Results of the 2013 Water Quality Survey of Eleven Lakes Located in the Carleton River Watershed Area of Digby and Yarmouth Counties, Nova Scotia

Prepared for

Nova Scotia Environment

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SUMMARY

Water quality surveys carried out by Nova Scotia Environment (NSE) between 2008 and 2012 within the Carleton, Meteghan, and Sissiboo River watersheds have shown a number of lakes within these watersheds to be seriously degraded, primarily with respect to high nutrient over-enrichment resulting in the development of high algal concentrations. These studies have also shown the degradation in water quality to be primarily a result of high phosphorus inputs resulting from releases emanating from mink farming operations. As a result, the Nova Scotia Department of Agriculture developed and enacted the Fur Industry Act, which includes a number of regulations designed to reduce the impact of fur farming operations on water quality.

In order to assess water quality trends in the survey lakes, NSE has encouraged and supported efforts to establish a long-term water quality monitoring program that could be executed with the aid of a volunteer community based organization. Such a program would serve to evaluate the efficacy of mitigation programs and controls implemented to reduce the impacts of fur farming operations on water quality. In 2013, a monitoring program was designed and initiated to further develop the database on annual changes in water quality, and to determine its suitability as a long-term monitoring program that could be carried out by a community based organization.

The results of the survey indicate that there has been no significant change in water quality within the lakes being monitored. Nutrient and chlorophyll *a* levels are still very high in many of the lakes, and many contain bottom waters having very low dissolved oxygen levels during the summer period when the lakes are thermally stratified. None of the lakes exceeded the Health Canada guidelines for total blue-green algal numbers or microcystins in 2013.

With respect to the suitability of the 2013 monitoring program as a model for one that could be carried out by a volunteer based community organization, it appears that it may be too labour intensive for the current level of volunteerism. Suggestions are made as to how the program could be simplified to reduce both costs and effort.

Table of Contents

List of Figures

Page

List of Tables

Results of the 2013 Water Quality Survey of Eleven Lakes Located in the Carleton River Watershed Area of Digby and Yarmouth Counties, Nova Scotia

1. Background

Over the last several years, Nova Scotia Environment (NSE) has carried out water quality studies on a number of lakes located within the Carleton, Meteghan and Sissiboo River watersheds. These studies have shown many of the lakes to be seriously degraded as a result of high phosphorus inputs resulting from releases emanating from mink farming operations. In some instances the high algal concentrations contained species of cyanobacteria (blue-green algae) known to produce microcystins, a toxin that, under certain conditions, may be harmful to humans, livestock and wildlife. As a result, the Nova Scotia Department of Agriculture has established the Fur Industry Regulations aimed at reducing these impacts on water quality. In order to evaluate the efficacy of mitigation programs and controls implemented to reduce nutrient related impacts, NSE has supported efforts to establish a long-term water quality-monitoring program that captures the annual changes in water quality. Accordingly, in 2013 a water quality study was designed and implemented that could form the basis of a routine annual survey to meet this need, and one that could in the future be carried out primarily by a community volunteer based organization. In 2013, the Tusket River Environmental Protection Association (TREPA) carried out this survey with the assistance of the Acadia Center for Estuarine Research (ACER) of Acadia University.

The primary objectives of this study were to: (1) further develop the database on water quality within the surveyed lakes; (2) determine how water quality has varied on an annual basis over the period in which surveys have been carried out and; (3) to determine if the survey design employed in 2013 is adequate in terms of the frequency of monitoring, the parameters being monitored and its suitability for a long-term volunteer based community monitoring effort.

2. Approach and Methods

The basic approach and water sampling methodologies were the same as those used in prior surveys carried out by NSE, the details of which are described in Brylinsky (2011). There were, however, some differences in the lakes sampled, frequency of sampling, number of sites sampled within each lake, and number of water quality parameters measured. These were as follows:

- Wentworth Lake was added to the lakes being surveyed. This is a relatively large lake through which the Carleton River flows but which was not included in earlier NSE surveys. A NSE nutrient sourcing study (Brylinsky 2012) showed this lake to be a major sink for nutrients entering the Carleton River system.

- In order to determine the degree of seasonal variation in water quality, the number of times per year each lake was surveyed was increased from one to three (spring, summer and fall).

- Water quality sampling at each lake was limited to the one deep water station previously used in all other surveys (i.e., no samples were collected at the inlets or outlets of each lake).

- Fecal coliform bacteria numbers and water turbidity were not measured.

Although five annual water quality surveys were carried out between 2008 and 2013, not all were carried out at the same time of year. Three (2008, 2011 and 2013) were carried out during the summer period, one (2010) was carried out entirely during the fall, and one (2009) was carried out partly in late summer (Sloans and Fanning Lakes), but mainly in fall. No surveys were carried out in 2012. In order to assess annual variations in water quality it is important that the comparisons be carried out during the same season because of the difference water column stratification has on surface water quality. As a result, analyses of annual changes in water quality in this report were limited to surveys carried out during the summer period.

3. Results

The complete database for all NSE surveys carried out to date is available as an Excel database. Appendix I contains the database used in this analysis, and Appendix II contains a series of bar graphs for each lake illustrating the results of all surface water surveys carried out between 2008 and 2013.

3.1 Annual Variation in Lake Trophic Status

Lake tropic status is typically based on the level of phosphorus (the nutrient most commonly limiting in freshwater systems), chlorophyll *a* (a measure of algal biomass) and Secchi depth (a measure of water clarity). Phosphorus is considered the causal parameter and chlorophyll *a* and Secchi depth are considered response parameters (i.e., high phosphorus levels lead to high algal biomass (chlorophyll *a*) which in turn results in low water transparency). The Organization for Economic Cooperation and Development (OECD) has developed a set of boundary condition guidelines for evaluating the trophic status of a waterbody based on these parameters (Table 3.1.1). One shortcoming of these guidelines is that Secchi depth may not be an appropriate trophic parameter for many of the lakes surveyed in this study due to their naturally high color, and subsequently low transparency, resulting from highly coloured leachates entering the lakes from the natural degradation of coniferous vegetation within their drainage basin.

Table 3.1.1 OECD boundary conditions for trophic categories

Trophic Category	Parameter		
	Total Phosphorus (µg/L)	Chlorophyll *a* (µg/L)	Secchi Depth (m)
Oligotrophic	< 10	< 2.5	> 6.0
Mesotrophic	≥ 10 - < 35	≥ 2.5 - < 8.0	≥ 1.5 - ≤ 6.0
Eutrophic	≥ 35	≥ 8.0	< 1.5

The annual variation in summer surface and bottom total phosphorus levels for all NSE surveys carried out between 2008 and 2013 is shown in Fig. 3.1.1. Of particular note is that many of the lakes located downstream of Placides exhibited their highest phosphorus levels in 2013.

Based on surface water phosphorus levels alone, Nowlans and Placides varied little annually and were highly eutrophic in all years surveyed. Both of these lakes are located within areas having the highest concentration of mink farms. Parr also exhibited eutrophic conditions in most years. Porcupine and Ogden exhibited significant continual increase over the years of monitoring.

Hourglass Lake was within the lower eutrophic level in all survey years and was the only lake that showed a trend of decreasing phosphorus levels over the survey period. This is a headwater lake with no major stream or river inputs, and an outlet that flows into the Carlton River. There are no mink farming operations located within its watershed, but there is a finfish aquaculture operation located along the lake's shoreline and it is likely that the decrease in phosphorus in 2013 is related to changes in its effluent releases or a reduction in the scale of its operation.

Wentworth Lake, which was surveyed for the first time in 2013, fell within the lower eutrophic category. Provost, was mostly within the borderline area between oligotrophic and mesotrophic levels. Vaughan exhibited a slight increase from oligotrophic to mesotrophic over the years surveyed. Sloans is the only lake to have remained within the oligotrophic category during all survey years.

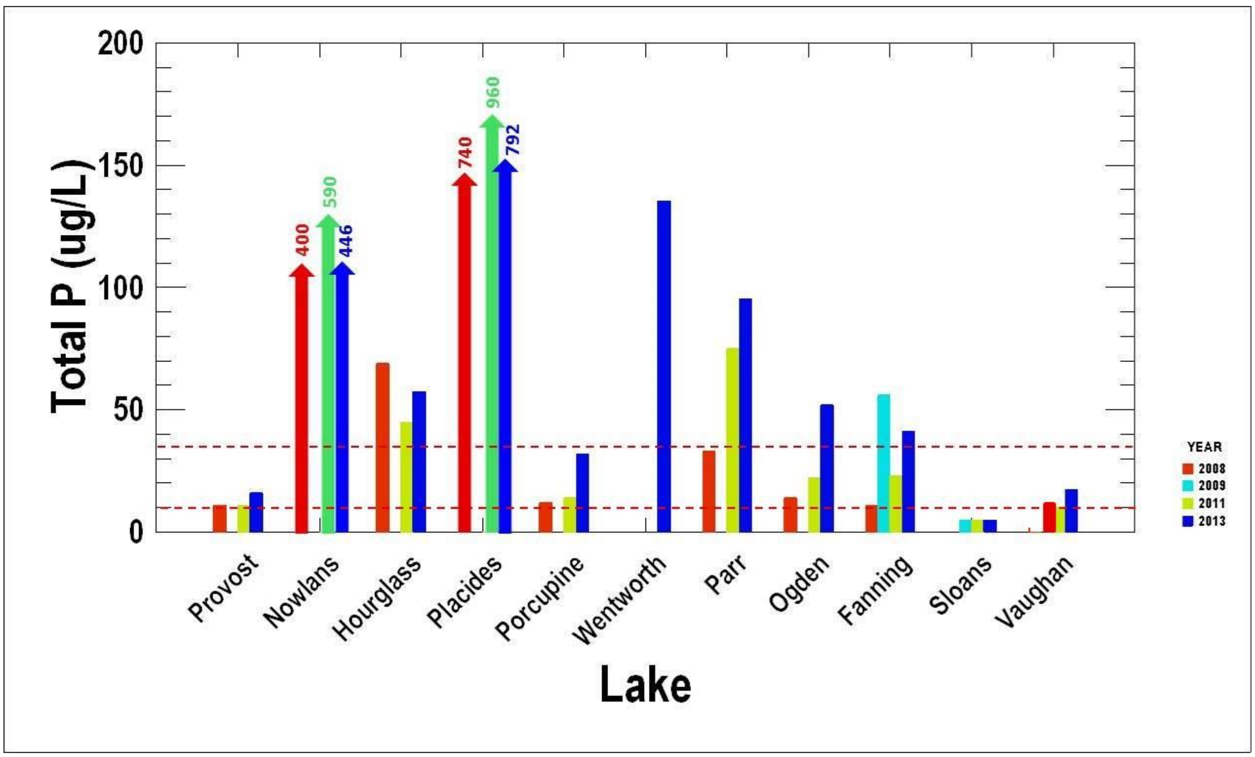

Fig. 3.1.1 Annual variation in summer surface total phosphorus concentration (red lines indicate upper OECD boundary guidelines for oligotrophic and mesotrophic categories). Note that only two lakes (Fanning and Sloans) were sampled during summer in 2009.

The annual variation in summer chlorophyll *a* levels is shown in Fig. 3.1.2. In many instances there is considerable difference between the trophic categories based on total phosphorus levels and those based on chlorophyll *a* levels. Provost and Nowlans were eutrophic in all survey years. Sloans was the only lake that was consistently within the oligotrophic category. The remaining lakes showed a considerable variation in trophic status between years.

Some, but not all, of the discrepancy in the trophic status based on phosphorus and chlorophyll *a* levels can be explained by differences in water colour and the influence that water color has on algal growth. The phosphorus and chlorophyll *a* OECD boundary guidelines are based largely on lakes having low water colour and assumes that only phosphorus, and not light availability, limits algal growth. Fig 3.1.3 illustrates the level and annual variation in water colour among the surveyed lakes and shows lakes having low water colour can have relatively high chlorophyll *a* levels, and lakes with high phosphorous levels can have relatively low chlorophyll *a* levels if water colour is also high. It also shows that water colour itself has significant annual variation which further complicates the degree to which lakes respond to variations in phosphorus levels.

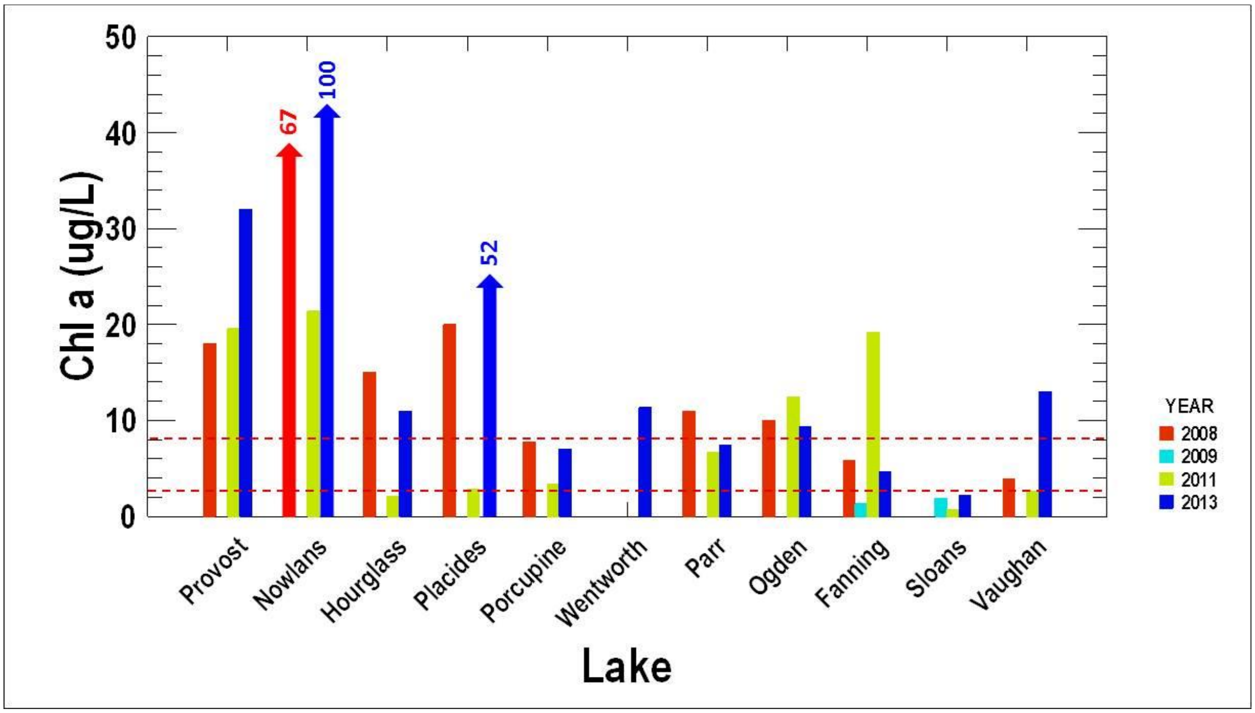

Fig. 3.1.2 Annual variation in summer chlorophyll *a* concentration (red lines indicate upper OECD boundary guidelines for oligotrophic and mesotrophic categories). Note that only two lakes (Fanning and Sloans) were sampled during summer in 2009.

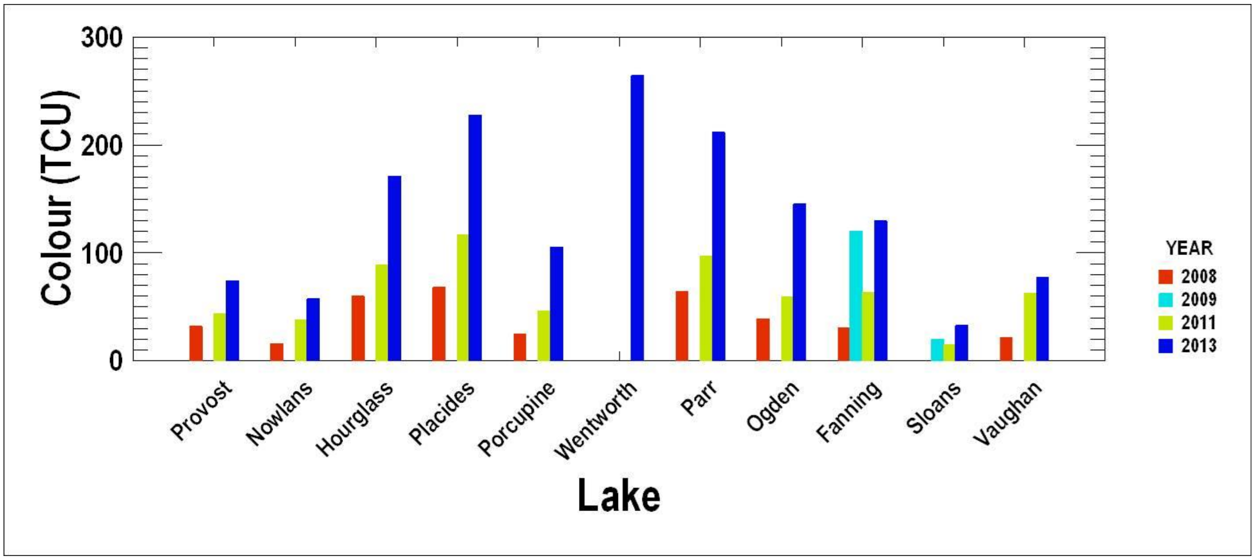

Fig. 3.1.3 Annual variation in summer surface water colour. Note that only two lakes (Fanning and Sloans) were sampled during summer in 2009.

Because of the strong influence water colour has on water transparency, Secchi depth (Fig. 3.1.4) is a poor indicator of trophic status for lakes having high water color. Of the three OECD trophic parameters, chlorophyll *a* is the best indicator of trophic status for the lakes being surveyed and, based on this single parameter, all but Sloans Lake have experienced high mesotrophic or eutrophic conditions over the period in which the surveys have been carried out. Sloans Lake, which never exceeded oligotrophic chlorophyll *a* levels, is a relatively isolated headwater lake that does not appear to be receiving any high nutrient inputs.

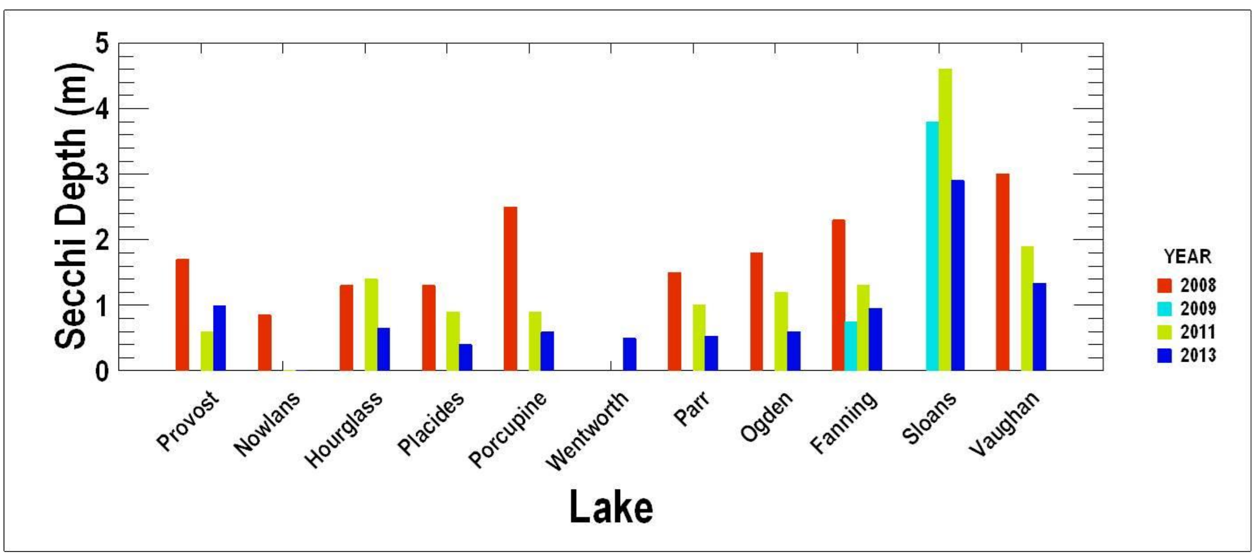

Fig. 3.1.4 Annual variation in summer Secchi depth. Note that only two lakes, (Fanning and Sloans) were sampled during summer in 2009.

In addition to phosphorus, nitrogen is also an essential nutrient for algal growth. Unlike phosphorus, however, there are no generally accepted guidelines for the concentrations that correspond to lake tropic categories. Fig 3.1.5 illustrates the annual variations in total nitrogen for summer surface waters. The general trends are similar to those observed for total phosphorus, the highest concentrations occurring in the upper regions of the Meteghan and Carleton River watersheds where the highest concentration of mink farms is located.

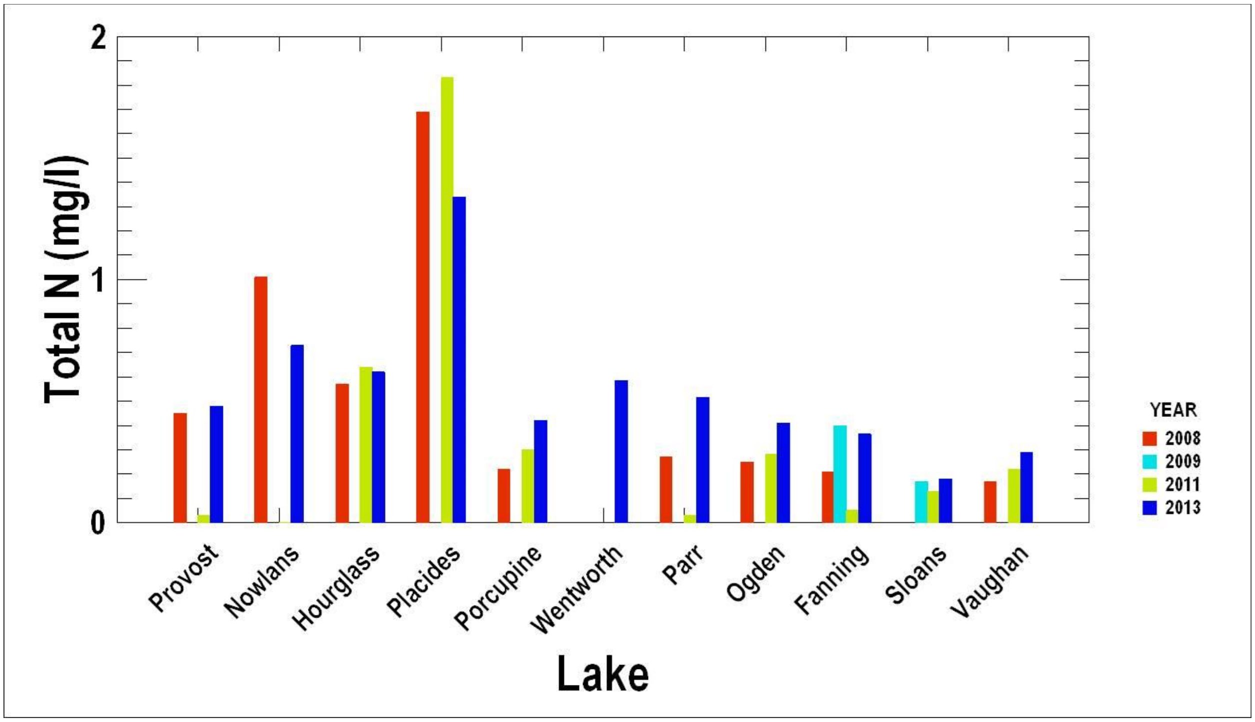

Fig. 3.1.5 Annual variation in summer surface total nitrogen concentration. Note that only two lakes, (Fanning and Sloans) were sampled during summer in 2009 and analysis of the 2011 sample for Nowlans Lake could not be analyzed by the laboratory due to technical problems.

3.2 Seasonal Variation in Trophic Parameters

Prior to 2013, all of the lake surveys were carried out only once per year. In an effort to determine the seasonal variation in water quality, three surveys were carried out in 2013, one in spring prior to the lake having developed thermal stratification of the water column, once in summer when the lakes were thermally stratified, and once in fall after the lakes had destratified. This seasonal sampling strategy is typical of community-based monitoring programs. The seasonal variation during 2013 in those water quality parameters mostly responsible for determining trophic status is illustrated in Fig 3.2.1.

In most lakes, total phosphorus levels were lowest during spring and about equal during summer and fall. This was also true of water colour.

Spring chlorophyll *a* levels tended to be lower than summer values in most lakes. Fall values were lowest. This is somewhat atypical of most lakes in that spring and fall chlorophyll *a* levels are usually greater than during summer as a result of water column turnover bringing nutrient rich bottom waters to the surface. The lower summer chlorophyll *a* levels are a result of phosphorous, which is mainly in the particulate form, having settled out of the upper water column leading to a reduction in algal growth. Because of the high levels of dissolved inorganic phosphorus present, which does not settle, the summer surface waters remain high in nutrients.

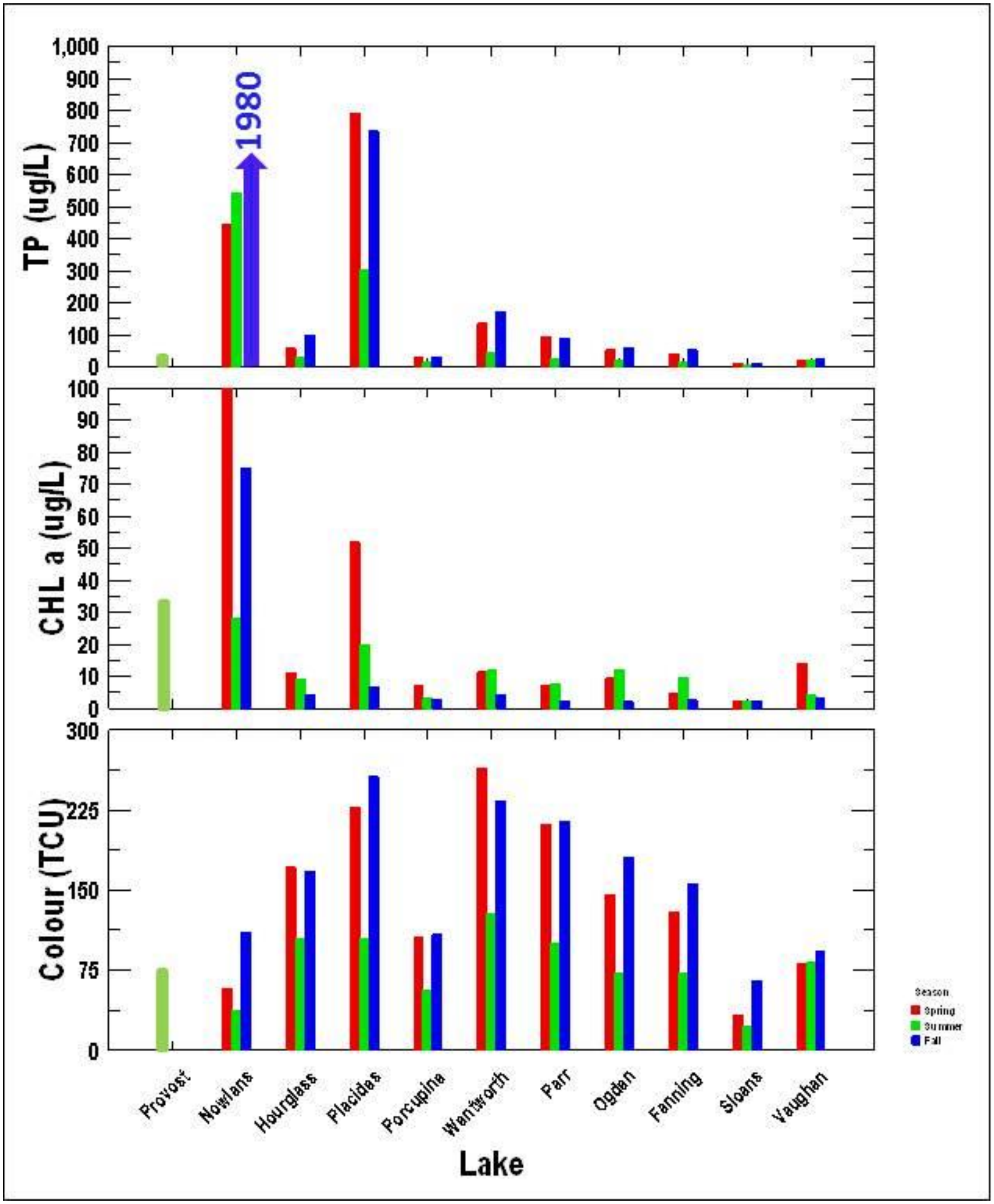

Fig. 3.2.1 Seasonal variation in water quality parameters determining lake trophic status in 2013.

3.3 Comparison of Nutrient Levels in Surface and Bottom Waters

Both surface and bottom summer water samples were collected only during the 2011 and 2013 water quality surveys. Total phosphorus and nitrogen levels at the surface and bottom generally exhibited the same trends, but bottom water levels were often higher (Fig 3.3.1.). Of particular note is that bottom water levels were considerably higher in Placides Lake and to a lesser degree Hourglass Lake.

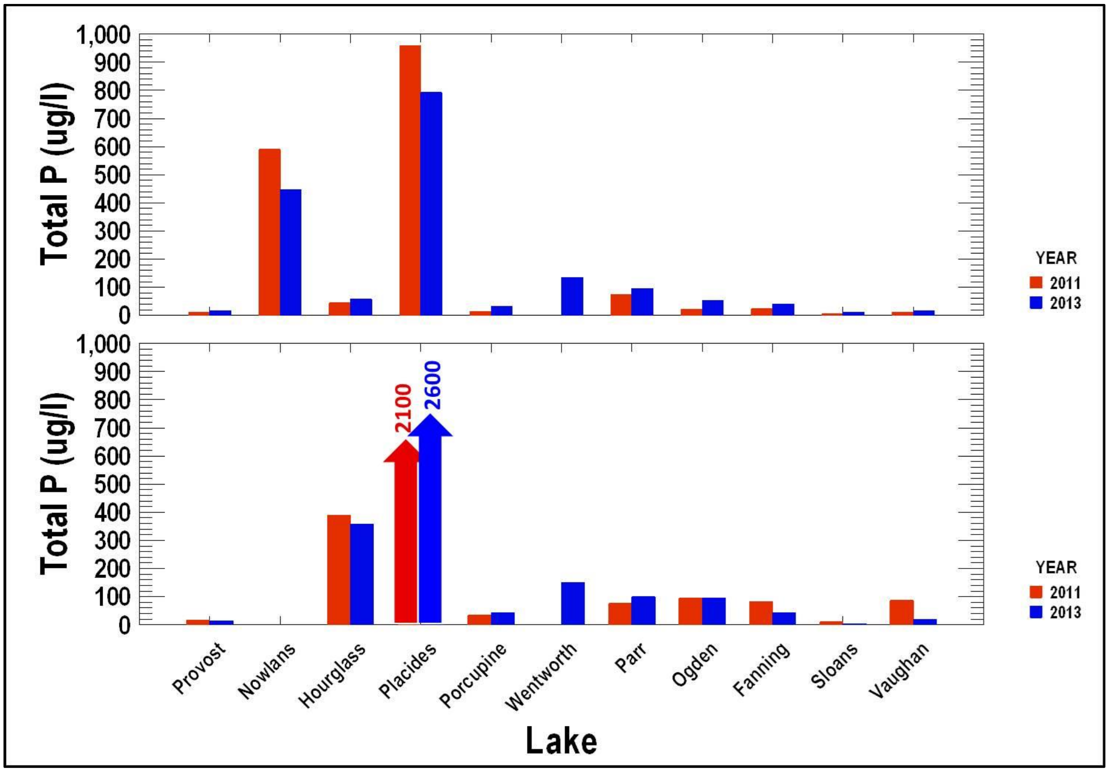

Fig. 3.3.1 Comparison of summer surface (uppe**r)** and bottom (lower) total phosphorus levels (Note: bottom water samples were not collected at Nowlans Lake in either year).

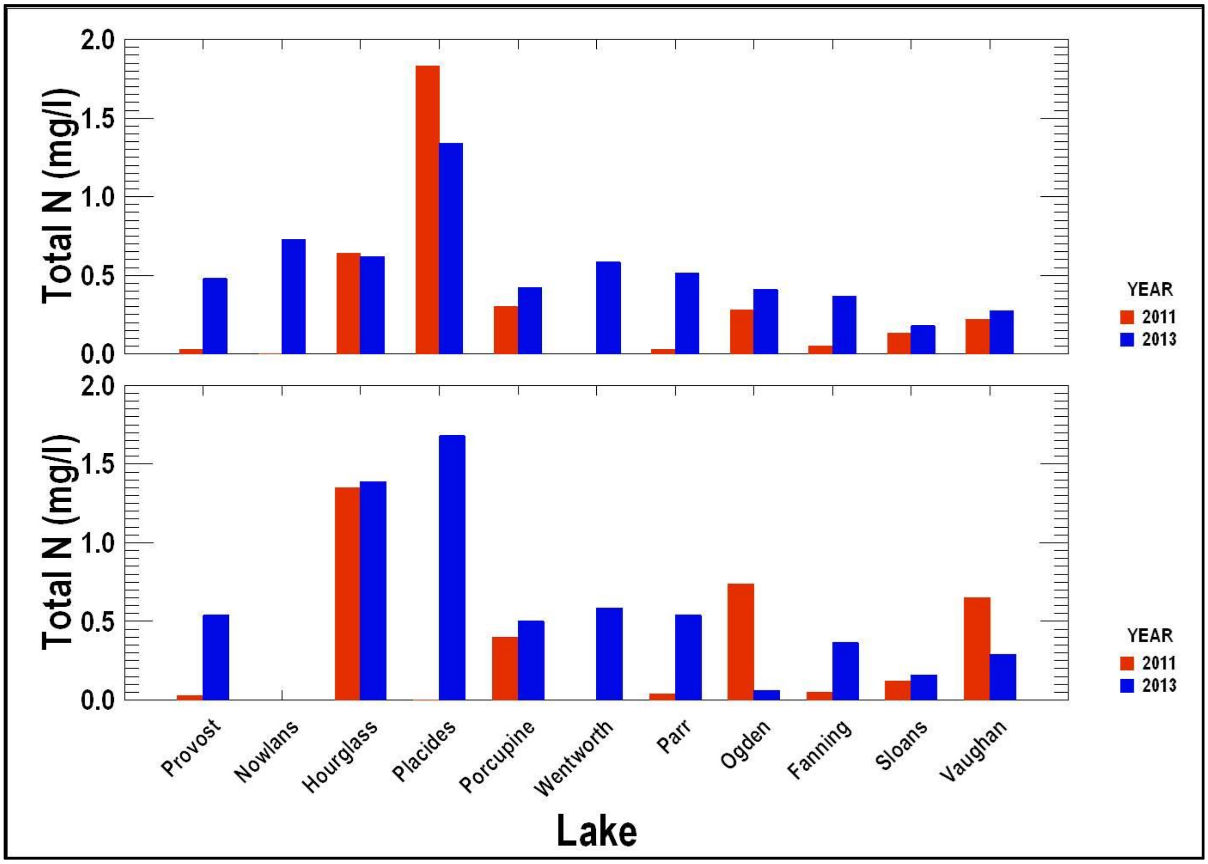

Fig. 3.3.2 Comparison of summer surface (uppe**r)** and bottom (lower) total nitrogen levels. (Note: bottom water samples were not collected for Nowlans in 2011 or 2013 and analysis of the 2011 surface sample could not be analyzed by the laboratory due to technical problems).

3.4 Ratios of Total and Inorganic Nutrients

Because algae are not able to assimilate nutrients present in particulate form, their growth is determined largely by the availability of nutrients in the dissolved inorganic form. As a result, the ratio of total phosphorus and total nitrogen to the inorganic forms of phosphorus and nitrogen provides additional information on the availability of nutrients for algal growth. The ratios for surface waters carried out during the summer water quality surveys (Fig. 3.4.1) indicate that for phosphorus most of nutrients are present in the dissolved form. This is unusual for lakes not subjected to nutrient over-enrichment, which typically have most of their phosphorus in the particulate form, and partly explains the high chlorophyll *a* levels observed in the lake surveys.

The ratios for nitrogen are less than for phosphorus, but indicate that for some of the lakes a significant portion of the nitrogen is in the dissolved inorganic form.

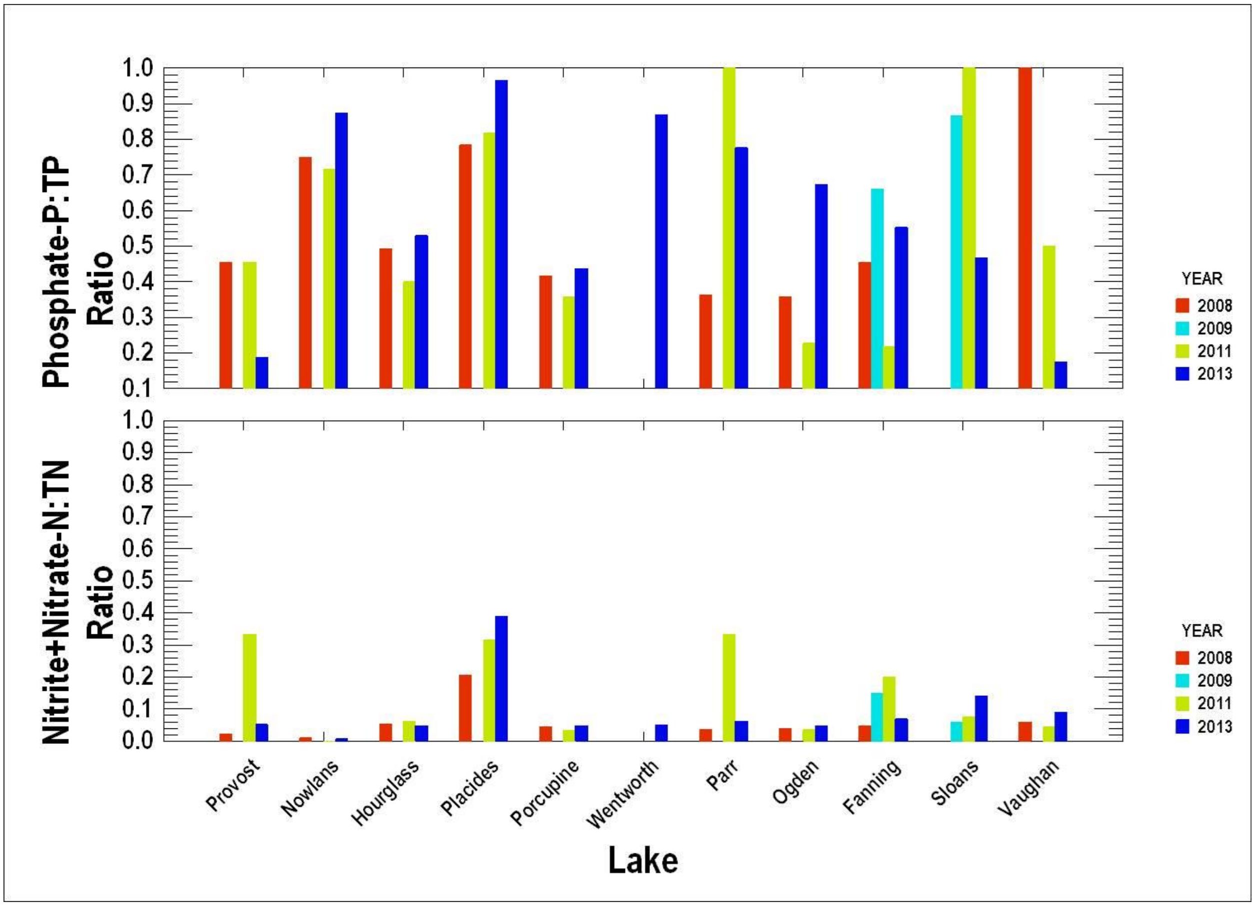

Fig 3.4.1 Annual variation in ratios of total phosphorus and inorganic-P and total nitrogen and inorganic-N for summer surface waters.

3.5 Water Temperature and Dissolved Oxygen

Depth profiles of water temperature and dissolved oxygen for all surveys carried out since 2008 during the August summer period when the lakes are most likely to exhibit their strongest thermal stratification are illustrated in Figs. 3.5.1a to 3.5.1c. The only lakes that did not exhibit summer thermal stratification are Parr and Wentworth, both of which are relatively shallow. All other lakes exhibited dissolved oxygen profiles characteristic of either mesotrophic or eutrophic lakes. Placides, Porcupine, Hourglass, Ogden, Fanning and Vaughan were often completely anoxic below the depth of the thermocline. The most severe anoxic conditions occurred in 2011.

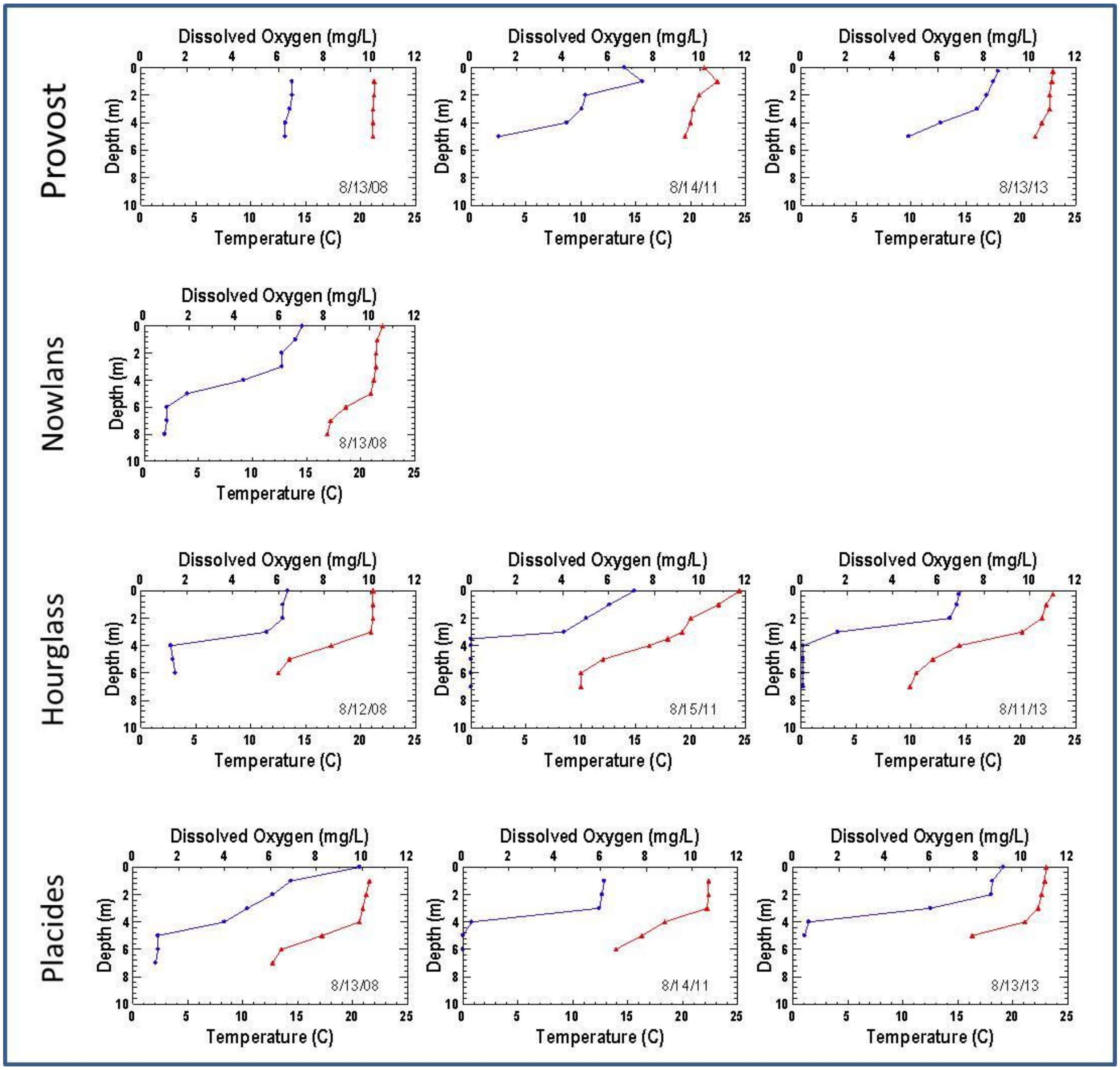

Fig. 3.5.1a Depth profiles of water temperature (▲) and dissolved oxygen (●) during periods of summer water column stratification**.**

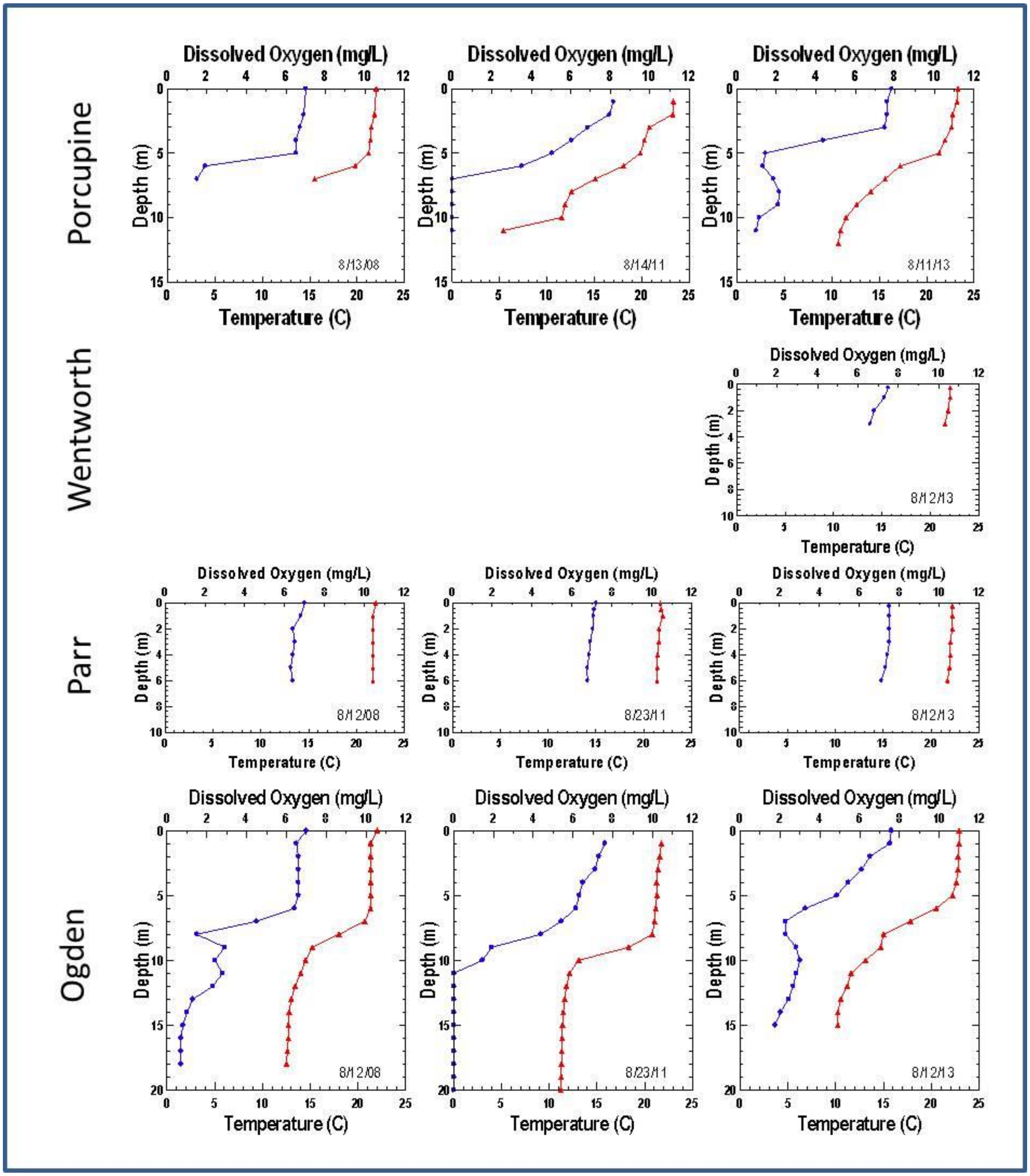

Fig. 3.5.1b Depth profiles of water temperature (▲) and dissolved oxygen (●) during periods of summer water column stratification**.**

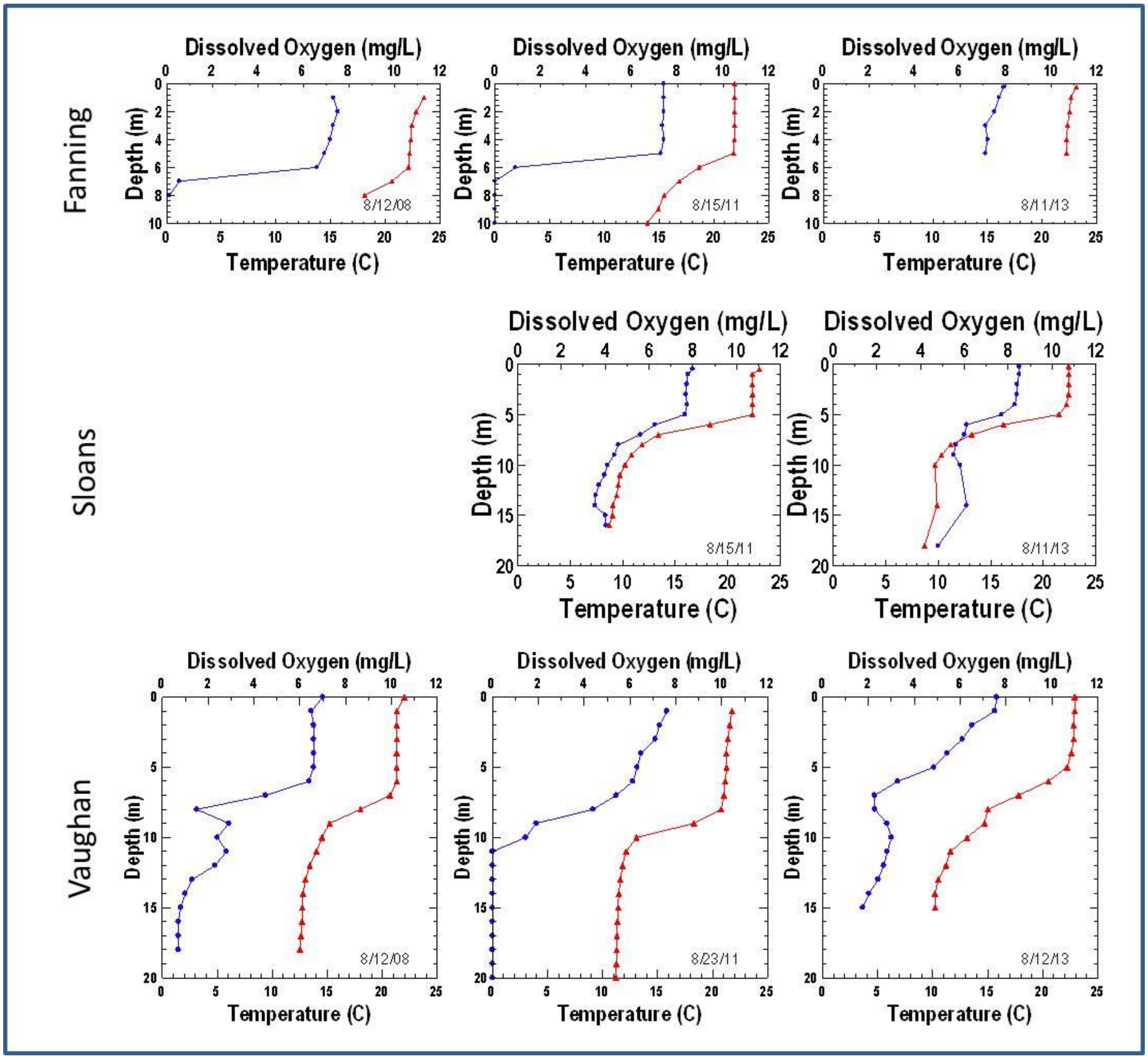

Fig. 3.5.1c Depth profiles of water temperature (▲) and dissolved oxygen (●) during periods of summer water column stratification**.**

3.6 Conductivity, Alkalinity and pH

Conductivity, alkalinity and pH are relatively conservative water quality parameters and the values for each lake showed little annual variation (Fig.3.6.1). Most of the lakes fell either slightly below or just above the lower CCME pH guideline for protection of freshwater aquatic life. Alkalinity, an indication of a lake's ability to buffer changes in pH, is relatively low in most lakes making them susceptible to the impacts of acid precipitation.

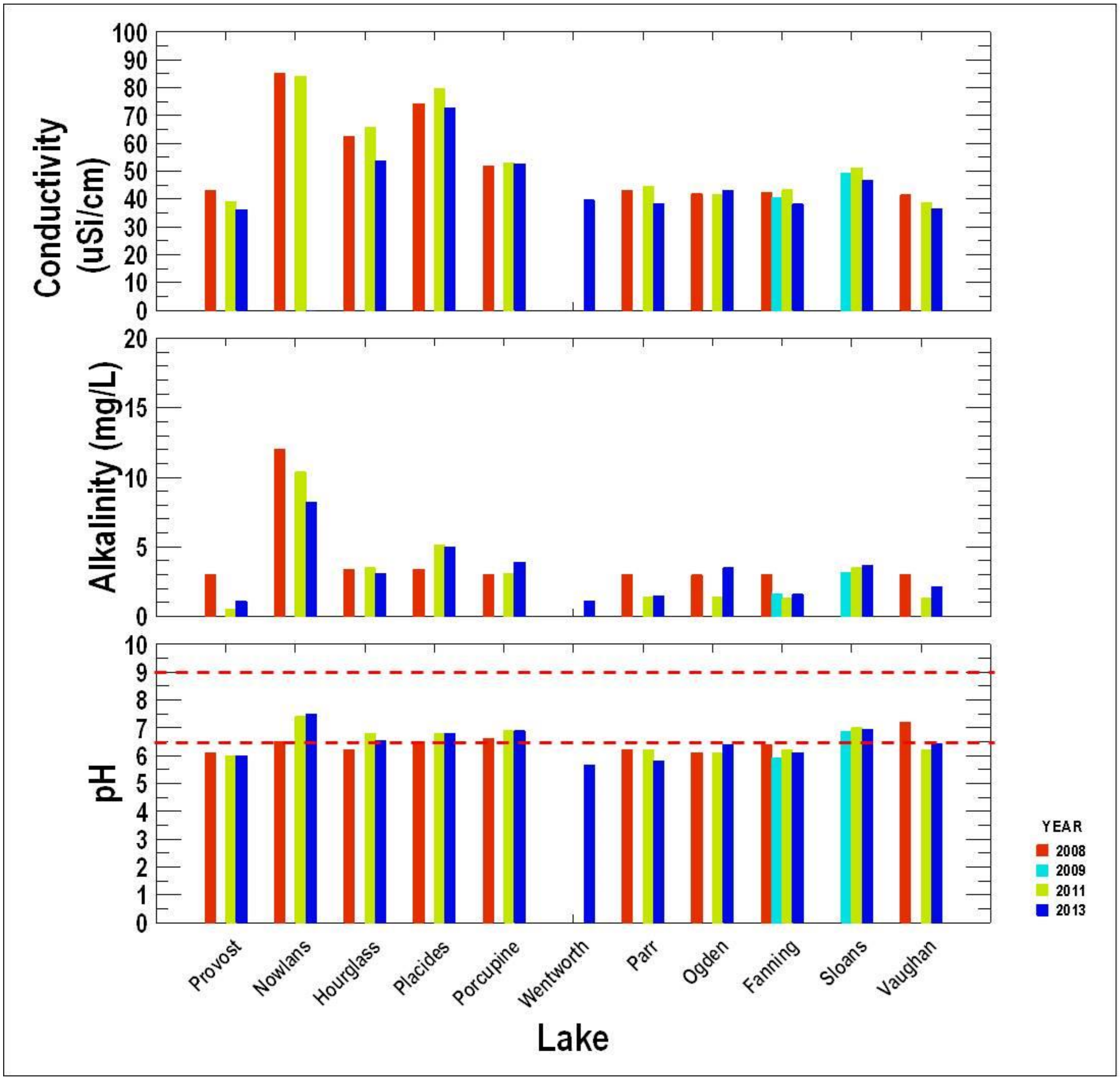

Fig. 3.6.1. Annual variation conductivity, alkalinity and pH for surface water during summer (red lines indicate the lower and upper boundaries of the CCME guidelines for pH).

3.7 Water Quality Guidelines

Table 3.4.1 summarizes the values of each lake for CCME (2013) guidelines for Protection of Freshwater Aquatic Life and Health Canada water quality guidelines relevant to recreational use. The Health Canada guideline for Secchi depth is related to water clarity and its influence on the ability to see objects in the water column that may be a risk to swimmers. Secchi Disk depth often fell below the guideline of >1.2 m due largely to the naturally high colour of most lakes.

Table 3.7.1. Summary of annual results for parameters having CCME or Health Canada guidelines (numbers in red indicate guideline was exceeded).

Lake	Year	Parameter (Numbers in parenthesis represent guideline values)				
		Secchi Depth (>1.2 m)	pH (6.5-9.0)	Blue Green Algae (<100,000 cells/ml)	Microcystins (<20 µg/L)	
					Free	Total
Provost	2008	1.7	6.1	492	< 0.20	-
	2009	1.1	5.9	10	< 0.20	-
	2010	1.7	6.0	38	< 0.20	-
	2011	0.6	6.0	450	< 0.20	< 0.20
	2013	1.0	6.0	-	-	-
Nowlans	2008	0.9	6.5	94,125*	0.30	-
	2009	0.8	7.3	138,333*	< 0.20	-
	2010	0.6	8.0	27,725*	< 0.20	-
	2011	-	7.4	78,900	< 0.20	11.82
	2013	-	7.3	88,600	-	< 0.20
Hourglass	2008	1.3	6.2	48	< 0.20	-
	2009	0.6	6.2	33	< 0.20	-
	2010	1.3	6.8	6	< 0.20	-
	2011	1.4	6.1	145	< 0.20	< 0.20
	2013	0.7	6.2	0	-	< 0.20
Placides	2008	2.5	6.6	56	< 0.20	-
	2009	1.3	6.6	2	< 0.20	-
	2010	2.0	6.9	20	< 0.20	-
	2011	0.8	6.9	870	< 0.20	< 0.20
	2013	0.4	7.5	0	-	< 0.20
Porcupine	2008	2.5	6.6	56	< 0.20	-
	2009	1.3	6.6	2	< 0.20	-
	2010	2.0	6.9	20	< 0.20	-
	2011	0.8	6.9	870	< 0.20	< 0.20
	2013	0.6	6.9	2,080	-	< 0.20
Wentworth	2013	0.5	5.6	-	-	< 0.20
Parr	2008	1.5	6.2	2,220	< 0.20	-
	2009	0.5	5.4	267	< 0.20	-
	2010	0.8	6.2	102	< 0.20	-
	2011	1.0	6.1	2,670	< 0.20	< 0.20
	2013	0.5	5.7	220	-	< 0.20
Ogden	2008	1.8	6.1	1,210	< 0.20	-
	2009	0.6	5.8	195	< 0.20	-
	2010	1.0	6.3	2,480	< 0.20	-
	2011	1.0	6.2	4,030	< 0.20	< 0.20
	2013	0.6	6.4	1,490	-	< 0.20
Fanning	2008	2.3	6.4	2,644*	< 0.20	-
	2009	0.7	5.9	5	< 0.20	-
	2010	1.2	6.4	4370*	< 0.20	-
	2011	1.3	6.2	70,100*	< 0.20	< 0.20
	2013	1.0	5.9	12,000	-	< 0.20

Table 3.7.1 (Con't.). Summary of annual results for parameters having CCME or Health Canada guidelines (numbers in red indicate guideline was exceeded).

Lake	Year	Parameter (Numbers in parenthesis represent guideline values)				
		Secchi Depth (>1.2 m)	**pH** (6.5-9.0)	**Blue Green Algae** (<100,000 cells/ml)	**Microcystins (<20 µg/L)** Free	Total
Sloans	2009	3.8	6.9	1,901*	< 0.20	-
	2010	4.3	7.0	3,075	< 0.20	-
	2011	4.6	6.9	856	< 0.20	< 0.20
	2013	3.2	6.8	3,410	-	< 0.20
Vaughan	2008	3.0	6.3	408	< 0.20	-
	2009	0.9	6.2	0	< 0.20	-
	2010	1.2	6.2	13*	< 0.20	-
	2011	1.8	6.2	160	< 0.20	< 0.20
	2013	1.2	6.2	240	-	< 0.20

*Number based on mean value of two or more samples collected at different locations.

Details of the blue-green algal species present and their individual numbers in each lake for each survey year are contained in Table 3.7.2. In the 2013 survey, all of the lakes except Placides and Hourglass contained at least one species of blue-green algae and *Microcystis sp.* was only present in one (Nowlans) of the lakes surveyed. None of the lakes exceeded the Health Canada guidelines for total blue-green algal numbers or microcystins in 2013.

Table 3.7.2 Summary of annual composition of blue green algal numbers and species composition**.**

Lake	Date	BGA (cells/ml)	Microcystis*	Anabaena*	Aphanocapsa	Oscillatoria*	Pseudoanabaena	Aphanothece	Spirulina	Aphanizomeneon*	Planktolyngbya	Aphanocapsa	Gomphosphaeria
Provost	08/27/08	492		484						8			
Provost	10/27/09	10					10						
Provost	10/01/10	38		8			30						
Nowlans	08/28/08	98100	840	1620						608	2		
Nowlans	08/28/08	104000	28600	1230						272			73500
Nowlans	08/28/08	78800	16200	704						638			
Nowlans	10/15/09	120000					30			120000	20		
Nowlans	09/26/10	24800	21600				74			3200			
Nowlans	09/26/10	57600	54100							3570			
Nowlans	08/26/11	78900	77500	186						120	1050		
Nowlans	08/07/13	88600	81600	930	4000					2110			
Hourglass	08/27/08	48								48			
Hourglass	10/20/09	33									33		
Hourglass	09/26/10	6				6							
Hourglass	08/13/13	0											

Table 3.7.2 (Con't.) Summary of annual composition of blue green algal numbers and species composition**.**

Lake	Date	BGA (cells/ml)	Microcystis*	Anabaena*	Aphanocapsa	Oscillatoria*	Pseudoanabaena	Aphanothece	Spirulina	Aphanizomenon*	Planktolyngbya	Aphanocapsa	Gomphosphaeria
Placides	08/27/08	64								64			
Placides	10/21/09	424					65				359		
Placides	09/27/10	0											
Placides	08/13/13	0											
Porcupine	08/28/08	56				56							
Porcupine	10/27/09	2									2		
Porcupine	09/27/10	20					20						
Porcupine	08/06/13	2080		1890		90	60				40		
Parr	09/04/08	2220			824					1390			
Parr	10/22/09	267					98			6	163		
Parr	09/27/10	102		22					80				
Parr	08/12/13	220		220									
Ogden	08/15/08	1210		940		16				256			
Ogden	10/22/09	195					130				65		
Ogden	09/28/10	2480		2480									
Ogden	06/06/13	1490		1490									
Fanning	08/28.08	128		24		32				72			
Fanning	10/15/08	5160		5140							17		
Fanning	10/13/09	5								1	4		
Fanning	09/30/10	7340		6940	20	372							
Fanning	10/12/10	14000		14000									
Fanning	08/11/13	12000		12000									
Sloans	09/09/09	3880					125	1250					2500
Sloans	09/09/09	5110					16	2500			97		2500
Sloans	11/05/09	100						100					
Sloans	09/09/09	2070						1250			500		324
Sloans	11/05/09	100											30
Sloans	11/05/09	216			50					4			162
Sloans	10/01/10	278			80		108	20					70
Sloans	08/11/13	3410						1550					1860
Vaughan	09/05/08	408								408			
Vaughan	10/28/09	0											
Vaughan	09/30/10	26				8	18						
Vaughan	09/30/10	0											
Vaughan	08/13/13	240		200			40						

4. Discussion

Despite having completed five annual surveys over a period of six years, it remains difficult to identify any significant consistent changes in water quality. It is, however, obvious that most of the lakes surveyed are still experiencing exceptionally high levels of nutrients and severe consequences of nutrient over-enrichment as evidenced by the high chlorophyll *a* levels and development of anoxic conditions during periods of summer water column stratification. Although many mink farm operators are in the process of implementing actions aimed at reducing nutrient releases which can affect watercourses, it will likely take considerable time before improvements in water quality become evident. Just how long this will take depends on the degree of reduction in nutrients entering the lakes, and the amount of nutrients that have already become sequestered in the bottom sediments of each lake.

The monitoring program carried out in 2013 required a great amount of effort and may need to be modified if it is to be carried out by a volunteer based community group, especially in its early stages before volunteers are fully engaged and have gained the experience required for the monitoring protocols. Consideration should be given to reducing the number of lakes and/or parameters being monitored, and the frequency of sampling until a greater number of volunteers have been recruited to participate in the monitoring program. It is recommended that NSE personnel and the existing community volunteers meet to consider these options prior to any future monitoring activities. It may also be advisable to include other stakeholder groups in this discussion to help coordinate efforts to manage development in the study watersheds, better support ongoing monitoring efforts, and to better achieve water resource protection to meet community needs.

5. Acknowledgements

Jeremy Broome, research technician, assisted ACER in the field work for the 2013 survey. Field work carried out by TREPA was ably assisted by Jennifer Vacon, a summer student and, the following volunteers: Marcel Comeau (Hourglass and Wentworth Lakes) Wayne Brittain (Parr Lake) Randy Cleveland (Lake Fanning) Alex Cunningham (Raynards Lake), Adele D'Entement-Richard (Sloans Lake), Marcus Dietrich (Sloans) Jill Raynard (Vaughn Lake) and Veralynn Rogers-Bonnar (Vaughn Lake). The TREPA Board, particularly Erin Comeau, Treasurer, participated in the planning and administering of the project.

6. References

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Appendix I. Database Used in Analyses.

Watershed	Lake	Date	Sample Depth (m)	Secchi Depth (m)	Chlorophyll *a* (µg/L)	Color (TCUs)	Total P (µg/L)	Phosphate-P (µg/L)	Total N (mg/L)	Nitrite+Nitrate-N (mg/L)	Conductivity (µSi/cm)	Alkalinity (mg/L)	pH
Sissiboo	Provost	8/14/08	0.0	1.70	18	32.0	11	5	0.45	0.010	43.0	3.0	6.1
Sissiboo	Provost	10/26/09	0.0	1.10	2.8	68.0	20	6	0.31	0.010	40.4	1.1	5.9
Sissiboo	Provost	10/26/09	4.1			70.0	20	6	0.28	0.010	39.1	1.0	5.6
Sissiboo	Provost	9/30/10	0.0	1.70	20.3	36.0	16	5	0.29	0.040	40.9	1.0	6.0
Sissiboo	Provost	8/14/11	0.0	0.60	19.6	43.8	11	5	0.03	0.010	39.1	0.5	6.0
Sissiboo	Provost	8/14/11	6.0			55.4	16	5	0.03	0.011	39.6	0.1	6.0
Sissiboo	Provost	8/13/13	0.3	0.99	32.0	74.3	16	<5	0.48	<0.01	36.2	1.1	6.0
Sissiboo	Provost	8/13/13	4.0			86.4	14	<5	0.54	<0.01	36.5	1.6	6.2
Meteghan	Nowlans	8/13/08	0.0	0.85	67	16.0	400	300	1.01	0.010	85.3	12.0	6.5
Meteghan	Nowlans	10/14/09	0.0	0.80	57.7	33.0	380	29	0.68	0.010	82.4	9.5	7.3
Meteghan	Nowlans	10/14/09	5.7			31.0	380	26	0.61	0.010	83.2	9.8	7.3
Meteghan	Nowlans	9/25/10	0.0	0.55	64.5	15.0	420	287	1.06	0.010	89.7	12.9	8.5
Meteghan	Nowlans	8/22/11	0.0		21.4	38.4	590	423		<0.01	84.2	10.4	7.4
Meteghan	Nowlans	04/30/13	0		28	37.8	544	524	0.90	0.210		8.6	7.3
Meteghan	Nowlans	08/07/13	0		100	57.4	446	390	0.73	<0.01		8.2	7.5
Meteghan	Nowlans	10/21/13	0		75	110.8	1980	1655	3.29	0.460		21.9	7.4
Carleton	Hourglass	8/13/08	0.0	1.30	15	60.0	69	34	0.57	0.030	62.5	3.4	6.2
Carleton	Hourglass	10/19/09	0.0	0.60	3.8	134.0	78	57	0.86	0.210	55.2	2.1	6.2
Carleton	Hourglass	10/19/09	6.3			147.0	79	50	0.86	0.220	55.4	2.1	6.2
Carleton	Hourglass	9/26/10	0.0	1.25	13	58.0	50	22	0.35	0.010	63.5	2.9	6.8
Carleton	Hourglass	8/13/11	0.0	1.40	2.1	89.0	45	18	0.64	0.040	65.7	3.5	6.8
Carleton	Hourglass	8/13/11	6.0			167.0	390	330	1.35	0.010	81.1	10.9	7.2
Carleton	Hourglass	5/7/13	1.3	1.07	9.3	104.7	30	10	0.45	0.005	51.4	3.0	6.6
Carleton	Hourglass	7/8/13	0.8	0.68	15.0	180.7	59	32	0.68	0.060	55.7	2.8	6.4
Carleton	Hourglass	7/8/13	7.0	0.68		288.5	341	305	1.39	<0.01	56.9	10.7	7.1
Carleton	Hourglass	8/12/13	0.3	0.63	7.0	161.7	56	29	0.56	<0.01	51.7	3.4	6.7
Carleton	Hourglass	8/12/13	7.0			270.8	374	172	2.19	<0.01	62.2	12.6	7.2
Carleton	Hourglass	10/29/13	0.3	0.82	4.2	167.7	98	79	0.92	0.170	37.1	3.4	6.6
Carleton	Placides	8/13/08	0.0	1.30	20	68.0	740	580	1.69	0.350	74.2	3.4	6.5
Carleton	Placides	8/13/08	7.0			202.0	5200	3440	2.95	0.020	87.8	24.0	6.3
Carleton	Placides	10/20/09	0.0	0.45	0.6	190.0	720	661	11.33	1.100	78.4	2.8	6.5
Carleton	Placides	10/20/09	5.8			207.0	700	680	2.80	1.100	77.3	2.9	6.4
Carleton	Placides	9/26/10	0.0	0.70	15.5	90.0	820	705	1.23	0.470	87.8	4.7	6.9
Carleton	Placides	9/26/10	6.0			97.0	830	652	1.28	0.540	89.6	5.2	6.9
Carleton	Placides	8/22/11	0.0		2.8	117.0	960	786	1.83	0.580	79.8	5.1	6.8
Carleton	Placides	8/22/11	5.0			132.7	2100	1780	4.32	0.160	129.6	15.9	7.2
Carleton	Placides	04/30/13	0	0.80	20	104.5	302	278	1.26	0.720	77.1	0.5	6.7
Carleton	Placides	08/06/13	0	0.40	52	227.8	792	764	1.34	0.520	72.6	5.0	6.8
Carleton	Placides	08/06/13	5			393.9	2600	2600	1.68	0.350	88.4	13.9	7.1
Carleton	Placides	10/21/13	0	0.40	6.9	256.5	735	706	1.57	0.700		5.3	7.5
Carleton	Placides	10/21/13	5			258.1	745	700	1.58	0.070		4.9	6.6
Carleton	Porcupine	8/12/08	0.0	2.50	7.8	25.0	12	5	0.22	0.010	51.9	3.0	6.6
Carleton	Porcupine	8/12/08	6.0			87.0	21	5	0.40	0.010	59.8	9.5	6.3
Carleton	Porcupine	10/26/09	0.0	1.20	1.3	75.0	34	11	0.46	0.060	50.1	3.0	6.6
Carleton	Porcupine	10/26/09	12.7			79.0	33	17	0.40	0.070	49.8	3.0	6.7
Carleton	Porcupine	9/26/10	0.0	1.95	2.8	39.0	21	5	0.25	0.010	51.5	3.1	6.8
Carleton	Porcupine	9/26/10	10.5				0	13	0.26	0.010	52.6	3.4	6.8
Carleton	Porcupine	8/14/11	0.0	0.90	3.4	46.6	14	5	0.30	0.010	53.0	3.1	6.9
Carleton	Porcupine	8/14/11	10.0			72.3	34	18	0.40	0.080	55.5	2.8	6.8
Carleton	Porcupine	04/30/13	0	2.60	3.2	56.7	13	<5	0.32	0.070	58.3	2.6	6.7
Carleton	Porcupine	08/05/13	11			89.5	44	27	0.50	0.140	60.8	4.6	6.9
Carleton	Porcupine	08/06/13	0	0.59	7	105.3	32	14	0.42	0.020	52.7	3.9	6.9
Carleton	Porcupine	10/21/13	0	1.00	2.8	108.1	32	17	0.45	0.080	86.5	3.8	6.8
Carleton	Porcupine	10/21/13	12			108.6	34	17	0.47	0.080	86.5	3.8	6.8

Appendix I. Database Used in Analyses (Con't.)

Watershed	Lake	Date	Sample Depth (m)	Secchi Depth (m)	Chlorophyll *a* (µg/L)	Color (TCUs)	Total P (µg/L)	Phosphate-P (µg/L)	Total N (mg/L)	Nitrite+Nitrate-N (mg/L)	Conductivity (µSi/cm)	Alkalinity (mg/L)	pH
Carleton	Wentworth	5/7/13	0.5	0.63	12.0	128.0	46	24	0.30	<0.01	36.8	1.2	5.9
Carleton	Wentworth	7/8/13	0.7	0.53	8.7	278.2	111	97	0.59	0.050	40.4	0.5	5.4
Carleton	Wentworth	7/8/13	3.0			273.2	125	92	0.59	<0.01	35.9	0.5	5.4
Carleton	Wentworth	8/12/13	0.3	0.46	14.0	250.6	160	138	0.58	0.010	38.8	1.7	5.9
Carleton	Wentworth	8/12/13	3.0			252.5	174	144	0.58	<0.01	38.7	1.7	5.9
Carleton	Wentworth	10/28/13	0.2	0.63	4.3	233.6	171	151	0.66	0.120	32.4	2.2	6.0
Carleton	Parr	8/14/08	0.0	1.50	11	64.0	33	12	0.27	0.010	43.0	3.0	6.2
Carleton	Parr	10/21/09	0.0	0.53	0.9	176.0	96	75	0.56	0.070	42.3	1.0	5.4
Carleton	Parr	10/21/09	6.2			178.0	95	75	0.56	0.070	42.6	1.0	5.4
Carleton	Parr	8/24/10	0.0	1.00	6.7	97.2	75	75	0.03	0.010	44.6	1.4	6.2
Carleton	Parr	8/24/10	6.0			99.0	76	46	0.04	0.010	49.5	5.2	7.0
Carleton	Parr	9/26/10	0.0	0.75	13	86.0	61	31	0.33	0.010	44.4	1.1	6.2
Carleton	Parr	8/25/11	0.0	1.0	6.7	97.2	75	75	0.03	0.010	43.6	0.9	6.1
Carleton	Parr	8/25/11	6.0			99.0	76	76	0.04	0.010	45.2	1.2	6.3
Carleton	Parr	5/5/13	0.5	0.96	7.8	100.4	25	12	0.25	<0.01	36.4	0.5	5.8
Carleton	Parr	7/8/13	0.3	0.55	8.7	223.9	86	68	0.50	<0.01	39.0	1.2	5.6
Carleton	Parr	7/8/13	7.0	0.55		232.9	92	73	0.54	<0.01	35.0	1.6	5.9
Carleton	Parr	8/12/13	0.3	0.51	6.1	199.6	105	80	0.53	0.040	37.6	1.8	6.0
Carleton	Parr	8/12/13	6.0	0.51		216.6	107	82	0.54	0.040	37.5	1.5	5.8
Carleton	Parr	10/28/13	0.3	0.55	2.3	214.3	88	72	0.53	0.040	29.9	1.7	5.8
Carleton	Ogden	8/14/08	0.0	1.80	10	39.0	14	5	0.25	0.010	41.9	3.0	6.1
Carleton	Ogden	8/14/08	18.0			152.0	97	51	0.80	0.010	45.1	5.0	5.9
Carleton	Ogden	10/22/09	0.0	0.63	1	86.0	14	5	0.25	0.010	41.9	3.0	6.1
Carleton	Ogden	10/22/09	18.0			152.0	97	51	0.80	0.010	45.1	5.0	5.9
Carleton	Ogden	9/27/10	0.0	0.95	18.8	58.0	29	8	0.35	0.050	43.8	1.5	6.3
Carleton	Ogden	9/27/10	16.0			206.0	260	194	1.79	0.010	62.3	11.8	7.0
Carleton	Ogden	8/24/11	0.0	1.20	12.5	59.2	22	5	0.28	0.010	41.6	1.4	6.1
Carleton	Ogden	8/24/11	15.0			107.1	94	38	0.74	0.020	49.5	5.2	7.0
Carleton	Ogden	04/30/13	0	1.42	12	72.2	22	14	0.26	0.005	40.9	1.2	6.1
Carleton	Ogden	04/30/13	14			141.9	96	72	0.59	0.130	40	2.5	6.4
Carleton	Ogden	08/06/13	0	0.60	9.4	145.3	52	35	0.41	0.020	43	3.5	6.4
Carleton	Ogden	08/06/13	14			141.9	96	72	0.06	0.130	54.6	2.5	6.4
Carleton	Ogden	10/21/13	0	0.70	2.1	180	61	50	0.44	0.020	86.5	1.8	6.1
Carleton	Ogden	10/21/13	16			345.5	206	148	0.69	0.005	86.5	4.4	6.7
Carleton	Fanning	8/16/08	0.0	2.30	5.8	31.0	11	5	0.21	0.010	42.3	3.0	6.4
Carleton	Fanning	8/16/08	9.0			137.0	97	55	0.62	0.010	50.6	10.0	6.5
Carleton	Fanning	9/12/09	0.0	0.75	1.3	120.0	56	37	0.40	0.060	40.6	1.6	5.9
Carleton	Fanning	9/12/09	7.9			122.0	60	37	0.40	0.060	41.1	1.5	5.9
Carleton	Fanning	10/12/09	0.0	0.75	1.3	120.0	56	37	0.40	0.060	40.6	1.6	5.9
Carleton	Fanning	10/12/09	7.9			122.0	60	37	0.40	0.060	41.1	1.5	5.9
Carleton	Fanning	9/30/10	0.0	1.15	21.9	55.0	21	5	0.35	0.060	44.6	1.8	6.4
Carleton	Fanning	8/17/11	0.0	1.30	19.2	63.1	23	5	0.05	0.010	43.3	1.3	6.2
Carleton	Fanning	8/17/11	9.0			202.2	82	54	0.05	0.010	49.9	5.4	7.0
Carleton	Fanning	5/5/13	0.5	1.30	9.7	72.4	17	7	0.22	<0.01	36.0	1.3	6.1
Carleton	Fanning	7/7/13	0.9	0.90	5.6	128.2	37	22	0.33	<0.01	38.6	1.4	6.0
Carleton	Fanning	7/7/13	5.0	0.90		133.4	41	27	0.35	<0.01	38.0	1.6	6.2
Carleton	Fanning	8/11/13	0.9	1.01	3.8	131.4	45	23	0.40	<0.01	37.7	1.8	6.2
Carleton	Fanning	8/11/13	5.0	1.01		130.6	44	26	0.38	<0.01	37.6	1.9	6.3
Carleton	Fanning	10/20/13	0.3	0.58	2.6	156.3	52	39	0.42	0.060	31.5	1.8	6.1
Carleton	Sloans	9/9/09	0.0	3.80	1.9	20.0	5	5	0.18	0.010	50.0	3.2	6.9
Carleton	Sloans	9/10/09	0.0	3.80	1.8	20.0	5	5	0.15	0.010	47.6	3.1	6.8
Carleton	Sloans	9/10/09	16.0			14.0	5	5	0.15	0.030	49.5	3.4	6.7
Carleton	Sloans	9/10/09	19.0			15.0	7	5	0.19	0.060	53.5	3.7	6.8

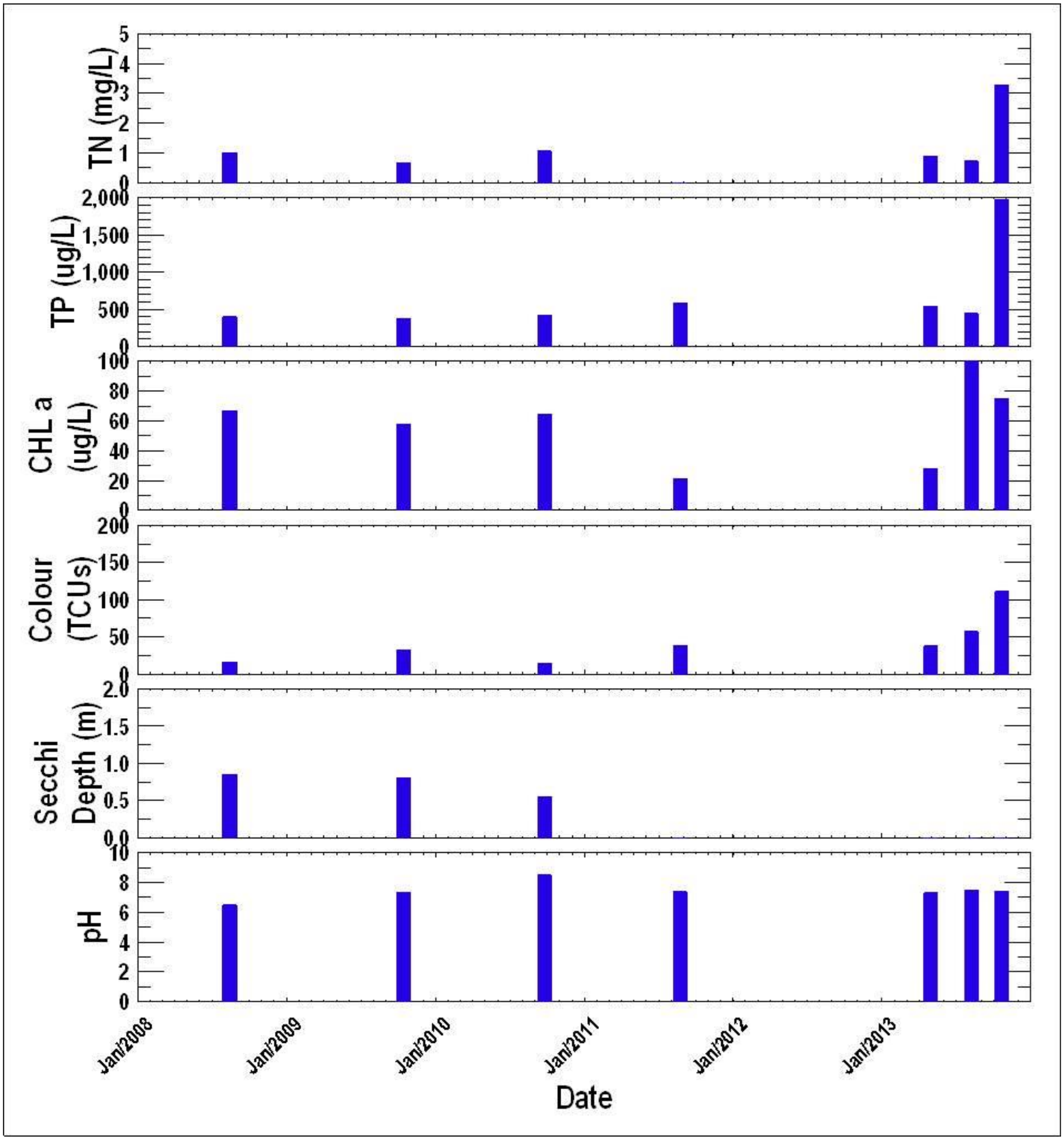
Appendix I. Database Used in Analyses (Con't.)

Watershed	Lake	Date	Sample Depth (m)	Secchi Depth (m)	Chlorophyll *a* (µg/L)	Color (TCUs)	Total P (µg/L)	Phosphate-P (µg/L)	Total N (mg/L)	Nitrite+Nitrate-N (mg/L)	Conductivity (µSi/cm)	Alkalinity (mg/L)	pH
Carleton	Sloans	9/13/09	0.0	3.80	1.9	20.0	5	<5	0.18	0.010	50.0	3.2	6.9
Carleton	Sloans	9/13/09	19.0			15.0	7	<5	0.19	0.060	53.5	3.7	6.8
Carleton	Sloans	11/4/09	0.0	3.20	1.2	21.0	6	<5	0.22	0.010	52.0	4.1	6.9
Carleton	Sloans	11/4/09	22.0			44.0	12	<5	0.25	0.010	59.1	6.7	7.0
Carleton	Sloans	9/30/10	0.0	4.30	1.8	12.0	9	5	0.12	0.010	52.4	3.7	7.0
Carleton	Sloans	9/30/10	0.0	4.30	1.9	10.0	5	5	0.12	0.010	49.9	3.6	7.0
Carleton	Sloans	9/30/10	9.0		1.4	15.0	5	5	0.10	0.010	49.7	4.0	6.8
Carleton	Sloans	9/30/10	14.0		0.7	18.0	7	5	0.08	0.010	62.7	4.7	6.9
Carleton	Sloans	9/30/10	15.0		1.1	23.0	7	5	0.10	0.010	50.9	4.2	6.8
Carleton	Sloans	8/15/11	0.0	4.60	0.7	15.3	5	5	0.13	0.010	51.2	3.5	7.0
Carleton	Sloans	8/15/11	14.0			16.9	10	5	0.12	0.020	51.9	3.5	6.9
Carleton	Sloans	5/6/13	0.5	3.65	2.3	22.0	3	<5	0.14	<0.01	38.7	4.0	7.0
Carleton	Sloans	7/3/13	2.6	2.65	2.0	29.2	18	6	0.16	<0.01	42.3	3.8	6.9
Carleton	Sloans	7/3/13	18.0	2.65		19.2	4	<5	0.14	<0.01	35.8	4.1	6.8
Carleton	Sloans	8/11/13	0.3	3.15	2.4	36.3	5	<5	0.20	<0.01	51.2	3.5	7.0
Carleton	Sloans	8/11/13	17.0			18.7	4	<5	0.18	<0.01	51.9	3.5	6.9
Carleton	Sloans	10/20/13	20.0	3.30		64.8	11	<5	0.23	<0.01	35.9	6.9	7.1
Carleton	Vaughan	9/4/08	0.0	3.00	3.9	22.0	12	5	0.17	0.010	41.4	3.0	7.2
Carleton	Vaughan	9/4/08	14.0			148.0	45	5	0.73	0.010	48.8	9.1	6.3
Carleton	Vaughan	10/27/09	0.0	0.90	1.3	88.0	33	14	0.40	0.060	40.5	1.8	6.2
Carleton	Vaughan	10/27/09	18.5			88.0	34	16	0.39	0.060	40.8	1.9	6.2
Carleton	Vaughan	9/30/10	0.0	1.20	2.8	69.0	18	18	0.34	0.040	41.5	1.6	6.2
Carleton	Vaughan	9/30/10	0.0	1.75	1.5	120.0	19	5	0.32	0.040	36.4	1.0	5.5
Carleton	Vaughan	9/30/10	12.0		0.01	181.0	78	43	0.50	0.010	55.7	8.9	7.1
Carleton	Vaughan	8/16/11	0.0	1.90	2.6	63.0	10	5	0.22	0.010	38.6	1.3	6.2
Carleton	Vaughan	8/16/11	15.0			112.0	87	61	0.65	0.010	55.3	7.9	7.2
Carleton	Vaughan	4/30/13	0.5	1.45	4.2	82.4	19	7	0.32	0.050	45.0	1.5	6.2
Carleton	Vaughan	7/4/13	1.5	1.50	12.0	74.1	15	<5	0.26	<0.01	39.2	2.0	6.4
Carleton	Vaughan	7/4/13	12.0	1.50		81.1	23	12	0.31	<0.01	40.2	3.2	6.6
Carleton	Vaughan	8/13/13	0.3	1.17	14.0	81.0	20	<5	0.29	<0.01	39.9	2.2	6.5
Carleton	Vaughan	8/13/13	14.0			79.8	15	<5	0.27	<0.01	57.7	2.1	6.5
Carleton	Vaughan	10/29/13	0.3	1.20	3.3	92.7	26	8	0.42	0.070	29.8	2.2	6.4

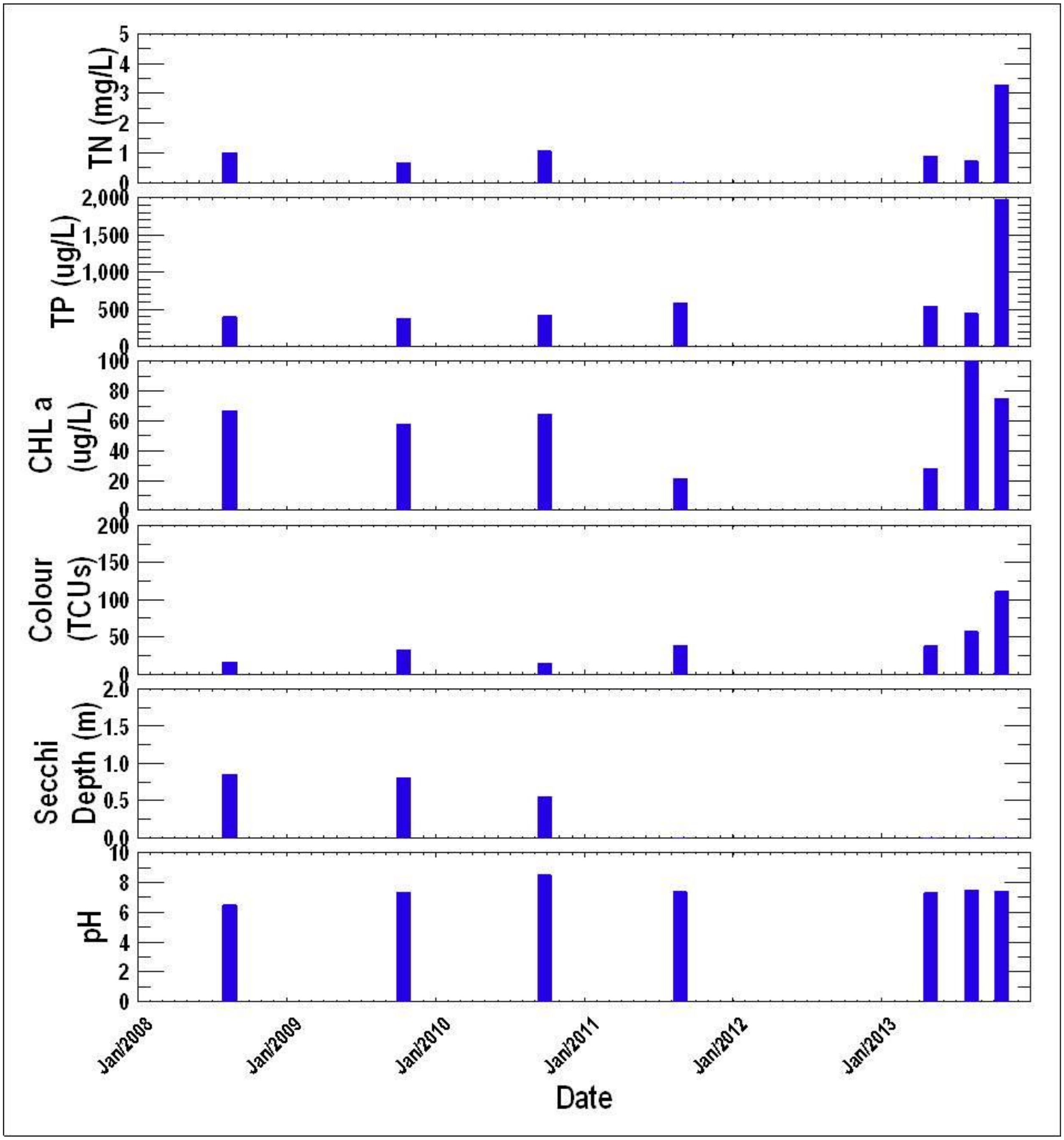
Appendix II

Bar Graphs of Survey Results for Surface Waters

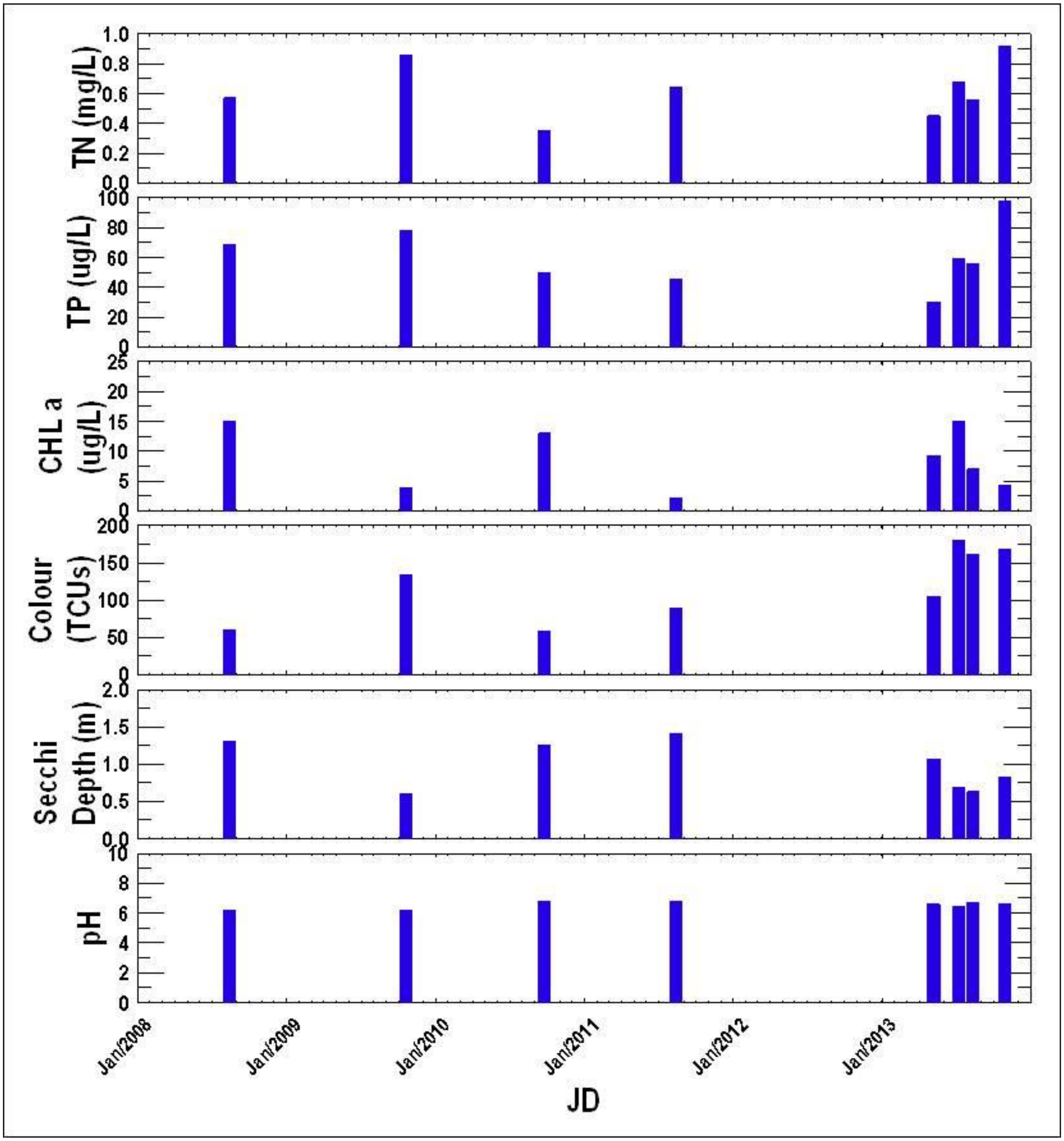
[NOTE: In making comparisons between lakes, note that axes scales differ among lakes.]



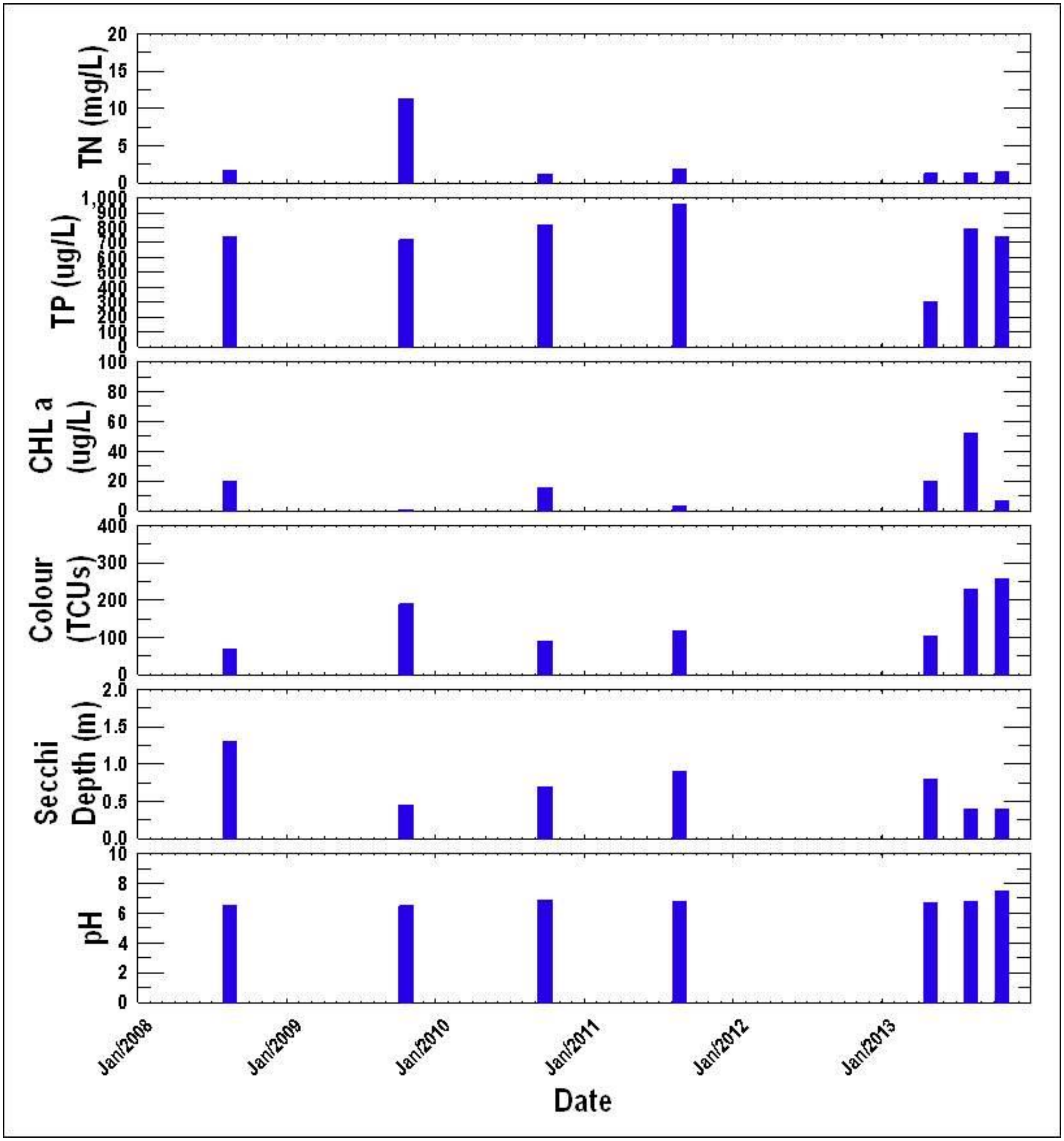
Provost Lake



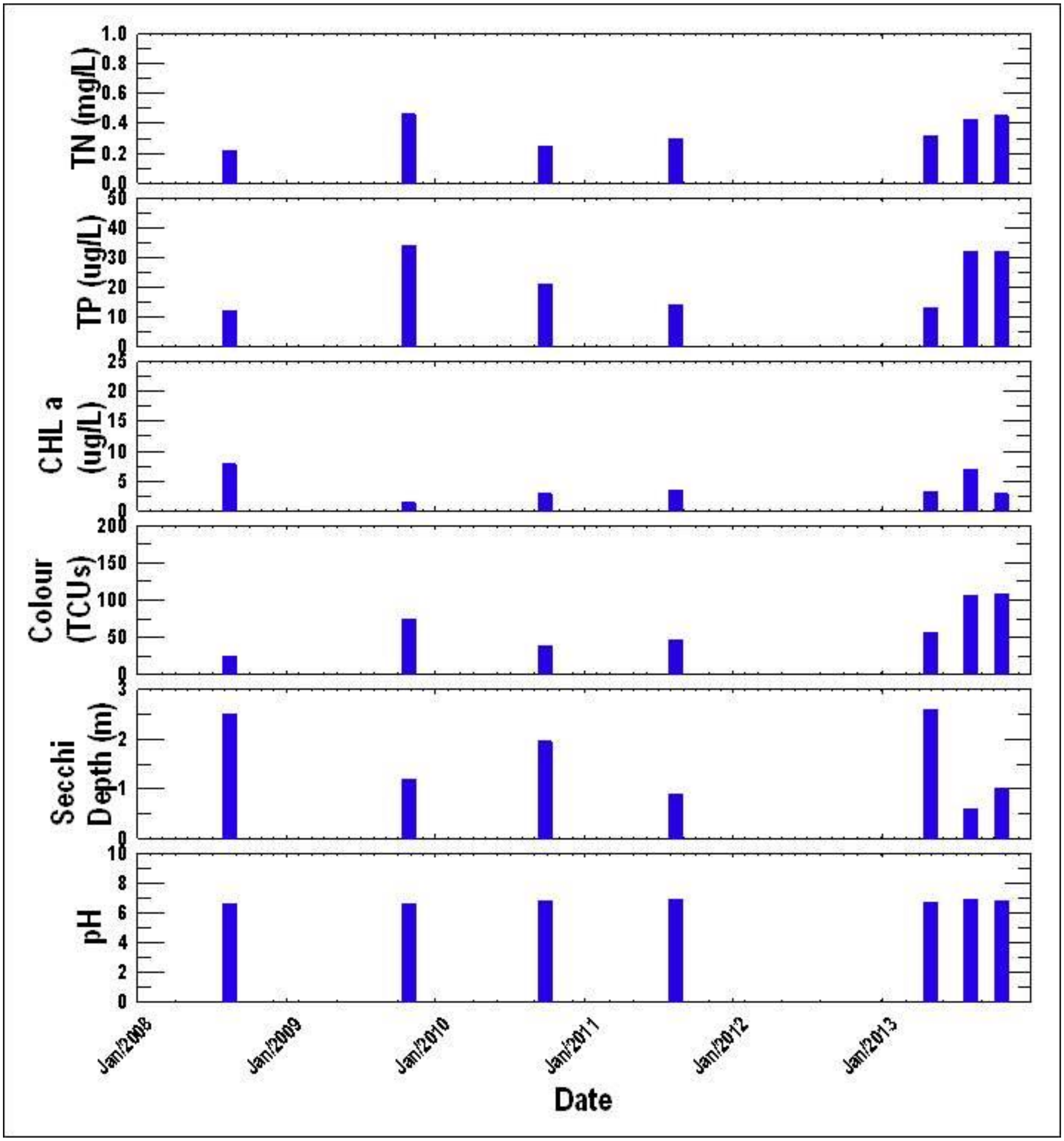
Nowlans Lake



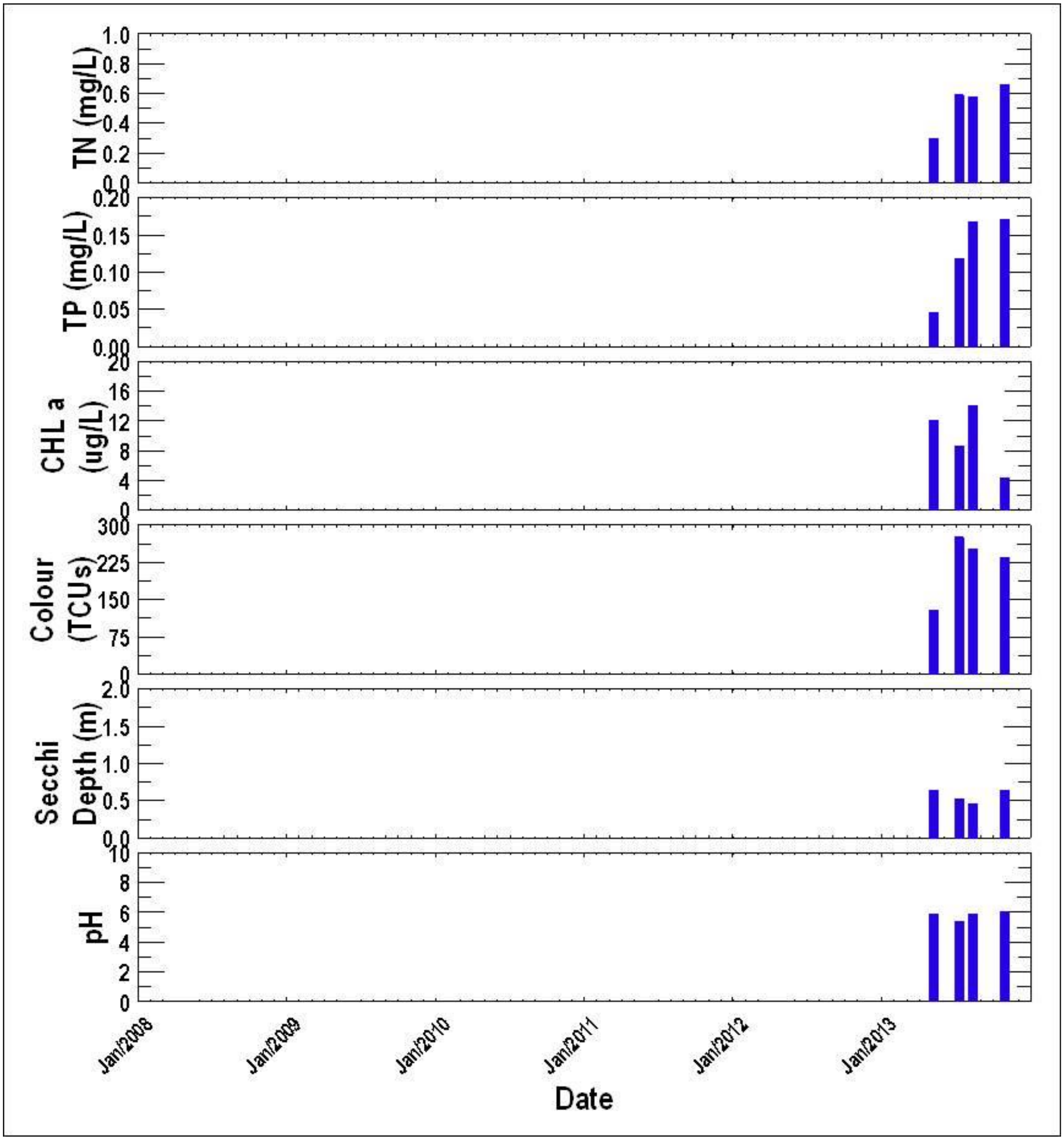
Hourglass Lake



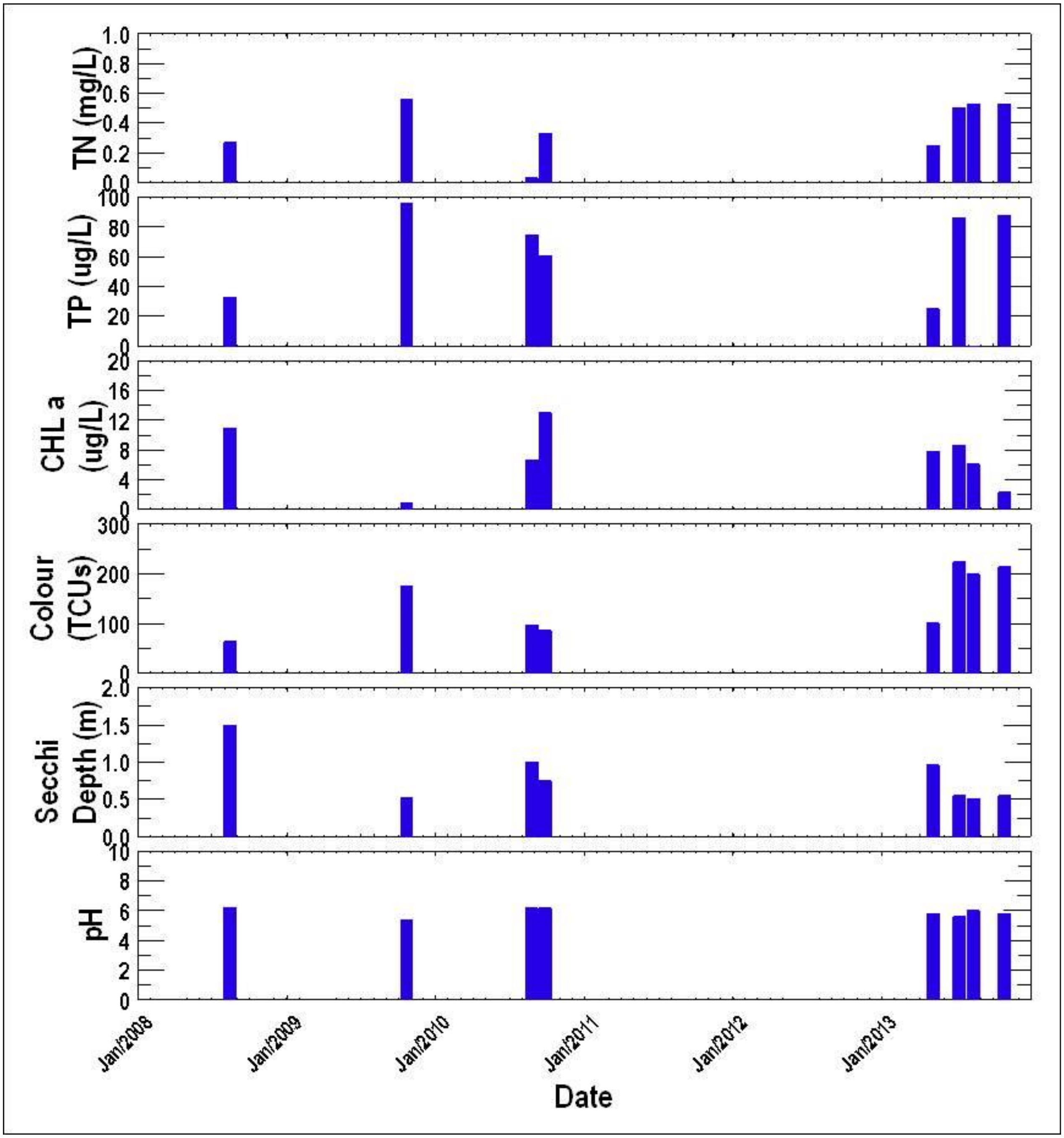
Placides Lake



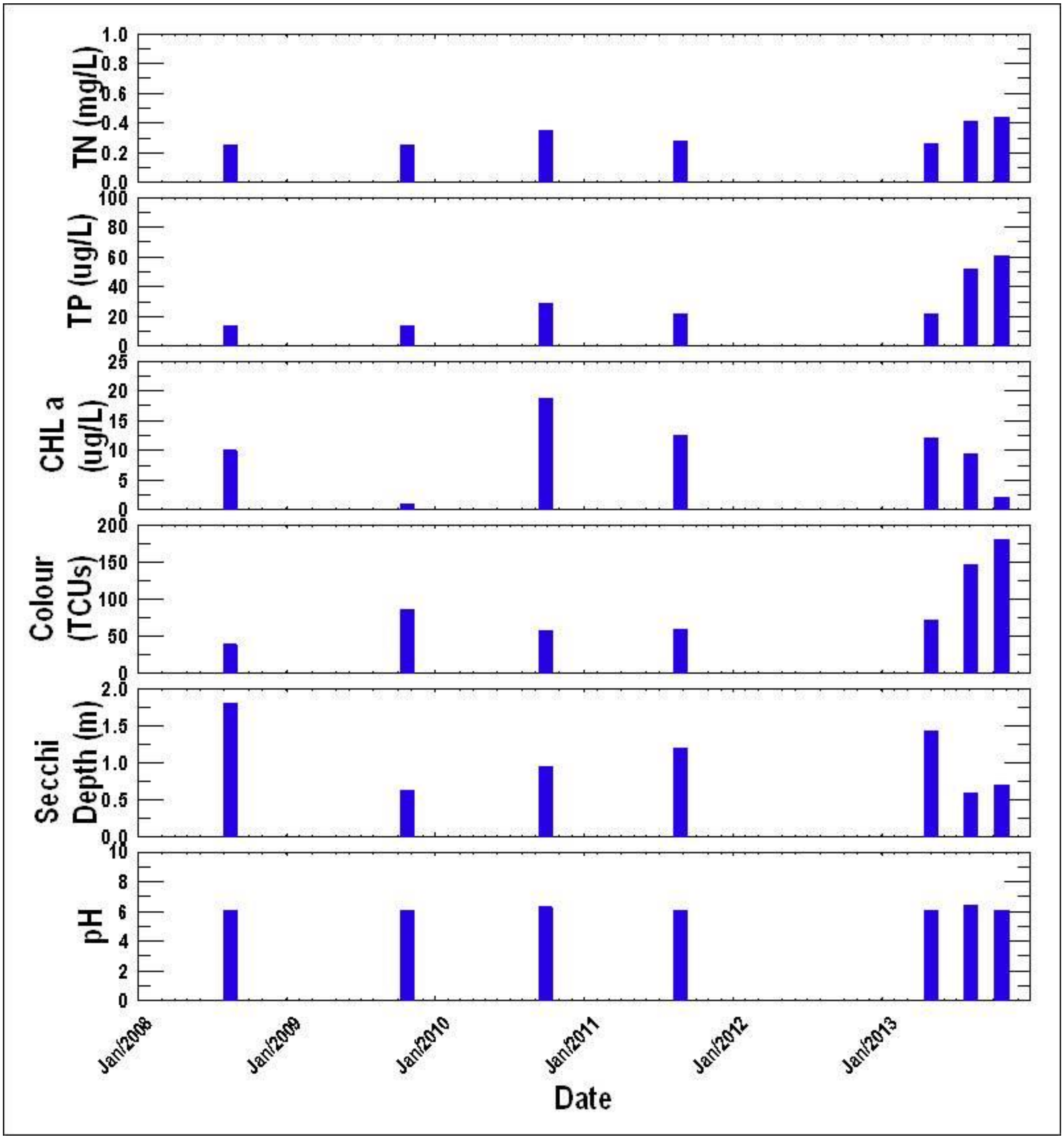
Porcupine Lake



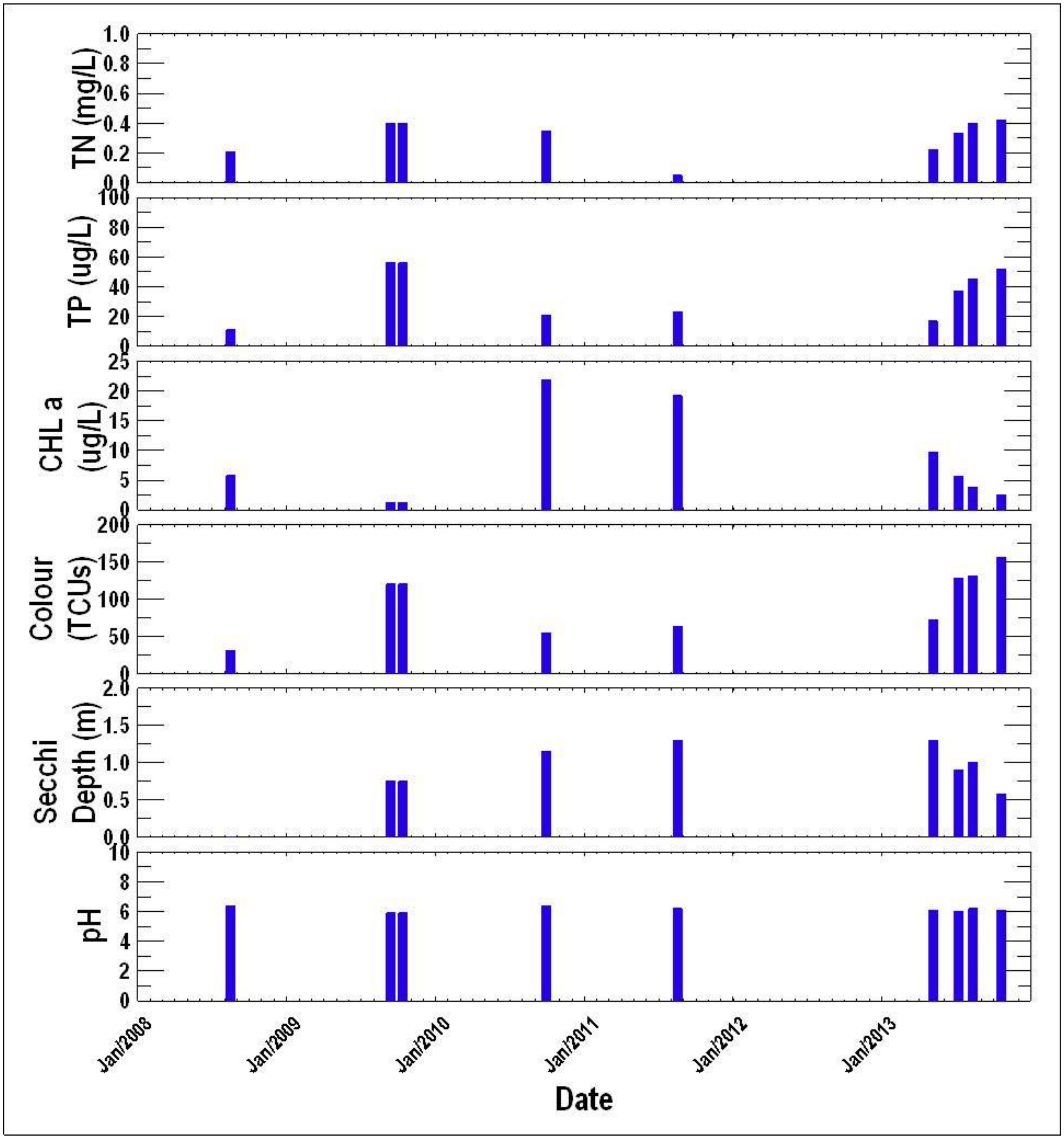
Wentworth Lake


TN (mg/L)
TP (ug/L)
CHL a (ug/L)
Colour (TCUs)
Secchi Depth (m)
pH
Jan/2008
Jan/2009
Jan/2010
Jan/2011
Jan/2012
Jan/2013
Date

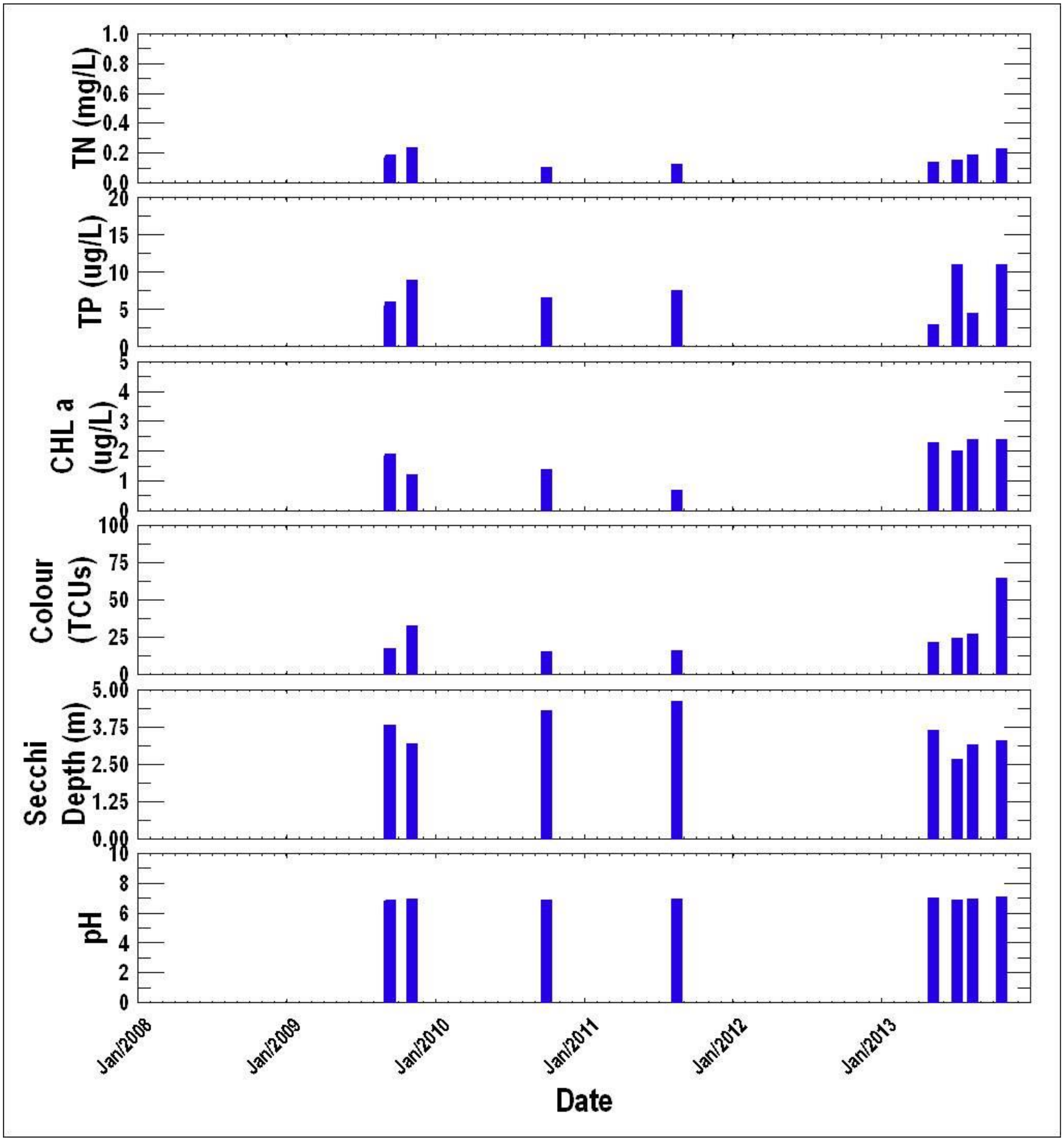
Parr Lake


TN (mg/L)
TP (ug/L)
CHL a (ug/L)
Colour (TCUs)
Secchi Depth (m)
pH
Jan/2008
Jan/2009
Jan/2010
Jan/2011
Jan/2012
Jan/2013
Date

Ogden Lake

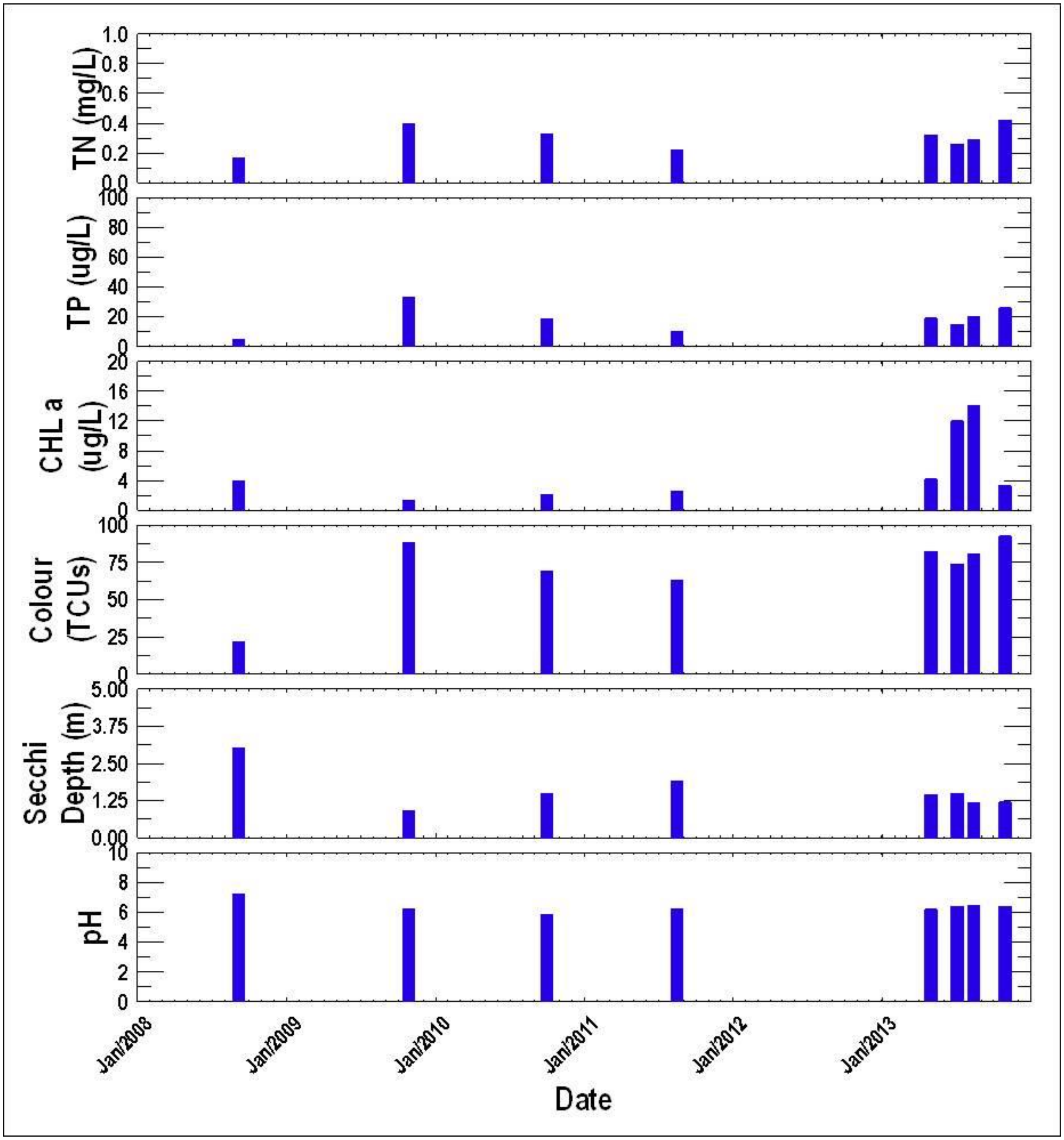


Fanning Lake



TN (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
TP (ug/L)
20
15
10
5
0
CHL a (ug/L)
5
4
3
2
1
0
Colour (TCUs)
100
75
50
25
0
Secchi Depth (m)
5.00
3.75
2.50
1.25
0.00
pH
10
8
6
4
2
0
Jan/2008
Jan/2009
Jan/2010
Jan/2011
Jan/2012
Jan/2013
Date

Sloans Lake



Lake Vaughan