Hutchinson

Environmental Sciences Ltd.

Lake of Bays Water Quality Report 2013

Prepared for: Lake of Bays Association
Job #: J100013

June 27, 2014

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

Hutchinson
Environmental Sciences Ltd.

3-1 Taylor Road, Bracebridge, ON P1L 1S6 | 705-645-0021
Suite 202 – 501 Krug Street, Kitchener, ON N2B 1L3 | 519-576-1711

June 27, 2014 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 2013 – final report

I am pleased to submit this final report for the Lake of Bays Water Quality Monitoring Program results from the summer of 2013. As in previous years, bacteria and total phosphorus concentrations were well below applicable Provincial guidelines indicating excellent water quality. Total phosphorus concentrations at the deepwater sites, however, still indicate a statistically significant increasing trend over time since 2002. Mean annual concentrations are correlated to regional precipitation patterns over the summer months suggesting that the trend may be the result of natural variability related to differences in precipitation.

Please don't hesitate to contact me if you have any questions or concerns.

Sincerely,
Hutchinson Environmental Sciences Ltd.

T. KRR

Tammy Karst-Riddoch, Ph.D.
tammy@environmentalsciences.ca

Signatures

Report prepared by:

Tammy Karst-Riddoch, Ph.D.
Senior Aquatic Scientist

Report reviewed by:

Deborah Sinclair, M.Sc.
Senior Aquatic Scientist

Table of Contents

List of Figures

List of Tables

Appendices

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 earlier monitoring results were very consistent between sites and years. 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 sampled in 2013, and will be sampled again in 2015, 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 and bacteria monitoring completed by the LOBA in 2013 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 bacteria and total phosphorus concentrations on five occasions during the summer of 2013 (July 1 and 21, August 5, 18, and 28). The sampling and analytical methods in 2013 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 22 sites throughout Lake of Bays to include deep, open water locations ('Deepwater' sites, n=9), nearshore sites adjacent to developed ('Disturbed' sites, n=4) and undeveloped shorelines ('Nearshore Undisturbed' sites, n=6), and areas influenced by discharge from the Oxtongue and Hollow rivers ('River' sites, n=3) (Table 1, Figure 1).

2.1.1 Bacteria

Bacteria samples were collected at the same sites as those visited for total phosphorus sampling. Bacteria were sampled at a depth of 22 – 30 cm at both near-shore and deep water locations and care was taken to prevent contamination.

The bacteria counts were based on the use of "Coliplates" (EBPI). Coliplates are a manufactured product in which 96 cells are inoculated with sampled water, incubated for a 24-hour period and then assessed for both total coliform and *Escherichia coli* (*E. coli*) concentration based on comparison of the colorimetric response of each cell against a Most Probable Numbers chart. The detection limit for the Coliplate methodology is 3 colony forming units (cfu) in 100 mL of water. This means that if zero Coliplate cells turn colour after incubation, the lowest number of bacteria that can be reported is <3 cfu/100 mL. For the LOBA data, values of <3 cfu/100 mL are reported as 1 cfu/100 mL for statistical evaluation of the data, but note that the actual value can be 0 to 2 cfu/100 mL.

2.1.2 Phosphorus

At each Deepwater site, a 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.

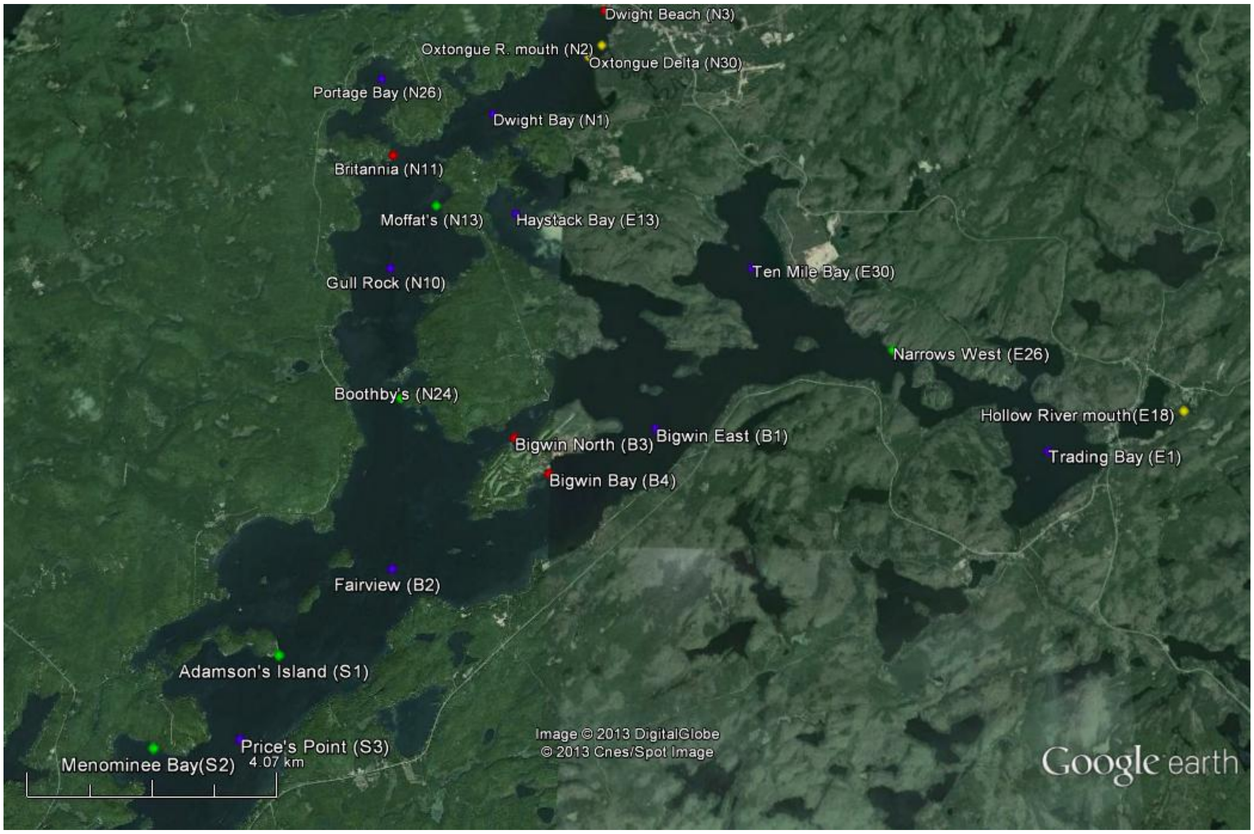
Samples were directly poured into the glass tubes used for phosphorus analysis, stored in a cool place and submitted for analysis to the Trent University laboratory at the Ministry of the Environment (MOE)'s Dorset Environmental Science Centre (DESC).

Table 1. 2013 Sampling Sites and Dates

Site Name	Total Phosphorus Sampling					Bacteria Sampling				
	1-Jul	21-Jul	5-Aug	18-Aug	28-Aug	1-Jul	21-Jul	5-Aug	18-Aug	28-Aug
Deep Water Sites										
Bigwin East	1	2	1	2	1	1	2	1	3	1
Dwight Bay	2	1	2	2		2	1	3	2	1
Fairview	2	1	1	2	2	2	1	1	2	2
Gull Rock	1	2	1	1	1	1	3	1	3	3
Haystack Bay	1	1	1	1	2	1	1	3	3	2
Portage Bay	1	1	1	1	1	1	1	1	1	1
Price's Point	2	1	2	1	2	2	1	2	1	2
Ten Mile Bay	1	1	1	1	1	1	1	1	1	1
Trading Bay	2	-	2		1	2	-	1	-	1
Disturbed Sites										
Bigwin Bay	1	1	1	1	1	1	1	1	1	1
Bigwin North	1		1	1	2		1	1	3	2
Britannia		1	1	1	1	1	1	1	3	3
Dwight Beach	1	1	1	1	1	1	1	3	1	1
Nearshore Undisturbed										
Adamson's Island	1	1	1	1	1	1	3	1	1	3
Boothby's	2	-	2	-	1	2	3	2	3	3
Menominee Bay	1	2	1	1	1	1	2	1	1	1
Moffat's	1	-	1	2	1	1	3	3	2	3
Narrows West	1	-	1	2	-	1	1	3	2	-
River Sites										
Hollow River mouth	1	-	1	-	1	1	1	3	1	1
Oxtongue Delta	1	2	1	1	2	1	2	1	1	2
Oxtongue mouth	1	1	1	1	1	1	1	1	1	1

Notes: 1 = single sample collected, 2 = field duplicate samples collected, 3 = field and laboratory duplicate samples collected, - = no sample collected

Figure 1. Map of Lake of Bays and Sites Sampled by the LOBA in 2013.



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 Bacteria

Quality control measures for bacteria included:

1. The inclusion of a sample of distilled water by one volunteer sampler at one selected site for each sample date for bacterial analysis as a field blank;
2. The inclusion of a field duplicate on at least one sampling date for each site (n_{sites}=17); and
3. Submission of water samples to the Central Ontario Analytical Laboratory (COAL) (n=12), an accredited laboratory in Orillia, Ontario, for membrane filtration analysis of total coliform and E. coli for comparison with the Coliplate method. COAL has a reportable range from 0 to >80 cfu/100 mL for potable water samples and <4 to >8 cfu/100 mL for recreational water samples.

2.2.2 Total Phosphorus

2.2.2.1 Field Duplicates

Field duplicates for total phosphorus were collected at 13 sites in 2013 to assess the variability of results related to sampling and analytical procedures (Table 1).

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) (B. Clark, former Lake Partner Program Coordinator, DESC, Pers. Comm.). 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 that would explain the measured differences and 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.

In previous LOBA monitoring reports, bad splits were identified in the LOBA dataset for samples with >4 μg/L and >40% difference between duplicates, and the higher value was removed from further analysis. The Province of Ontario now recommends that bad splits should be considered as duplicate samples that are >35% different and/or have an absolute difference of >5 μg/L (Hyatt et al., 2012). Bad splits for all total phosphors sample pairs collected by LOBA since the beginning of the monitoring program were reassessed using this guidance.

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. 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 Bacteria

Bacteria (*E. coli* and total coliform) levels were compared to the Provincial Water Quality Objectives (PWQO) for recreational water use (Ministry of the Environment and Energy 1994). For total coliform, the PWQO is 1,000 colony forming units (cfu) per 100 mL, based on a geometric mean for a series of water samples. The MOE recommends that this objective be used as a guideline only, and that 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. This objective is intended to protect swimming and bathing beaches for recreational use. 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.

Although the five sampling visits to Lake of Bays did not occur within one, but two months, we calculated geometric means from the five dates as a reasonable approximation of the degree of bacterial contamination over the summer season.

2.3.2 Total Phosphorus

Total phosphorus concentrations were compared by site and site type for the 2013 monitoring period and long-term annual trends were evaluated by site type and compared to long-term DMM spring monitoring data.

Mean total phosphorus concentrations in Lake of Bays were evaluated against the revised Provincial Water Quality Objective for lakes located on the Precambrian Shield (PWQO; MOE et al., 2010). The revised PWQO allows phosphorus concentration to be increased by 50% over a modeled 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). If the total phosphorus concentration of a lake is less than the revised PWQO, then the lake is not considered to be impaired due to phosphorus loads from shoreline development.

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 results for the same lake, as they do not include the effect of dilution from the bottom layers of water and do not include the same months of measurement.

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

Basin	Revised PWQO Threshold (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

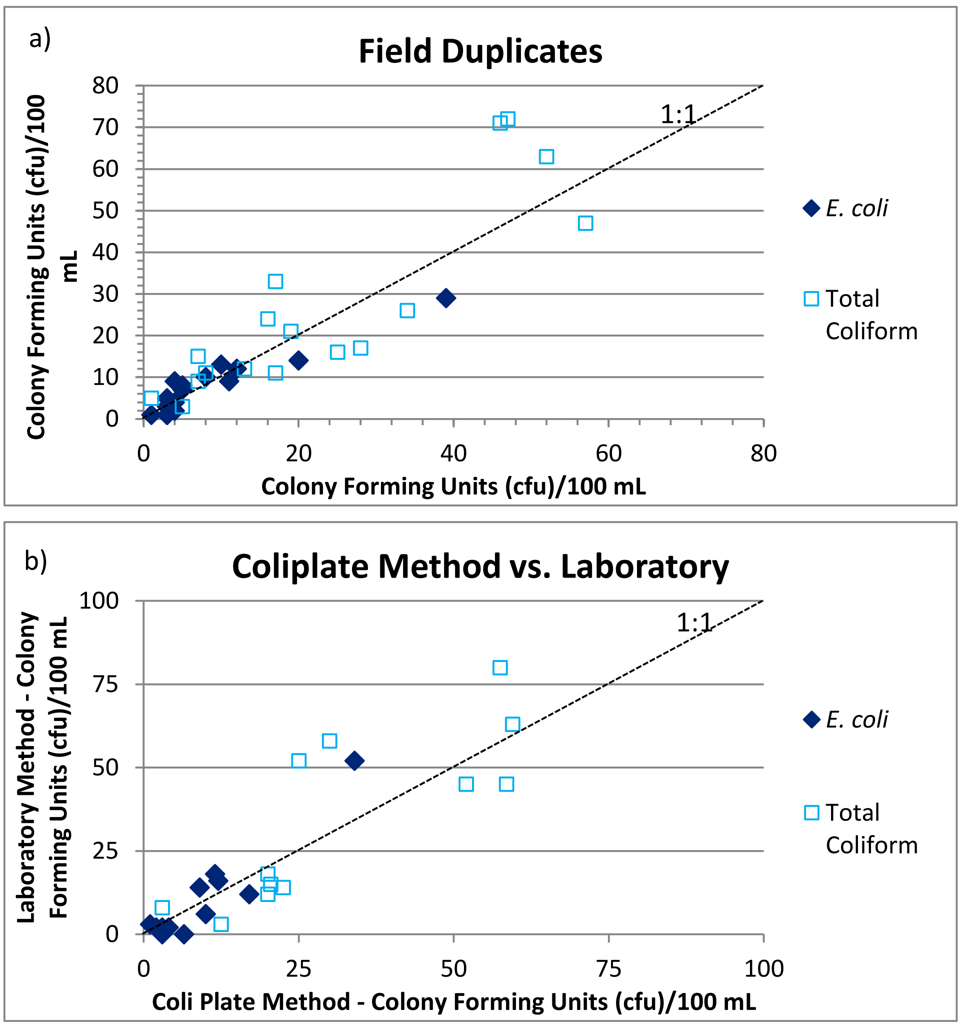
3. 2013 Monitoring Results

3.1 Quality Control

3.1.1 Bacteria

The quality control program in 2013 again yielded positive results that provide 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 10 cfu/100 mL for *E. coli* and 25 cfu/100 mL for total coliform. Similarly, differences between the Coliplate and laboratory results were low with a maximum difference of 18 cfu/100 mL for *E. coli* and 28 cfu/100 mL for total coliform. Laboratory results tended to provide higher bacteria concentrations than the coliplate method, but the absolute results of the two methods are still very similar and would provide for the same overall conclusion regarding bacterial contamination.

Figure 2. Comparison of *E. coli* and total coliform results between a) field duplicates and b) laboratory and Coliplate methods.



3.1.2 Total Phosphorus

3.1.2.1 Field Duplicates

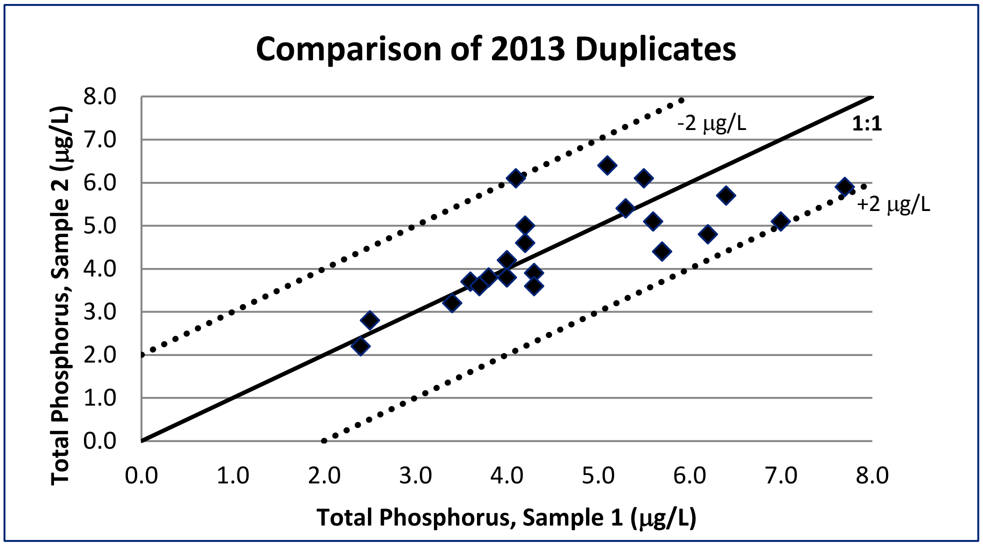
The quality control program continues to provide a high degree of confidence in the sampling protocols and analyses for total phosphorus with only one bad split (i.e., 5 µg/L and >35% difference between sample pairs) out of 22 field duplicates collected in 2013. Since 2005 when field duplicate sampling began, bad splits have occurred in 12 of 95 (13%) field duplicate samples (Figure 3, Table 4). A large number of the bad splits occurred in 2006, and since then, only 7% of the duplicate samples have been bad splits. The mean difference between field duplicates was 0.6 µg/L in 2013 and 0.6 µg/L in all previous years (2005-2012) 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, 2005-2013

Site	Date	TP1 (µg/L)	TP2 (µg/L)
Adamson's Island	1-Sep-06	*7.7*	4.1
Bigwin North	2-Sep-11	*5.9*	3.7
Dwight Bay	1-Sep-06	9.2	*31.9*
Fairview	7-Aug-06	4.3	*7.5*
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*
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: Sample values in italics are considered to be contaminated and are excluded from further analyses.

Figure 3. Total Phosphorus Field Duplicates in Lake of Bays, 2013.



3.1.2.2 Outliers

A total of 38 samples were identified as outliers in the LOBA dataset using the Grubb's test, one of which occurred in the 2013 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 2002-2013 Dataset Based on Grubb's Test (*p* <0.5) Excluding River Sites.

Site	Date	Outlier TP (μg/L)
Adamson's Island	18-Jul-11	15.1
	18-Aug-13	9.9
Bigwin Bay	15-Jul-02	9.6
Bigwin East	14-Jul-08	9.0
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
	18-Aug-13	21.6
	28-Aug-13	13.3
Dwight Bay	19-Jul-10	11.7
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
	1-Sep-06	14.1
	6-Aug-07	11.8
	17-Jul-09	57.7
	31-Aug-12	22.4
Menominee Bay	4-Jul-05	11.0
Moffat's	5-Aug-02	36.7
	6-Aug-07	15.1
	5-Aug-13	11.4
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	11.0

3.2 Bacteria

Bacteria levels in Lake of Bays were low on all sampling events at all sites and did not pose any human health risk with respect to exposure from recreational activity on the dates sampled in the summer of 2013.

Absolute and geomean bacteria counts were well below the PWQO of 100 cfu/100 mL for *E. coli* and 1,000 cfu/100 mL for total coliform at all sampling sites (Table 6). The highest bacteria counts were observed in the river-influenced and nearshore sites, a pattern that has been observed in previous years in Lake of Bays and that is expected as rivers and nearshore areas are more exposed to bacteria sources from wildlife and riverside development in comparison to the offshore deepwater sites.

Table 6. Summer Geomean *E. coli* and Total Coliform Concentration in Surface Water, 2013

Site	*E. coli* (cfu/100 mL)	Total Coliform (cfu/100 mL)
Deep water		
Bigwin East	2	4
Dwight Bay	3	12
Fairview	1	2
Gull Rock	2	5
Haystack Bay	1	5
Price's Point	2	4
Ten Mile Bay	2	5
Trading Bay	4	8
Portage Bay	2	7
Disturbed		
Bigwin Bay	2	6
Bigwin North	3	12
Britannia	1	5
Dwight Beach	3	8
Nearshore Undisturbed		
Adamson's Island	4	9
Boothby's	2	12
Hollow River mouth	3	8
Menominee Bay	3	6
Moffat's	2	13
Narrows West	10	20
Oxtongue Delta	3	10
River		
Hollow River mouth	3	18
Oxtongue mouth	5	13

3.3 Total Phosphorus

The summer total phosphorus concentration of sites monitored in Lake of Bays ranged from 2.3 to 10.4 µg/L, with a mean concentration of 5.0 µg/L (Table 7, Figures 4 to 7). 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 (5.3 μg/L), Ten Mile (5.7 μg/L), Trading (2.5 μg/L) and Portage (5.7 μg/L) bays were below the revised PWQO (background plus 50% threshold values) for these basins (see Table 2) as determined by the District Municipality of Muskoka's Lake System Health Program (2005) and as such, existing human development has not adversely impaired water quality of these bays. In 2012, Portage Bay was sampled in response to concerns about construction activities related to shoreline development that occurred that summer. High total phosphorus concentration in 2012 (9.6 μg/L) exceeded the revised PWQO threshold value of 6.3 μg/L for South Portage Bay[1] as well as previous measured concentrations from 2007 that included a nearshore undisturbed site and a deepwater site near Wee Island in the bay, with an average total phosphorus concentration of 6.5 μg/L and 5.6 μg/L, respectively. A return to lower phosphorus concentrations in Portage Bay in 2013 suggest that the elevated concentration in 2012 may have been a short-term response to the construction activities. Alternately, the variable phosphorus concentrations could reflect natural variability in the bay as total phosphorus concentrations at most other sites in Lake of Bays also declined in 2013 relative to 2012.

The mean total phosphorus concentration for Haystack Bay of 7.3 μg/L exceeded the revised PWQO for this bay of 6.8 μg/L in 2013. Phosphorus concentrations were variable over the course of the summer ranging from 4.0 μg/L on August 31st to 10.3 μγ/L on August 20th (Table 7), and mean annual phosphorus concentrations have also been variable, with phosphorus concentration also exceeding the threshold in 2006 (Figure 8). The long term average total phosphorus concentration ($TP_{2002\text{-}2013}$ = 5.4 μg/L), however, is below the revised PWQO. These results illustrate that Haystack Bay has variable phosphorus concentrations within and between years, but overall, concentrations do not reflect impairment of water quality.

At other lake sites without DDM thresholds, total phosphorus concentrations were below the lowest Lake of Bays threshold of 5.9 μg/L for Trading Bay, with the exception of Dwight Beach (6.8 mg/L) and Oxtongue mouth (8.1 mg/L). Dwight Beach, however, is below the threshold for Dwight Bay, and higher total phosphorus concentrations are expected at the Oxtongue mouth due to river influence. Total phosphorus concentrations below the revised PWQO thresholds indicate excellent water quality with respect to phosphorus at all of the monitoring sites.

---

[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).

Table 7. Total Phosphorus Concentrations (µg/L) in Lake of Bays, 2013

Site ID	Site Name	1-Jul	23-Jul	4-Aug	20-Aug	31-Aug	Mean
Deep Water							**5.2**
B1	Bigwin East	4.3	5.4	4.2	6.8	3.9	4.9
B2	Fairview	3.7	5.1	5.1	4.4	4.1	4.5
E1	Trading Bay	2.3		2.7		2.6	2.5
E13	Haystack Bay	7.6	7.7	6.7	10.3	4.0	7.3
E30	Ten Mile Bay	5.5	6.1	5.1	6.9	5.1	5.7
N1	Dwight Bay	3.8	5.4	6.1	5.8		5.3
N10	Gull Rock	3.2	3.9	3.5	5.7	3.4	3.9
N26	Portage Bay	3.9	5.3	5.3	7.6	6.4	5.7
S3	Price's Point	3.3	7.3	6.1	7.5	4.6	5.8
Disturbed							**5.2**
B3	Bigwin North	3.2		4.7	5.7	5.5	4.8
B4	Bigwin Bay	4.3	5.0	4.2	5.1	3.7	4.5
N11	Britannia		5.3	2.9			4.1
N3	Dwight Beach	4.1	6.6	10.4	6.7	6.0	6.8
Nearshore Undisturbed							**4.8**
E26	Narrows West	3.6		4.5	5.4		4.5
N13	Moffat's	3.9			4.1	3.6	3.9
N24	Boothby's	4.1		3.7		5.2	4.3
N30	Oxtongue Delta	4.7	5.8	6.8	10.3	4.2	6.3
S1	Adamson's Island	3.1	5.1	5.4		2.4	4.0
S2	Menominee Bay	3.1	5.1	2.9	5.9	4.4	4.3
River							**8.1**
N2	Oxtongue mouth	6.0	10.0	8.0	8.6	8.0	8.1
All sites							**5.8**
All sites excluding River sites							**5.0**

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 9). As observed in previous monitoring years, total phosphorus concentrations were more variable at the nearshore sites (disturbed and nearshore undisturbed) than the deepwater sites, which is consistent with greater responsiveness of nearshore areas to local changes in phosphorus due to runoff events and uptake by plants in shallow areas. Mean summer concentrations, however, were similar between nearshore disturbed and undisturbed sites (Figure 9), supporting previous conclusions that shoreline disturbance is having little impact on phosphorus concentrations. The average total phosphorus concentration measured at the Oxtongue mouth River site was higher relative to the lake sites likely reflecting phosphorus inputs from the river.

Figure 4. Total phosphorus concentrations in Lake of Bays 2013, Deepwater sites.

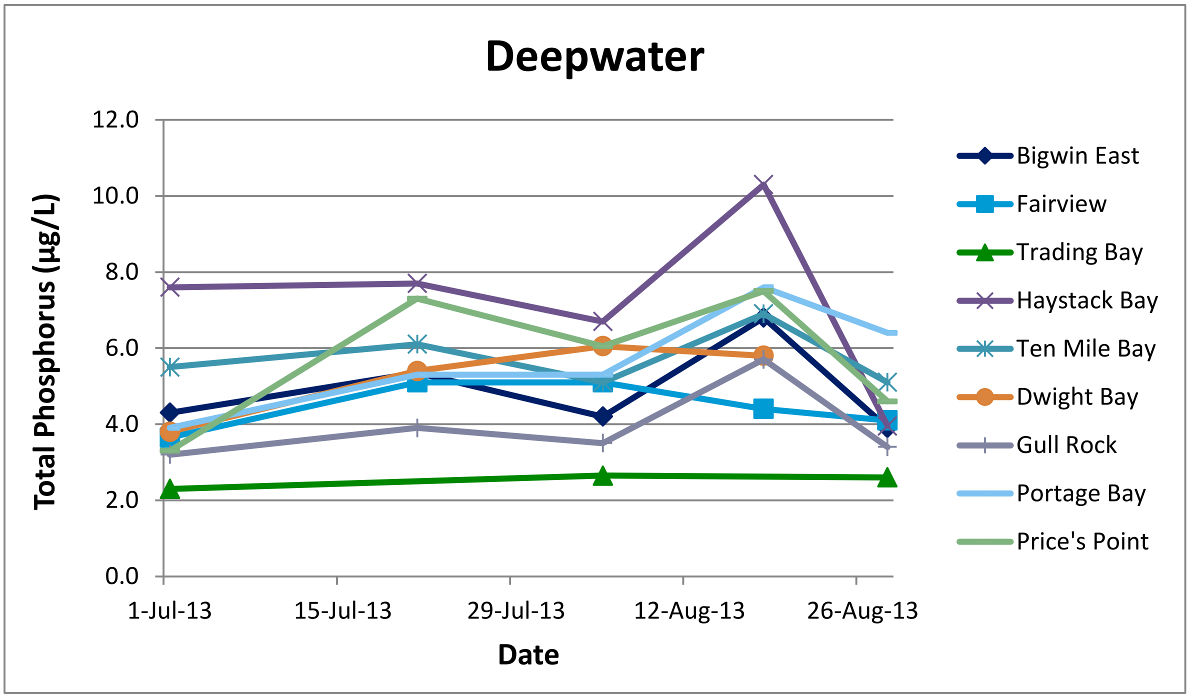


Figure 5. Total phosphorus concentrations in Lake of Bays 2013, Nearshore Undisturbed sites.

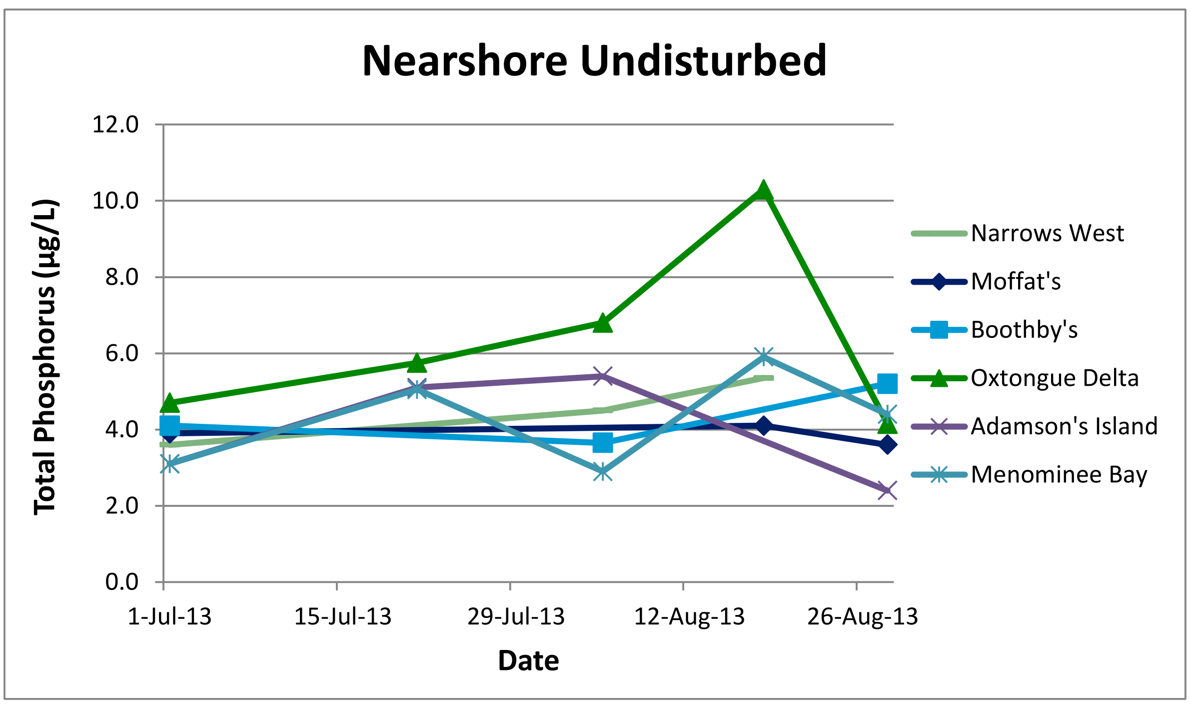


Figure 6. Total phosphorus concentrations in Lake of Bays 2013, Disturbed sites.

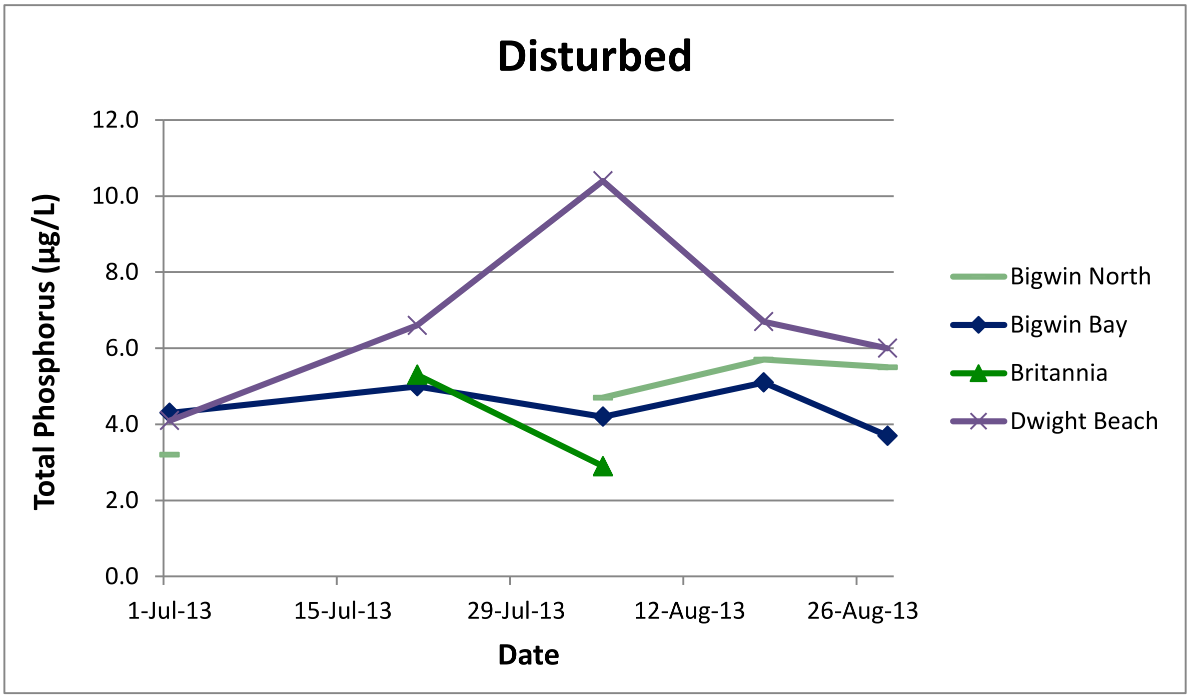


Figure 7. Total phosphorus concentrations in Lake of Bays 2013, River sites.

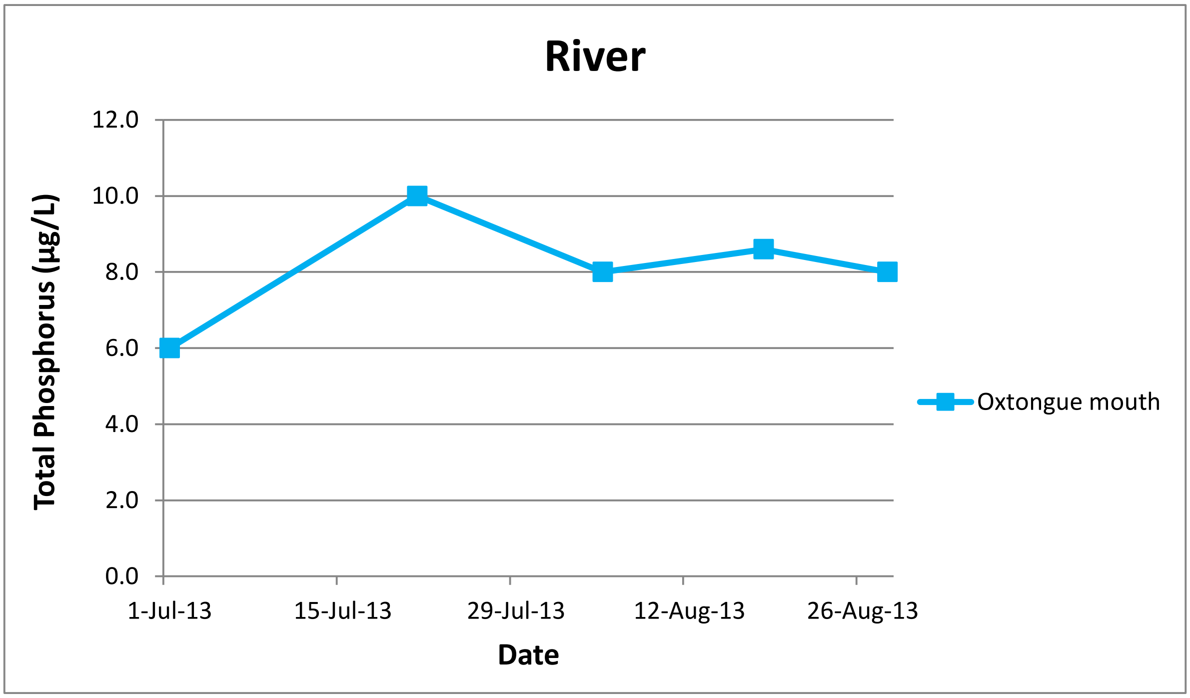


Figure 8. Mean summer total phosphorus concentration at Haystack Bay (2002-2013).

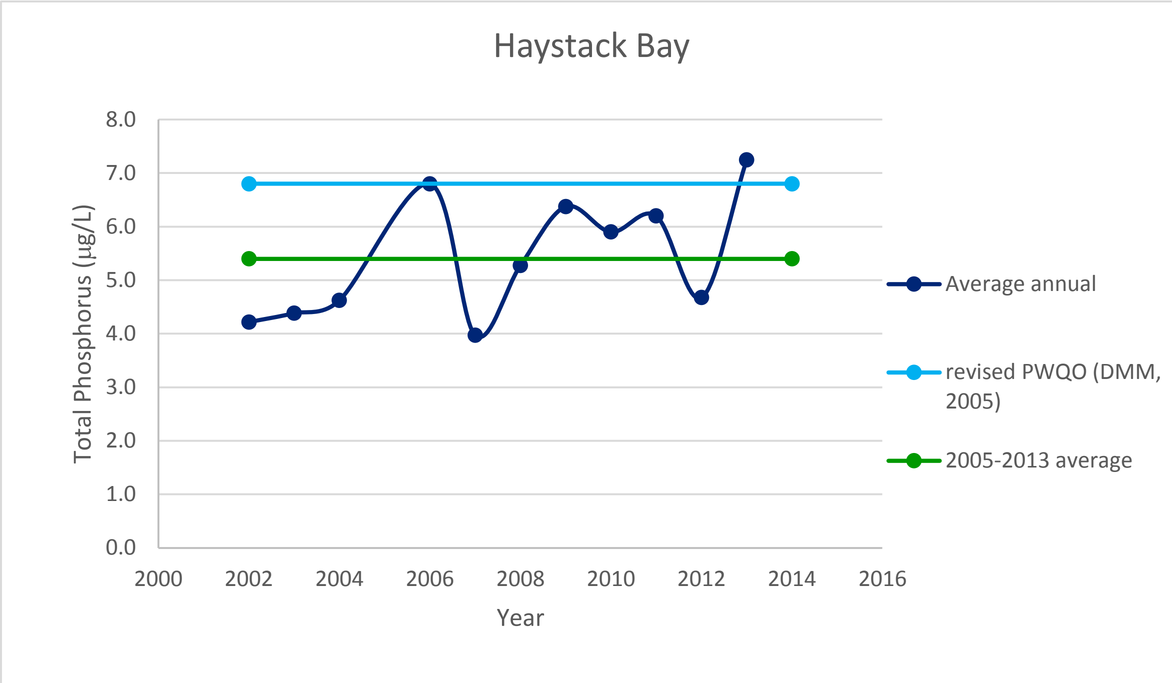
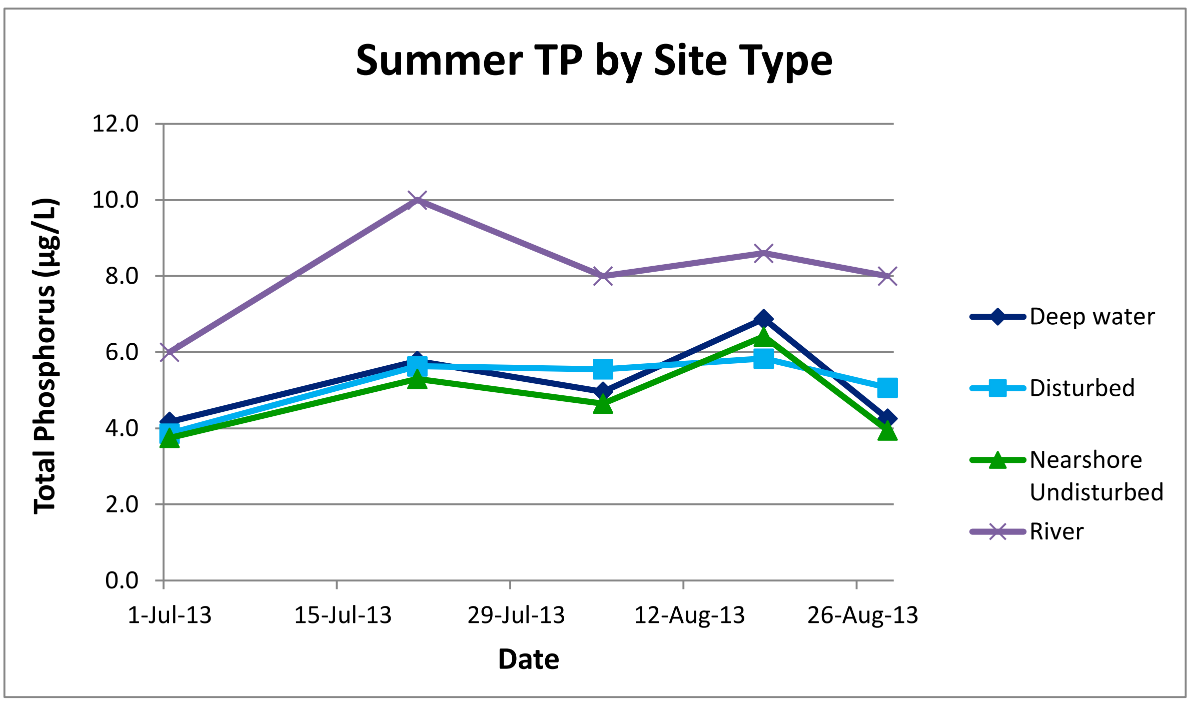


Figure 9. Total phosphorus concentrations in Lake of Bays 2013 by Site Type.



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 collected samples including QA/QC samples ranged from 50 in 2002 to 123 in 2012, with a total of 1,089 samples collected at the end of the 2013 program (Table 8). The large number of sites monitored and samples collected under 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.

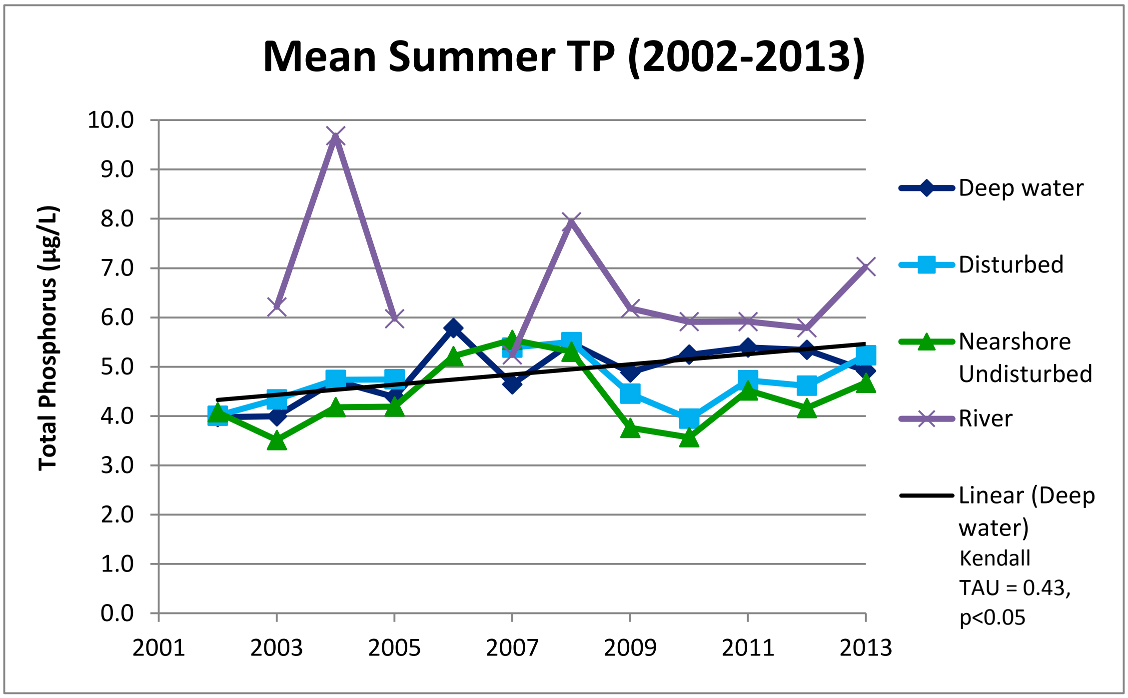
Table 8. Number of Total Phosphorus Samples Collected by the Lake of Bays Monitoring Program (2002-2012)

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
Total # of Samples	526	184	254	125	1,089

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) and was not monitored in 2013. Portage Bay (N26) was only sampled in 2012 and and 2013 and had relatively higher phosphorus concentrations than the other deepwater sites 2012, 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 10). 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 10. Long-term trends (2002-2012) in means summer euphotic zone total phosphorus (TP) by Site Type.



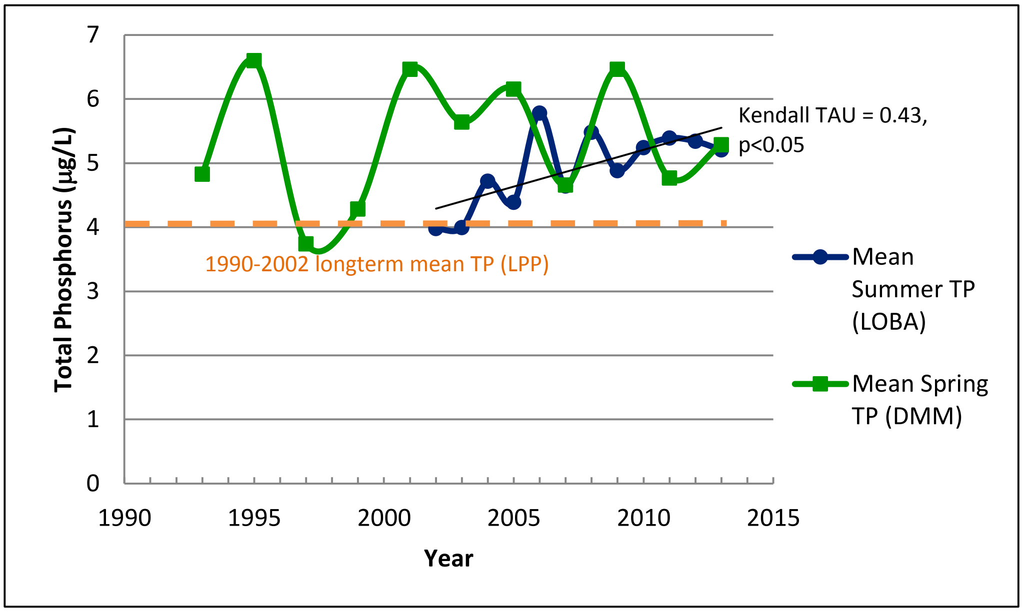
Note: Little Trading Bay and Portage Bay (Deepwater sites) are not included as they displayed total phosphorus concentrations that were significantly higher than other deepwater sites and are not representative of deepwater sites in Lake of Bays

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 = 0.43, n=12, p<0.05) with an average annual increase in of 0.12 µg/L/yr (Sen's slope estimate) for a total average increase of 1.5 µg/L over 12 years (Figures 10 and 11). 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 over the same time period (2003-2013), which has been more highly variable than the summer LOBA data between sample years (Figure 11). 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

[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.*

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 $spring_{02-13}$ = 5.5 µg/L, LOBA TP $summer_{02-13}$ = 4.9 µg/L).

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

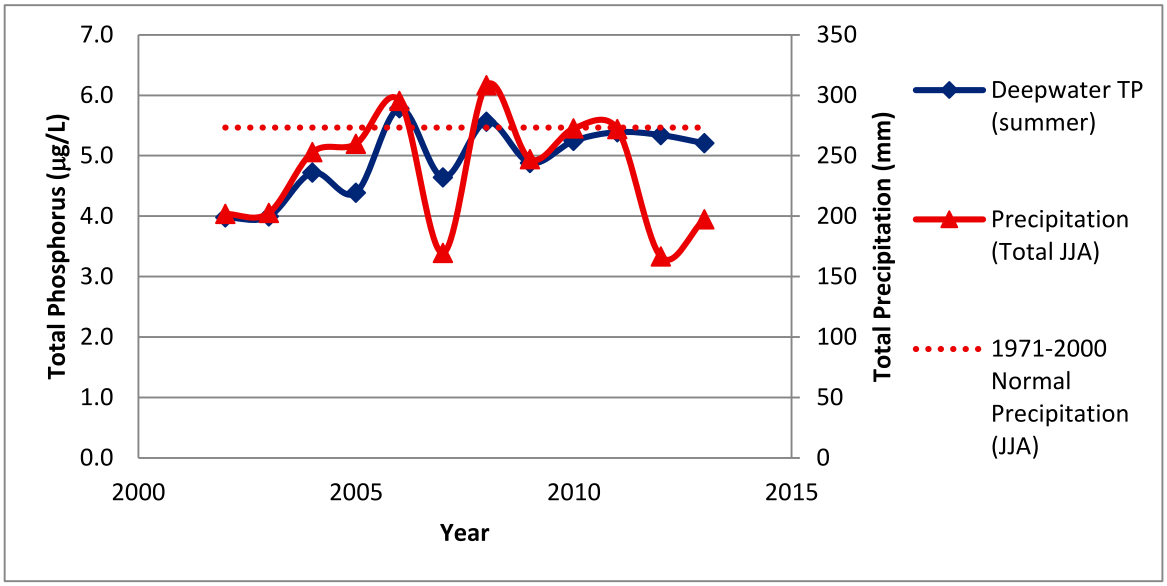


Note: LOBA sites exclude Little Trading Bay and Portage Bay. DMM sites include Dwight, Haystack, Rat, South Muskoka River, South Portage, Ten Mile and Trading bays.

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 12-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=11, $p<0.01$), 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 12). 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 12. Mean summer euphotic zone total phosphorus in Deepwater areas of Lake of Bays and total summer precipitation (June, July, August) 2002-2013.



Note: Climate data from Environment Canada stations Beatrice (Stn. 6110607, 2006-2013), Beatrice 2 (Stn. 6110606, 2002-2006) and Muskoka A (Stn. 6115525, 2002-2013).

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 nine of the 12 monitoring years (Figure 12). 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 12 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 2013 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 2013 and from previous years are as follows:

1. The LOBA monitoring program continues to provide high quality bacteria and phosphorus data. Phosphorus concentration data had only one bad split between field duplicate samples (of a total of 22 sample pairs) and 4 statistical outliers (of a total of 116 samples) in 2013.

2. Bacteria levels were low on all sampling events at all sites, well below the PWQO for recreational use.

3. 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 (i.e., revised PWQO of background phosphorus concentration +50%), with the exception of Haystack Bay. Haystack Bay has variable phosphorus concentrations within and between years, but long-term mean phosphorus concentration is within the revised PWQO and does not reflect impairment of water quality.

4. Total phosphorus concentration in Portage Bay declined in 2013 to values below the revised PWQO from elevated concentrations observed in 2012 that were coincident with construction activities. This suggests that potential impacts of construction activities were short term, however, it is recommended that this site be monitored again in 2014.

5. Total phosphorus concentrations were highest in river sites compared to lake sites, and were more variable in shallow nearshore areas (Nearshore undisturbed and Disturbed sites) than Deepwater sites as expected due to natural processes.

6. There is a significant increasing trend in mean summer total phosphorus concentration in deepwater sites of Lake of Bays from 2002 to 2013. 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.

7. Total phosphorus concentrations at the deepwater sites should be monitored closely in future years as the change to higher concentrations 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.

6. References

AECOM, 2009:
Lake of Bays Water Quality Report 2007-2008. Prepared for the Lake of Bays Association. September 2009.

Grubbs, F. 1969:
Procedures for Detecting Outlying Observations in Samples. Technometrics 11, 1-21.

Gartner Lee Limited (GLL), 2005:
Recreational Water Quality Management in Muskoka. Prepared for District Municipality of Muskoka.

Gartner Lee Limited (GLL), 2008:
Review of Long-Term Water Quality Data for the Lake System Health Program. Technical Report for the District Municipality of Muskoka, September 18, 2008.

Hutchinson Environmental Sciences Limited (HESL), 2011:
Lake of Bays Water Quality Report 2010. Prepared for the Lake of Bays Association, November, 2011.

Hyatt, C.V., A.M. Paterson and E. Stainsby, 2012:
Lakeshore Capacity Model Users' Manual. Version 4.2. Prepared for the Province of Ontario, Fall 2012.

Ontario Ministry of Environment and Energy (MOE), 1994:
Water Management Policies Guidelines. Provincial Water Quality Objectives of the Ministry of Environment and Energy. July 1994

Ontario Ministry of the Environment (MOE), 2010:
Lakeshore Capacity Assessment Handbook – Protecting Water Quality in Inland Lakes on Ontario's Precambrian Shield. Queen's Printer for Ontario. May 2010.

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

WATER QUALITY SAMPLING PROCEDURES

General:

1. Check for equipment, including:
   - -metre depth pole (if required)
   - -thermometer
   - -cooler and ice packs
   - -sterilized jars, phosphorus tubes, duplicates
   - -secchi depth disc and jar (if required)
   - -data sheets and pen
2. verify that you have the appropriate boating safety equipment on board and that the weather is safe for sampling
3. record air temperature on data sheet as you leave the dock. Then attach thermometer to a rope in preparation for taking water temperature at sampling sites.
4. at each site, complete the data sheet, recording any factors or conditions that may make the sampling trip unusual or that may have an influence on sample results (eg. cloudy water, unusual activity in the area, presence of waterfowl)

Coliform and E coli testing

Near shore sample collected 22 – 30 cm. below the surface in water that is 1 m. in depth
Deep water samples also collected 22 – 30 cm. below the surface of the water.

1. Carefully and correctly assemble the jars required for the specific site (all should be named and number coded)
2. Remove the cap/lid from the jar/bottle **without touching the inside of the lid or jar**, and place carefully, upside down on a flat stable surface
3. Grip the bottle at the base and plunge it into the water in a downward motion to the a depth of 22 – 30 cm. (9 – 15 in). The bottle goes in **upside down** (open end to lake bottom) and the appropriate depth is roughly around your elbow.
4. Adjust the bottle position in your hand so that the bottle is now parallel to lake surface and lake bottom, facing forward and **collect sample by sweeping the bottle forward** (forward, not up). This directional motion is important so that the water being collected in the bottle/jar does not pass over your hand. Collect water from that 22 – 30 cm. depth and then bring bottle to surface.
5. Empty it slightly (if it is full to the brim) and then recap bottle.
6. Store in the cooler chest.

7. **re quality control sample (lab and field duplicates).** Quality assurance is necessary to validate that the sampling and processing protocols have been followed appropriately. It is very important that these procedures are followed in order to ensure high quality results …

   If we are running duplicates (field and lab) on your site, there will be a large sampling jar, clearly marked, as well as a smaller one. Using the large jar, take your sample as per the steps outlined above. As soon as the sample is obtained, recap the jar (without touching interior of lid or jar) and shake it two or three times to ensure a uniform distribution of the discreet bacteria in the water sample. Immediately transfer some of the sample to the smaller jar. Cap both jars and store both jars. The contents of the small jar are the sample, part of the remaining content of the large jar becomes the field duplicate and the balance of water in the large jar is sent for a quality control test at the Central Ontario Analytical Laboratory in Orillia.

The last part of quality assurance is distilled water. After the site sample and field duplicate have been collected, open the distilled water jug and fill the collection jar marked Distilled Water. Cap the glass bottle and place it in the cooler with the ice pack. Distilled water is, or should be, free of coliforms and e coli, and running a distilled water sample through our process (sterilized jars, sampling volunteers, Deb working the coliplates) is an excellent test of the scientific rigour of our program.

Near shore Phosphorus testing:

sample collected 22 – 30 cm. below the surface in water that is 1 m. in depth

There are always a test tube **and** a PET jar associated with each phosphorus site (and sometimes extra test tubes for quality assurance purposes). The PET jar is used to actually collect the sample, which is then transferred to the test tube(s).

1. Carefully and correctly assemble the jars required for the specific site (all should be named and number coded)
2. Remove the top from the PET jar without touching the inside of top or jar and place in a flat, stable place.
3. **Rinse the jar in surface water at site.**
4. Rinse the filter (plastic funnel and filter cloth) in surface site water (filter stored in freezer bag.)
5. Grip the bottle at the base and plunge it into the water in a downward motion to the a depth of 22 – 30 cm. (9 – 15 in). The bottle goes in **upside down** (open end to lake bottom) and the appropriate depth is roughly around your elbow.
6. Adjust the bottle position in your hand so that the bottle is now parallel to lake surface and lake bottom, facing forward and **collect sample by sweeping the bottle forward** (forward, not up). This directional motion is important so that the water being collected in the bottle/jar does not pass over your hand. Collect water from that 22 – 30 cm. depth and then bring bottle to surface.
7. Take the top off the test tube, being careful not to touch the inside of the top or the test tube interior.
8. Gently swirl the water in the PET jar (don't spill it!) and then filter the water from the PET jar into the test tube using the filter (funnel plus filter cloth) provided. Fill the test tube to the line marked near the top of the test tube (want a tiny bit of air space in the tube for the lab to add some material.) Be prepared … the filter cloth is a pain in the neck but it is important to filter out zooplankton which can distort phosphorus readings.
9. Cap tightly – both test tube and PET jar – and put both in the cooler.

Note: be careful with the filters … they are light and blow away easily and it is also easy to lose/damage the filter cloths. **There is one filter per sampler for the entire summer!**

Deep Water Phosphorus Testing

sample is collected 10 – 15 m.(metres, not centimeters) below the surface in deep water

While the process of collecting and filtering the sample is the same as that for near shore phosphorus, the sample is collected from further down in the water column. The process is as follows:

1. Attach the rope to the Secchi disc and measure the secchi depth by lowering the disc over the side of the boat until it disappears from view. It may take a bit of playing with it to verify when it actually disappears. Haul it up until you see it again and then slowly lower it. (Know that in 8 years of doing this, I have NEVER had a secchi reading anywhere on Lake of Bays of less than 4.5 metres, and have occasionally had them up to 8 metres.) As you pull the disc back to the surface, count the number of metres (the rope is calibrated in 1 metre intervals.) Record this number. Redo to double check.
2. Record the colour of the water (orangey brown, bluey-green, etc.)
3. Attach the calibrated rope to the container for the secchi collection jar.
4. Rinse the collection jar in surface site water.
5. Lower the bottle (now in the weighted container to a distance that is **2 X** the secchi depth you observed and recorded above (the sample is being collected at a level to which light penetrates and given the refraction of light, that distance is 2 X the depth at which you could last see the disc.) The bottle should be lowered in a quick, smooth, but controlled motion (Don't let it free fall.)
6. Pull the container and collection jar back to the surface at a steady pace.
7. Use this water to rinse and fill the PET jar.
8. Swirl the water in the PET jar and then pour into the test tube **through the filter.** Fill test tube to the indicated line (just shy of full.)
9. Cap and place test tube and PET jar in cooler.

Re quality assurance for phosphorus … near shore and deep water:

Quality assurance is necessary to validate that the sampling and processing protocols have been followed appropriately. It is very important that these procedures are followed in order to ensure high quality results …

1. If we are running phosphorus duplicates on your site, there will be an extra test tube, clearly marked as the field duplicate. Simply fill that second test tube in the same manner as the first, taking the time to gently swirl the contents of the PET jar before pouring water into the second test tube through the funnel and filter cloth Cap test tubes and PET jar and store in cooler.

2. The last part of quality assurance is distilled water. After the site sample and field duplicate have been collected, open the distilled water jug and fill the clearly marked test tube to the line (7/8th full). Cap and store with rest of samples from that particular site.

Appendix B. LOBA Total Phosphorus and Bacteria Data