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November 1, 2011 Project #: J100013

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 2010 – Final Report

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 2010 monitoring program, and discusses long-term total phosphorus concentrations that have been observed since the onset of the program in 2002.

I thank you for your insightful comments in your email of October 31st and have revised the draft report accordingly.

I look forward to seeing the results of the 2011 monitoring program and would be pleased to assist LOBA with the summary of these data and with plans for sampling in 2012.

Sincerely,

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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.

Until the summer of 2000, monitoring in Lake of Bays was limited to tracking water clarity and spring phosphorus concentration under the Ontario Ministry of the Environment's Lake Partner Program. 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 2004, the program was again expanded to monitor phosphorus concentrations in near-shore areas. Over the course of the program, site selection has changed reflecting changes in focus with an ever-increasing understanding of water quality conditions in Lake of Bays. Since 2009, sampling has focussed on deep water sites, with reduced sampling in enclosed bays (e.g., South Portage Bay, Rat Bay, Little Trading Bay) and river sites that were sampled in previous years (e.g., Narrows, Hollow River). The monitoring program, however, continues to monitor river influenced sites. This approach continues to allow comparison with other water quality programs, such as the Lake Partner Program and the District Municipality of Muskoka (DMM) spring monitoring program, which collect data in central, deep areas of the lake. It also reflects experience collected through the years of the program, which showed that lake water quality is different from river water quality and that nearshore sites can show very local effects that are not representative for whole-lake water quality trends.

Bacteria was not sampled in 2010, but will be sampled in 2011 and every other year thereafter. The sampling frequency for bacteria was reduced because results have been very consistent over the course of the monitoring program and 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.

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 nutrient that limits growth of algae in most freshwater systems on the Canadian Shield. 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 a deterioration of water clarity and decrease deep-water oxygen concentrations that affect coldwater fish habitat.

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. Data collected by the Lake Partner Program, however, have shown a long-term decline in water clarity since the mid-1990s, and the LOBA data showed somewhat increased average phosphorus concentrations from 2002 to 2008 (AECOM, 2009). In 2009, however, the trend of increasing total phosphorus concentrations was not continued and there was no evidence from spring monitoring by the District of Muskoka

for an increasing total phosphorus trend. In this report we present the results of the summer phosphorus monitoring completed by the LOBA in 2010 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

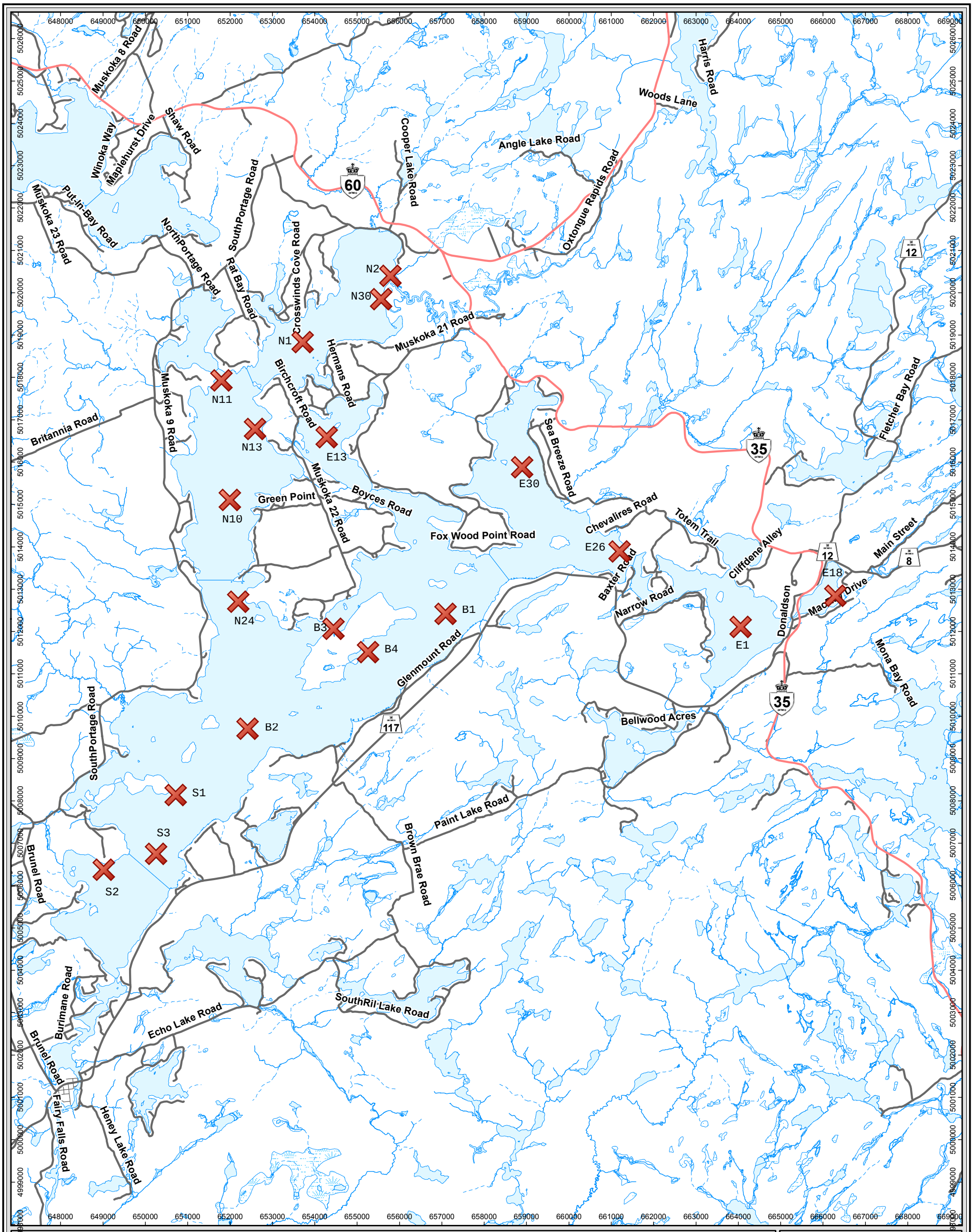
Volunteers, coordinated by the LOBA Environment Committee, collected samples for analysis of total phosphorus concentrations on five occasions during the summer of 2010 (July 5 and 19, August 2 and 16, and September 7). The sampling and analytical methods in 2010 were consistent with those used in previous 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 19 locations throughout Lake of Bays to include deep, open water locations ('deepwater' sites), nearshore sites adjacent to developed ('Disturbed' sites) and undeveloped shorelines ('Nearshore Undisturbed' sites), and other areas of interest, e.g., areas influenced by discharge from the Oxtongue and Hollow rivers ('River' sites). Sites monitored in 2010 are illustrated in Figure 1.

At each deep water 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 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).



Basemapping from Ontario Ministry of Natural Resources
Orthophotography:

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W E
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1:85,000
UTM Zone 17N, NAD 83

Legend

- Intermittent Stream
- Permanent Stream
- Waterbody Segment
- Wetland Area, Permanent
- Sampling Site

J100013
Figure 1.
2010 Monitoring Sites
(modified from AECOM, 2009)

Lake of Bays

AECOM

2.2 Quality Control

2.2.1 Field Duplicates

In order to assess the variability of results related to sampling and analytical procedures, 12 field duplicates for total phosphorus were collected and analyzed in 2010.

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.

2.2.2 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. In the past, outliers in the LOBA total phosphorus data were identified and removed from analysis based on professional judgement.

In this study, 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 1), 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 1. 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

Total phosphorus concentrations were compared by site and site type for the 2010 monitoring period and long term annual trends were evaluated by site type and compared to LPP and DMM 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 b) thresholds set for Lake of Bays by the District Municipality of Muskoka (DDM). The 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.

In addition to the interim PWQO, the MOE suggests that for recreational lakes on the Canadian Precambrian Shield, phosphorus should only 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, 2011). 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 2; Gartner Lee Ltd., 2005). Thresholds range from 5.9 µg/L in Trading Bay to 8.0 µg/L in Little Trading Bay.

Table 2. 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. 2010 Monitoring Results

3.1 Quality Control

3.1.1 Field Duplicates

The quality control program continues to provide a high degree of confidence in the sampling protocols and analyses for total phosphorus. In 2010, only one set of the 12 field duplicates (from Ten Mile Lake collected September 7th) had a variance greater than 4 µg/L and since 2002, bad splits occurred in 4 of 46 (8.7%) field duplicate samples (Figure 2, Table 3). The higher value was discarded in each case from the dataset as described in Section 2.2.1. The mean difference between field duplicates was 0.6 µg/L in 2010 and 0.9 µg/L in all years (2002-2010) 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.

Figure 2. Total Phosphorus Field Duplicates in Lake of Bays, 2010.

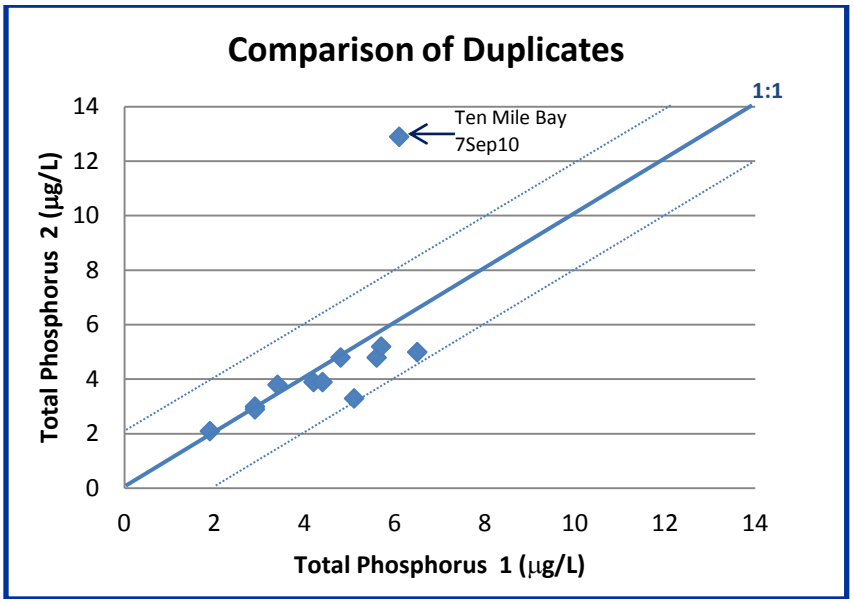


Table 3. Summary of Bad Splits Between Total Phosphorus Field Duplicates in Lake of Bays, 2002-2010

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.

3.1.2 Outliers

A total of 19 samples were identified as outliers in the LOBA dataset using the Grubb's test, including 8 outliers that were identified in previous years of the program (Table 4). 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.

Table 4. Summary of Outliers in the LOBA 2002-2010 Dataset Based on Grubb's Test (p <0.5)

Site	TP (µg/L)	Date	Previous Outlier	Mean TP[1] (µg/L)
Bigwin Bay	9.6	15-Jul-02		4.4
Bigwin North	62.7	23-Aug-04	✓	5.1
Britannia	12.6	1-Sep-03	✓	4.1
	9.4	1-Sep-05		
	8.4	4-Aug-08		
Dwight Bay	0.7	14-Jul-03	✓	5.2
	11.7	19-Jul-10		
Fairview	12.3	17-Jul-09	✓	4.6
	12.5	31-Aug-07		
Gull Rock	16.9	14-Jul-03	✓	4.7
Haystack Bay	57.3	6-Sep-04	✓	5.1
	14.1	1-Sep-06		
	12.8	6-Aug-07		
	10.8	6-Aug-07		
Menominee Bay	11.0	4-Jul-05		4.1
Moffat's	25.9	5-Aug-02	✓	4.2
Price's Point	12.7	2-Aug-10		5.0
Ten Mile Bay	10.2	21-Aug-06		5.3
Trading Bay	13.7	19-Aug-02	✓	4.8

Notes: [1]mean total phosphorus concentration with outliers removed

3.2 Total Phosphorus

The 2010 summer total phosphorus concentration of sites in Lake of Bays ranged from 2.0 to 13.8 µg/L, with a mean concentration of 4.7 µg/L (Table 5, Figures 3 to 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 (MOE, 1994). Moreover, the mean 2010 summer total phosphorus concentrations in Dwight, Haystack, Ten Mile and Trading bays were below the DMM's threshold values (background total phosphorus concentration +50%) and all other sites without DDM thresholds were below the lowest Lake of Bays threshold of 5.9 µg/L, further indicating excellent water quality with respect to phosphorus.

With few exceptions, total phosphorus concentrations varied little over the course of the summer growing season and displayed no consistent directional changes for any site type (deepwater, disturbed, nearshore undisturbed or river) (Figures 3 to 7). This differs from previous years when a general decreasing trend often occurred from early summer to late summer, which is commonly observed in oligotrophic lakes as phosphorus is increasingly taken up by aquatic plants including algae over the growing season.

Table 5. Total Phosphorus Concentrations in Lake of Bays, 2010

Site ID	Site	05-Jul	19-Jul	02-Aug	16-Aug	07-Sep	Mean
			Deep water				
B1	Bigwin East	5.2	4.8	4.6	7.6	6.4	5.5
B2	Dwight Bay	5.8	***11.7***	3.6	3.4	6.6	4.8
E1	Fairview	4.7	5.4	5.5	4.1	6.4	5.0
E13	Gull Rock	3.9	4.4	8.6		5.0	5.5
E30	Haystack Bay	6.2	6.1	5.0	5.4	6.8	5.9
N1	Price's Point	4.2	4.1	***12.7***	7.3	5.1	5.2
N10	Ten Mile Bay	5.2	5.3	5.2	4.2	6.1	5.2
S3	Trading Bay	3.6	6.6	4.3	4.6	6.8	4.9
			Disturbed				
B3	Bigwin Bay	3.0	6.0	3.2	3.0	2.7	3.6
B4	Bigwin North	3.6	3.3	5.1	6.6	3.8	4.5
N11	Britannia	2.9	3.8	2.7	4.6	4.9	3.8
			Nearshore Undisturbed				
E26	Adamson's Island	2.8	3.1	2.5	2.7	3.0	2.8
N13	Boothby's	3.3	2.9	6.4	7.4	2.9	4.3
N24	Menominee Bay	3.5	2.0	3.4	2.0	3.4	2.7
S1	Moffat's	4.2	2.3	3.3	4.7	4.2	3.8
S2	Narrows West	4.2	4.9	5.8	3.2	3.4	4.3
			River				
E18	Hollow River Mouth	4.0	4.0	5.5	5.4	3.4	4.6
N2	Oxtongue Delta	4.5	4.0	4.7	3.1	3.5	4.0
N30	Oxtongue mouth	8.1	13.8	6.8	10.4	8.0	9.4

Figure 3. Total phosphorus concentrations in Lake of Bays 2010, Deepwater sites.

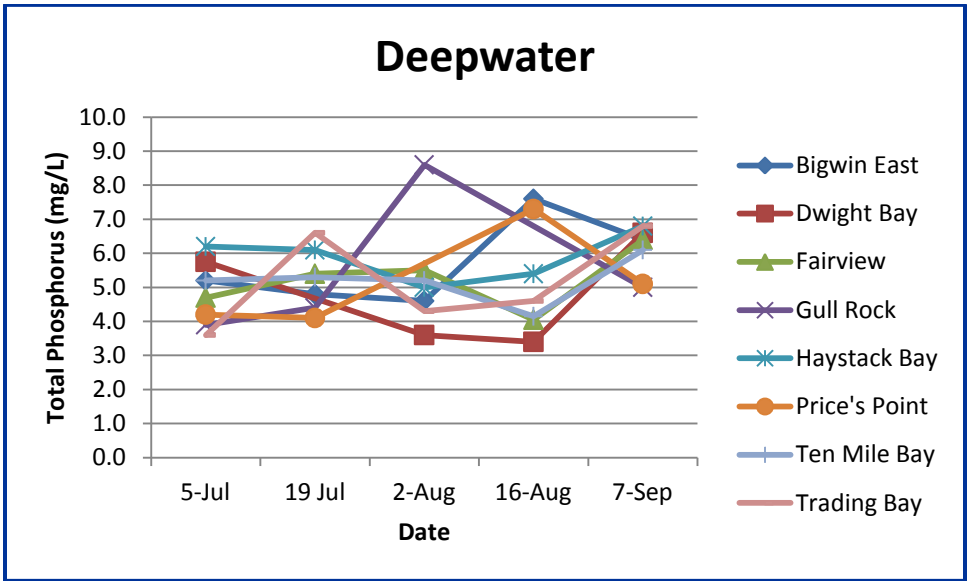


Figure 4. Total phosphorus concentrations in Lake of Bays 2010, Nearshore Undisturbed sites.

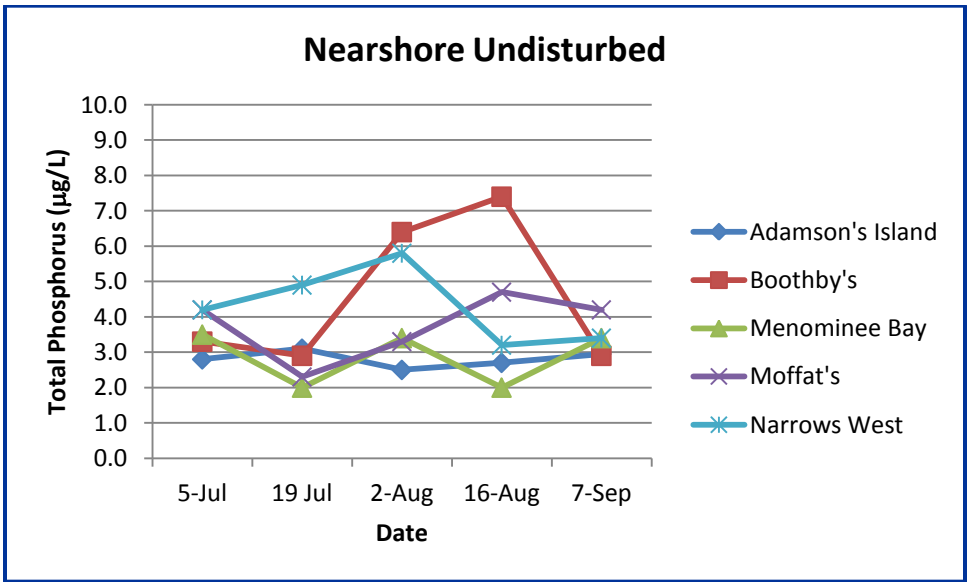


Figure 5. Total phosphorus concentrations in Lake of Bays 2010, Disturbed sites.

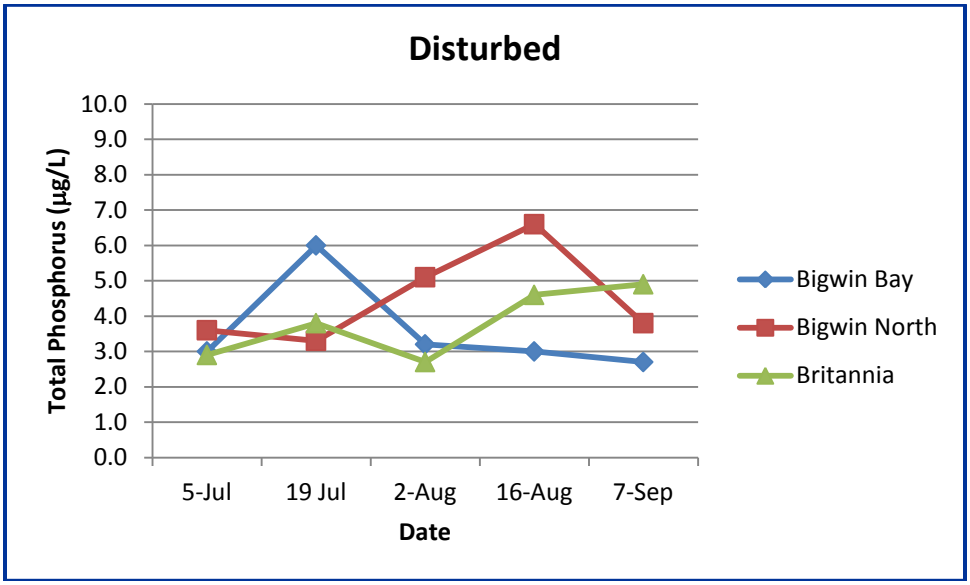


Figure 6. Total phosphorus concentrations in Lake of Bays 2010, River sites.

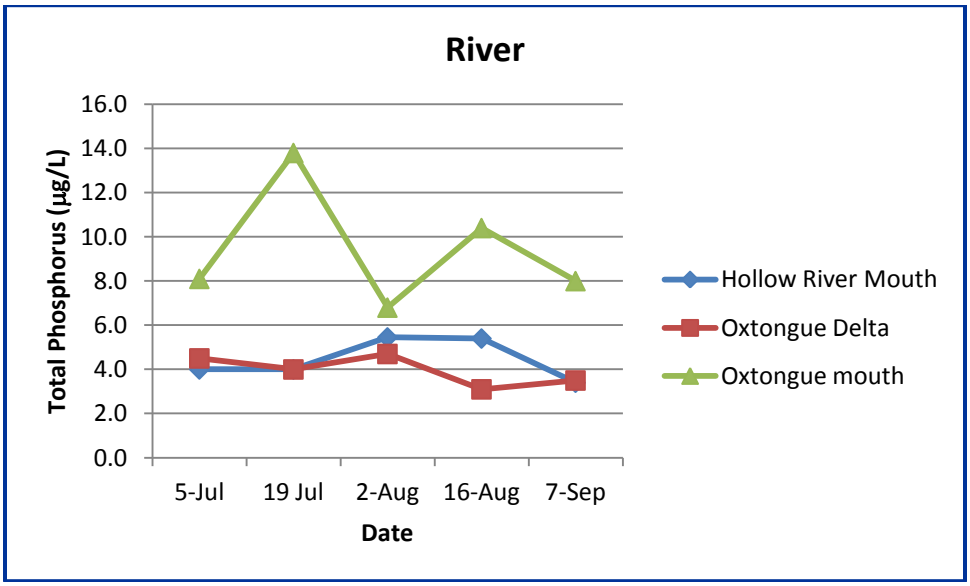
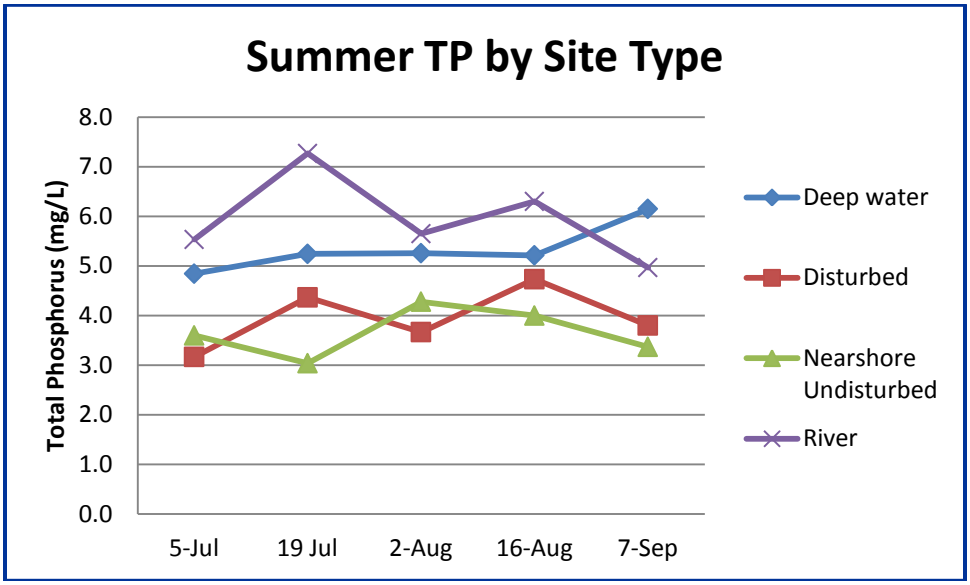


Figure 7. Total Phosphorus Concentrations in Lake of Bays 2010 by Site Type



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

The 'river' site at the mouth of the Oxtongue River had the highest phosphorus concentrations of all the sites (Figure 6), which is expected as rivers transport soil and other particles that contain phosphorus. The total phosphorus concentration in rivers is also strongly influenced by runoff events following summer rains. The two highest concentrations observed at the Oxtongue River site occurred on July 19th and August 16th, coincident with moderate to heavy rainshowers[1] on those days the day preceding sampling. The Oxtongue Delta site, which is further removed from the mouth of the river, however, had lower concentrations that were more similar to those of other nearshore sites. This suggests that inputs from the Oxtongue River settle out rapidly in the lake such that the Oxtongue Delta site was more strongly influenced by inlake processes than river inputs. The Hollow River mouth site had similar total phosphorus concentrations as the Oxtongue Delta site and other nearshore sites, also suggesting little river influence at this location at the time of sampling.

'Disturbed' and 'undisturbed nearshore' sites displayed similar phosphorus concentrations suggesting that there is little impact of shoreline disturbance on phosphorus concentrations (Figure 7). On average, these sites had lower phosphorus concentrations than the deepwater sites likely due to uptake by aquatic plants that are more abundant in shallower water (Figure 7).

[1] *Information from Environment Canada's National Climate Data and Information Archive (www.climate.weatheroffice.gc.ca) for Muskoka Station 6115529. Postings were not yet complete for 2010 data and precipitation data were not available at the time of report production.*

4. Long-term Phosphorus Trends

The Lake of Bays Water Quality Monitoring Program has been consistently collecting data over the summer season for nine years at numerous locations throughout the lake (Table 6). The yearly number of collected samples including QA/QC samples ranged from 50 in 2002 to 108 in 2008, with a total number of 727 samples collected at the end of the 2010 program. This data set provides an excellent opportunity to assess long-term trends and variability in Lake of Bays total phosphorus over the years. All data collected by the LOBA monitoring program since 2002 are provided in Appendix B.

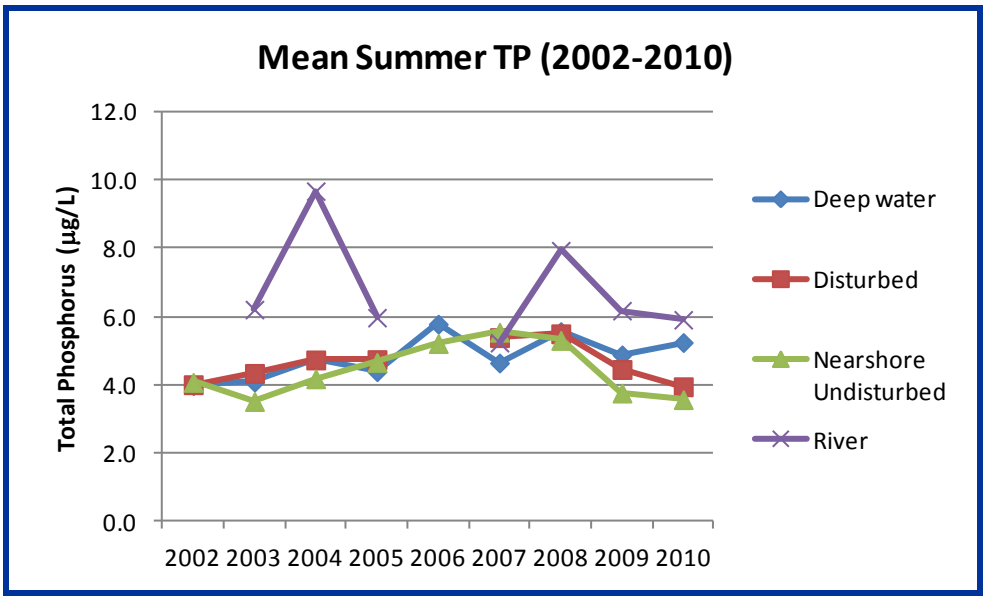
Table 6. Number of Total Phosphorus Samples Collected by the Lake of Bays Monitoring Program (2002-2010)

Site Type	2002	2003	2004	2005	2006	2007	2008	2009	2010	2002-2010
Deep water	30	39	28	29	53	49	48	47	46	369
Disturbed	15	22	13	8		9	13	15	15	110
Nearshore Undisturbed	5	7	5	14	22	32	32	20	29	166
River		16	7	8		10	15	10	16	82
All Site Types	**50**	**84**	**53**	**59**	**75**	**100**	**108**	**92**	**106**	**727**

For the purpose of summarizing trends over the years, we calculated mean phosphorus concentrations per site type and per year. Median concentrations were used to summarize trends in the 2009 LOBA report due to variability in the data. With the removal of outliers from the data set, however, the mean and median concentrations are similar such that mean concentrations now provide representative values. In addition to the outliers identified in Section 3.1.2, the Little Trading Bay (E20) deepwater site was removed from the Deepwater class for analysis of long term trends because total phosphorus concentrations (2005-2008) at this site are significantly higher than 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 which 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). These changes to the handling of the data have resulted in minor changes to the mean concentrations and patterns of observed trends that were reported in previous LOBA monitoring reports.

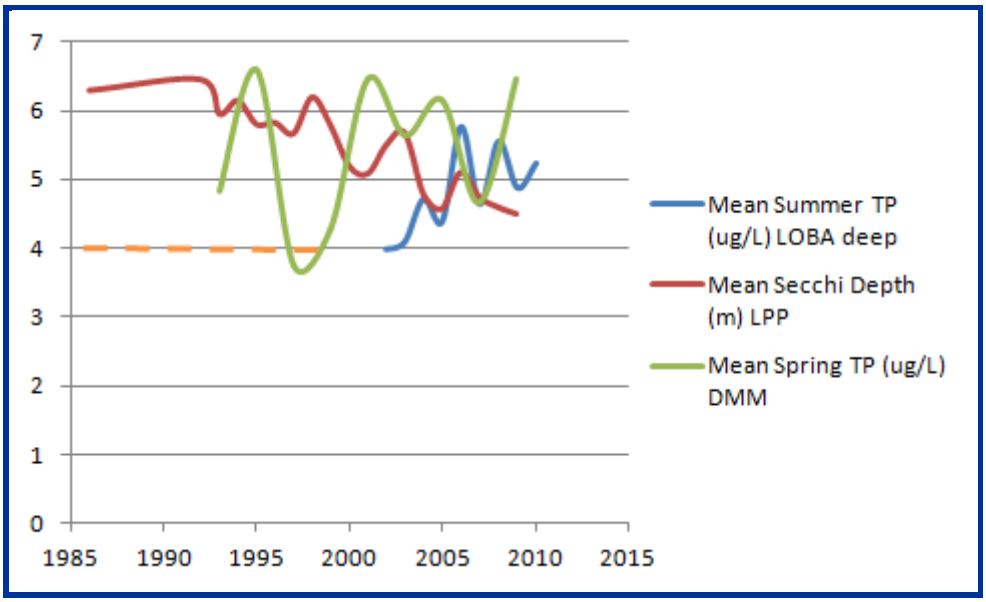
Since 2002, the mean summer total phosphorus concentrations have ranged between ~3 and 6 µg/L in the deepwater and nearshore sites (Figure 8). The river-influenced sites have been more variable with generally higher concentrations that have ranged from ~5 to 10 µg/L. Overall, these concentrations are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

Figure 8. Long-term Trends (2002-2010) in Mean Summer Total Phosphorus by Site Type



In previous LOBA monitoring reports, a potential increase in summer total phosphorus concentrations was noted over the monitoring period, which was coincident with a decrease in water clarity (as Secchi depth, Lake Partner Program data, Figure 9). These observations suggested increasing lake productivity in Lake of Bays over the monitoring period from 2002 to 2008. The trend of increasing phosphorus concentrations, however, did not continue in 2009 and 2010, when generally lower concentrations than in 2006-2008 were recorded at the nearshore sites. At the deepwater sites, mean total phosphorus concentrations appeared to have stabilized. As described in previous reports, interannual variability in total phosphorus concentrations is expected due to differences in weather patterns, shoreline development, localized nutrient uptake by plants and changes in the food chain, etc. Water clarity can be influenced by factors other than increased lake productivity (i.e., increased algal concentrations) such as inputs of dissolved organic carbon (DOC). It is possible, therefore, that the previously observed trends in total phosphorus concentration and water clarity are part of natural variability in the system and not indicative of a directional change due to human influence or climate change related factors. Further support for natural variability is provided by spring total phosphorus monitoring data collected by the DMM, which has been highly variable between sample years but without evidence of trends (Figure 9). The main cause for inter-annual changes in spring total phosphorus concentrations (DDM data) is 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. Despite annual differences in the two monitoring programs, they provide similar long term mean phosphorus concentrations for the open water sites from 2002 to 2010 (TP spring = 5.7 µg/L, TP summer = 4.9 µg/L).

Figure 9. Long-term Trends in Secchi Depth, Spring and Summer Total Phosphorus in Deep Areas of Lake of Bays.



Notes: Summer TP measured by the LOBA only includes only deep water sites, in order to allow comparison with DMM and LPP data that are consistently collected in deep areas.
LPP Secchi Depth was measured in different bays before and after 2003 (Bigwin Channel, Dwight Bay, Fairview Island Channel, Gull Island Channel, Haystack Bay, Trading Bay from 1992 to 2003, in Little Trading Bay and South of Britania Bay from 2004 to 2009).

5. Summary

The total phosphorus concentrations collected by the Lake of Bays Association over the summer of 2010 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 2010 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 and were below applicable DMM thresholds for phosphorus;

2) The Grubb's test provides a statistical means to identify extreme values that could influence the evaluation of trends in the data. Evaluation of outliers should be repeated each year;

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

4) The previously described increasing trend in total phosphorus concentrations did not continue in 2009 and 2010, with values decreasing at nearshore sites and remaining stable at deepwater sites, which suggests that the 2002-2008 increase was due to natural variability.

6. References

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

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

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

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

Gartner Lee Limited, 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.