.1
N2	Oxtongue mouth	6.3	7.5	6.3	6.4	5.4	6.4
All sites							**5.1**

Figure 3. Total Phosphorus Concentrations in Lake of Bays 2012 by Site Type



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

Of all the sites monitored in 2012, 3 sites differed notably from other sites of the same type, including Portage Bay (Deepwater), Adamson's Island (Nearshore Undisturbed) and Bigwin Bay (Disturbed; Figures 4 to 7).

Portage Bay differed from other Deepwater sites on July 23rd when total phosphorus concentrations increased substantially to 12.9 µg/L above the mean of 5.0 µg/L measured at the other stations on that sample sampling date (Figure 4). On August 4th, concentrations were still high (11.6 µg/L) compared to the other Deepwater sites. During the August 31st sampling event, concentrations decreased to 7.7 µg/L, but were still higher than those measured at the other sites. As previously described, Portage Bay was sampled in 2012 due to concern regarding construction activities. This site should continue to be monitored to assess whether the higher total phosphorus concentrations were due to construction that year or due to natural variability.

Adamson's Island differed from other Nearshore Undisturbed sites on August 31st with a higher total phosphorus concentration of 7.9 µg/L (Figure 5). At the disturbed sites, total phosphorus concentrations were variable throughout the summer and ranged from 3.1 to 7.0 µg/L with the highest concentration measured at Bigwin Bay (7.0 µg/L) on the August 31st sampling event (Figure 6). This value, however, is within the range of variability for Disturbed sites that has been observed previous years.

Figure 4. Total phosphorus concentrations in Lake of Bays 2012, Deepwater sites.

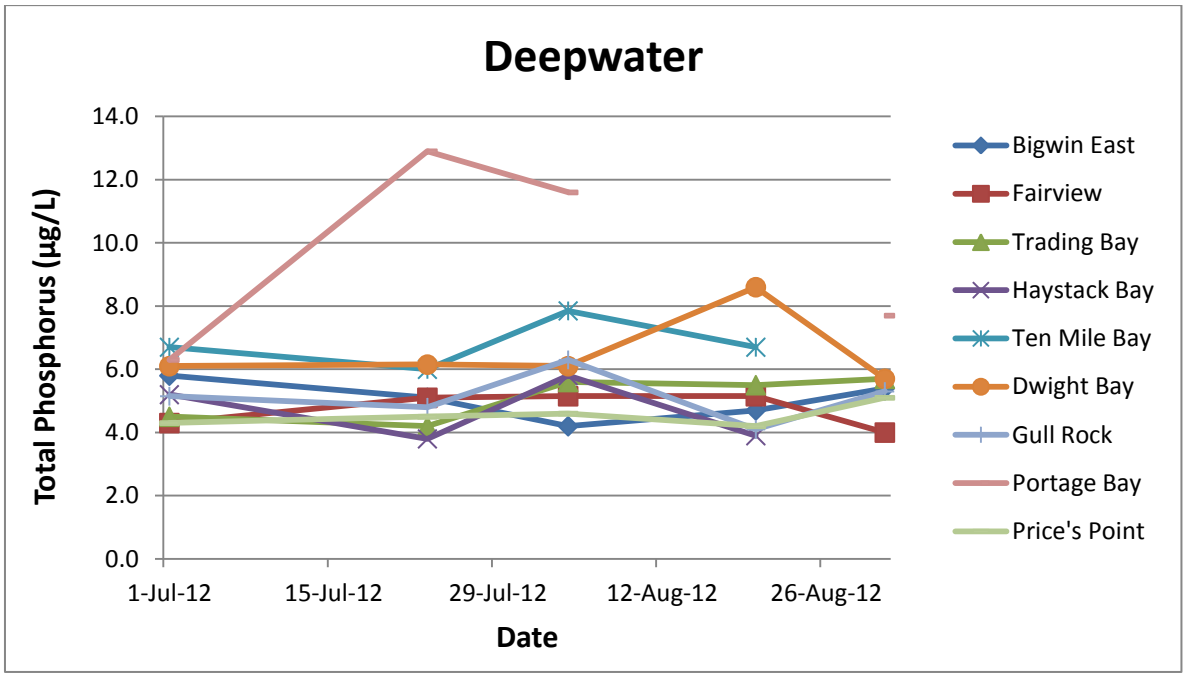


Figure 5. Total phosphorus concentrations in Lake of Bays 2012, Nearshore Undisturbed sites.

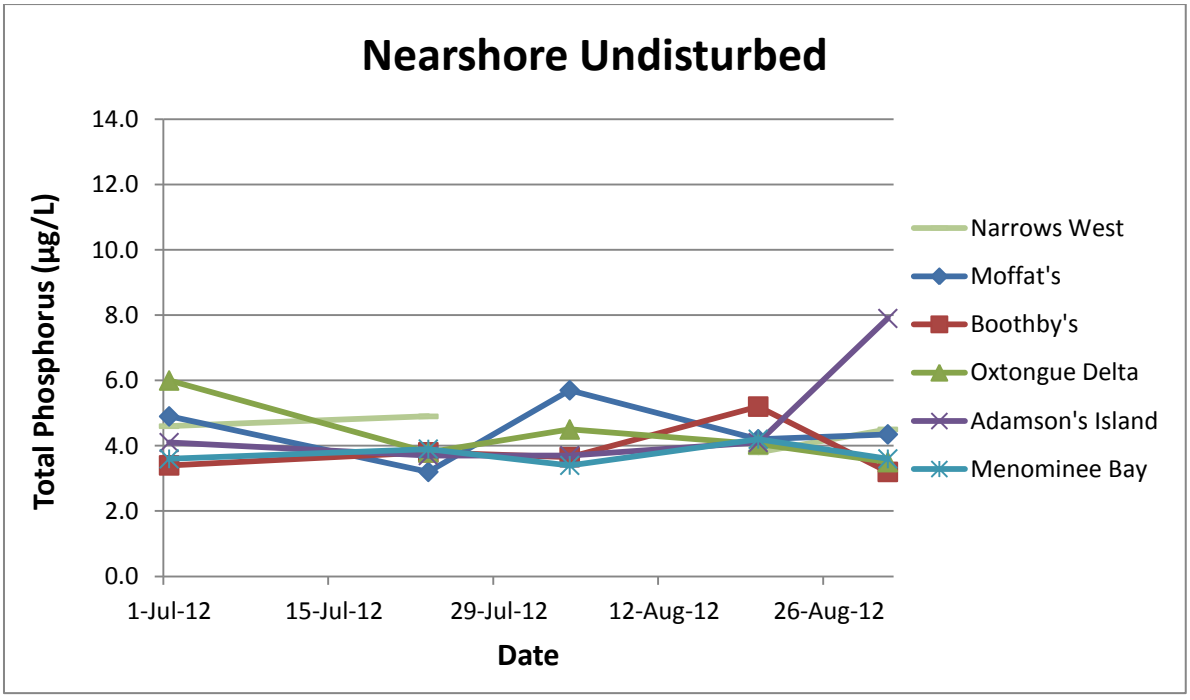


Figure 6. Total phosphorus concentrations in Lake of Bays 2012, Disturbed sites.

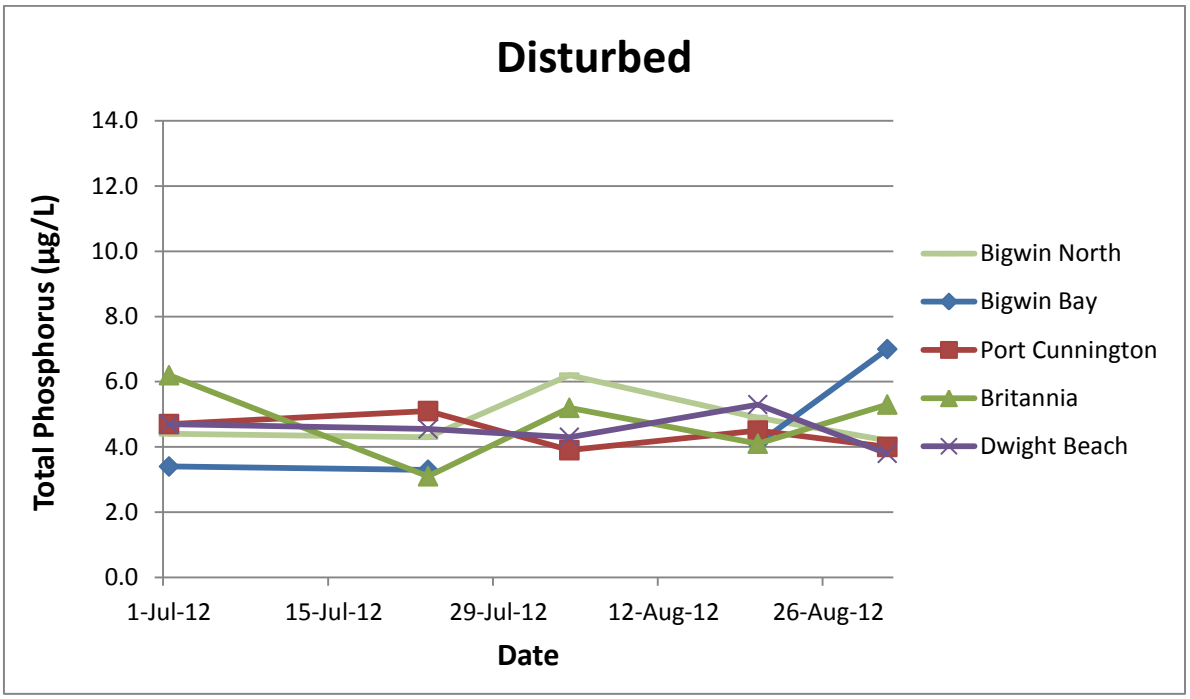
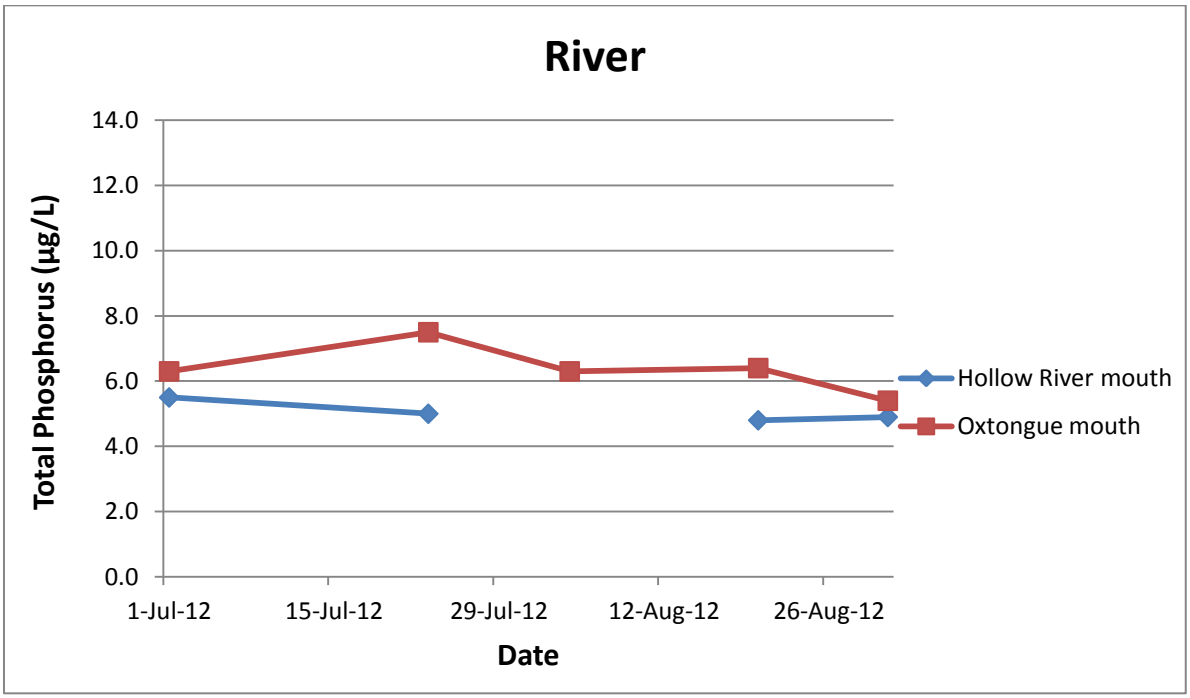


Figure 7. Total phosphorus concentrations in Lake of Bays 2011, River sites.



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 (Table 7). The yearly number of collected samples including QA/QC samples ranged from 50 in 2002 to 123 in 2012, with a total of 960 samples collected at the end of the 2012 program. This data set provides an excellent opportunity to assess long-term trends and variability in Lake of Bays total phosphorus. All data collected by the LOBA monitoring program since 2002 are provided in Appendix B.

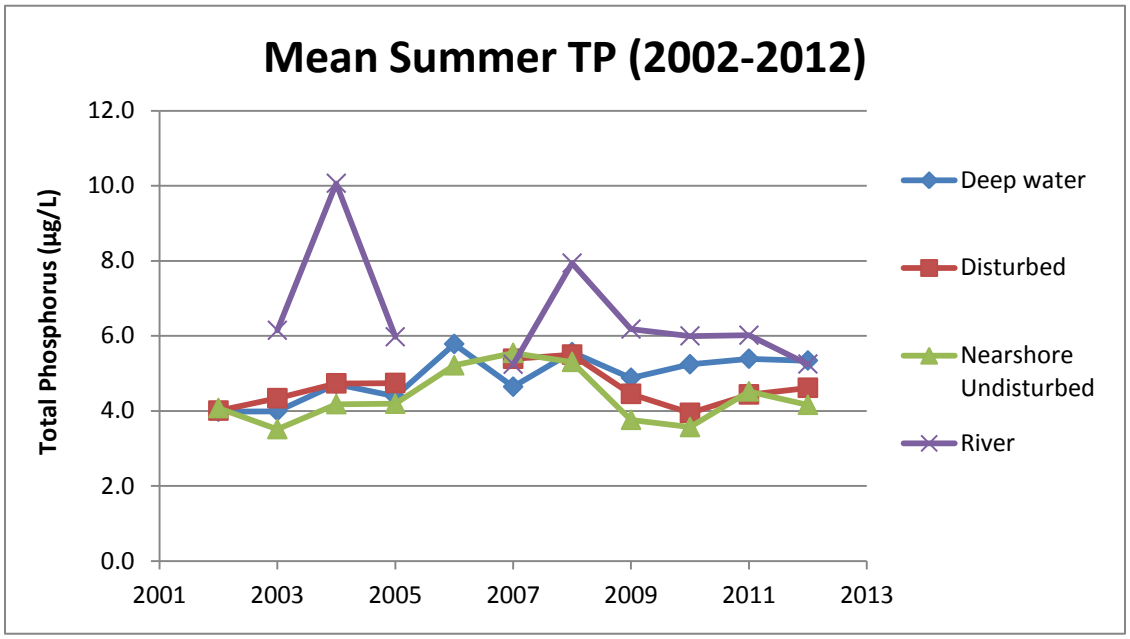
Table 7. Number of Total Phosphorus Samples Collected by the Lake of Bays Monitoring Program (2002-2012)

Site Type	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
Deep water	30	39	28	29	52	49	48	47	45	44	51	462
Disturbed	15	22	13	8		10	13	15	15	28	26	165
Nearshore Undisturbed	5	7	5	14	20	31	32	21	29	28	37	229
River		16	7	8		10	15	10	16	13	9	104
Total	50	84	53	59	72	100	108	93	105	113	123	960

To summarize trends over the years, mean phosphorus concentrations were calculated per site type and per year using all of the LOBA data with the exception of data from Little Trading Bay and Portage Bay (both Deepwater sites). As described in the 2010 monitoring report, the Little Trading Bay (E20) site was removed from the Deepwater class for analysis of long-term trends because total phosphorus concentrations (2005-2008) at this site were significantly higher than at other deepwater sites and do not reflect the overall conditions of deepwater areas in the lake. Little Trading Bay is a relatively small distinct basin located at the far east end of Lake of Bays and is likely influenced by inputs from the Hollow River that discharges at the east end of the bay and the bay likely receives little water from the main body of the lake (i.e., little mixing). Portage Bay (N26) was only sampled in 2012 and had relatively higher phosphorus concentrations than the other deepwater sites in that year which may be due to localized construction activities and not reflective of overall deepwater conditions in the lake.

Since 2002, the mean summer total phosphorus concentrations have ranged between ~3 and 6 µg/L in the Deepwater, Disturbed and Nearshore Undisturbed sites (Figure 8). The river-influenced sites have been more variable with generally higher concentrations that have ranged from ~5 to 10 µg/L. Overall, these concentrations are low and continue to reflect the low primary productivity or oligotrophic conditions in Lake of Bays.

Figure 8. Long-term trends (2002-2012) in means summer euphotic zone total phosphorus (TP) by Site Type.

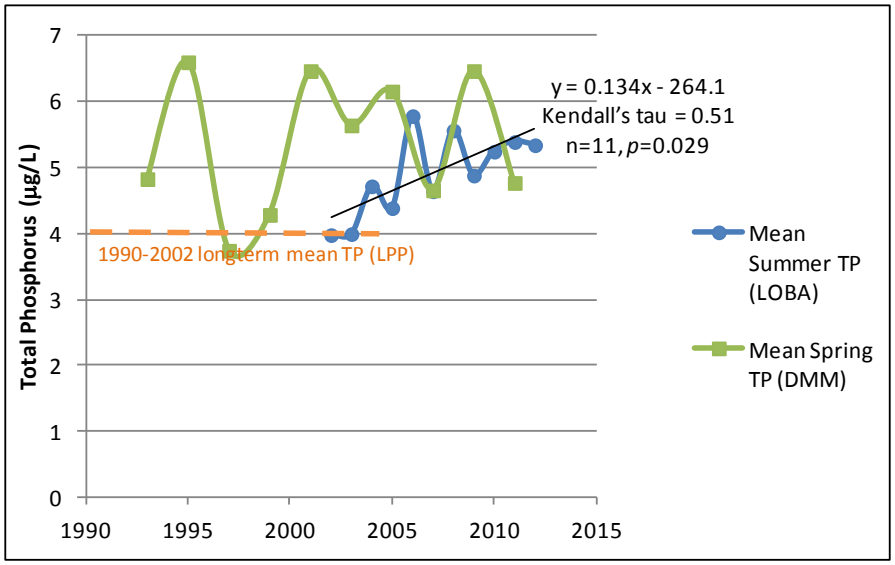


Note: Little Trading Bay and Portage Bay (Deepwater sites) are not included as they displayed total phosphorus concentrations that were significantly higher than other deepwater sites and are not representative of deepwater sites in Lake of Bays

There has been is a significant increasing trend in mean summer total phosphorus concentration of the Deepwater sites (excluding Little Trading Bay and Portage Bay) since 2002 (Kendall's test for Trend, Kendall's tau = 0.51, n=11, *p*=0.029) with an average annual increase in of 0.14 µg/L/yr (Sen's slope estimate) for a total average increase of 1.5 µg/L over 11 years (Figure 9). This trend was noted in previous LOBA monitoring reports, which was coincident with a decrease in water clarity (as Secchi depth, Lake Partner Program data[2]). A similar trend, however, was not observed in the spring total phosphorus monitoring data collected by the DMM, which has been more highly variable than the summer LOBA data between sample years (Figure 9). The main cause for greater interannual changes in spring total phosphorus concentrations (DDM data) than summer concentrations (LOBA) is most probably related to the varying intensity 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 may mask long-term trends in lake total phosphorus concentration that have been observed in the summer months. Despite annual differences in the two monitoring programs, they provide similar long-term mean phosphorus concentrations for the deepwater sites (DMM TP $spring_{02\text{-}11}$ = 5.5 µg/L, LOBA TP $summer_{02\text{-}11}$ = 4.9 µg/L).

[2] *The LPP Secchi depth data collected after 2002 were only available from Little Trading Bay and south of Britania Bay. The Little Trading Bay site is not representative of Lake of Bays as described in this report and the exact location of the monitoring site south of Britania Bay is not known. The LPP Secchi Depth data is therefore not readily comparable to the LOBA data.*

Figure 9. Long-term trends in mean spring overturn (DMM data) and mean summer euphotic zone total phosphorus in Deepwater areas of Lake of Bays.

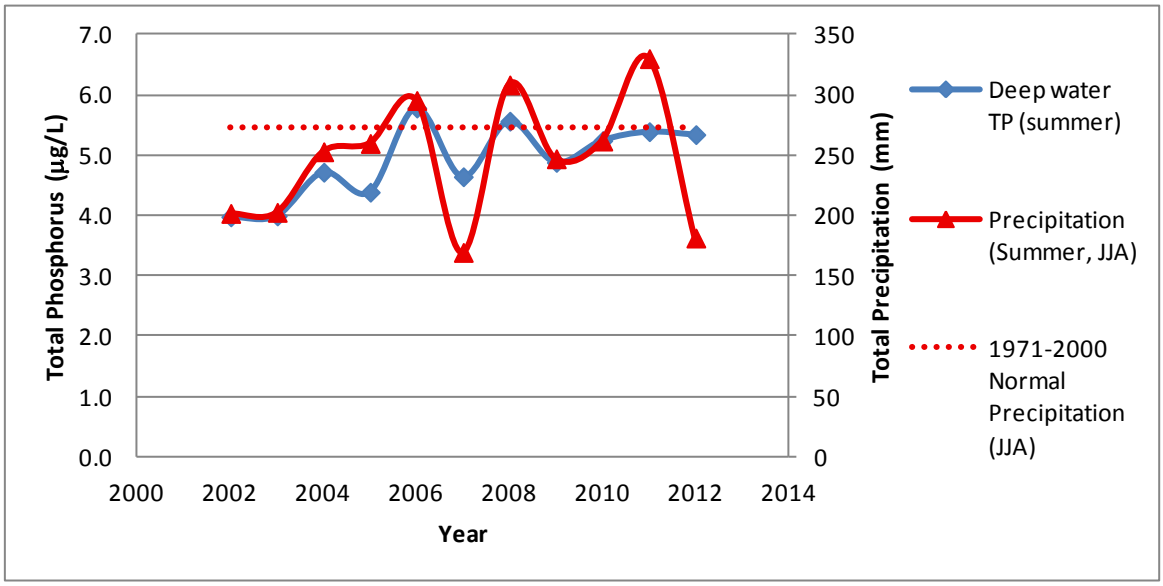


Note: LOBA sites exclude Little Trading Bay and Portage Bay. DMM sites include Dwight, Haystack, Rat, South Muskoka River, South Portage, Ten Mile and Trading bays.

The observed trend in phosphorus at the Deepwater sites may reflect natural interannual variability for the lake. Interannual 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, etc. Based on long-term monitoring records from Precambrian Shield lakes, the natural variability in total phosphorus concentration is approximately 20% (Bev Clark, pers. comm., former coordinator of MOE's Lake Partner Program), that is, annual total phosphorus concentrations can deviate by +/-20% from the long-term mean due to natural causes. Mean total phosphorus concentration at the Deepwater sites has ranged from 4.0 to 5.8 µg/L, which is within 20% of the 11-year long term mean of 4.9 µg/L, and therefore within the expected range of natural variability. It is possible, therefore, that in time, phosphorus concentrations will recover and the increasing trend will not continue.

Support for natural variability due to weather patterns is provided by a comparison of phosphorus concentrations with precipitation records near Lake of Bays. Mean total precipitation over the summer months (June-August; JJA) observed at Environment Canada climate stations at Beatrice and Muskoka is significantly correlated to mean summer total phosphorus concentration (Spearman rho = 0.95, df=10, $p<0.01$), such that higher total phosphorus concentration was generally observed in years with higher summer precipitation and lower concentrations observed when summer precipitation was lower (Figure 10). Precipitation plays a strong role in phosphorus concentration in lakes, affecting phosphorus loads to the lake in runoff from the catchment and from deposition of phosphorus in rain directly to the lake surface.

Figure 10. Mean summer euphotic zone total phosphorus in Deepwater areas of Lake of Bays and total summer precipitation (June, July, August) 2002-2012.



Note: Climate data from Environment Canada stations Beatrice (Stn. 6110607, 2006-2012), Beatrice 2 (Stn. 6110606, 2002-2006) and Muskoka A (Stn. 6115525, 2002-2009).

While there is a strong relationship between summer precipitation and total phosphorus concentrations in Lake of Bays, there is no statistically significant trend to higher summer precipitation over the 2002-20012 period (Mann Kendall, p >0.05), which would be expected if precipitation was driving the increase in phosphorus, and overall, precipitation has been lower than the long-term normal rainfall (1971-2000) in eight of the 11 monitoring years (Figure 10). This would suggest that other factors are also contributing to variability and the increasing trend in phosphorus. There may, however, be localized differences in precipitation at Lake of Bays and at the Environment Canada monitoring stations used in this analysis. Further analysis using long-term climate data from nearby stations monitored by DESC may be of use to better resolve the influence of precipitation and other climatic variables on phosphorus concentration in Lake of Bays.

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, MOE 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 observed trends in Lake of Bays. The MOE 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.

Some increase in total phosphorus concentration is expected in Lake of Bays due to shoreline development and this may be contributing to the observed summer trend. For example, for the main basin of the lake (including Dwight Bay), the DMM water quality model (Gartner Lee Ltd.,

2005) predicts an increase in phosphorus concentration (as ice-free mean concentration) of 0.72 μg/L over 'natural' conditions with full buildout of all existing lots of record on the lake once all phosphorus from the septic systems has reached the lake. The migration of phosphorus from septic systems to a lake can be slow (in some cases moving only 1 m per year according to MOE (pers.comm., Bev Clark, former MOE scientist)), taking many years to reach the lake. It is possible that some phosphorus from existing septic systems has only started reaching the lake. The increase in phosphorus concentration predicted by the DMM model, however, is for the ice free season, from April to November and is not readily comparable to the summer LOBA monitoring. The spring phosphorus concentration collected by DMM can be converted to ice free mean concentration, and as previously noted, there has been no trend in this data set.

In summary, there are several potential causes for the increasing trend in summer total phosphorus concentration in Lake of Bays including natural variability, regional or local environmental change (i.e., climate change, acid deposition, invasive species, etc.), and increased phosphorus inputs from human sources. These factors may be acting together as "multiple stressors" to elicit the observed changes in total phosphorus concentration over the past 11 years in Lake of Bays. Phosphorus dynamics in Lake of Bays is therefore a complex issue that cannot be resolved by the present study. The change in phosphorus concentrations at the Deepwater sites, however, is directional, and should be monitored closely in future years. Adding Secchi depth water clarity measurements at the Deepwater sites would provide a gauge of potential changes in algal productivity that could be used, in conjunction with the phosphorus data, to assess long-term trends.

5. Summary

The total phosphorus data collected by the Lake of Bays Association over the summer of 2012 were of high quality and indicated continued excellent water quality at all sampling sites in the Lake of Bays. The main results of data analyses from 2012 and from previous years are as follows:

1) Total phosphorus concentrations are characteristic of lakes with low primary productivity and meet the highest Provincial standards for protection from algae bloom development. All were below applicable DMM thresholds for phosphorus (background phosphorus concentration +50%), with the exception of Portage Bay.

2) The average total phosphorus concentration in Portage Bay was above the DMM threshold of 6.3 μg/L for South Portage Bay. 2012 was the first year samples were collected from Portage Bay. Further data are necessary to determine if the 2012 data is reflective of actual conditions in the bay, and if so, to assess possible causes for higher concentrations. It is recommended that this site be monitored in 2013.

3) The Grubb's test provides a statistical means to identify extreme values for total phosphorus that could influence the evaluation of trends in the data. Evaluation of outliers should be repeated each year with the entire data set.

4) Total phosphorus concentrations were highest in river sites compared to lake sites, as expected due to natural processes.

5) There is a significant increasing trend in mean summer total phosphorus concentration in deepwater sites of Lake of Bays from 2002 to 2012. Phosphorus concentrations over that time period are, however, within 20% of the mean which is considered as the range of natural variability for Precambrian Shield lakes in Ontario. This fact, the close relationship between phosphorus concentration and summer precipitation and the lack of a similar observed trend in spring overturn phosphorus concentrations collected by the DDM suggest that the trend may be due to natural fluctuations and not the result of an increase in total phosphorus inputs from human sources.

6) Total phosphorus concentrations at the deepwater sites should be monitored closely in future years as the change is directional. Secchi disk depth measurements should be added at the Deepwater sites to provide a gauge of productivity that can be used to assess long term trends.

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