A SUMMARY AND CRITICAL REVIEW OF THE WATER QUALITY OF FOURTEEN ISLAND LAKE, ONTARIO 1975 to 2008

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MARCH 2009

Executive Summary

The following report examines the historical record with respect to water quality monitoring and documentation for Fourteen Island Lake, Mink (Sigsworth) Lake, Little John Lake and Little John's Sister Lake located in Portland District in the Township of South Frontenac, Province of Ontario.

Fourteen Island Lake has received periodic attention over the past 33 years (1975 to 2008) with respect to documentation of water quality. The Ministry of Natural Resources (MNR), Ministry of the Environment (MOE) and the Fourteen Island Mink Lake Association (FIMLA) have each played a role in monitoring water quality. The FIMLA provided volunteer sampling under the MOE Self-Help Program in 1993 and in recent years under the MOE Lake Partner Program. There is only one date for which data could be located for Mink (Sigsworth) Lake and only one year of data available for each of Little John Lake and Little John's Sister Lake.

There are considerable gaps in the dataset as a result of discontinuous monitoring efforts. As a consequence the dataset does not allow for a meaningful trend through time analysis for most parameters. While the data does not allow for a rigorous statistical analysis, an impartial analysis shows that there has been little change, if any, in water quality over the 33-year period of record. There is analytical data and discussion included on greater than 20 different parameters.

The trophic state indicator parameters and the oxygen-temperature profile data have received the most sample effort. The analysis indicates the possibility of a slight improvement in water clarity, a slight decline in both chlorophyll and total phosphorus concentrations. Based solely on the trophic state indicators, Fourteen Island Lake would be classified as mesotrophic based on phosphorous concentrations and deep-water oxygen conditions. Water clarity values would classify Fourteen Island Lake as oligotrophic.

Poor deep-water oxygen conditions are endemic to Fourteen Island Lake, Mink Lake and Little John Lake. This is largely the result of lake morphometry and local topographic conditions. The oxygen-temperature dataset is deficient and requires at least one year sample effort from spring overturn until late fall on each of the above lakes.

The Fourteen Island Mink Lake Association should continue to sample under the MOE Lake Partner Program for as long as possible. In addition, water clarity recordings are the most cost effective method to begin building a long-term water quality database for these lakes.

Acknowledgments

The following persons are acknowledged as having contributed to the collection of the data from the files and archives of the various offices.

Julie Munro - Surface Water Specialist, QRCA

Victor Castro - Surface Water Evaluator, MOE Eastern Region, Kingston

Shenaz Sunderani - Technician, Environmental Standards Division MOE, 135 St. Clair Ave. Toronto

Bev Clarke - Coordinator Lake Partner Program, MOE Dorset

Cam McCauley - Fish and Wildlife Biologist, MNR, Kingston

Brett Dark - Vice-President - Fourteen Island Mink Lake Association

Gord Rodgers - President – Fourteen Island Mink Lake Association

The above persons have contributed by way of providing access to the data and assisting with locating archived material.

As the reader will find, the staff of these agencies, particularly the water quality technicians and field biologists, have worked over the years to document water quality in an effort to understand the effects of human impacts on this aquatic ecosystem. Also volunteers from the Fourteen Island Mink Lake Association have added to the database by collecting water samples under the Ministry of the Environment Self-Help Program and the Lake Partner Program.

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1.0 INTRODUCTION

The following report examines the water quality record of Fourteen Island Lake, Mink (Sigsworth) Lake, Little John Lake and Little John's Sister Lake with the intent to provide a compendium of data and information for the present and future use of the Fourteen Island Mink Lake Association. The aim is make available under one cover as much of the water quality record as can be attained in order to inform the reader regarding the efforts of government agencies and volunteers for the Fourteen Island Mink Lake Association to document water quality conditions over the period of record.

The parameters used to qualify and quantify water quality are discussed in the context of the Ontario Provincial Water Quality Objectives, where objectives are available. A further goal is to examine those parameters that are affected by human activity within the watershed for possible trends in water quality over the period of record if the dataset permits.

What follows is an examination of the majority of water quality parameters for which there was enough data to develop either descriptive statistics and or a trend through time analysis. A few parameters may be found on the accompanying CD that are not discussed herein. These parameters either do not have much relevance to characterizing the water quality of the lakes or have insufficient data available.

Appendix 1 contains the edited raw data in tabular form. Most of this data was acquired in electronic form from the Ministry of Environment. The un-edited raw data can be viewed on the CD that accompanies the report. The report, tables and graphs and appendices are also included on the CD.

The tables in Appendix 1 are arranged in order by station description file (SDF) code. The Ministry of the Environment assigns station description file numbers for sampling locations. The 17-0035 section of the SDF number refers to the Napanee River watershed; the 700 series numbers refer to samples collected under a formal survey such as the Recreational Lakes Program or the Acid Precipitation in Ontario Study. The 01 trailer on the code refers to a lake sample; a 02 would refer to a stream sample.

17-0035-706-01 FOURTEEN ISLAND LAKE
17-0035-720-01 LITTLE JOHN LAKE
17-0035-721-01 LITTLE JOHN'S SISTER
No SDF number MINK (SIGSWORTH) LAKE

<u>Within each one of the station description file numbers, the parameters for that station are listed alphabetically</u> and descriptive statistics are calculated and tabulated where applicable. The number of samples, maximum, minimum, mean and standard deviation are provided. The extraneous data, for example weather data and remarks codes etc. from the raw data set are have been removed and are not summarized.

It should be noted that there are keystroke errors in the raw data set. Where keystroke errors were obvious, corrections were made however in less obvious circumstances the data was considered anomalous and could not be used in this evaluation.

Over the period of record the reporting of results often resulted in changes in units between years and sometimes within years. In the raw data some results were initially recorded in milligrams per litre (mg/L) and then later in micrograms per litre (ug/L). Where this occurred the units have all been standardized in this summary to a common unit.

Values that were clearly anomalous in the raw data set were identified and removed in order for the balance of the data set to be of value. In some situations the entire data set for a particular parameter was considered anomalous; the values are summarized and identified as anomalous but were not used for discussion purposes. The material in Appendix 3 consists largely of photocopied pertinent material from various published reports and unpublished summaries from MOE and MNR.

The parameters of primary interest with respect to human impacts on water quality are the lake trophic status parameters. These include water clarity (Secchi disc depths), chlorophyll a, total phosphorus (TP), total nitrogen (TN), TN:TP ratios and oxygen concentrations in the hypolimnion. As such, these parameters received the greatest amount of sample effort over the period of record.

2.0 PARAMETER DISCUSSION AND SUMMARY

The parameters are listed below in alphabetical order. Each parameter has an introductory discussion with respect to the relevance to lake water quality and the PWQOs, if applicable. The discussion of the findings particularly pertinent to each lake is provided in BOLD FONT. Graphs are intended to be standalone. The reader may wish to bypass the discussion altogether and simply read the graphs. Each graph contains a dialogue box with an abbreviated version of the discussion. The yearly mean values, the trend line, the regression formula and correlation coefficient and the descriptive statistics are all presented on the graphs where the dataset permits. Individual data for each parameter can be found summarized in the tables in Appendix 1, Appendix 2 and also in photocopies of water quality summaries located in Appendix 3.

2.1 ALKALINITY

Alkalinity is one of many chemical parameters that are determined to characterize water quality. The alkalinity value helps to distinguish hard water lakes from soft water lakes. The Provincial Water Quality Objective (PWQO) for alkalinity indicates that the alkalinity should not be decreased by more than 25% of the natural ambient concentrations. This type of an occurrence would only occur in the presence of some form of point source industrial discharge.

Alkalinity, pH and conductivity are commonly recorded together. The alkalinity of water is a measure of the capacity of the carbonate-bicarbonate system to buffer the water against a change in pH. Lakes with high alkalinity have a greater potential to neutralize runoff and precipitation that is high in acids.

The Acid Precipitation in Ontario Study (APIOS) classified lakes that had an alkalinity value of less than 10 mg/L as being susceptible to acidification and those of greater than 25 mg/L as not being sensitive to acidification. Lakes with high alkalinity values are referred to as hard water lakes and are able to buffer or neutralize the effects of acid precipitation. In hard water lakes, lakes located in limestone formations or with calcareous glacial deposits, the alkalinity values for temperate area lakes range from 30 to 150 mg/L. Soft water lakes on Precambrian Shield bedrock areas typically have alkalinity values in the range of 5 to 10 mg/L. In lakes highly productive in algae, the alkalinity values will rise in the epilimnion as a result of photosynthetic activity.

The average alkalinity value in Fourteen Island Lake is 71.5 mg/L for the period of record (1975, 1983, 1985, 1987). The average alkalinity values for Little John and Little John's Sister are 97.7 mg/L and 78.64 mg/L (1985) respectively. Lakes with alkalinity values above 25 mg/L are not sensitive to the effects of acid precipitation. Despite the fact that Fourteen Island Lake is located on Precambrian Shield bedrock it has a high alkaline content in the sandstone and glacial deposits within the watershed. This high alkalinity value is typical of a hard water lake and as a result one would expect to find elevated pH and conductivity values.

Lakes with high alkalinity values while protected against acidification are prone to colonization by zebra mussels due to the availability of calcium carbonate.

2.2 ALUMINUM (Al)

The PWQO for total aluminum is 0.075 mg/L for waters with a range in pH of 6.5 to 9.0. Natural or ambient sources of aluminum occur as a result of weathering of minerals from bedrock. Aluminum is mobilized from poorly buffered soils and bedrock when subjected to acid precipitation. The high alkalinity, hardness, and pH of the water in Fourteen Island Lake indicate that mobilization of aluminum as a result of acid precipitation is not likely to be a significant factor.

Only one aluminum value was found in the dataset. Fourteen Island Lake was determined to have an aluminum value of 0.0250 mg/L (1987). This is considerably below the PWQO.

2.3 CALCIUM (Ca)

Calcium (Ca) is one of the four cations along with magnesium (Mg), sodium (Na) and potassium (K) that act in concert to determine water hardness. Waters with high alkalinity and high hardness typically have high cation concentrations. The four cations typically occur in concentrations with Ca>Mg>Na>K. There is no PWQO for calcium.

Sampling for calcium on Fourteen Island Lake was undertaken during the years 1975, 1983, 1985 and 1987. The mean value over the period is 24.1 mg/L. The mean values (1985) for Little John's and Little John's Sister are 27.6 mg/L and 23.1 mg/L respectively.

By comparison, Ashby Lake (Denbigh, Ontario) an acid sensitive lake with an alkalinity of 12 mg/L has a mean calcium concentration of 5.8 mg/L.

2.4 CHLORIDE (Cl)

Chloride is a natural salt found in most surface waters. Sources include atmospheric deposition from rainfall at concentrations of 0.3 to 1.5 mg/L in central North America (Hutchinson, 1975). Coastal maritime deposition rates are much higher due to atmospheric sources. Some limestone bedrock types may also contribute chloride through weathering and inflow of chloride contaminated ground water. Wetzel (1983) indicates that the average chloride content for uncontaminated lake waters is 8.3 mg/L.

Chloride concentrations are not typically influenced by human activities with the exception of industrial or agricultural sources. There is no PWQO for chloride.

Fourteen Island Lake has chloride results for 1975, 1983, 1985 and one value in 1987. The mean value (both surface and bottom samples) for the period of record is 7.12 mg/L. Little John Lake and Little John's Sister Lake were sampled for chloride in 1985. The mean values are 9.88 mg/L and 7.14 mg/L respectively. Other local lakes have similar chloride concentrations; Charleston Lake has a whole lake mean value of 7.06 mg/L while the whole lake mean value for Bobs Lake is 7.8 mg/L.

2.5 CHLOROPHYLL a, b, and c

Algae or phytoplankton densities are used as an indicator of lake trophic status. Since algae are microscopic plants that contain chlorophyll, a surrogate measurement of the algae density is a measure of the chlorophyll concentration. Chlorophyll is the green pigment in living plants. There are three chlorophyll pigments, chlorophyll a, b, and c. Chlorophyll c is sometimes referred to as acidified chlorophyll or corrected chlorophyll a. There is a strong relationship between water clarity, phosphorus concentration and chlorophyll a concentrations. As phosphorus concentrations increase, chlorophyll a concentrations increase and water clarity decreases. If phosphorus concentrations continue to increase, periodic blooms of blue-green algae will occur which can cause toxicity, taste and odour problems. An average phosphorus concentration in excess of 20 ug/L will lead to high chlorophyll a concentrations and potentially nuisance concentrations of algae.

Algal densities and algae community types are also indicators of aquatic ecosystem health. Algae growth is natural in lakes but becomes problematic when lakes become enriched with plant nutrients or fertilizers. In situations where nutrient concentrations become excessive, the algae community composition shifts from the green algae, indicators of a healthy ecosystem, to the blue-green algae, indicators of an enriched eutrophic or contaminated system.

Chlorophyll a is a parameter commonly analyzed for when determining lake trophic status. Increased algae concentrations result in increased chlorophyll concentrations. As algae concentrations increase water clarity decreases. Lakes may be categorized according to chlorophyll a concentrations as follows:

Chlorophyll a (ug / L)	(< 3)	(3 – 6)	(> 6 – 10)	(>10)
Trophic Status	Oligotrophic	Mesotrophic	Eutrophic	
Classification	Excellent	Good	Fair	Poor

There is no PWQO for chlorophyll. Chlorophyll a samples and Secchi disc values are commonly collected at the same time. The greater the chlorophyll a concentration the more algae there is and therefore the less clear the water. The focus of the MOE Self-Help Program was sampling for these two parameters. All lake surveys have commonly sampled for these parameters. Chlorophyll pigments b and c have not been used to characterize lake trophic status. The analytical results for these pigments are provided in raw dataset on the CD but otherwise are not discussed herein.

Lake productivity as determined by chlorophyll a and the importance of the relationship between chlorophyll a, nutrient concentrations and water clarity, coupled with the long period of record for this parameter allow for an examination of the trend trough time.

The mean chlorophyll a concentration for Fourteen Island Lake for the period of record is 2.136 ug/L (n=61). The period of record for chlorophyll a sampling is from 1975 to 1993. There is enough data for Fourteen Island Lake to examine the trend through time (see Figure 1 following this page). The data for this graph is derived mostly from the MOE Recreational Lakes Program and the MOE Self-Help Program (1993). Chlorophyll a values for the years 2002, 2003, 2006 and 2007 are derived from total phosphorus values collected under the MOE Lake Partner Program (LPP). The algorithm is presented in the LPP Technical Notes (see Appendix 1 Tables for Chlorophyll a).

There is much variability in the data. The trend line appears to indicate a decline in chlorophyll a concentrations however the regression analysis indicates a very weak relationship (R^2= 0.04) and therefore there is no trend in the dataset. The mean of

means value for chlorophyll a for the period of record is 2.30 ug/L. Fourteen Island Lake would therefore be classified as oligotrophic on the basis of this parameter.

Little John Lake has a mean chlorophyll a value of 1.90 ug/L (n=15, 1985); on the basis of this one year of data and this one parameter the lake would be classified as oligotrophic. Little John's Sister has a reported mean chlorophyll a value of 3.98 ug/L (n=16, 1985); this lake would be classified as mesotrophic on the basis of this one parameter. There are not enough years of data to develop a trend through time analysis for either of these two lakes.

2.6 CLARITY (SECCHI DISC DEPTH) – WATER CLARITY

Water clarity is the parameter of which people are most familiar. The clarity is affected by suspended particles that include clay, and colloidal sized particles from shoreline erosion, agricultural runoff, tree pollen and also algae concentrations. Clarity is also affected by concentrations of tannins and lignin that may impart a dark colour to the water. Water clarity is measured using a Secchi disc, a 20 centimetre disc painted black and white in opposite quadrants. It is lowered into the water on a calibrated line to determine the depth of light penetration through the water.

The Secchi disc measures the depth to which light penetrates and therefore is a good indicator of how far down in the water column algae (phytoplankton) may grow and photosynthesize. It is also a good indicator of the depth to which aquatic vascular plants (aquatic weeds) may grow as long as suitable substrate exists at that depth for the establishment of a root mass. Because lake productivity (algae growth) varies with water temperature, photoperiod (daylight length) and changes in available nutrient supply over the growing season, water clarity needs to be documented many times over the ice-free season to get a meaningful Secchi disc depth value.

Water clarity measurements were recorded as part of the MOE Self-Help Program and the Recreational Lakes Program. It is also a parameter that is included in the MOE Lake Partner Program. As such, an extensive database exists for this parameter from which a comparison can be made between present and historical values or with other lakes.

The PWQO for water clarity states that 'water in swimming areas should be sufficiently clear to estimate depth or to see submerged swimmers who may require assistance. Water clarity should be such that, if the bottom is not visible, the water should have a Secchi disc transparency of at least 1.2 metres'. Lakes may be categorized according to clarity as follows:

Secchi Disc Depth (m)	(> 5.0)	(3 – 5)	(1.2 - < 3.0)	(< 1.2)
Trophic Status	Oligotrophic	Mesotrophic	Eutrophic	
Classification	Excellent	Good	Fair	Poor

There are large ranges in water clarity for natural waters that are unrelated to human influence. For this reason water clarity is a parameter that is not used alone to guide decisions regarding water quality management. Water clarity values are interpreted along with other parameters such as nutrient concentrations (phosphorus and nitrogen), algae densities as determined through chlorophyll a analysis and oxygen concentrations when making management decisions with respect to protection of water quality.

The period of record for water clarity on Fourteen Island Lake is 1975 to 2008. Very good ice-free season Secchi depth recordings were made during the years 1975, 1983, 1985 and 1993. Unfortunately, there are considerable gaps in the period of record and in the more recent years, 2001 to 2008, there were very few recordings completed each year. As such, the dataset does not lend itself to a rigorous trend through time analysis (see Figure 2 following this page).

The trend line indicates an improvement in water clarity however more years of a comprehensive sample effort are required before a definitive statement can be made with respect to increasing water clarity. The regression analysis indicates the strength of the relationship over time is generally weak (R^2 = 0.55). The presence of zebra mussels in Fourteen Island Lake is also having an influence on water clarity due to the ability of this invasive species to filter particulates out of the water column.

For the years with a complete Secchi disc depth dataset Fourteen Island Lake begins the season (May) with the same average water clarity (see Figure 3 following page). The lake has just completed spring overturn and the accumulated nutrients in the bottom become mixed with the water column and results in increased productivity in the form of a diatom and algae bloom. This results in similar average water clarity values each year. As the season progresses, diatom concentrations decline and water clarity generally increases during the late summer as a result. Water clarity generally declines again at the time of the fall mixing period as the accumulated nutrients in the bottom waters are returned to the surface and promote increased algal growth again.

Fourteen Island Lake would be classified as oligotrophic on the basis of a mean Secchi disc depth of 5.782 metres for the period of record. Only two years (1985 & 1993) out of the ten-year period of record failed to meet the criteria of 5.0 metres of water clarity for the oligotrophic category.

No Secchi disc depth recordings could be located for either Little John Lake or Little John's Sister Lake.

2.7 COLOUR

The colour of water is determined as a further method to characterize water type. The main determinant of colour is dissolved organic matter. Extremely hard waters with marl sediments are aqua blue in colour while soft waters with bogs in the headwaters may be dystrophic and range in colour from dark brown to tea coloured. Different analytical methods produce results as either true colour (after filtration) or apparent colour (before filtration). Colour is imparted to the water as a result of reflection of light from dissolved substances and seston. Seston refers to all particulate material found in the water column.

There is no PWQO for colour.

For Fourteen Island Lake sampling for colour was undertaken in 1975, 1983 and 1985. Unfortunately the depth recordings are not available in the electronic dataset. The mean value of 16.2 Hazen colour units is a mean of all the recordings for this parameter, both surface and bottom values included. If the sample results could be separated the expected surface colour would be expected to be < 10 Hazen Units for Fourteen Island Lake. As might be expected the water colour darkens for Little John and Little John's Sister due to acidic bogs and wetland drainage headwater to these lakes. These wetlands leach humic acids high in organic material, tannins and lignins that impart a tea colour to the drainage waters.

For Little John Lake and Little John's Sister Lake the mean surface water Hazen colour units are 25.3 HCU and 31.0 HCU respectively. Because Little John's Sister Lake is too shallow to stratify the colour is uniform throughout the water column. Little John Lake stratifies and therefore accumulates organic material in the bottom waters. The bottom waters of Little John Lake have a mean Hazen colour unit value of 140.3 HCU. Refer to further discussion under the heading iron below.

2.8 CONDUCTIVITY OR SPECIFIC CONDUCTANCE

Specific conductance or conductivity is a numerical expression of the ability of water to conduct an electric current. It is reported in either microsiemens per centimeter (uS/cm) or micromhos per centimeter (umhos/cm)[the reciprocal of ohms]. It is a measure of both dissolved ions especially dissolved minerals and particulate concentrations in the water. As more dissolved solids are added to the water the conductivity increases. Specific conductance in natural surface waters range between 50 and 1000 uS/cm. Conductivity levels are higher in contaminated waters. Conductivity in the laboratory is always measured at 25 oC; ambient conductivity is recorded on site at ambient temperatures.

An empirical relationship exists between conductivity and total dissolved solids; specific conductance multiplied by 0.65 closely approximates total dissolved solids (TDS).

The conductivity value can also be used as a quick estimate of the concentrations of a number of anions and cations. For example Hutchinson (1975) indicates that for a lake with a conductivity of 220 umhos/cm, the following could be expected: salinity 129.7 mg/L, sodium 8.7 mg/L, potassium 3.2 mg/L, magnesium, 5.2 mg/L, calcium 31.1 mg/L, carbonate 54.4 mg/L, sulphate 18.4 mg/L and chloride 8.7 mg/L. From the preceding discussion it was already shown that for Fourteen Island Lake the mean calcium concentration is 24.1 mg/L and the mean chloride value was 7.12 mg/L. One should infer from this that the conductivity level for Fourteen Island Lake should be less than 220 umhos/cm.

There is no PWQO for specific conductance (conductivity).

Conductivity values are available for 1975, 1983 and 1985. The mean of mean value for Fourteen Island Lake as a whole is 186.6 umhos/cm (conductivity @25oC). During periods when the lake is stratified, surface conductivity values are moderately lower than bottom samples due to the accumulation of dissolved and particulate materials at the bottom.

Little John and Little John's Sister have mean conductivity values of 222.1 and 177.9 umhos/cm respectively.

2.9 HARDNESS

The hardness of water is a surrogate measurement of the concentration of calcium and magnesium salts, largely combined with bicarbonate and carbonate as well as sulphates, chlorides and other anions of mineral acids. The carbonate hardness can be removed by boiling. This causes precipitation of $CaCO_3$, essentially the hard water scale that deposits on a kettle. The fraction of calcium and magnesium that remains in solution as sulphates, chlorides and nitrates after boiling constitutes the residual non-carbonate hardness.

Hardness is expressed in mg/L of $CaCO_3$ equivalents.

There is no PWQO for hardness.

Hard water lakes, lakes located in limestone formations or with calcareous glacial deposits have hardness values on the order of 100 mg/L for temperate area lakes. Soft water lakes on Precambrian Shield bedrock areas typically have hardness values below 50 mg/L.

As a comparison, Ashby Lake (Denbeigh, Ontario) an acid sensitive soft water lake with an alkalinity of 12 mg/L has a mean calcium concentration of 5.8 mg/L and a hardness value of 25 mg/L. Loughborough Lake (South Frontenac Township) is a hard water lake that lies completely in a limestone basin. It has an alkalinity of 114 mg/L and a hardness value of 127 mg/L.

The mean hardness values for these lakes are as follows: Fourteen Island Lake- 81.5 mg/L, Little John Lake – 96.4 mg/L and Little John's Sister Lake – 82.4 mg/L.

2.10 IRON (Fe)

The PWQO for total iron in an unfiltered water sample should not exceed 300 ug/L in order to protect aquatic life. Iron is present in most rocks and soils as well as in ore deposits. Weathering and mineralization processes act to mobilize iron. Other sources include the atmospheric deposition from the burning of fossil fuels and the corrosion of iron fabricated products. Iron concentrations are usually higher in the bottom waters where there is opportunity for re-suspension from the sediments.

Iron has a complex chemistry in water and the form of iron is dependant upon the amount of oxygen, carbon dioxide and the pH. Iron easily complexes with many other chemicals. Iron is not known to accumulate in fish flesh and is relatively easily metabolized. The toxic or detrimental effects stem from the ability of some iron complexes to adsorb to gill surfaces, egg masses etc.

The PWQO of 0.300 mg/L (300 ug/L) is more stringent than the USEPA value of 1.000 mg/L (1,000 ug/L).

Fourteen Island Lake has analytical results for iron during the years 1975, 1983 and 1985. The whole lake average value is 0.085 mg/L (85 ug/L). There is little difference between surface and bottom result values for Fourteen Island Lake and there are no recorded values > than 300 ug/L.

For Little John Lake the mean surface sample result is 117 ug/L while the mean bottom sample result is 3,617 ug/L. All of the bottom sample results exceed the 300 ug/L PWQO. The elevated iron levels in the bottom waters may be a reflection of the anoxic (poor oxygen) conditions that exist in Little John Lake. Wetzel (1983) reports that where decomposition of organic materials occur in productive, thermally stratified lakes with small deep basins, especially those that receive flow of bog waters high in humic organic matter, hypolimnetic accumulations of iron can be excessive with levels exceeding 250 mg/L (250,000 ug/L). Little John Lake has all of these characteristics including the expected poor oxygen conditions in the hypolimnion (see the discussion under oxygen). Little John Lake also receives flow from the humic bog waters headwater to Little John's Sister Lake.

Iron levels in Little John's Sister Lake are also high with a mean value of 230 ug/L. This lake is too shallow to stratify and therefore does not experience the contributing factor of anoxia as does Little John Lake however Little John's Sister receives flow from acidic bogs in the watershed. These humic acids are a significant source of iron.

2.11 MAGNESIUM (Mg)

There is no PWQO for magnesium. Magnesium (Mg) is one of the cations along with calcium (Ca), sodium (Na) and potassium (K) that are quantified to characterize water.

Typically these cations have concentrations with Ca>Mg>Na>K. Hutchinson (1975) reports that for lakes with conductivity values of 180 uohms/cm that Mg and Ca values should be 4.2 and 25.0 mg/L respectively.

Fourteen Island Lake has a mean conductivity value of 186.6 uohms/cm, a mean Mg value of 4.963 mg/L and a mean Ca value of 24.1 mg/L. The values for Little John Lake are very similar, a mean Mg value of 6.79 and a mean Ca value of 27.6 mg/L.

Little John's Sister Lake has a mean conductivity value of 177.9 uohms/cm, a mean Mg value of 5.99 mg/L and a mean Ca value of 23.1 mg/L. There is nothing unusual about any of these findings.

2.12 NITROGEN - Total Nitrogen = (Ammonia + Ammonium, Nitrate and Nitrite and Total Kjeldahl Nitrogen)

The chemistry of nitrogen in natural ecosystems is very complex. The five major forms of nitrogen in fresh water are organic nitrogen (TKN), ammonia (NH_3), ammonium (NH_4), nitrate (NO_3), and nitrite (NO_2). Only the last three, NH4, NO3 and NO2 are readily available to aquatic plants. In most monitoring programs these three nitrogen compounds, plus total Kjeldahl nitrogen (TKN), which is a measurement of organic nitrogen, are usually determined.

2.12.1 AMMONIUM (NH4)

Ammonium (NH_4) is considered non-toxic. The conversion of ammonium to ammonia occurs more readily in the presence of low pH (acidic conditions) and also with increasing temperature. There is no PWQO for ammonium (NH_4).

2.12.2 AMMONIA (NH_3)

Ammonia (NH_3) and ammonium (NH_4) are transitional forms of nitrogen. In the presence of oxygen in the water these forms become nitrite (NO_2) and nitrate (NO_3); it is also incorporated into living organic matter where it is quantified as total Kjeldahl nitrogen (TKN). The toxicity of ammonia is very complex and is also affected by both pH and temperature.

The PWQO for concentrations of un-ionized ammonia (NH_3) should not exceed 0.02 mg/L (20 ug/L) for the protection of aquatic life. Ammonia nitrogen (NH_3) is present in most healthy systems at a low concentration, usually less than 1.0 ug/L. It is a by-product of decomposition. In eutrophic systems and lake bottoms where oxygen concentrations are depleted, ammonia concentrations can increase and become lethal to benthic organisms and some fish.

Ammonia enters natural water systems from many sources including precipitation, agricultural runoff, municipal and industrial discharges. Indirect sources are the biochemical transformation of nitrogenous organic material during the decomposition process and also from the excretion of ammonia by biota.

2.12.3 NITRATE, NITRITE and TKN

Nitrate nitrogen (NO_3) is available for uptake by plants and values are important in defining lake trophic status. Typical concentrations are less than 0.05 mg/L (50 ug/L) for healthy lakes. In eutrophic water bodies the concentration of nitrate (NO_3) is usually low in the surface waters due to demand and uptake by algae. Total Kjeldahl nitrogen (TKN), the organic nitrogen values become high in eutrophic waters because the nitrogen is tied up in the algae. In the deep portion of eutrophic lakes where there is little or no oxygen the NO_3 becomes replaced by NH_3. Ammonium nitrogen (NH_4) is a transient form between ammonia nitrogen (NH_3) and NH_4 under anoxic conditions. Nitrite nitrogen (NO_2) in healthy systems is typically at very low concentrations of less than 0.005 mg/L (5 ug/L); it occurs as a transient form of nitrogen between NH_3 and NO_3 under conditions where oxygen is present.

Total nitrogen (TN) is simply the sum of the concentrations of all the forms. Total nitrogen (TN) to total phosphorous (TP) ratios are important. TN: TP ratios are generally greater than 20:1 in oligotrophic, very healthy lakes. A ratio of 16:1 is found in algae communities typical of mesotrophic lakes. In eutrophic systems TN: TP ratios are about $\leq$12:1 and favour the production of blue green algae.

There are no PWQOs set for TKN, nitrate or nitrite, nor is there an objective set for total nitrogen. The only form of nitrogen considered to be toxic is ammonia (see discussion under ammonia and ammonium).

A comprehensive nitrogen dataset for Fourteen Island Lake is available for the years 1975, 1983, and 1985; only one sample for nitrogen is available for 1987. Because both Fourteen Island Lake and Little John Lake stratify and both experience some late season anoxia, the nitrogen values are discussed below for both surface and bottom samples. Little John's Sister Lake is too shallow to stratify so there is no differentiation between surface and bottom results.

The Kjeldahl nitrogen (TKN) results for the surface for all three lakes show that the majority of the nitrogen occurs as TKN; this is the nitrogen that is tied up in pelagic biomass or algal cells. It is clear that Little John's Sister is the most productive (eutrophic) with a mean TKN value of 0.6973 mg/L and Fourteen Island Lake is the least productive with a mean surface TKN value of 0.4008 mg/L.

TABLE 1 NITROGEN SUMMARY

NITROGEN SUMMARY - SURFACE SAMPLES (1.0 m below surface)

	Mean TKN mg/L	Mean NH4 mg/L	Mean NO2 mg/L	Mean NO3 mg/L	Total Nitrogen mg/L
Fourteen Island Lake *	0.4008	0.0366	0.0023	0.0364	0.4761
Little John Lake**	0.6120	0.0260	0.0028	0.0200	0.6608
Little John's Sister Lake** ^	0.6973	0.0645	0.0031	0.0200	0.7849

***1975, 1983, 1985**

**** 1985**

^ Too shallow to become stratified

NITROGEN SUMMARY - BOTTOM SAMPLES (1.0 m above bottom)

	Mean TKN mg/L	Mean NH4 mg/L	Mean NO2 mg/L	Mean NO3 mg/L	Total Nitrogen mg/L
Fourteen Island Lake*	0.618	0.2314	0.0085	0.1713	1.0292
Little John Lake**	3.2833	2.6900	0.0093	0.0633	6.0459
Little John's Sister Lake** ^	0.6973	0.0645	0.0031	0.0200	0.7849

***1975, 1983, 1985**

**** 1985**

^ Too shallow to become stratified

It is noteworthy that the TKN values greatly increase in the bottom waters of the two lakes that stratify and experience oxygen loss in the hypolimnion; this is particularly severe in Little John Lake. TKN values increase from 0.6120 mg/L at the surface to 3.2833 mg/L in the bottom of Little John Lake. This is an indication of the loading of organic material into the bottom and the resultant oxygen depletion. Total nitrogen values increase tenfold, from 0.6608 mg/L at the surface to 6.0459 mg/L in the hypolimnion of Little John Lake.

There is a good probability of late summer ammonia concentrations exceeding the PWQO in the bottom waters of both Fourteen Island Lake and Little John Lake due to the high NH4 values.

2.12.4 TOTAL NITROGEN (TN)

There are not enough years of data to develop any trend through time analysis for total nitrogen for any of the three lakes. The average of the surface and bottom sample results produce a whole lake total nitrogen value. The whole lake TN values are Fourteen Island Lake (0.7526 mg/L), Little John Lake (3.3534 mg/L) and Little John's Sister (0.7849 mg/L). Little John's Sister Lake has the highest surface TN value due to the loading of organic materials from the headwater bogs and also because it is too shallow to settle out the organic material into the bottom waters.

2.12.5 TOTAL NITROGEN to TOTAL PHOSPHORUS RATIO (TN:TP)

Total nitrogen (TN) is simply the sum of the concentrations of all the forms of nitrogen. Total nitrogen (TN) to total phosphorous (TP) ratios are used to characterize lake trophic status. TN:TP ratios greater than 20:1 are considered to represent oligotrophic lakes or very healthy lakes. In eutrophic systems TN:TP ratios are about 12:1 or lower and favour the production of blue green algae. The year 2000 Lake Partner Program Technical Notes deviate from this definition and uses the TN:TP ratio of 25:1 as the lower criteria for oligotrophic lakes.

TABLE 2

FOURTEEN ISLAND LAKE TN:TP RATIO

YEAR	MEAN TN (ug/L)	MEAN TP (ug/L)	TN:TP
1975, 1983, 1985	476.1	20.7	23

Using only the data for the years with measured nitrogen data and based on the calculated TN/TP ratio of 23:1 Fourteen Island Lake would be classified as oligotrophic (i.e. TN/TP ratios > 20). If one assumes that the nitrogen values have not changed since the early years of measurement and one uses all the years with phosphorous data to determine the mean value then the TN/TP ratio becomes 30.7:1 and Fourteen Island Lake would be clearly in the oligotrophic category.

LITTLE JOHN LAKE TN:TP RATIO

YEAR	MEAN TN (ug/L)	MEAN TP (ug/L)	TN:TP
1985	661	18.4	35.9

Little John Lake would be considered to be oligotrophic on the basis of the TN:TP ratio (661/18.4 =35.9:1).

2.13 ORGANIC CARBON – Dissolved Organic Carbon (DOC) Total Organic Carbon (TOC)

Total organic carbon (TOC) consists of both dissolved and particulate organic carbon. It is composed of humic substances and degraded plant (algae) and animal (zooplankton) materials. It can be considered as a surrogate measurement for algae levels, similar to chlorophyll a. TOC content in natural waters range from 1 to 30 mg/L. The higher values are indicative of eutrophication. Runoff from agricultural lands and nutrients from septic systems can increase the TOC values when algae concentrations rise. Values of 3.0 mg/L or lower are considered to represent oligotrophic conditions, an indication of a healthy lake.

Only one TOC value was located in the dataset. Fourteen Island Lake has a reported TOC value of 4.50 mg/L (November 5, 1987). An ice-free season mean value would be expected to be lower. By November of any given year the lake would undergo fall overturn and the nutrients that accumulated in the bottom during the stratified period are released to the surface and organic carbon levels increase as a result.

2.14 OXYGEN and TEMPERATURE

The importance of documenting oxygen and temperature conditions for the basins in Fourteen Island Lake, Mink Lake and Little John Lake cannot be understated. Maintaining oxygen conditions below the thermocline is critical to the management of habitat for coldwater fish species such as lake trout, rainbow trout, splake and / or other coldwater biota; maintaining good oxygen values in the hypolimnion also plays and important role in nutrient re-suspension from the sediments. Some effort has been undertaken by MNR and MOE to document surface to bottom oxygen and temperature values. Oxygen and temperature data are available for Fourteen Island Lake during the years 1975, 1983, 1985, 2007 and 2008. Little John and Little John's Sister also have oxygen and temperature profiles available for the year 1985 and Mink Lake for 2008.

These profiles are typically collected during the ice-free period from prior to the spring mixing period until fall overturn. For any given year, the most critical period during the year for deep-water oxygen concentrations is late summer or early fall. Conditions become progressively poorer towards the end of that window and may extend well beyond the end of September until the fall overturn.

Profiles recorded for dates outside of the critical period are also important in order to document the success of the spring and fall mixing periods as well as to document the rate of oxygen depletion in the hypolimnion. Lakes or lake basins with ample oxygen in the deepwater portion (hypolimnion) may not become depleted over the entire season while other lake hypolimnions or distinct lake basins may become depleted of oxygen by early August. It is therefore important not to rely on the oxygen conditions of any one lake basin to characterize conditions for the lake as a whole.

Some variability should be expected in the springtime oxygen concentrations in the hypolimnion after stratification is set up in any given year. A long cold spring period with lots of wind ensures complete mixing and infusion of oxygenated water to the lake bottom. A short spring with a few hot calm days may be enough to set up stratification early; this may occur before complete mixing and therefore the hypolimnion has the potential to begin the season with less than saturated oxygen conditions or begin the period of lake stratification at an earlier date; this sets the stage for a longer than normal lake stratification period.

Once a lake becomes stratified after the spring warming period, oxygen depletion begins in the bottom water portion and continues through to the fall mixing period. The surface waters warm and oxygen is depleted from the bottom up. For cold water species such as lake trout, habitat is reduced from above due to heating and from below due to loss of oxygen. Warm water species such as bass, walleye and pike are less affected because oxygen concentrations at the depth of or immediately above the thermocline are replenished due to mixing from above through photosynthesis by phytoplankton in the euphotic zone and through infusion from the atmosphere.

While a change in the rate of heating of the surface waters is not typically associated with shoreline development practices, the advent of global warming may play an important role in the number of days each year that a lake is stratified. With global warming the probability exists that lakes will warm earlier each spring and stay stratified for a longer period into the fall. This increases the number of days for oxygen depletion to act. This possibility alone brings added importance to the need for control of nutrient export from shoreline development and tributary sources. There is a direct relationship between nutrient concentrations at the lake bottom, the number of days of stratification and oxygen loss from the hypolimnion. An increase in nutrient supply to the lake results in an increase in plankton growth and subsequently an increase in the rate of loss of oxygen from the hypolimnion. Under anoxic conditions at the mud-water interface, nutrients previously sequestered in the sediments will be released into the water column again and may be available for algae/plant growth when the lake mixes again.

After about September 30th the surface waters begin to slowly cool; the cooling continues until fall overturn when the lake mixes and oxygen conditions are restored to the hypolimnion in early to mid November.

2.14.1 FOURTEEN ISLAND LAKE – Temperature and Oxygen

Oxygen and temperature recordings have been undertaken on 23 different occasions on Fourteen Island Lake (see Appendix 2). Eight profiles were completed in 1975 spanning the May to November ice-free period. The May 8th and 20th profiles indicate that the lake became stratified early and quickly in 1975. It is likely that incomplete mixing occurred prior to stratification (See Figure 4 following page). The bottom of the thermocline becomes firmly established at 10 metres depth by early summer; oxygen values remain good above the thermocline but quickly

decline to very low concentrations in the hypolimnion below the thermocline (See Figure 5 August 14th, 1975 profile following page). The November 4th, profile shows that the lake remains stratified and has yet to undergo fall turnover before the ice-cover becomes established. The spring mixing period is more complete in the years 1983 and 1985; May oxygen values are much improved when compared against the 1975 data (see profiles in Appendix 2).

The oxygen profiles for August 23rd, 1983, August 15th, 1985 show a modest improvement in hypolimnetic oxygen values to a depth of 20 metres however below 20 metres depth, oxygen values are again very poor (See Figures 6 and 7 following page). Both of these oxygen graphs and an August 31st, 2007 profile display oxygen loss or depletion at about the bottom of the thermocline with a small improvement in concentration below. Due to the density difference between the warm surface water and the cold bottom water, the algae and organic material that settles from the epilimnion slows up and becomes more concentrated at the bottom of the thermocline. Two factors come into play; bacterial decomposition of this material uses up oxygen and zooplankton forage here due to the abundance of food and during respiration use up oxygen as well. This oxygen sag is called a metalinmetic minima. It is relatively common in lakes that are deep and also nutrient enriched.

The Ministry of Natural Resources recorded an oxygen profile on August 31st, 2007 (See Figure 8 following page) that shows atypically good oxygen values for Fourteen Island Lake. Unfortunately, there are no early spring oxygen values for this year to confirm that perhaps the lake experienced a year with complete mixing and therefore could sustain good hypolimnetic oxygen values into the late summer. Nor are there other mid-summer year 2007 oxygen profiles with which to compare. A repeat survey conducted on September 26th, 2008 (See Appendix 2) confirmed the expected poor oxygen values below the thermocline typical of values recorded in years prior to 2007.

Oxygen concentrations for all the early season survey dates indicate that Fourteen Island Lake has difficulty undergoing complete mixing during the spring overturn period. This situation occurs because the basins are relatively small in surface area and deep and are protected by large hills. There is not a large fetch (distance from shore to shore) to allow for strong winds to act; it takes a lot of wind energy to cause the lake to mix to the bottom resulting in spring overturn and infusion of oxygen into the bottom waters. It only takes a few days in early May of stable hot weather to set up stratification and prevent the lake from complete mixing; the lake therefore begins the season in an oxygen deficit.

MNR staff completed another dissolved oxygen–temperature profile on September 26th, 2008 at a location near to the entrance of Mink Lake, a basin off of Fourteen Island Lake. This profile shows anoxic conditions for all depths below the top of the thermocline. It compares favourably with the profile from the Site 1 location for the same date and also a profile recorded on September 29, 1975 (see Appendix 2).

2.14.2 MINK (SIGSWORTH) LAKE – Temperature and Oxygen

On September 26th, 2008 the Ministry of Natural Resources staff recorded the only oxygen profile that has been completed on Mink (Sigsworth) Lake. This profile was located over a water depth of 27 metres and shows severe oxygen loss from the bottom of the thermocline to the lake bottom. (See Figure 9 following page). This lake basin has all the characteristics discussed above for Fourteen Island Lake. The basin is small, deep, protected by high hills and has a short fetch shore to shore; all are characteristics that cause incomplete spring mixing and poor late season hypolimnetic oxygen conditions as a result.

2.14.3 LITTLE JOHN LAKE – Temperature and Oxygen

Oxygen and temperature recordings have been completed on 7 different occasions on Little John Lake in 1985 (see Appendix 2). Profiles were completed spanning the May to November ice-free period. The May 23rd, 1985 profile indicates that the lake became stratified early and that incomplete mixing occurred prior to stratification (See Figure 10 following page). Poor oxygen concentrations are particularly evident below 11 metres depth.

The bottom of the thermocline becomes firmly established at 7-8 metres depth by early summer; oxygen values remain good above the thermocline but quickly decline to very low concentrations in the hypolimnion below the thermocline (See Figure 11 profile following page). The October 2nd profile shows that the lake remains stratified and oxygen values below 7.0 metres of depth are close to anoxic. An incomplete profile recorded on November 8th, with only surface and bottom recordings of oxygen and temperature indicate that Little John Lake has yet to undergo fall turnover before the ice-cover becomes established (see data and profiles in Appendix 2).

2.14.4 LITTLE JOHN'S SISTER LAKE – Temperature and Oxygen

Oxygen and temperature recordings have been completed on 7 different occasions on Little John' Sister Lake in 1985 (see Appendix 2). Profiles were completed spanning the May to November ice-free period. The May 23rd, 1985 profile indicates that the lake is mixed completely too the bottom.

Little John's Sister Lake is only 4.0 to 4.5 metres deep and therefore is not deep enough to become stratified. It therefore would be expected to have the same temperature surface to bottom and to be completely mixed surface to bottom for the entire season. Oxygen values would also be expected to be the good top to bottom. The data and profiles for July 24th and August 15th follow this page (Figure 12).

Little John's Sister actually could be considered to be stratified when the ice sheet is formed. The ice sheet prevents the lake from mixing and under conditions of deep snow depth photosynthesis is prevented under the ice. Shallow productive lakes such as this can experience anoxia under the ice resulting in late winter or early spring fish kills.

2.15 pH

The PWQO states that pH should be maintained within the range of 6.5 to 8.5 units in order to protect aquatic life. Both alkaline and acidic waters may cause irritation to anyone using the water for recreational purposes. The range in pH for body contact recreational purposes is much wider than the objective. The objective is set to protect aquatic life.

The acidity of water is measured by determining pH values. The pH scale is from zero to 14 units with 7.0 representing a neutral value. Values below 7.0 are acidic and values above 7.0 are basic. Because the pH scale is a logarithmic scale every pH unit is a factor of 10 times difference from the next closest unit. A lake with a pH of 8.0 is therefore 10 times more basic than a lake with a pH of 7.0 units. Lakes with high alkalinity can neutralize acids and therefore the pH of these lakes would be expected to be above 7.0 units.

Photosynthesis fixes or removes carbon dioxide. Carbon dioxide in water forms a weak carbonic acid. Therefore in productive lakes the surface waters have pH values that are higher than the bottom waters. Under conditions of excessive productivity the pH may raise to 8.0 or 9.0 units. When pH levels are reduced to 6.0 units or lower, acidity levels begin to become toxic to the life stages of many aquatic organisms and some species of fish.

For Fourteen Island Lake the pH values range from 6.7 units to 8.3 units with a mean value of 7.57 units. Little John's Sister has a mean pH value of 7.56 units; Little John Lake has a mean pH of 7.39 units. These values indicate that acidity levels remain well within the PWQO for the protection of aquatic life for all three lakes.

2.16 PHOSPHORUS (TOTAL PHOSPHORUS – TP)

Total phosphorous concentrations are important indicators of lake trophic status. Phosphorous is a natural plant nutrient found in lakes. It provides one of the building blocks needed for plant growth. Phosphorous is typically in limited supply, outperformed by nitrogen by a ratio of greater than 20:1. Total phosphorous is the limiting nutrient in aquatic ecosystems. It is for this reason that the Ontario Lakeshore Capacity Study (OLCS) focused on phosphorous as the key parameter. It is also the reason the Policies, Guidelines and Provincial Water Quality Objectives (PWQOs) of the Ministry of the Environment July 1994 set objectives for phosphorous on lakes.

The PW QOs have two thresholds for total phosphorous; one is set at average TP concentrations for the ice-free period of ≤10 ug/L. This level protects lakes that are at or below 10 ug/L from becoming enriched to a level above 10 ug/L; these lakes are categorized as oligotrophic. The second threshold of average TP concentrations of 20 ug/L is the upset limit for lakes. This limit is set to avoid nuisance concentrations of algae in lakes; lakes exceeding an average of 20 ug/L of phosphorous are eutrophic. Elevated phosphorous concentrations lead to increased surfactant foaming, increased aquatic vascular plant growth in some lakes and in severe situations the production of excess algae, which limits light penetration and deep-water oxygen loss.

The PWQO states 'the following phosphorous concentrations should be considered as general guidelines which should be supplemented by site specific studies: To avoid nuisance concentrations of algae in lakes, average total phosphorous concentrations for the ice-free period should not exceed 20 ug/L. A high level of protection against aesthetic deterioration will be provided by a total phosphorous concentration for the ice-free period of 10 ug / L or less. This should apply to all lakes naturally below this value'. Lakes which at present have TP values which are above but close to 10 ug / L would have to be modeled to determine if natural values would fall below the 10 ug / L objective.

In situations where there are high concentrations of phosphorous, light penetration is reduced due to increased algae and blue-green algae blooms replace aquatic vascular plants. High concentrations of algae and aquatic plants lead to excessive oxygen depletion in the deeper bottom water portions of the lake both during the summer stratification period and under the ice cover. Lake that experience severe oxygen depletion in the hypolimnion (deep water portion) also have elevated nutrient levels in the bottom.

Phosphorous concentrations in lakes are increased by changes in landuse that results in increased supply from the land, shoreline septic systems, removal of shoreline trees (buffer strips) and the addition of fertilizer to shoreline lawns and agricultural applications as well as others. Phosphorous became the focus of interest for lake surveys and was included as a parameter for analysis in the MOE Recreational Lakes Program more recently in the Lake Partner Program.

There is an established algorithm with chlorophyll. Chlorophyll a concentrations can be calculated using phosphorous values. The formula for predicting total phosphorous concentration [TP] from chlorophyll a and visa versa is taken from the Ontario Lakeshore Capacity Study (OLCS) trophic status model. The formula is:

Log CHL a = 1.45 log (TP ug/L) – 1.14

There are many other accepted algorithms for this relationship. The Lake Partner Program Technical Notes offer the following formula:

CHL a = 0.323 (TP ug/L) – 1.46 R2 = 0.78; n = 74

Using the 1.84 ug/L mean chlorophyll a _ value from the 1993 Self-Help Program volunteer effort on Fourteen Island Lake and applying each of the above algorithms the predicted total phosphorous is 9.3 ug/L and 10.2 ug/L respectively. These predicted phosphorous values fall within the year-to-year natural variability for Fourteen Island Lake and closely match the more recent LPP results since the year 2000.

2.16.1 PHOSPHORUS (TP) FOURTEEN ISLAND LAKE

Measured phosphorous data is available for surface samples for Fourteen Island Lake for seven years spanning the period 1975 to 2007. For the years 1975, 1983, and 1985 intensive sampling was undertaken from early season to late fall and included both surface samples (1.0 metre depth) and bottom samples (1.0 metre off bottom). Lakes that stratify and experience anoxia in the bottom waters have elevated bottom water TP concentrations.

Sampling for phosphorous since the year 2000 has only included spring-time samples under the Lake Partner Program (LPP). While the analytical procedures used under the LPP are much improved and more accurately represent TP values, only one sample is collected per year; as a result the dataset is not as strong for more recent years.

The surface phosphorous results indicate that phosphorous levels have declined in Fourteen Island Lake since 1975 (Figure 13 following page). This decline may be partially due to new sampling and analytical procedures.

The mean of means value is 15.5 ug/L over this time period. The trend line for the measured TP indicates a decline in TP values for the 7-year dataset. The relationship is relatively weak with an R^2 value of only 0.53. Any changes in analytical protocol are not addressed and may play a role in the trend results. The mean of mean value of 15.5 ug/L places Fourteen Island Lake in the moderately enriched or mesotrophic category based on this parameter. Even if the 1975 data is not included in the mean of means calculation the mean value of 13.1 ug/L will also characterize the lake as mesotrophic.

If only the data for the year 1975 is considered then the mean phosphorous value would exceed the PWQO of 20 ug/L for TP. All of the mean values for the years of survey since 1983 are below the PWQO of 20 ug/L for lakes with warm water fisheries. It should be clear that the PWQO applies only to surface water TP values.

For lakes such as Fourteen Island Lake, Mink Lake and Little John Lake that may undergo partial mixing in the spring and that experience very poor to anoxic oxygen conditions at the bottom, nutrient concentrations are elevated both due to accumulations as a result of decomposition of organic material settling from above

and also from the re-suspension or release of nutrients from the sediments in the presence of anoxic conditions at the mud-water interface.

The Figure 14 shows the difference between mean surface and bottom TP concentrations. There is between six to nine times as much phosphorous in the lake bottom as there is measured at the surface. The consequence of this accumulation of both phosphorous and nitrogen (see discussion under nitrogen above) leads to heavy blooms of diatoms and algae at the time of fall turnover when these nutrients are made available at the surface again.

2.16.2 PHOSPHORUS (TP) LITTLE JOHN LAKE

Little John Lake becomes stratified and also experiences poor oxygen conditions in the hypolimnion; as a consequence there is a significant difference in TP values between surface and bottom sample results. The mean surface TP value is 18.4 ug/L and the mean bottom TP value is 970 ug/L; the concentration of phosphorous in the hypolimnion of Little John Lake is greater than fifty times as much as is in the surface waters.

The surface mean TP value of 18.4 ug/L is below the PWQO of 20 ug/L. Little John Lake would be considered to be mesotrophic based on TP alone. When the TN:TP ratio is considered (661/18.4=35.9:1) then Little John Lake would be considered to be oligotrophic on the basis of this ratio.

2.16.3 PHOSPHORUS (TP) LITTLE JOHN'S SISTER LAKE

Little John's Sister Lake is too shallow to stratify and therefore surface and bottom values for temperature, oxygen and nutrients are all the same respectively. With respect to phosphorous, the mean value is 32 ug/L (surface) and 31 ug/L (bottom) (See Appendix 1). These mean values exceed the PWQO of 20 ug/L. The elevated phosphorous in Little John's Sister can be attributed to the large extent of wetlands headwater to the lake and also to the fact that phosphorous does not have the opportunity to settle out and be sequestered into the sediments.

2.17 RESIDUE (TOTAL), RESIDUE (PARTICULATE) and RESIDUE (FILTERED)

There is no PWQO for either total or particulate residue.

Total residue is a measure of the material left after a measured amount of water is evaporated. The residue remaining consists largely of only a few salts. These include the carbonates, sulphates, chlorides of calcium, magnesium and potassium, silicic acids, and small amounts of nitrogen, phosphorus, iron, manganese and organic material such as algal cells (Rutner, 1963). Rutner reports that the majority of lakes fall in the 100 to 200 mg/L range for total residue and lakes with low alkalinity (low dissolved salts) typically have total residue concentrations of less than 50 mg/L. The determination of specific conductance is used as a surrogate method to estimate the concentrations of these same salts.

Residue samples were collected for Fourteen Island Lake for the years 1975, 1983 and 1985. There is no difference between surface and bottom sample results. The mean value for 23 samples collected over the period of record is 125.5 mg/L. Residue values can be found summarized in Appendix 1. This mean value is in keeping with the range of values reported by Rutner, (1963).

As a comparison, Ashby Lake (Denbeigh, Ontario) an acid sensitive lake with an alkalinity of 12 mg/L and a mean calcium concentration of 5.8 mg/L has a mean residue value of 34 mg/L.

The mean residue value for Little John Lake (1985) is 144.0 mg/L (n=10); bottom samples are higher with a mean value of 167.2 mg/L (n=5) than the surface samples with a mean value of 120.8 mg/L (n=5). This observation is supported by and explained in the preceding discussions under nutrients and oxygen. The organic material settling from above is concentrated in the bottom waters of Little John Lake. All the values are within the range of those reported by Rutner.

The mean residue value for Little John's Sister Lake (1985) is 116.4 mg/L.

2.18 SODIUM (Na)

There is no Provincial Water Quality Objective (PWQO) set for sodium.

Sodium (Na) is one of the four cations along with calcium (Ca) magnesium (Mg), and potassium (K) that act in concert to determine water hardness and salinity. Waters with high alkalinity and high hardness typically have high cation concentrations. The four cations typically occur in concentrations with Ca>Mg>Na>K.

Wetzel (1983) reports that the mean sodium level for hard water lakes is 4.0 mg/L. Sodium is a requirement of blue green algae. The enrichment of waters with high levels of sodium combined with phosphorus promotes the blue green algae blooms associated with eutrophication. High levels of sodium and phosphorus are found in domestic effluent. Wetzel reports further that maximum growth of several species of blue green algae occurs at a concentration of sodium of 40 mg/L.

The whole lake mean sodium value for Fourteen Island Lake is 2.69 mg/L (n=24). The sodium levels range from a mean value of 3.20 to 1.90 mg/L. These values fall in the range of what might be expected for a moderately hard water lake. Little John Lake has a mean sodium concentration of 4.71 mg/L. The mean sodium concentration for Little John's Sister Lake is 3.61 mg/L (N=12).

3.0 SUMMARY

Fourteen Island Lake has not received a lot of attention since 1985 with respect to documentation of water quality. It has been 24 years since an intensive water quality survey has been undertaken. The Ministry of Natural Resources (MNR), Ministry of the Environment (MOE), and the Fourteen Island Mink Lake Association (FIMLA) have each played a role in monitoring water quality since 1975. The Fourteen Island Mink Lake Association (FIMLA) has volunteered under the former MOE Self-Help Program (1993) and in more recent years under the MOE Lake Partner Program (2002, 2003, 2006 and 2007).

Fourteen Island Lake is managed as a warm water walleye, pike and bass fishery by the MNR. As such, it has been the focus of some recent efforts (2007 and 2008) to document water quality, particularly as it pertains to documenting oxygen and temperature conditions.

From this analysis of the available data it is apparent that there has not been much change in water quality over the 33-year period of record (1975 to 2008) although there are gaps in the dataset and it is sporadic and incomplete for some years. There is analytical data on greater than 20 different parameters, the most relevant of which are discussed above. The trophic state indicator parameters (clarity, total phosphorous and chlorophyll a) and the oxygen-temperature profile data have received the most sample effort. It is these parameters that may allow for a trend analysis and that are used to characterize the lake trophic status.

Unfortunately, water quality data is very limited for Mink (Sigsworth) Lake, Little John Lake and Little John's Sister Lake; survey data for the latter two is only available for the year 1985.

The period of record for water clarity on Fourteen Island Lake is 1975 to 2008. Very good complete ice-free season Secchi depth recordings were made during the years 1975, 1983, 1985 and 1993. Unfortunately, there are considerable gaps in the data over the period of record and in the more recent years, 2001 to 2008, there were very few recordings completed each year. As such, the dataset does not lend itself to a rigorous trend through time analysis. The indication from the analysis is that water clarity is improving. Fourteen Island Lake is classified as oligotrophic on the basis of a mean Secchi disc depth of 5.782 metres. No Secchi disc depth recordings could be located for any of Mink Lake, Little John Lake or Little John's Sister Lake.

Another trophic state indicator is chlorophyll a _. Analysis for this parameter was undertaken from the early 1970s to 1993. There is much variability in the chlorophyll a data set for Fourteen Island Lake and it does not lend itself to a trend through time analysis. The mean of means value for chlorophyll a for the period of record is 2.30 ug/L. Fourteen Island Lake would therefore be classified as oligotrophic on the basis of this parameter.

Little John Lake has a mean chlorophyll a value of 1.90 ug/L on the basis of this one parameter the lake would be classified as oligotrophic. Little John's Sister has a reported mean chlorophyll a value of 3.98 ug/L and is classified as mesotrophic on the basis of this one parameter. There is only one year of data available for either of these two lakes.

Phosphorous concentration is also a trophic state indicator. There is a 7-year dataset for this parameter for Fourteen Island Lake. The trend line for TP indicates a decline in TP although the relationship is relatively weak with an R^2 value of only 0.53. The mean value of 15.5 ug/L places Fourteen Island Lake in the moderately enriched or mesotrophic category based on this parameter.

For lakes such as Fourteen Island Lake, Mink Lake and Little John Lake that may undergo partial mixing in the spring and that annually experience very poor to anoxic oxygen conditions at the bottom, nutrient concentrations are elevated both due to accumulations as a result of decomposition of organic material settling from above and also from the re-suspension or release of nutrients from the sediments in the presence of anoxic conditions at the mud-water interface.

There is between six to nine times as much phosphorous in the lake bottom as there is measured at the surface. The consequence of this accumulation of both phosphorous and nitrogen leads to heavy blooms of diatoms and algae at the time of fall turnover when these nutrients are made available at the surface again. This can become very problematic if nutrient loadings from shoreline development or other sources are not controlled.

Little John Lake becomes stratified and also experiences poor oxygen conditions in the hypolimnion; as a consequence there is a significant difference in TP values between surface and bottom sample results. The mean surface TP value is 18.4 ug/L and the mean bottom TP value is 970 ug/L; the concentration of phosphorous in the hypolimnion of Little John Lake is greater than fifty times as much as is in the surface waters. The surface mean TP value of 18.4 ug/L is below the PWQO of 20 ug/L. Little John Lake would be considered to be mesotrophic based on TP alone.

Little John's Sister Lake is too shallow to stratify and therefore surface and bottom values for temperature, oxygen and nutrients are all the same respectively. With respect to phosphorous, the mean value is 32 ug/L. This mean value exceeds the PWQO of 20 ug/L. Little John's Sister Lake would be considered to be eutrophic based on TP alone.

Collectively, while the three parameters are separate and distinct, the data indicates that each individually is supportive of the other. Water clarity has improved, total phosphorous appears to have declined and chlorophyll a concentrations have not changed. This observation provides some confidence to the conclusion that conditions for these three parameters have not declined and may in fact have improved very slightly over the period of record.

Using only the data for the years with measured nitrogen data and based on the calculated TN/TP ratio of 23:1 Fourteen Island Lake would be classified as oligotrophic (i.e. TN/TP ratios > 20). Little John Lake would be considered to be oligotrophic on the basis of the TN:TP ratio 35.9:1.

The most critical parameter for Fourteen Island Lake is the poor oxygen concentrations recorded in the hypolimnion of each of the basins. Oxygen and temperature recordings have been undertaken on 23 different occasions on Fourteen Island Lake. The oxygen data indicates very poor conditions exist from mid-summer through to fall turnover each year. The probability is that due to lake morphometry and local topography, the lake does not experience complete mixing during the spring overturn period for some years.

The oxygen profiles recorded in August of 1983 and 1985 show a modest improvement in hypolimnetic oxygen values to a depth of 20 metres however below 20 metres depth, oxygen values are again very poor. An oxygen profile recorded September 26th, 2008 confirms the poor late season oxygen conditions continue to exist in more recent years.

Only one oxygen-temperature profile has been recorded on Mink (Sigsworth) Lake. This profile also shows severe oxygen loss from the bottom of the thermocline to the lake bottom. This lake basin has all the characteristics discussed above for Fourteen Island Lake. The basin is small, deep (27 m), protected by high hills and has a short fetch shore to shore; all are characteristics that cause incomplete spring mixing and poor late season hypolimnetic oxygen conditions as a result.

For Little John Lake profiles were completed in 1985 spanning the May to November ice-free period. The May profile indicates that the lake became stratified early and that incomplete mixing occurred prior to stratification; as a result poor oxygen concentrations are particularly evident below 11 metres depth. Mid and late summer profiles indicate anoxic conditions in the hypolimnion.

Little John's Sister Lake is only 4.0 to 4.5 metres deep and therefore is not deep enough to become stratified. It therefore would be expected to have the same temperature surface to bottom and to be completely mixed with the same oxygen concentrations surface to bottom for the entire season. Shallow productive lakes such as this can experience anoxia under the ice resulting in late winter or early spring fish kills.

4.0 RECOMMENDATIONS

Each of Fourteen Island Lake, Mink Lake, Little John Lake and Little John's Sister Lake are deficient in a good complete-season phosphorous dataset since at least 1985. The Fourteen Island Mink Lake Association should try to acquire, for at least one year, a more intensive phosphorous sampling effort throughout the ice-free season. This may be possible through the Ministry of Environment Lake Partner Program.

In addition, water clarity can easily be recorded for each of these lakes on an annual basis. Water clarity recordings can provide the longest dataset for the best value to allow for trend through time analysis. This will require volunteers to commit to recording the clarity at least twice monthly from as soon after ice-out as possible until the fall overturn period. The recordings should be recorded at the same locations each time and preferably under conditions of light winds with the boat anchored.

Because each of Fourteen Island Lake, Mink Lake, and Little John Lake experience poor deep-water oxygen conditions and because intensive whole season oxygen–temperature profiles have not been completed since 1985, it is time to collect current data for these parameters. Profiles should be recorded on these basins as soon after ice-out as possible to document spring overturn conditions and then at least monthly thereafter until late season in the fall. The findings will have ramifications with respect to fisheries management and shoreline development decisions.

5.0 LIST OF REFERENCES

Environment Canada, Inland Waters Directorate.1979. Water Quality Source Book – A Guide to Water Quality Parameters 88 pp.

Ontario Ministry of Municipal Affairs .1986. Lakeshore Capacity Study Trophic Status. 89 pp.

Ontario Ministry of the Environment .1993. Cottagers' Self Help Program - Enrichment Status of Lakes in the Southeastern Region of Ontario - 1992 (Summary Report) ISSN 0822-1251, 27 pp.

Ontario Ministry of the Environment .1993. Cottagers' Self Help Program - Enrichment Status of Lakes in the Southeastern Region of Ontario - 1992 ISSN 0822-1251, 148 pp.

Ontario Ministry of the Environment (Clark and Hutchinson) .1992. Measuring the Trophic Status of Lakes Sampling Protocols . 36 pp.

Ontario Ministry of Environment and Energy.1994. Water Management Policies Guidelines Provincial Water Quality Objectives of the Ministry of Environment and Energy. July 1994. 30 pp.

Ontario Lake Assessments. 2000. An Assessment of the Water Quality of Charleston Lake, Ontario 2000. 23 pp. plus appendices

Ontario Lake Assessments. 2002. An Assessment of the Water Quality of Charleston Lake and Tributary Streams, 2002. 34 pp. plus appendices

Ontario Lake Assessments. 2004. A Summary and Critical Review of the Water Quality of Charleston Lake, Ontario 1968 to 2003. 39 pp. plus appendices

Ontario Lake Assessments. 2006. A Summary and Critical Review of the Water Quality of Bobs and Crow Lake, Ontario 1972 to 2004. 39 pp. plus appendices

Hutchinson, G.E. 1975. A Treatise on Limnology. Volume 1. John Wiley and Sons, pp. 1015

Rutner, F. 1963. Fundamentals of Limnology. University of Toronto Press, pp. 295

Wetzel, R.G. 1983. Limnology. Saunders College Publishing, pp. 767

6.0 GLOSSARY

Algae – microscopic photosynthetic unicellular plants commonly found in water

Algorithm – a mathematical relationship one parameter to another

Alkalinity – a measure of the ability of water to neutralize acids; directly related to water hardness and calcium carbonate concentrations.

Anoxic – having a deficiency of oxygen

Benthic organisms – living things associated with the lake bottom

Biota - living organisms

Blue-green algae – microscopic plants associated with nutrient enriched conditions; known taste, odour and toxin producers; blue-green in colour ; often float on the surface

Cations – positively charged atoms (e.g. Na^{+1}, K^{+1}, Mg^{+2}, Fe^{+2}, Ca^{+2} etc)

Chlorophyll a – the green photosynthetic pigment found in living plants including algae

Diatoms – algae of the family Bacillariophyceae, 5000 species are known, may be unicellular, colonial or filamenteous

Epilimnion – the warm surface water layer in a lake of equal temperature that is mixed by the wind during the stratified period

Eutrophic – a nutrient enriched lake, high in phosphorous and nitrogen, high in algae concentrations, poor in clarity and with poor or no deep water oxygen concentrations.

Fetch – the uninterrupted straight line distance between two points across water

GPS - Global Positioning System; used to pin point locations on the earth surface.

Gram (gm) - is 1000 times smaller than a kilogram.

Humic – derived from humus; colloidal organic matter as the result of decomposition of plant and animal matter

Hypolimnion – the deep cold water layer below the bottom of the thermocline; lies below the metalimnion

Ion – the smallest size of particle; atom

Mesotrophic – lakes which are moderately enriched; between eutrophic and oligotrophic

Metalimnion – zone between the epilimnion and the hypolimnion; zone of most rapid temperature change with depth called the thermocline.

Metalimnetic minima – a condition where oxygen concentrations decline to low values at the bottom of the thermocline; oxygen concentrations then improve in the hypolimnion

Microgram (ug) - is 1000 times smaller than a milligram.

Milligram (mg) - is 1000 times smaller than a gram.

Minima – refers to an oxygen sag (low oxygen values) in the metalimnion

Morphometry – refers to lake size and shape; includes area, volume, fetch, maximum depth, mean depth, shoreline length etc.

Nutrients – elements required for plant growth; include phosphorous and nitrogen

Oligotrophic – lakes which are nutrient poor, deep, clear, cold, oxygen enriched, low algae concentrations, low phosphorous and nitrogen concentrations

PWQO – Ontario Provincial Water Quality Objectives

Organic – all living or dead and decomposing material from carbon based sources

Overturn – a physical process which a lake undergoes each spring and fall when water temperatures are equal top to bottom; wind energy mixes the lake causing overturn

Percent Saturation – refers to the amount of oxygen that water has relative to how much it would have at saturation for a specific temperature; 60 % saturation implies that 40% of what it could hold has been depleted.

Phytoplankton – free floating microscopic photosynthetic plants, algae, found throughout the water column

pH – a measure of the hydrogen ion concentrations; expressed as a measure of acidity on a scale from zero to fourteen with seven as neutral, less than 7 as acid, greater than 7 as basic.

SDF – Station Description File (number) – used by MOE to document sample locations

Seston – the totality of all free-floating living and non-living suspended matter in the water column

Summer stratification – the period when temperature difference between top and bottom are so great that the water in the lake is layered into warm surface epilimnion, a cold bottom hypolimnion and a zone of rapid temperature change in the middle called the metalimnion.

Thermocline – the depth at which the temperature changes by $\geq$ 1.0 oC / metre

Total organic carbon (TOC) – a measure of dissolved and particulate forms of carbon, carbon is an element in all living and formerly living things.

Trophic status – refers to the level of nutrient enrichment

UTM - Universal Transverse Mercator Grid; 1000 metre square grids laid over the globe which allows for detailed position locations; sometimes called military grid.

Zooplankton – microscopic and small aquatic animals that typically found throughout the water column