International Rainy-Lake of the Woods Watershed Board

FIRST ANNUAL WATER QUALITY REPORT

Submitted to
The International Joint Commission
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Introduction

The International Joint Commission (IJC) formed the International Rainy-Lake of the Woods Watershed Board (IRLWWB; the Board) to coordinate binational water quality improvement efforts in the Rain River-Lake of the Woods watershed and manage water levels and flows on the Rainy River and Rainy Lake (IRLWWB, 2014). The Board has a mandate to maintain awareness of water issues, and review and report on the ecological health of the aquatic ecosystem to the IJC. To fulfill this mandate, the Board requested water quality information and interpretive summaries with respect to science and monitoring activities undertaken by relevant agencies in the watershed for the period of 2012-2014.

In August 2015, the Board established a sub-group (Aquatic Ecosystem Health Committee) to track environmental issues for the boundary waters within the watershed, with the goal of supporting the on-going awareness of these issues by the Board and regular reporting to the IJC. The Committee has lead the preparation of this report on behalf of the Board.

The Rainy-Lake of the Woods watershed drains an area of approximately 70,000 square kilometers or 27,000 square miles. Approximately 59% of the watershed is in Ontario and Manitoba and 41% in Minnesota (IRLWWB, 2014). The main concerns regarding water quality in the basin are nutrient enrichment, algal blooms, aquatic invasive species and surface and groundwater contamination. Major reductions in industrial and municipal discharges have been achieved over the past four decades which have resulted in substantially lower loadings into the Rainy River; however elevated nutrient levels and algal blooms persist (Clark and Sellers, 2014).

This report synthesizes the information on water quality conditions in the basin received from agencies, with the intent of summarizing findings and highlighting key observations where appropriate in relation to established standards. As this is the first attempt by the Board to compile and assess water quality information in the basin, the decision was made to rely on agency interpretations only. Therefore, only those data that were made available in an interpreted format are presented. Complete summary information is included as appendices. Although a great deal of data were received, interpretive summaries only highlighted data regarding key water quality issues in the basin and did not provide a comprehensive account of all activities conducted in the basin. As such, this report contains a brief overview of current water quality conditions in the basin. Recommendations for future reporting are provided to support the Board in developing a standardized approach.

Sources of Information

Data were received from the following Canadian and United States federal, provincial, state and tribal agencies: Environment Canada (EC), United States Environmental Protection Agency (US EPA), United States Geologic Survey (USGS), Ontario Ministry of the Environment and Climate Change (MOECC), Ontario Ministry of Natural Resources and Forestry (MNRF), Minnesota Pollution Control Agency (MPCA), and Red Lake Department of Natural Resources (RL DNR). Full agency-prepared interpretive summary reports are included as appendices for reference. Some data were not accessible at the time of the request because they are not yet publicly available or are collected on a rotational basis outside the target reporting period.

A large volume of data was provided by partners which demonstrates broad agency interest in, and surveillance of, the basin. The geographic extent of sampling encompasses the boundary waters and

upstream into the surrounding drainage basin. The data are diverse and include continuous tributary monitoring for nutrient load estimation, grab sampling of Lake of the Woods and other boundary waters, citizen science programs, sediment chemistry, point source monitoring and cyanobacterial toxin analyses. While it is understood that significant effort would be required to interpret all the data received, the extent of the interpretation was focused on a subset of the information and where applicable, these data are described here. All data summaries contained information on current levels of phosphorus, the key nutrient of interest in the basin. The geographic scope of this report is to report on conditions in the Rainy River and Lake of the Woods (Figure 1).

Summary of Water Quality Conditions

In general, the data illustrate that substantial spatial variation exists with respect to nutrients in the Rainy Lake of the Woods basin. Nutrient levels, mainly phosphorus, in both waters and surficial sediments have exceeded IJC alert levels and other jurisdictional standards, in portions of the Rainy River, Lake of the Woods, and their tributaries as identified from current monitoring activities. IJC Alert levels are levels previously established by the IJC based on the most stringent criteria available.[1]

[1] Alert Levels are currently reviewed by the IJC through the Water Quality Objectives for Watershed Boards initiative

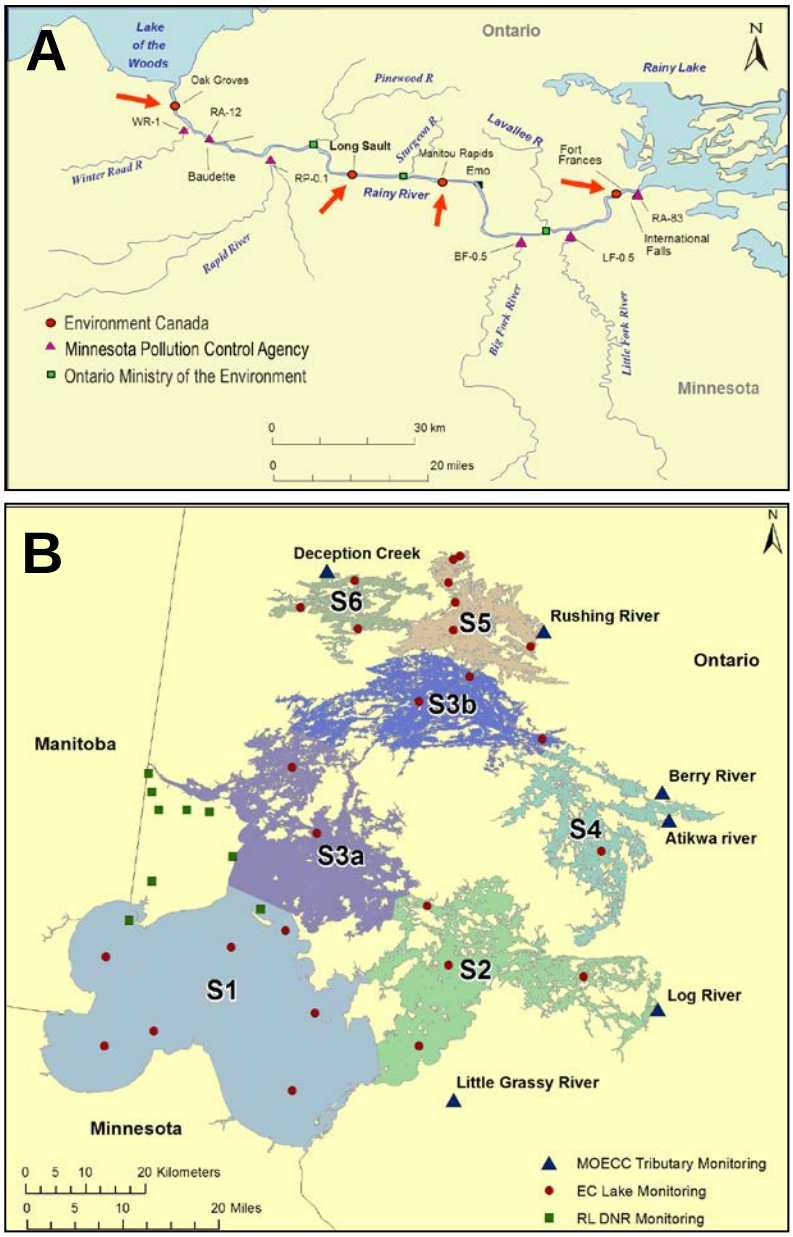

Figure 1: Monitoring locations identified from the interpretive summaries received for the Rainy River (A; IRLBC/IRRWPB 2010) and Lake of the Woods (B; adapted from EC, 2015). Panel B illustrates Environment Canada's separation of the Lake of the Woods into sub-basins developed from hydrodynamic modelling.

Rainy River

Monitoring in the Rainy River by EC and MOECC illustrate that phosphorus levels peak in the spring during the freshet and that levels in general, have remained more or less stable over the period of 2009 to 2014 for which data was provided. Spatially, Total Phosphorus (TP) levels are highest furthest downstream (Oak Groves), and lowest furthest upstream (Fort Frances). During the spring freshet, TP peaked at the mid-stream transects (Manitou Rapids and Long Sault) suggesting that elevated inputs could be entering the system from upstream tributaries (Big Fork, La Vallee, and Little Fork Rivers) in addition to point sources. Levels exceed the phosphorus IJC alert level of 30µg/L frequently during the

growing season at the river outflow (Oak Groves; Figure 2a). The highest phosphorus loads recorded during the 2010 to 2014 period occurred in 2014 during the flood of record event.

Similarly, tributary monitoring illustrates that phosphorus levels are frequently in excess of the IJC alert level (Figure 2b) in streams entering the Rainy River. Maximum phosphorus concentrations tend to occur with the spring freshet and a second smaller peak occurs in mid-summer. Phosphorus levels in tributaries have remained relatively constant during the period 2009 to 2014 and it is suggested that variability in precipitation events is likely responsible for seasonal differences. Information from tributaries in Minnesota for this time period were not available, however the MPCA reports from earlier assessments that that some of the downstream segments of the Little Fork River do not meet State standards for the protection of aquatic life due to elevated levels of turbidity and suspended sediments. Intensive assessments for the remaining watersheds in the basin are either underway or are scheduled in the upcoming years.

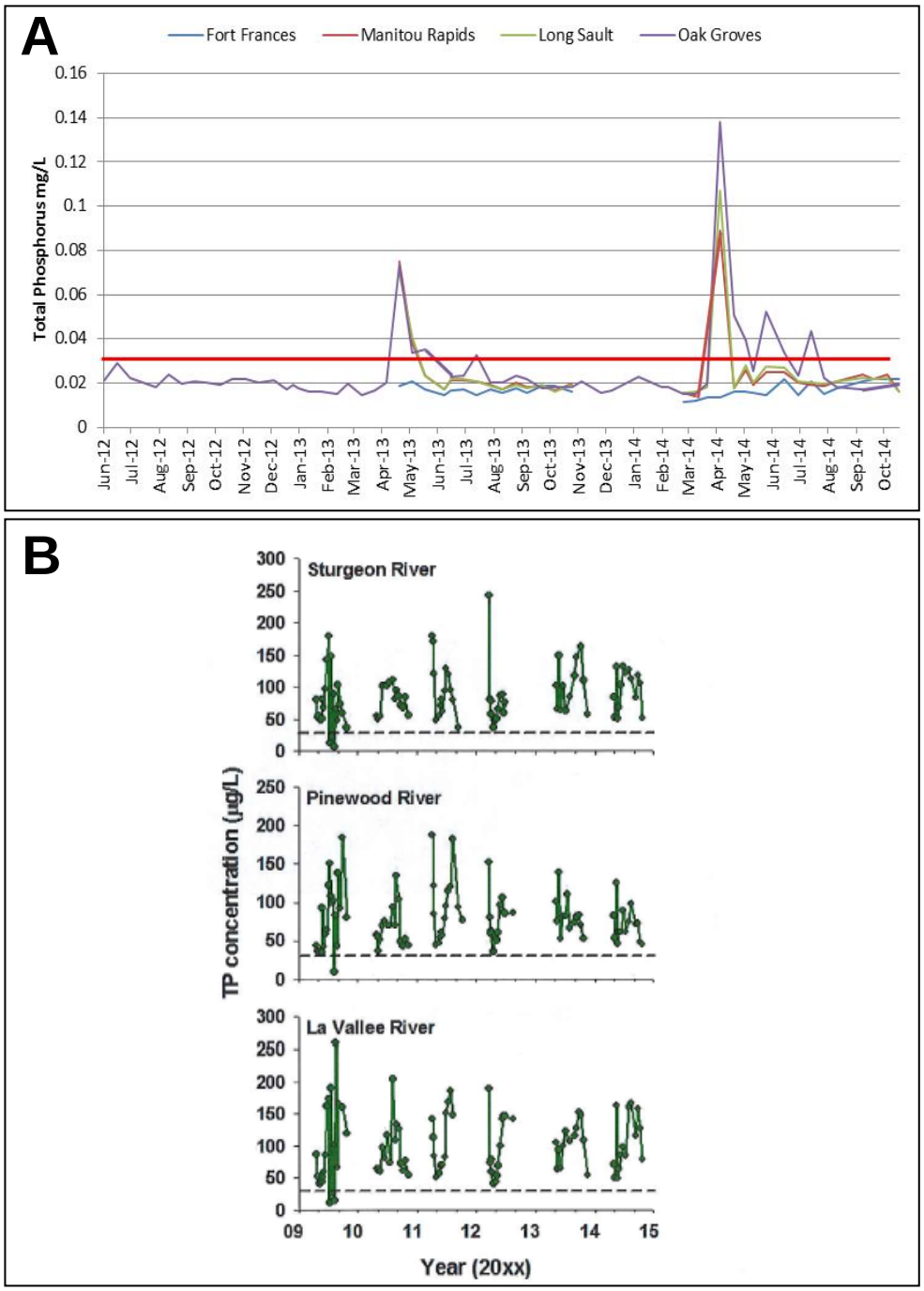

Figure 2: Summary of total phosphorus concentrations measured in the Rainy River (A; EC, mg/L) and in its main Canadian tributaries (B; MOECC, µg/L). The Rainy River alert level for phosphorus is denoted at 0.03mg/L (A) and 30µg/L (B) respectively.

There are a number of municipal and industrial point sources that discharge into the Rainy River. Compliance and discharge permitting information were received but were not made available in an interpreted format. Wastewater discharge to the Rainy River from industrial and municipal sources in Minnesota continue to exhibit consistent low loads as compared to historic levels (Appendix C). The New Gold Rainy River mine is expected to begin discharging into the Pinewood River in 2017. Environment

Canada has begun to collect baseline information on trace metals prior to the intended development and these data may be available for future reporting.

Lake of the Woods

In the Lake of the Woods, surface waters, surficial sediment, and the main tributaries are monitored by EC, MOECC, MPCA, and RL DNR. The major Canadian tributaries entering Lake of the Woods are monitored by MOECC (Figure 1B) and illustrate that there is a range in phosphorus levels entering the system (Figure 3). All tributaries are situated on the Canadian Shield; however those tributaries with low dissolved organic carbon (DOC) (Berry Creek, Rushing River, and Atikwa River) have markedly lower TP concentrations that rarely approach the alert level. Tributaries with relatively higher DOC (Deception Creek and Log River) have relatively higher TP concentrations, which frequently approach and exceed the alert level. The apparent relationship between DOC and phosphorus may be an important factor to consider in future monitoring efforts in the basin. Little Grassy River exhibits the highest TP concentrations and loadings and has been identified as a potentially important source of phosphorus entering the lake. Its outflow into the lake is situated in the south basin which is consistent with elevated phosphorus levels observed in lake monitoring data.

In general, TP concentrations at all tributaries are constant over the period 2009 to 2014, with the exception of Deception Creek, which appears to be increasing during the reporting period (Figure 3). Monitoring of tributaries entering the lake from the Northwest Angle in Minnesota illustrate elevated concentrations of phosphorus entering the southern basin with mean concentrations near or above the IJC alert level at all stations monitored by RL DNR (Appendix D).

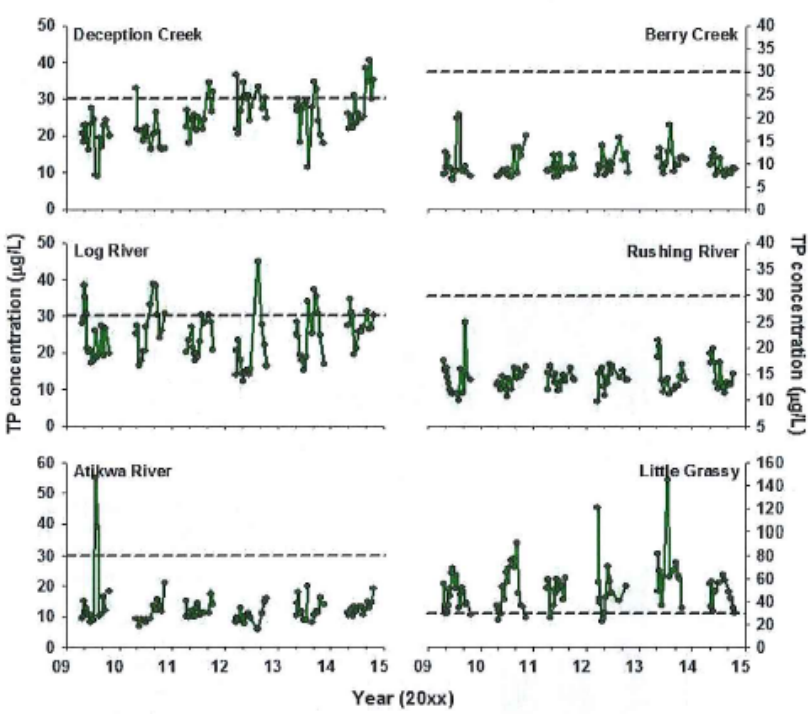

Figure 3: Total phosphorus concentrations measured in the major Canadian tributaries to the Lake of the Woods from 2009-2014 by MOECC. The Rainy River alert level for phosphorus is denoted at 30µg/L.

In general, phosphorus concentrations vary among the lake basins which comprise Lake of the Woods and by water depth (Figure 4). Surface water concentrations of phosphorus exhibit a south to north gradient and reflect the main nutrient available for algal growth. This in lake gradient is consistent with the elevated phosphorus concentrations entering the southern basin from the Rainy River and Little Grassy River. Surface water concentrations in the southern basins are near or exceeding the IJC phosphorus alert level. The southern basins are shallow, mix freely, and exhibit little difference between surface and bottom water concentrations. The northern basins are deeper and stratify, and exhibit much greater bottom water concentrations of phosphorus and nitrogen that are consistent with release of sequestered nutrients from sediments. The MPCA has intensively monitored the Lake of the Woods watershed in Minnesota, and classified the Lake as impaired for aquatic recreational use in 2008 due to eutrophication. These nutrient levels are consistent with current levels measured by EC and RL DNR.

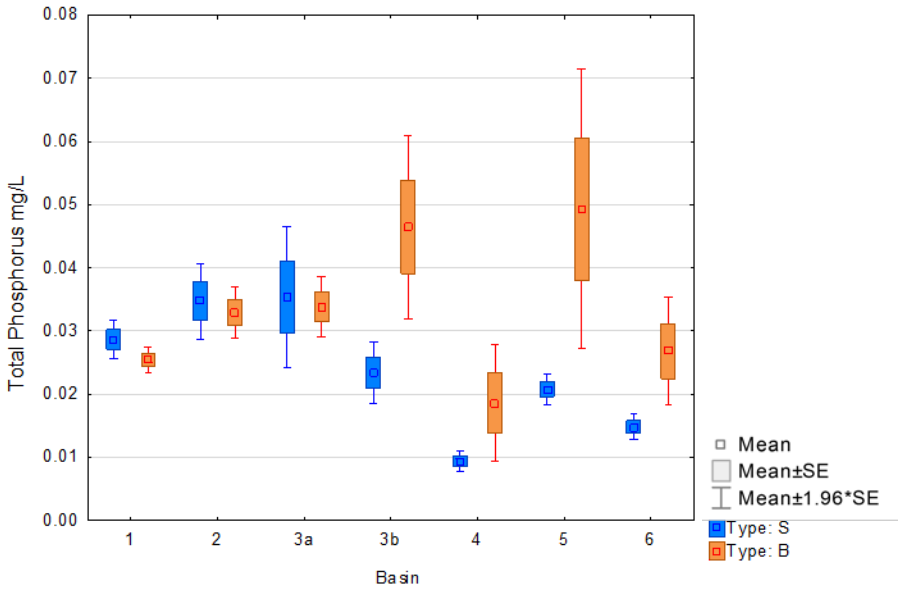

Figure 4: Average concentrations of total phosphorus in surface (S) and bottom (B) waters of the Lake of the Woods from 2012-2014 by sub-basin.

Surficial sediments in the Lake of the Woods have relatively high nutrient and metal concentrations that exceed Canadian jurisdictional standards (CCME, 1999; MOE, 1993). Total nitrogen and phosphorus exceed provincial sediment guidelines (MOE, 1993) and are consistent with the supposition that internal loadings are a source of elevated nutrients in the system. Environment Canada monitoring has illustrated that the deeper northern basins stratify during the summer months and can experience anoxic conditions that can facilitate nutrient release from sediments. The sampling of bottom waters exhibit elevated nutrient levels and is consistent with the internal loadings of nutrients. High levels of nutrients in the bottom waters would become available for algal growth at the surface during the fall turnover; this would support the persistence of algal blooms into the fall in the northern basins which has been observed in Lake of the Woods.

Chlorophyll a concentrations are often used as an indication of the productivity of a system and can provide evidence of algal bloom intensity. Sampling by Environment Canada during the period of 2012 to 2014 show that concentrations are generally higher in the southern portion of the lake (Figure 5); however conclusions drawn from discrete grab sampling in this system can be problematic due to the dynamic nature of blooms that can change quickly in extent and intensity as a result of variations in wind and wave action. Nutrient availability data in the southern basins of the lake are consistent with elevated chlorophyll concentrations. Recent anecdotal reports indicate that algal bloom intensity and frequency is high in these basins during the summer and fall.

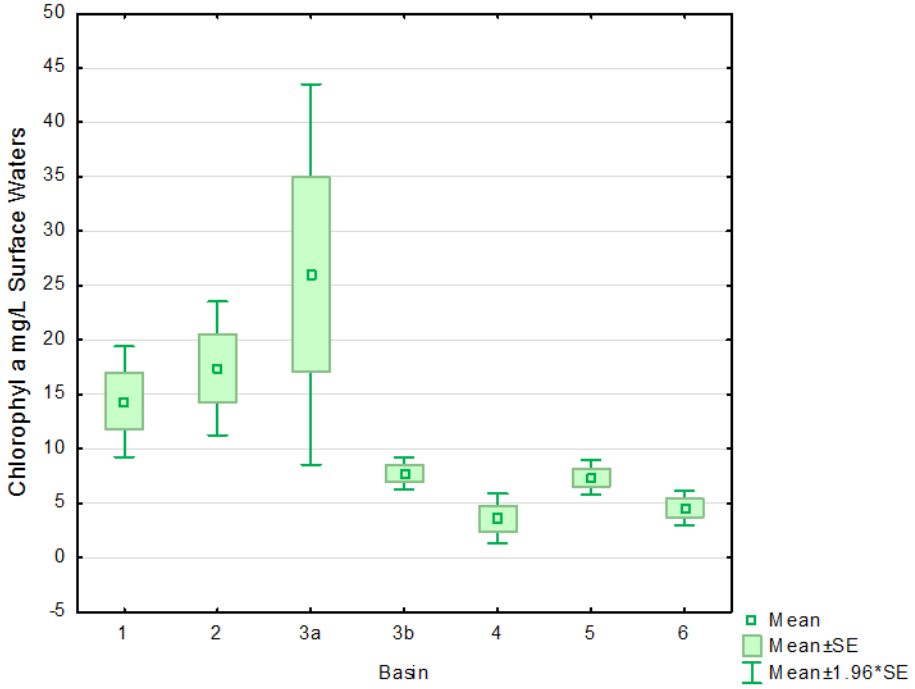

Figure 5: Average fall chlorophyll a concentrations from 2012-2014 in surface waters of the Lake of the Woods, by sub-basin.

Sediment sampling by Environment Canada exhibit that metal concentrations have exceeded the provincial low level effect in >25% of sampling sites for Arsenic, Chromium, Copper, Lead, Manganese, and Nickel. Manganese exceeded the provincial severe effect level in 39% of sites. Arsenic and mercury exceeded the Ontario severe effect level at one site each. The source of elevated concentrations of some metals in the sediments are unknown and could be the result of weathering of ore-bearing rocks or in some cases to past mining activities in the region, such as the gold mining boom at the beginning of the 20th century (Pascoe et al, 2014).

Beyond the Rainy River and Lake of the Woods, other monitoring programs collect information that could contribute to future water quality assessments. These data include existing programs that were either received but not available in a format for reporting or are ongoing.

Recommendations for Future Reporting

This document represents the first iteration of annual reporting by the committee. It does not represent the format for subsequent reporting. The content of this document is the result of those data that were made available in an interpreted format and is not a comprehensive account of all activities conducted in the basin. There may be reporting gaps that could be addressed once further reporting experience is gained.

The Board acknowledges that a great deal of data are being collected for a variety of programmatic areas (e.g. monitoring and compliance) and that future requests for information and interpretive summaries should reflect a more focused approach. It is recommended that specific water quality parameters of interest be selected for a representative suite of priority areas that can be measured against quantitative standards. Data on key parameters at priority areas is likely already being collected through agency monitoring, but represents a subset of their datasets. Therefore, such an approach would allow reporting that is achievable and repeatable, and would require less effort on the part of agencies to compile and interpret information; and less effort for the Board to summarize the information.

In order to ensure comprehensive data collection throughout the Rainy-Lake of the Woods Watershed the Board recommends immediate implementation of the of the Tiered Monitoring Proposal (Component 1: Tiered monitoring of river networks of the IJC's Water Quality Plan of Study for the Lake of the Woods Basin) and the Lake Monitoring Proposal (Component 2: Monitoring of transboundary lake systems, IJC POS)

The broad scope of the data received further highlights the need for a more coordinated and focused approach to reporting to meet the requirements of the IJC. Future consideration could be given to the role of the International Multi-Agency Arrangement (IMA) in supporting and participating in the coordination of data requests, data interpretation, and reporting. It is recommended that the Board move towards a reporting model that is an IMA-led initiative, which would allow for the IMA to become more formally involved in Board activities.

The Board's expanded geographic mandate beyond the Rainy River requires a review of the existing water quality objectives (c.1965; IRRWPB, 1974) and alert levels (IRRWPB, 1993). It is recommended that quantitative objectives be developed that can be assessed using key water quality parameters to facilitate timely, repeatable, and standardized reporting on the condition of waters in the basin. Revised objectives would reflect priority water quality issues in the basin such as nutrient enrichment and algal blooms, and would likely represent parameters that are already captured in agency monitoring programs. It is also recommended that alert levels be revised to reflect current guidelines and be re-evaluated at regular intervals or as necessary. Reporting could then be focused on summarizing current water quality monitoring results and exceedances.

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Appendices

Appendix A: Results of Environment Canada's Water Quality Monitoring and Surveillance Activities in the Lake of the Wood Watershed 2012-2014

Appendix B: Ontario Ministry of the Environment and Climate Change Lake of the Woods Tributary Monitoring

Appendix C: Minnesota Pollution Control Agency Response to Information Request

Appendix D: Red Lake Department of Natural Resources Data Summary

Results of Environment Canada's Water Quality Monitoring and Surveillance Activities in the Lake of the Woods Watershed 2012-2014

Environment Canada, WQMS 2015

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Summary:

1. Eutrophication: nutrient concentrations and chlorophyll a:
    - Concentrations of phosphorus in the Rainy River frequently exceeded the Rainy River Alert level pf 30 µg/l (IRRWPB, 1981) in the spring and summer of 2014, climbing as high as 138 µg/l. This maximum coincided with a flood of record.
    - Concentrations of nitrates/nitrites do not appear to be elevated in the Rainy River and were consistently below Canadian Water Quality Guidelines for the protection of aquatic life of 13 mg/L.
    - Between 2012 to 2014, chlorophyll-a concentrations in surface waters were highest in the southern portion of Lake of the Woods (zones S1, S2, and S3a) during the early fall when cyanobacterial blooms occur. TP (total phosphorus) and TN (total nitrogen) concentrations were also higher in this portion of the lake.

2. Sulphates and chloride:
    - Concentrations of sulphate are within the normal range for Ontario Rivers and have declined in a statistically significant manner from 2009 to 2014.
    - Chloride concentrations never exceeded the Rainy River Alert level of 100 mg/L, nor did they approach it. Concentrations of chloride near the outflow of the Rainy River also declined in a statistically significant manner from 2009 to 2014.
    - Although both of these trends detected in the data from the recent five-year period were statistically significant, they should be interpreted with caution. A future analysis of a longer data set will be undertaken to confirm the magnitude and direction of any trends.

3. Sediment chemistry:
    - Surficial sediments were relatively high in metals and nutrients, often exceeding provincial (OMOECC) and federal (CCME) sediment quality guidelines for the protection of aquatic life.
    - Copper, chromium, manganese, nickel and lead levels exceeded the Ontario sediment low-effect level (LEL) by more than 50% at a number of sites. Arsenic and mercury exceeded the Ontario severe-effect level (SEL) at one site apiece.
    - Concentrations of total nitrogen and phosphorus also exceeded provincial sediment quality guidelines, an indication of the large amount of sequestered nutrients.

Introduction:

This brief report outlines the most recent results of Environment Canada, Water Quality Monitoring and Surveillance (WQMS) division activities in the Lake of the Woods watershed from 2012 to 2014. It is intended as a supplement to the recent technical report released by Environment Canada summarizing its activities in the Lake of the Woods basin and updates the data found therein. EC's past activities in Lake of the Woods are discussed in: Results of Environment Canada's Lake of the Woods Science Initiative: http://ec.gc.ca/Publications/default.asp?Lang=En&xml=0BC88CE2-FEC9-4619-ABAB-27918DB58C69

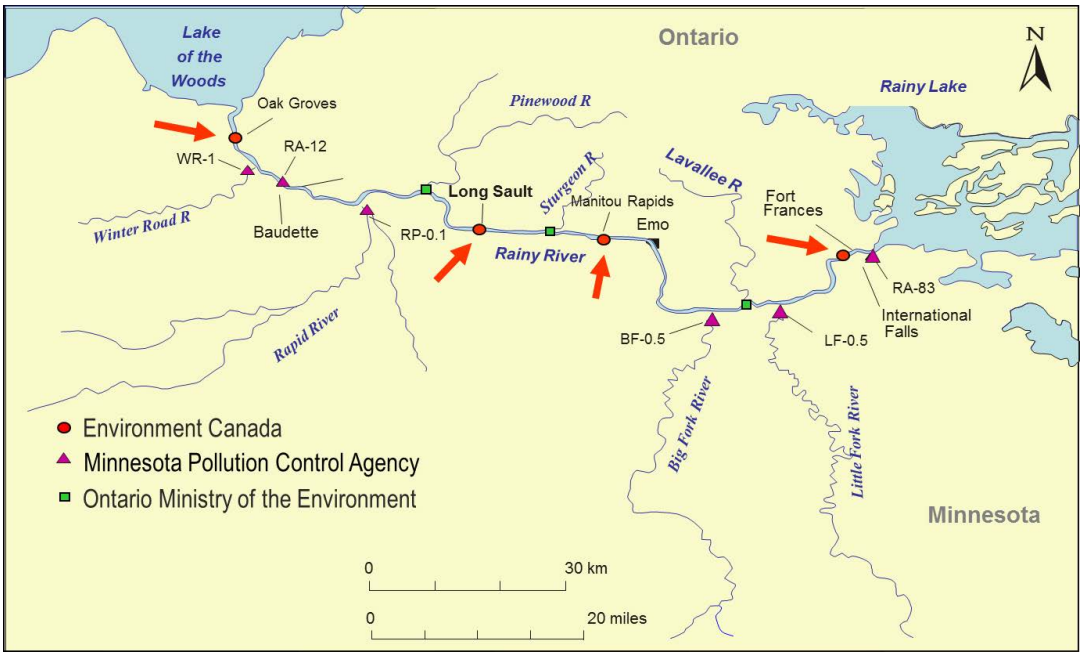


Figure 1 Water quality sampling sites on the Rainy River and its tributaries for Environment Canada, Minnesota Pollution Control Agency and the Ontario Ministry of the Environment (IRLBC-IRRWPB, 2010).

Rainy River:

EC-WQMS currently monitors water quality at four transects along the Rainy River: at the head of the river in Fort Frances, at two mid-river locations concurrent with water survey gages, Manitou Rapids and Long Sault Rapids and the downstream waters at the mouth of Lake of the Woods at Oak Groves (Fig. 1). At the time of last reporting water quality was monitored at the downstream Oak Groves location bi-weekly throughout the year while monitoring at the upstream stations occurred bi-weekly throughout the late spring, summer and fall seasons. Recently EC has adjusted its sampling efforts to better estimate loadings of key parameters. The downstream location at Oak Groves is sampled on an event basis, with frequency determined by the extent and duration of rain events and other influences on the hydrographic curve. This change brings us in line with our US counterparts, who are providing loading estimates

at other upstream locations. Sampling at our upstream transects has temporarily been extended into the winter and early spring seasons in order to facilitate the estimate of annual loadings at these locations. This will provide us with a more fulsome estimation of where loads enter the system along the Rainy River.

Here we report the results of ECs monitoring activities for major ions and nutrients in the Rainy River. Recently EC initiated the monitoring of trace metals in the main stem of the Rainy River at a number of locations; however the data is not yet available. This will provide baseline data for the Rainy River prior to intended gold mine developments underway. EC expects to begin reporting on nutrient and metal loadings to Lake of the Woods in mid to late 2015.

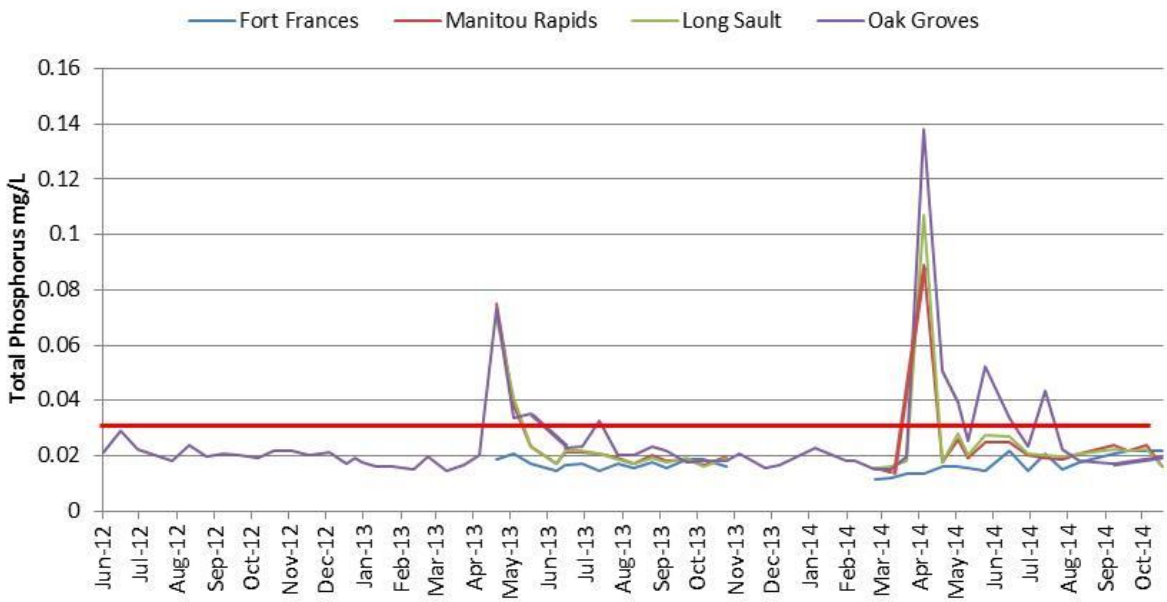
EC examined the recent five years of water quality monitoring data for the Rainy River for linear, monotonic trends. This was done using a seasonal Mann-Kendall test (Helsel and Hirsch, 1992; Tian and Fernandez, 1998). This test takes into account the seasonal variation in water quality parameters that are expected throughout the year, and evaluates the data for underlying linear trends. Although many of the trends detected in the data from the recent five year period were statistically significant, these short term trends should be interpreted with caution. No assumptions should be made in extrapolating these temporal trends beyond the five year period in which the data were measured. A future analysis of a longer data set will be undertaken to confirm the magnitude and direction of any trends.

Water Quality Parameters:

The Rainy River is the main tributary to Lake of the Woods providing approximately 75% of the hydraulic load to the lake and also approximately 75% of the total phosphorus inputs (Hargan *et al* 2011). Figure 2 shows total phosphorus concentrations during 2012 to 2014 at four transects. Phosphorus is lowest at the upstream site of Fort Frances. During the spring freshet, when phosphorus concentrations peak, concentrations are elevated at the mid-stream transects of Manitou and Long Sault Rapids suggesting elevate phosphorus levels entering the system upstream of Manitou Rapids, potentially from the Big Fork, Little Fork, and Lavalee Rivers in addition to point sources such as sewage treatment plants and paper mills. Concentrations of phosphorus frequently exceeded the Rainy River Alert level (IRRWPB 1981) for phosphorus of 30 µg/L in the spring and early summer of 2014, climbing as high as 138 ug/L. This maximum coincided with a flood of record.

Phosphorus peaks during the spring freshet were highest in 2013 and 2014, both being years of large hydraulic loads (Fig. 2). In general however, total phosphorus concentrations showed a significant decline between 2009 and 2014 ($p < 0.05$). While phosphorus is the main nutrient of concern in Lake of the Woods, other nutrients can contribute to algal bloom dynamics. Total Kjedahl nitrogen (TKN) represents the organic plus ammonia portion of nitrogen in the system. Figure 3 shows TKN from 2012-2014 in the Rainy River at four transects. TKN concentrations are highest in the spring and summer during the growing season. Again concentrations are higher at Manitou Rapids

during the spring freshet suggesting that much of the organic nitrogen entering the system during the freshet came from either point sources or the major tributaries entering the Rainy River between Fort Frances and Manitou Rapids.



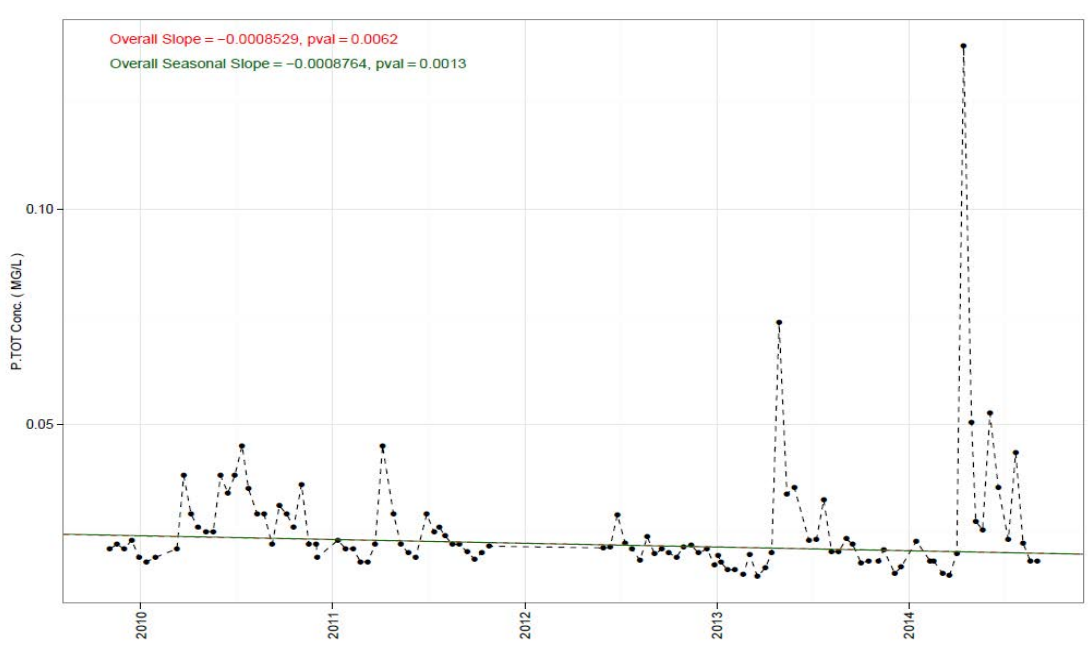


Figure 2. Total phosphorus concentrations on the Rainy River at 4 sampling transects for 2012-2014; the Rainy River Alert Level of 0.03 mg/L is shown in red for reference. The bottom graph shows the temporal variation in total phosphorus over five years from 2009-14 at the Oak Groves location near Lake of the Woods; the seasonal (green) and annual (red) trends are indicated.

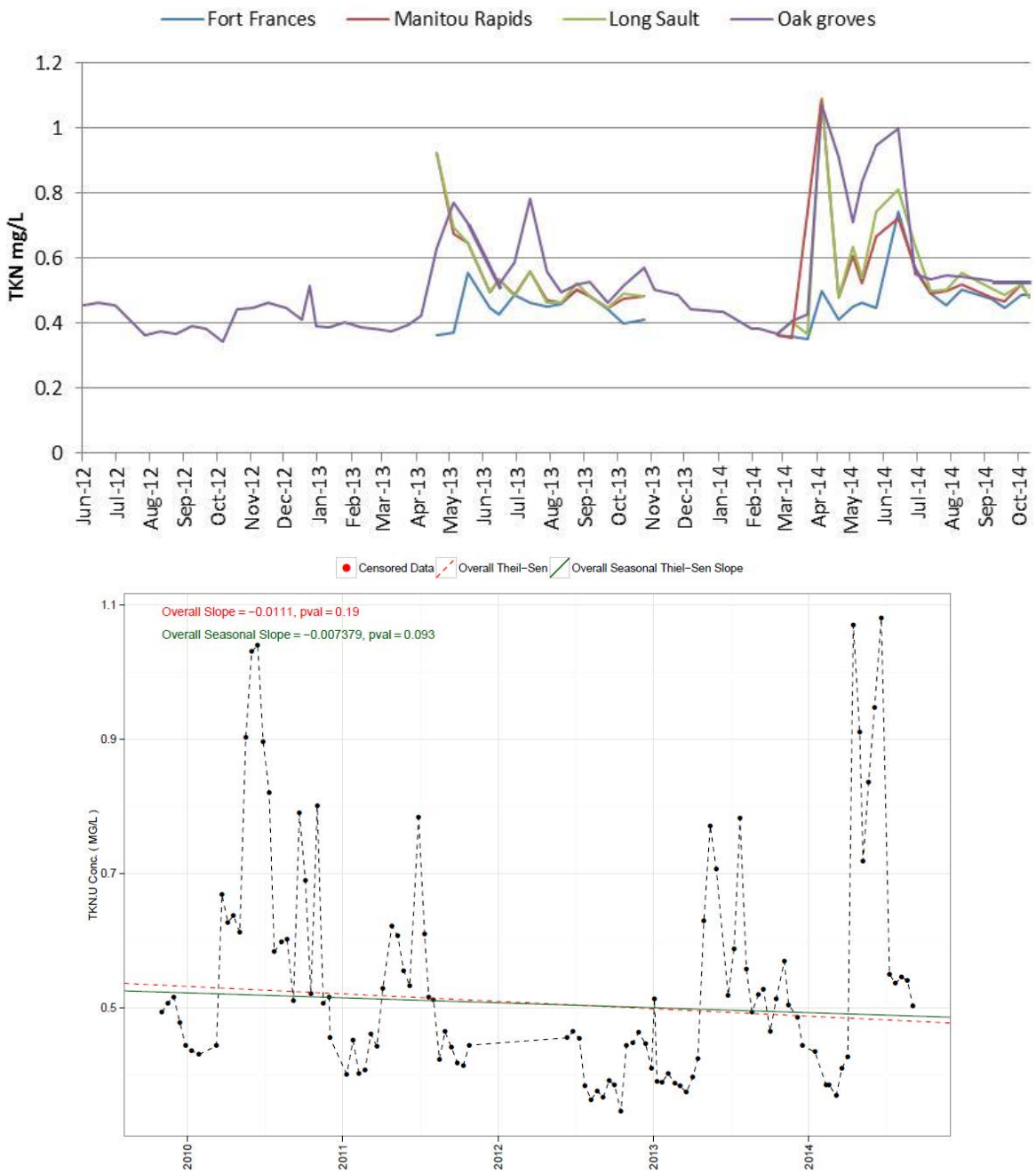
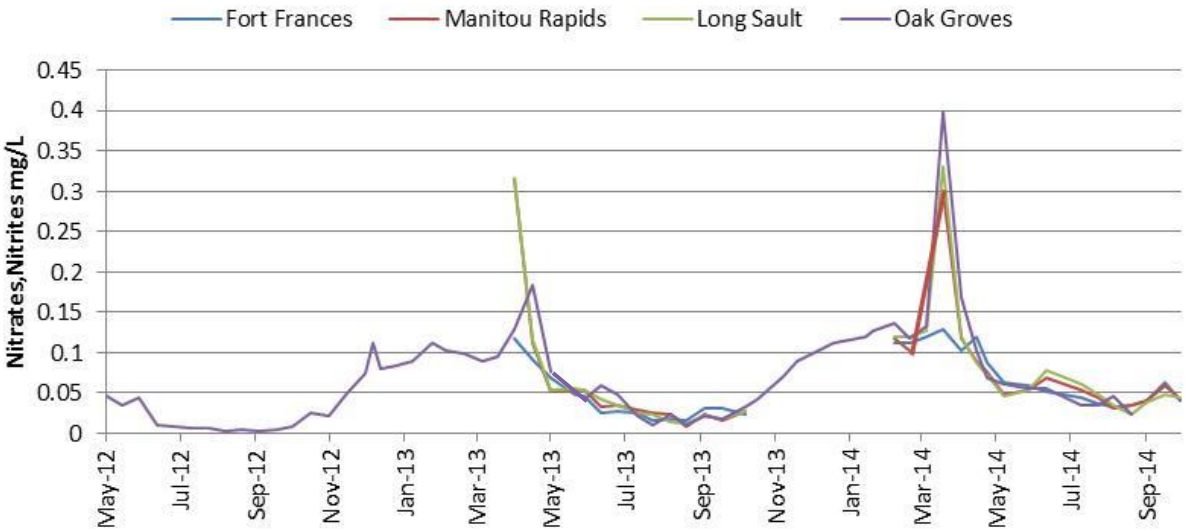


Figure 3. Total Kjedahl nitrogen (TKN) concentrations on the Rainy River at 4 sampling transects for 2012-2014. The bottom graph shows the temporal changes in TKN over five years from 2009-14 at the Oak Groves location near Lake of the Woods; the seasonal and annual slope are given.

Nitrate/nitrite represents a more biologically available form of nitrogen. Concentrations of nitrates/nitrites do not appear to be elevated in the Rainy River and were consistently below Canadian Water Quality Guidelines for the protection of aquatic life of 13 mg/L. Concentrations were highest in the spring and summer during the growing season (Fig. 4). Concentrations were often similar at upstream and downstream locations suggesting that the source of nitrates/nitrites is upstream of the Rainy River. The exception appears to be during the early portion of the freshet when concentrations rise strongly between Fort Frances and Manitou Rapids.

Concentrations of anions and cations are moderate in the Rainy River. Concentrations of sulphate were well within the normal range for Ontario Rivers. Sulphate concentrations declined significantly ($p < 0.05$) from 2009 to 2014, although short term trends should always be extrapolated with caution. Longer term data will be required to determine if this trend will continue (Fig. 5). Chloride concentrations never exceeded the Rainy River Alert level of 100 mg/L, nor did they approach it. Concentrations of chloride near the outflow of the Rainy River also declined in a statistically significant ($p < 0.05$) manner from 2009 to 2014 (Fig. 6).



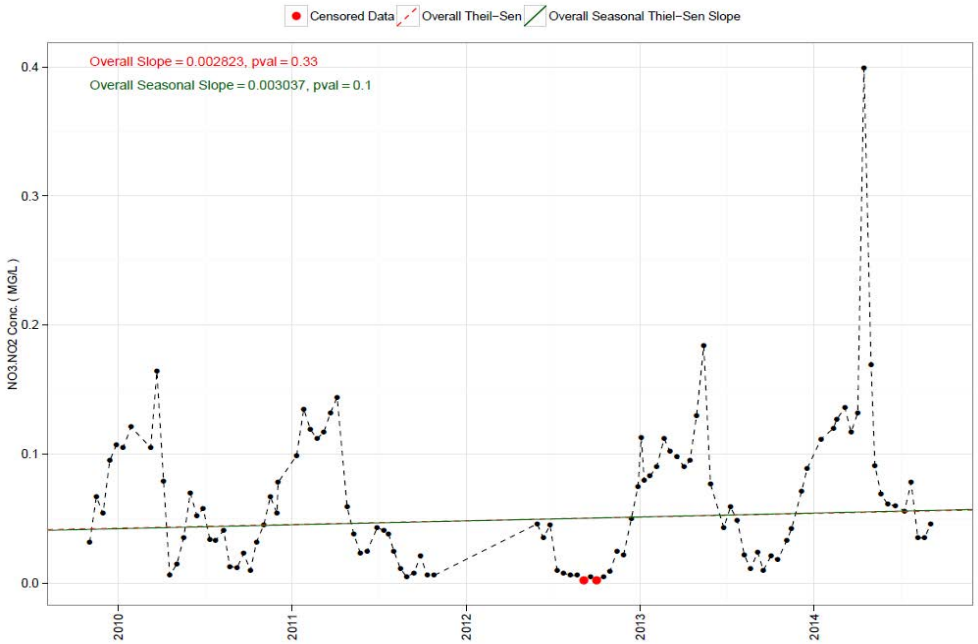


Figure 4. Total nitrate/nitrite concentrations on the Rainy River at 4 sampling transects for 2012-2014. The bottom graph shows the temporal changes over five years from 2009-14 at the Oak Groves location near Lake of the Woods; the seasonal (green) and annual (red) slope are given.

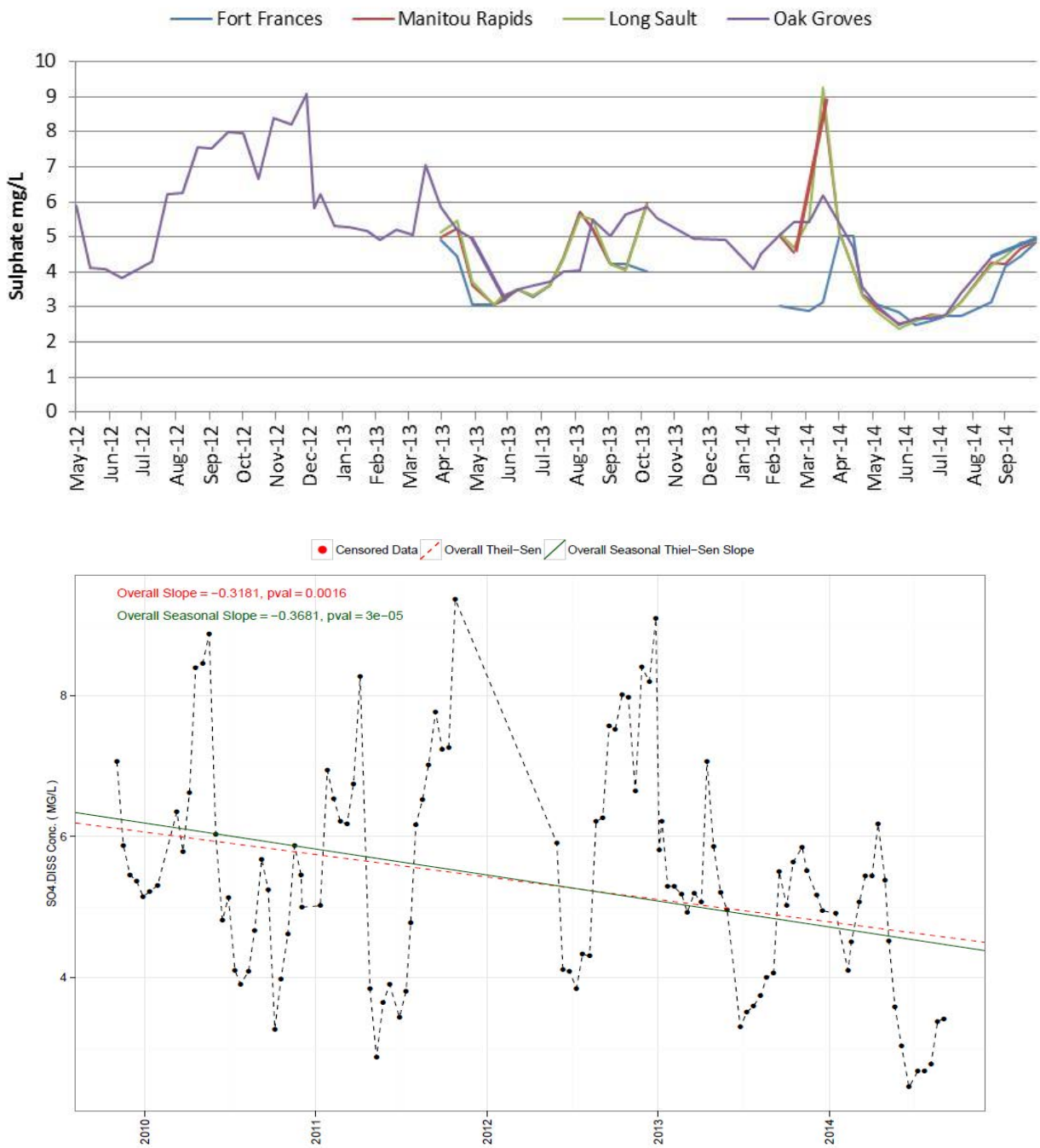


Figure 5. Total sulfate concentrations on the Rainy River at 4 sampling transects for 2012-2014. The bottom graph shows temporal changes over five years from 2009-14 at the Oak Groves location near Lake of the Woods; the seasonal (green) and annual slope (red) are given.

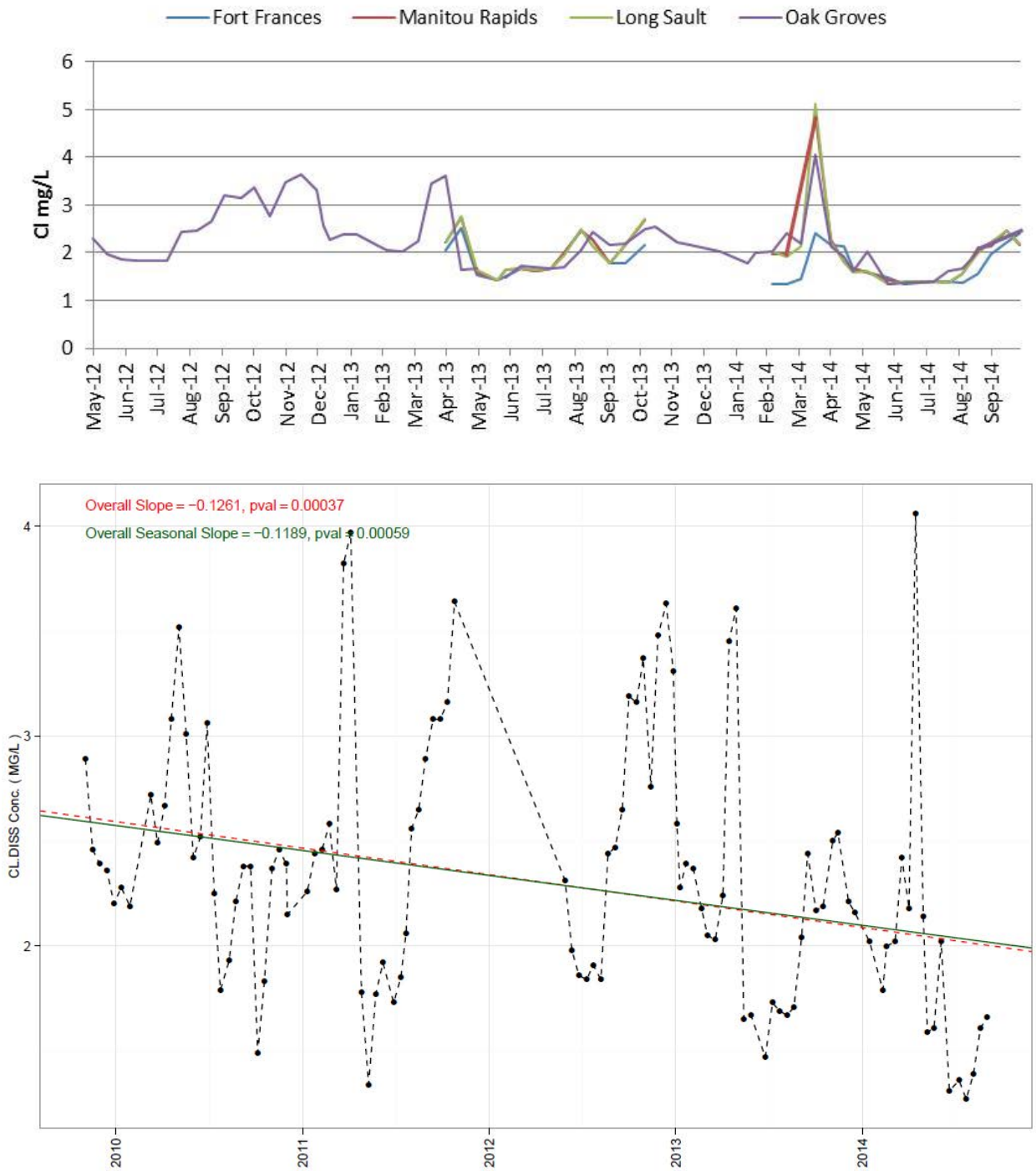


Figure 6. Chloride concentrations on the Rainy River at 4 sampling transects for 2012-2014. The bottom graph shows the temporal changes over five years from 2009-14 at the Oak Groves location near Lake of the Woods; the seasonal (green) and annual slope (red) are given in addition to significance values

Lake of the Woods:

Environment Canada-WQMS has been monitoring water quality at 27 sites in June and September on Lake of the Woods since 2008 (Fig. 7). Water was sampled at three depths: a discrete sample 1 meter below the surface, a discrete sample 2 meters from the bottom and, if a thermocline is present, an integrated sample from the surface to the metalimnion. In the fall, sediment samples were also collected by mini-box core to evaluate sediment chemistry and the benthic invertebrate community. Environment Canada researchers constructed a hydrological model of flow and nutrient transport in Lake of the Woods which divides the lake into six hydrological zones (Zhang *et al* 2013, Fig. 7). In this report, water quality information from 2012 to 2014 is summarized for each zone, in addition to information on individual sites.

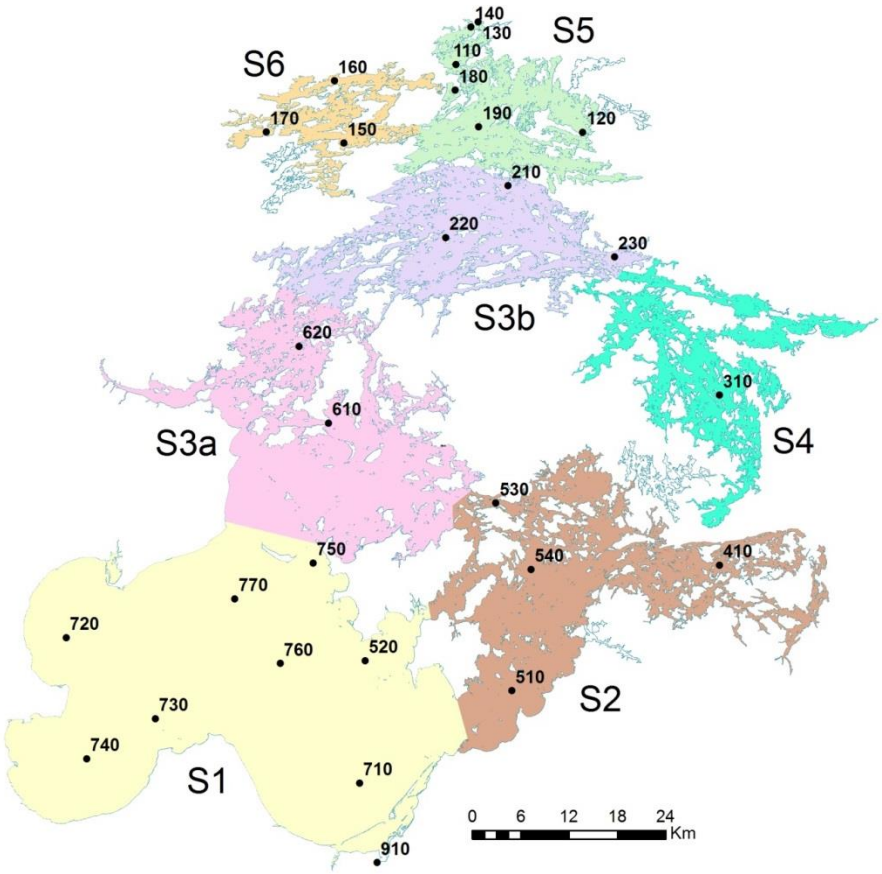


Figure 7. Map showing the location of Environment Canada water quality monitoring sites on Lake of the Woods. This map shows the location of the sites in the context of the major basins of the lake as identified by a hydrodynamic model of nutrient transport developed by Environment Canada.

Physical Limnology and Water Quality

Lake of the Woods occupies two distinct geological zones dividing the lake into a northern and southern portion differentiated by their mixing regimes and water quality. Glacial lacustrine sediments make up the southern portion of the lake resulting in open, shallow basins which are susceptible to mixing from wind (Zones S3a, S1, S2). The northern portion of the lake (Zones S3b, S4, S5, S6) lies on Precambrian shield and consists of smaller, deep basins with many islands. The smaller, sheltered basins of the northern portion of the lake allow for thermal stratification to develop in some areas during the summer months, particularly in zones S4, S5 and S6 (Fig. 8). During the period of thermal stratification bottom waters in the hypolimnion are isolated from the well oxygenated surface waters leading to a gradual reduction in oxygen saturation. In some cases oxygen concentrations in the hypolimnion fall below levels detrimental to sensitive fish stocks such as lake trout, which may be impacted at concentrations below 6 mg/L (Evans 2005); a condition which occurs consistently in some areas of zones S3b, S5 and S6 (Fig. 9). Some of the deeper, productive basins (stations 110, 120, 170, 180, 230) in these zones are prone to periods of anoxia during the summer months which see dissolved oxygen concentrations fall below 1 mg/L. Under these conditions there is concern regarding the release of bio-available dissolved phosphorus from the sediments to the water column in addition to impacts to the biota.

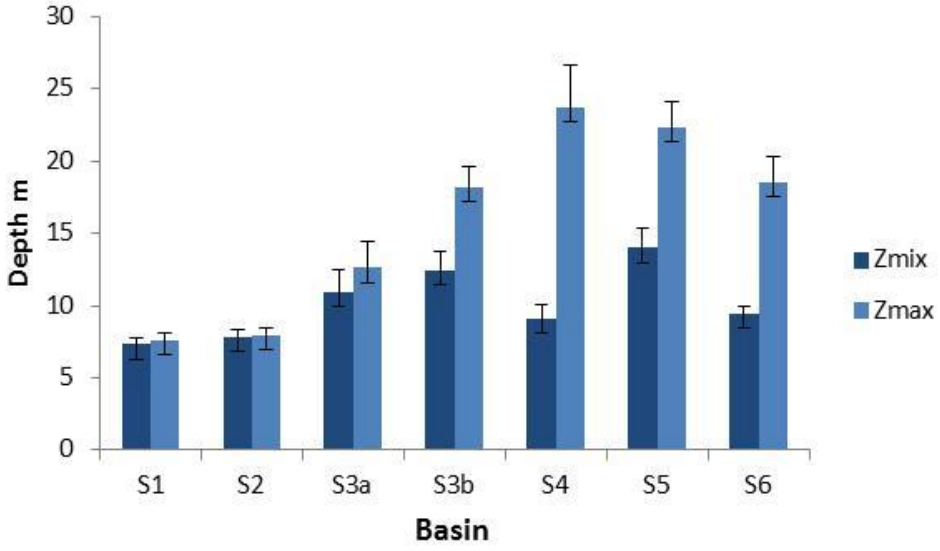


Figure 8. The presence of thermal stratification as indicated by the average depth of the mixed layer (Zmix) versus the bottom (Zmax) for each basin of Lake of the Woods.

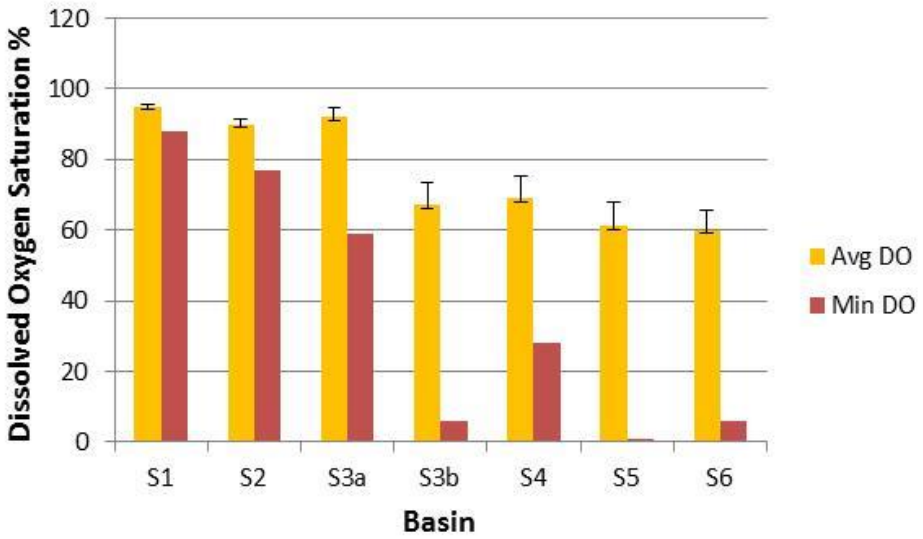


Figure 9. Average and minimum dissolved oxygen saturation in bottom waters of Lake of the Woods. Bars give standard error.

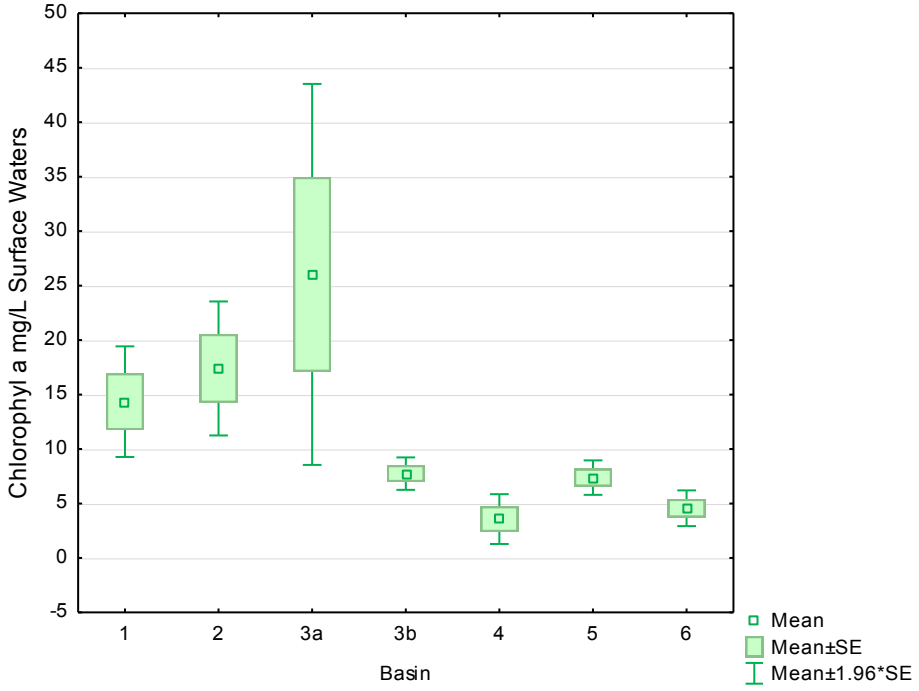


Figure 10. Average fall chlorophyll a concentrations from 2012-2014 in surface waters of the Lake of the Woods, by EC basin.

Chlorophyll a concentrations are often used as a surrogate of productivity and algal bloom intensity although on Lake of the Woods significant temporal variation in chlorophyll a concentrations surface waters as influenced by wind speeds and mixing make this difficult to estimate with grab sampling (Binding *et al* 2011). Between 2012 to 2014 chlorophyll a concentrations in surface waters were highest in the southern portion of the lake, (zones S1, S2 and S3a) during the early fall when cyanobacterial blooms

occur (Fig. 10). This was as expected as combined data sets have previously shown that phytoplankton biomass is higher on average in the southern portion of the lake (Zones S1,S2 S3a), and is positively correlated both with chlorophyll a and total phosphorus concentrations (Zhang *et al* 2013). Water clarity was also reduced in the southern zones of the lake, as indicated by Secchi depth (Fig. 11). Reduced water clarity in the southern zones is likely reflective of both the heavier blooms in the south, and increased turbidity from suspended sediments, which are scoured from the bottom and from the southern shoreline of the lake in the, particularly in zone S1. Figure 12 shows the relationship between Secchi depth and chlorophyll a concentrations in Lake of the Woods surface waters in the fall of 2014.

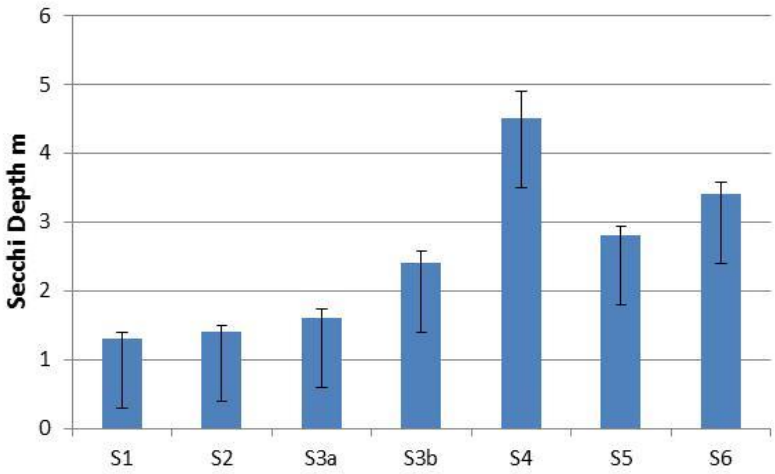


Figure 11. Average Secchi depth in basins of Lake of the Woods from 2012 to 2014.

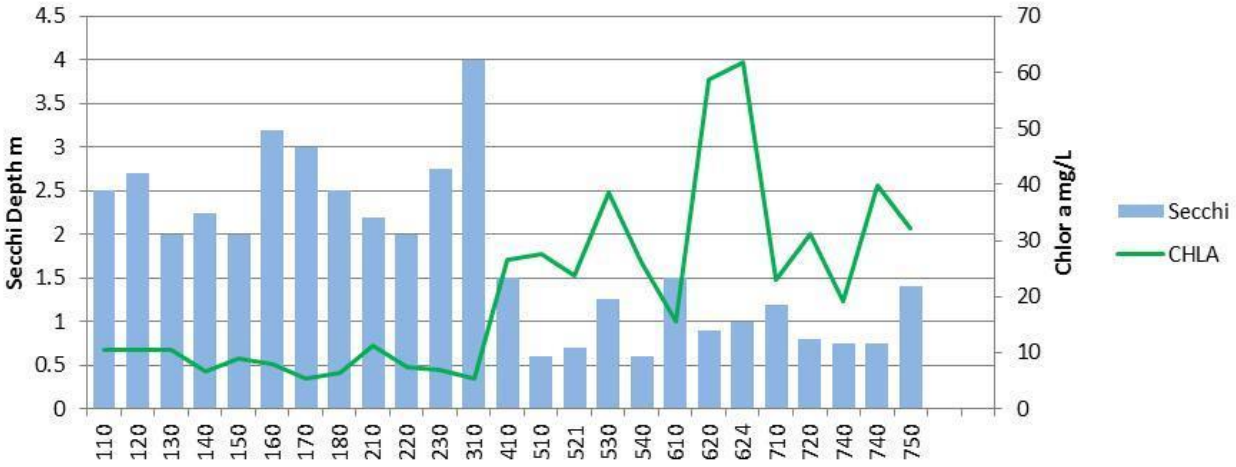


Figure 12. The relationship between Secchi depth and chlorophyll a concentrations in surface waters of EC sites on Lake of the Woods in the fall of 2014.

Water quality parameters vary amongst the hydrological basins in Lake of the Woods, related to flow and mixing regimes. In general similarities in water quality are seen along the main central corridor of the lake where water flows from the mouth of the Rainy River, north to the Winnipeg river while basins to the east such as Whitefish Bay (S4) and west such as Clear Water Bay (S6), isolated from the main flow, are somewhat differentiated. For many parameters, particularly nutrients, there is also a south to north gradient.

For anions and cations concentrations are most similar along the main flow of water from S1 to S3a, S3b to S5. Zones S6 and especially S4, which are isolated from the main flow are differentiated by higher concentrations of anions and cations in S4 (Clear Water Bay) and significantly lower concentrations of anions and cations in S6 (Whitefish Bay). An example is given below in Figure 13 for calcium concentrations, while other anions and cations follow a similar pattern. For more data on individual parameters see appendix A4. Concentrations of dissolved organic carbon (DOC) are highest in the southern zones of the lake (S1, S2, S3a), likely contributing to lower water clarity in these zones, and decline to the north, with concentrations in S4-Clearwater, the basin with the greatest water clarity, being particularly low (Fig. 14). In contrast dissolved inorganic carbon (DIC) is highest in the most northern basins, S5 and S6, while still be lowest in S4-Clearwater Bay (Fig. 15).

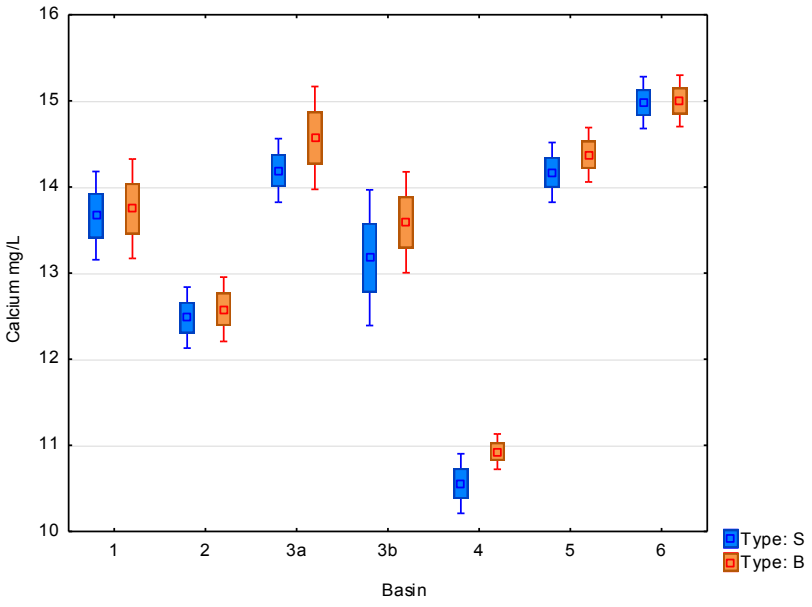


Figure 13. Mean (central point), standard error (box) and 2x standard error (whiskers) for calcium concentrations in basins in Lake of the Woods from 2012 to 2014 in surface (S) and bottom waters (B). Note data from each year included in error estimates.

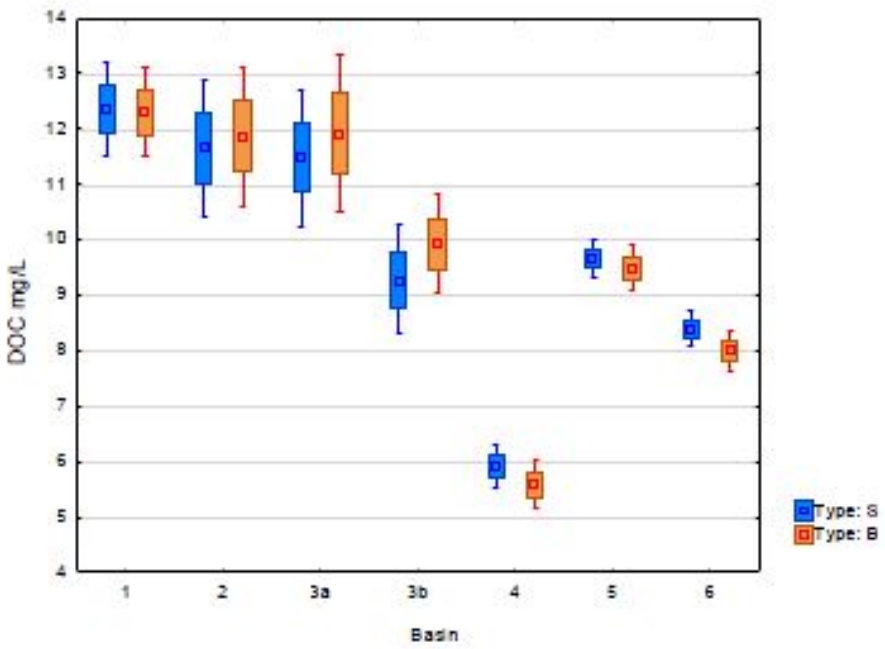


Figure 14. Average dissolved organic carbon (DOC) concentrations in basins of Lake of the Woods from 2012-2014. Note data from each year included in error estimates.

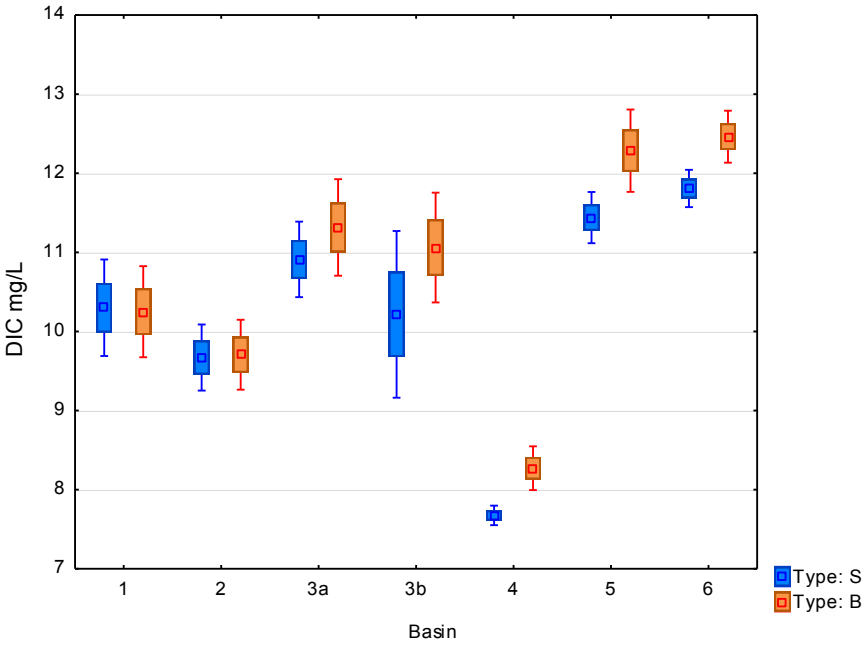


Figure 15. Averaged dissolved inorganic carbon (DIC) concentrations in basins of Lake of the Woods from 2012 to 2014. Note data from each year included in error estimates.

Nutrient concentrations vary amongst basins, being in general higher in the south, by depth in those basins where thermal stratification is a factor and in some cases also by season. Phosphorus is the key nutrient of interest in Lake of the Woods as it is often the limiting nutrient in the growth and severity of algal blooms on Lake of the Woods (Pascoe et al 2014). In general total phosphorus concentrations are higher later in the season, in the early fall during the period of cyanobacterial blooms as compared to June samples. Concentrations are also higher in bottom waters, particularly in the fall (Fig. 16).

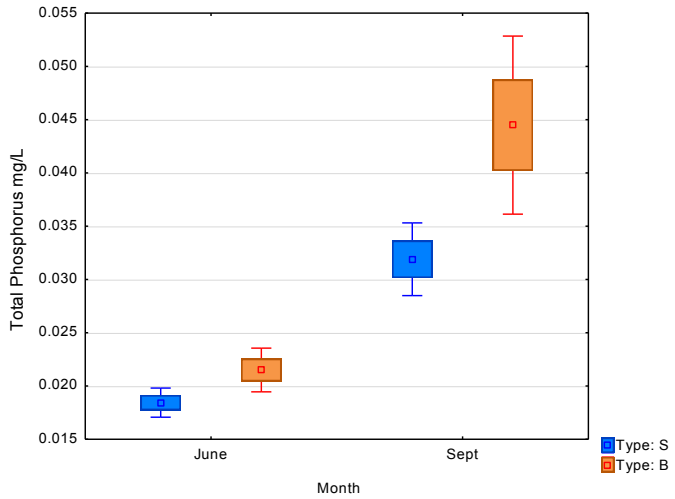


Figure 16. Average concentrations of total phosphorus in June and September of 2012-2014 in both surface waters (S) and bottom waters (B).

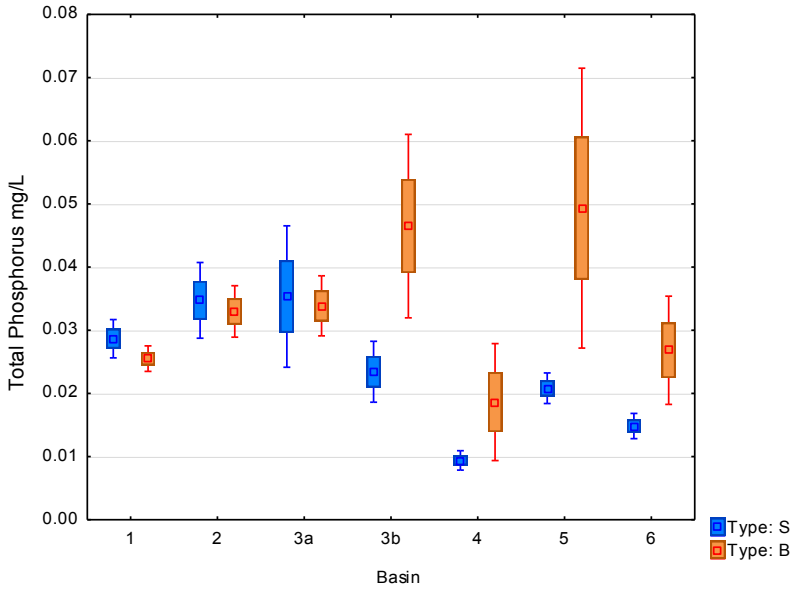


Figure 17. Average concentrations of total phosphorus amongst EC basins in Lake of the Woods from 2012-2014 in both surface (S) and bottom waters (B).

Total phosphorus concentrations vary by basin as well as depth. In general concentrations in surface waters, where phosphorus is available for algal bloom growth, are highest in the southern zones (S1, S2, S3a) and as significant thermal stratification does not develop in the south, concentrations are similar in bottom waters (Fig. 17). In the deeper, northern basins (S3b, S4, S5, S6) which undergo thermal stratification concentrations of total phosphorus are lower in surface waters but are significantly higher in bottom waters, sometimes exceeding concentrations seen in the southern basins particularly in S3b and S5. High concentrations of phosphorus in bottom waters of the north may be due to internal loadings from the sediments, particularly under anoxic conditions in the summer months during thermal stratification. Figure 18 shows concentrations of dissolved phosphorus, the form most available for phytoplankton growth. The highest concentrations are in the bottom waters of zones S3b and S5 which experience thermal stratification and are likely the result of internal loadings from sediments. It is important to note that this P is not available for phytoplankton growth until fall when the lake turns and the water column becomes mixed again, whereas dissolved P in surface waters may be depleted by the biota. Particulate phosphorus is highest in the southern portion of the lake in both surface and bottom waters. Much of this may be made up of particles of suspended sediments scoured from the bottom, although much of this particulate phosphorus may itself be cyanobacteria and other phytoplankton. Figure 20 shows the distribution of total phosphorus in the surface waters at water quality monitoring sites on Lake of the Woods in the fall of 2014. Note that concentrations were particularly high in Sabaskong Bay, Little and Big Traverse and were largely made up of particulate phosphorus coinciding with algal blooms.

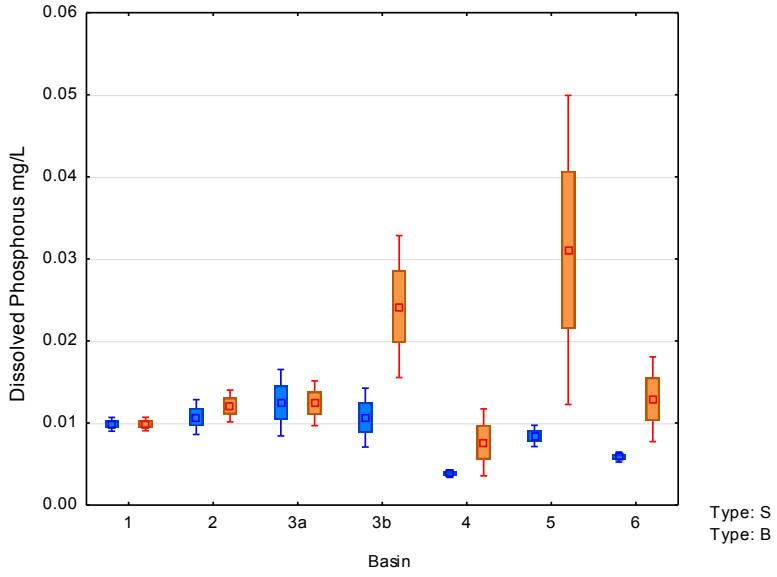


Figure 18. Average concentrations of dissolved phosphorus in basins of Lake of the Woods in surface (S) and bottom waters (B) from 2012 to 2014.

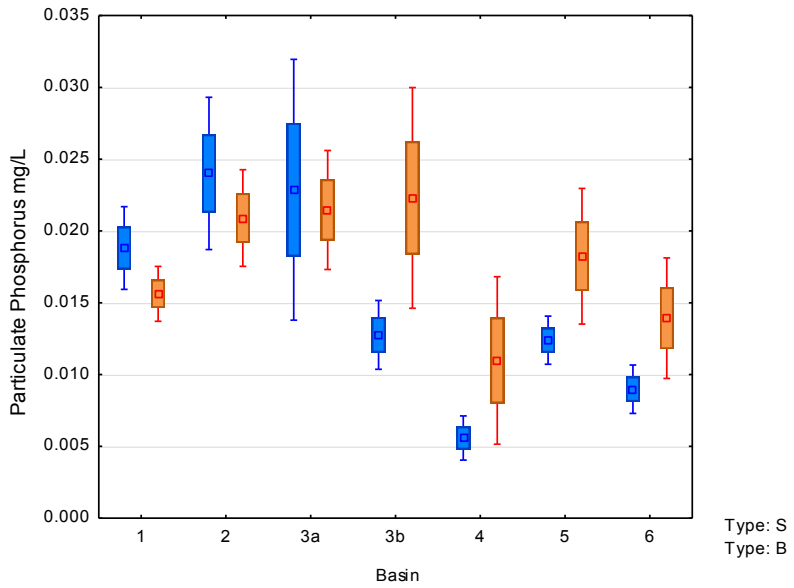


Figure 19. Average concentrations of particulate phosphorus in basins of Lake of the Woods in surface (S) and bottom waters (B) from 2012 to 2014.

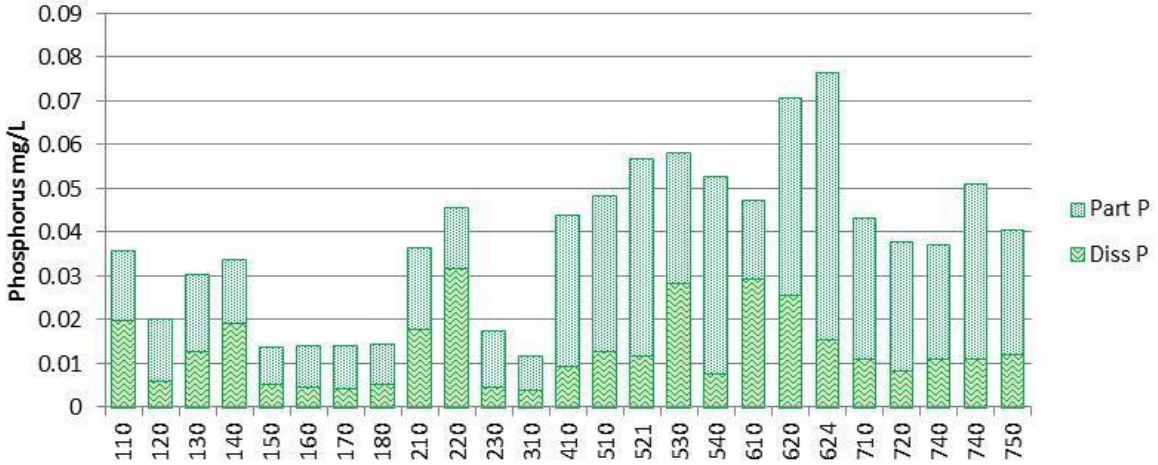


Figure 20. Particulate and dissolved phosphorus fractions in surface waters at specific monitoring stations on Lake of the Woods in the fall of 2014.

Nitrogen is another important nutrient in algal bloom dynamics. Although cyanobacterial assemblages in Lake of the Woods in the summer and fall are dominated by nitrogen fixing species (Chen 2009), there was some indication of nitrogen deficiency in the fall during bloom periods in Lake of the Woods, as indicated by the nitrogen deficit assay and the SSR index (Pascoe *et al* 2014, Chpt 6). Total nitrogen concentrations were generally higher in the south in basins S1, S2, S3a in addition to zone S5 near Kenora. In basins where thermal stratification is present in the summer months concentrations of total nitrogen were highest in bottom waters. Nitrates/nitrites and ammonia are more biologically available forms of nitrogen, and are required for phytoplankton growth, with the exception of nitrogen fixers. These compounds are also toxic to biota at higher concentrations. Ammonia concentrations in Lake of the Woods are well below

concentrations considered toxic to biota. They were highest in the bottom waters of zones S3b and S5, likely as a result of organic decomposition in the anoxic bottom waters of these basins, which are retained there during thermal stratification (Fig. 22). Concentrations of nitrates/nitrites are low to moderate in Lake of the Woods and are well below those concentrations toxic to biota. Concentrations were highest in bottom waters in the northern basins (S3b, S4, S5,S6) and were high in both surface

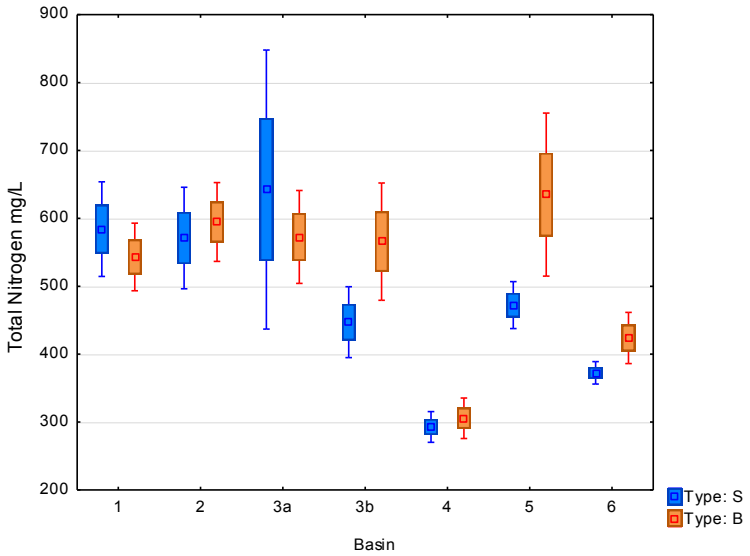


Figure 21. Average total nitrogen in surface (S) and bottom (B) waters of Lake of the Woods basins from 2012-2014.

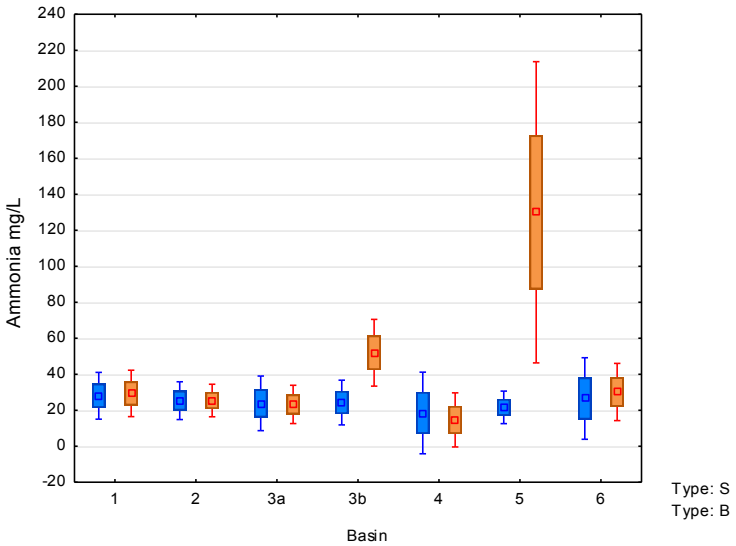


Figure 22. Average ammonia concentrations in basins of Lake of the Woods in both surface (S) and bottom waters (B) from 2012 to 2014.

and bottom waters of S6 Clear Water Bay although a few high surface concentrations in this zone likely resulted in a higher than representative average (Fig. 23). Figure 24 shows the distribution of different nitrogen fraction of surface waters in the fall of 2014. Note that dissolved available ammonia and nitrates make up a very small proportion of total nitrogen. Particulate organic nitrogen (PON) is highest in Big and Little Traverse.

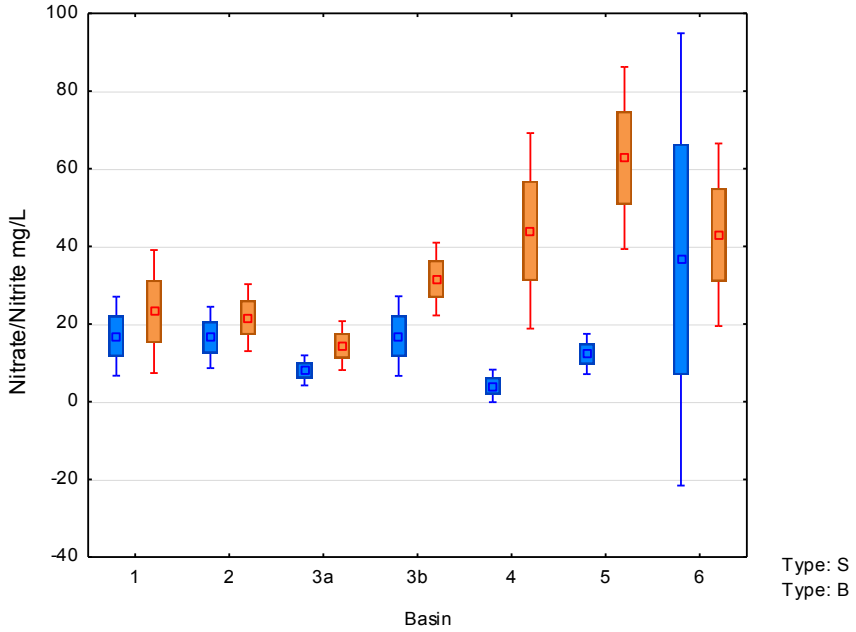


Figure 23. Average nitrate/nitrite concentrations in basins of Lake of the Woods in both surface (S) and bottom waters (B) from 2012 to 2014.

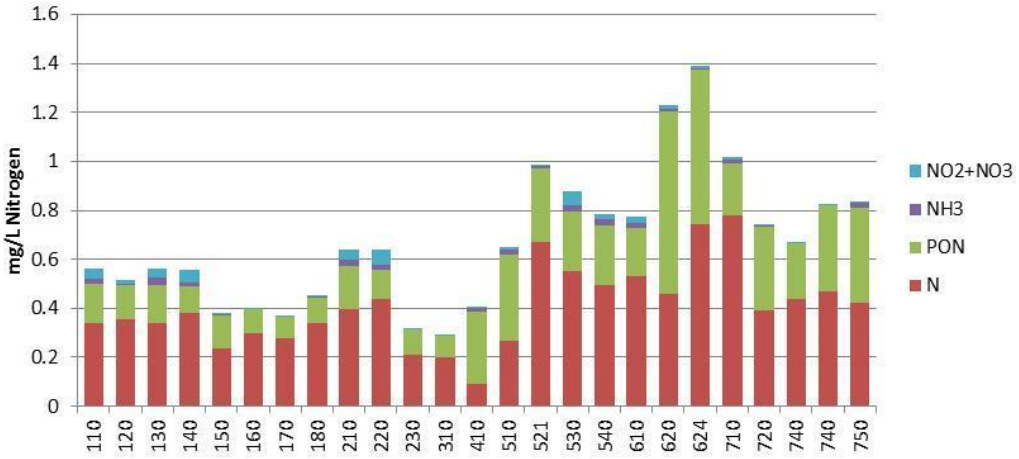


Figure 24. Nitrogen fractions in surface water quality sites on Lake of the Woods in the fall of 2014.

Benthic Monitoring:

EC-WQMS monitored both the benthic sediment and invertebrate community in Lake of the Woods. A description of the benthic invertebrate community can be found in Pascoe *et al* 2014. EC-WQMS is currently analyzing taxonomic data from additional benthic sites on the Lake with the intention of completing a CABIN model in the near future.

***Sediment chemistry*:**

Sediment chemistry was evaluated for 61 stations on Lake of the Woods between 2008 and 2013. Surficial sediments were relatively high in metals and nutrients, often exceeding provincial and federal sediment quality guidelines for the protection of aquatic life (CCME 1999, OMOE 1993). Table 1 shows a summary of these exceedances in Lake of the Woods sediment sites. Generally concentrations of metals exceeded lowest level effect guidelines in a number of sites for arsenic, copper, chromium, manganese, nickel and lead but rarely exceeded probable or severe effect levels. Arsenic and mercury exceeded the Ontario severe effect level at one site each. Concentrations of total nitrogen and phosphorus also exceeded provincial sediment quality guidelines, an indication of the large amount of nutrients sequestered in the sediments of Lake of the Woods.

Note: Sediment chemistry data is stored in Environment Canada's national CABIN database and is available upon request.

Table 1. Surficial sediment chemistry of benthic stations on Lake of the Woods based on 61 stations. Concentrations are given in ug/g. Also shown are Ontario's sediment guidelines for aquatic ecosystems at the low effect level (LEL) and the severe effect level (SEL) in ug/g (mg/kg) dry weight and the Canadian Council of Ministers of the Environment (CCME) guidelines for aquatic life probable effect levels (PEL) and the percentage of sites that exceed these guidelines.

Compound	MDL	Mean	Max	Ont LEL	% over	CCME SQG	% Over	CCME PEL	% over	Ont SEL	% over
Metals											
Arsenic	1	6.5	39.4	6	28%	5.9	31%	17	8%	33	2%
Cadmium	1	0.41	2.5	0.6	5%	0.6	5%	3.5	0%	10	0%
Chromium	1	40.6	57.0	26	89%	37.3	70%	90	0%	110	0%
Copper	1	31.3	61	16	72%	35.7	38%	197	0%	110	0%
Lead	5	25.8	47.0	31	26%	35	15%	91.3	0%	250	0%
Mercury	0.005	0.14	3.07	0.2	3%	0.17	5%	0.486	2%	2.0	2%
Manganese	1	1516	18000	460	80%					1,100	39%
Nickel	1	33.3	61.0	16	92%					75	0%
Zinc	1	93.5	133	120	15%	123	13%	315	0%	820	0%
Nutrients											
TOC %	0.1%	5.9%	15.8%	1%	98%					10%	5%
TKN	0.05	7087	15200	550	100%					4,800	84%
P – total	0.01	1233	4205	600	100%					2,000	8%

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Appendix

A1. Annual concentrations of nutrients at four locations on the Rainy River. Median concentrations are given ± standard deviations, followed by (minimum- maximums). All units are in mg/L. Where applicable, Rainy River Alert Levels are provided.

Compound	**NO_3 + NO_2**	**NH_3+ NH_4 Total**	**TKN-N**	**Total P**	**Dissolved P**
Alert Level	*NO_2 only	*NH_3 only		0.030	
Fort Frances					
2013 n = 14	0.030 ± 0.031 (0.016 - 0.118)	0.024 ± 0.01 (0.008 - 0.037)	0.45 ± 0.052 (0.36 - 0.56)	0.017 ± 0.002 (0.015 - 0.021)	0.006 ± 0.002 (0.005 - 0.012)
2014 n = 17	0.063 ± 0.035 (0.033 - 0.129)	0.022 ± 0.01 (0.005 - 0.038)	0.47 ± 0.09 (0.35 - 0.74)	0.016 ± 0.004 0.004 - 0.022	0.008 ± 0.001 (0.006 - 0.01)
Manitou Rapids					
2013 n = 14	0.031 ± 0.079 (0.009 – 0.032)	0.027 ± 0.018 (0.005 – 0.076)	0.49 ± 0.13 (0.45 – 0.92)	0.02 ± 0.015 (0.017 – 0.075)	0.007 ± 0.004 (0.006 – 0.022)
2014 n = 16	0.057 ± 0.065 (0.031 – 0.301)	0.022 ± 0.025 (0.009 – 0.116)	0.51 ±0.17 (0.36 – 1.09)	0.021 ± 0.018 (0.014 – 0.089)	0.009 ± 0.007 (0.006 – 0.037)
Long Sault					
2013 n = 14	0.03 ± 0.079 (0.013 - 0.316)	0.025 ± 0.018 (0.005 - 0.076)	0.49 ± 0.13 (0.45 - 0.92)	0.019 ± 0.014 (0.016 - 0.070)	0.007 ± 0.004 (0.06 - 0.022)
2014 n = 17	0.061 ± 0.072 (0.024 – 0.331)	0.022 ± 0.028 (0.008 – 0.132)	0.51 ± 0.18 (0.37 – 1.09)	0.021 ± 0.021 (0.016 - 0.107)	0.009 ± 0.011 (0.007 ± 0.053)
Oak Groves					
2012 n = 15	0.01 ± 0.022 (0.003 – 0.075)	0.017 ± 0.009 (0.005 – 0.035)	0.427 ± 0.043 (0.35 – 0.46)	0.021 ± 0.003 (0.017 – 0.029)	0.009 ± 0.002 (0.005 – 0.013)
2013 n = 25	0.077 ± 0.05 (0.01 – 0.184)	0.016 ± 0.016 (0.006 – 0.085)	0.50 ± 0.12 (0.37– 0.78)	0.02 ± 0.012 (0.015 – 0.073)	0.01 ± 0.008 (0.007 – 0.046)
2014 n = 26	0.074 ± 0.09 (0.024 – 0.40)	0.022 ± 0.048 (0.006 – 0.254)	0.547 ± 0.226 (0.37 – 1.08)	0.023 ± 0.026 (0.015 – 0.138)	0.012 ± 0.018 (0.007 – 0.10)

A2. Annual concentrations of dissolved major ions at four locations on the Rainy River. Median concentrations are given ± standard deviations, followed by (minimum- maximums). All units are in mg/L. Where applicable, Rainy River alert levels are provided.

Compound	Chloride	Sulphate	Calcium	Magnesium	Potasium	Sodium
Alert Level	100					
Fort Frances						
2013 n = 14	1.79 ± 0.36 (1.42 – 2.51)	4.13 ± 0.83 (3.1 – 5.7)	6.23 ± 0.49 (5.29 – 7.15)	1.92 ± 0.09 (1.7 – 1.98)	0.76 ± 0.09 (0.68 – 0.94)	2.5 ± 0.66 1.91 – 4.13)
2014 n = 17	1.57 ± 0.4 (1.33 – 2.41)	3.06 ± 0.88 (2.5 – 5.03)	6.16 ± 0.64 (5.85 – 7.8)	1.9 ± 0.19 (1.74 – 2.41)	0.70 ± 0.06 (0.61 – 0.84)	1.87 ± 0.61 (1.71 – 3.43)
Manitou Rapids						
2013 n = 14	1.89 ± 0.43 (1.43 – 2.75)	4.16 ± 0.97 (3.08 – 5.96)	8.1 ± 1.27 (7.05 – 10.9)	2.53 ± 0.46 (2.26 -3.69)	0.80 ± 0.29 (0.69 – 1.84)	2.57 ± 0.74 (1.91 – 4.13
2014 n = 16	1.885 ± 0.84 (1.37 – 4.88)	4.17 ± 1.58 (2.52 – 8.93)	8.45 ± 2.31 (6.84 – 16.6)	2.76 ± 1.07 (2.07 – 6.66)	0.77 ± 0.44 (0.63 – 2.50)	2.52 ± 0.78 (1.77 – 4.29)
Long Sault						
2013 n = 14	1.86 ± 0.43 (1.43 – 2.76)	4.15 ± 0.99 (3.08 – 5.93)	8.23 ± 1.30 (7.04 – 11.1)	2.63 ±0.48 (2.26 – 3.84)	0.80 ± 0.30 (0.69 – 1.84)	2.59 ± 0.73 (1.93 – 4.12)
2014 n = 17	1.92 ± 0.87 (1.35 – 5.12)	4.18 ± 1.66 (2.38 – 9.27)	8.65 ± 2.2 (7.04– 16.8)	2.85 ± 1.07 (2.17 – 6.89)	0.79 ± 0.52 (0.63 – 2.92)	2.84 ± 0.79 (1.73 – 4.36)
Oak Groves						
2012 n =15	2.65 ± 0.64 (1.84 – 3.63)	6.64 ± 1.76 (3.85 – 9.09)	9.66 ± 1.22 (7.46 – 11.2)	2.9 ± 0.51 (2.42 – 3.97)	0.84 ± 0.11 (0.64 – 1.00)	4.66 ± 1.25 (2.41 – 5.54)
2013 n = 25	2.18 ± 0.51 (1.47 – 3.61)	5.18 ± 0.90 (3.3 – 7.06)	9.03 ± 1.36 (7.34 – 12.2)	2.92 ± 0.55 (2.32 – 4.20)	0.81 ± 0.68 (0.71 – 2.13)	3.12 ± 0.68 (1.80 – 4.40)
2014 n = 26	1.86 ± 0.61 (1.27 – 4.06)	4.25 ±1.25 (2.45 – 6.18)	9.41 ± 2.70 (7.67 – 16.5)	3.19 ± 1.15 (2.4 – 5.9)	0.80 ± 0.77 (0.65 – 4.26)	2.32 ± 0.61 (1.57 – 3.54)

A3. Concentrations of dissolved major ions at surface (S) and bottom minus two meters (B) in the six hydrological basins of Lake of the Woods from 2012 – 2014. Mean concentrations are given ± standard deviations, followed by (minimum- maximums). All units are in mg/L.

Compound		Cl	SO_4	Ca	K	Mg	Na	DOC	DIC	SiO_2
S1	S	2.14 ± 0.22 (1.61 - 2.40)	4.93 ± 0.59 (3.27 - 5.6)	13.7 ± 1.3 (11.2 - 15.8)	0.93 ± 0.08 (0.75 - 1.08)	4.70 ± 0.47 (3.68 - 5.51)	3.00 ± 0.37 (2.17 - 3.42)	12.4 ± 1.8 (10.0 - 15.6)	10.3 ± 1.3 (7.9 - 12.1)	3.60 ± 1.26 (0.73 - 5.00)
	B	2.16 ± 0.22 (1.6 - 2.44)	4.97 ± 0.61 (3.26 - 5.5)	13.7 ± 1.5 (11.2 - 16.4)	0.93 ± 0.10 (0.7 - 1.12)	4.76 ± 0.53 (3.68 - 5.7)	3.02 ± 0.37 (2.17 - 3.40)	12.3 ± 1.6 (9.8 - 14.8)	10.3 ± 1.2 (8.0 - 12.1)	3.73 ± 1.34 (0.73 - 4.91)
S2	S	2.07 ± 0.23 (1.62 - 2.43)	4.43 ± 0.86 (2.8 - 5.6)	12.5 ± 0.9 (10.5 - 14.1)	0.93 ± 0.07 (0.74 - 1.04)	4.38 ± 0.37 (3.55 - 4.91)	2.93 ± 0.45 (2.16 - 3.56)	11.6 ± 2.6 (8.2 - 16.3)	9.7 ± 0.9 (8.4 - 11.2)	4.62 ± 1.93 (1.43 - 7.85)
	B	2.09 ± 0.24 (1.63 - 2.44)	4.40 ± 0.86 (2.15 - 5.6)	12.6 ± 1.0 (10.4 - 14.8)	0.90 ± 0.08 (0.73 - 1.04)	4.42 ± 0.45 (3.33 - 5.36)	2.92 ±0.45 (2.14 - 3.51)	11.9 ± 2.7 (8.1 - 16.1)	9.7 ± 1.0 (8.5 - 11.9)	4.67 ± 1.95 (1.49 - 7.94)
S3a	S	2.13 ± 0.19 (1.85 - 2.43)	4.84 ± 0.56 (3.9 – 5.41)	14.2 ± 0.7 (13.2 - 15.3)	0.92 ± 0.07 (0.81 - 1.02)	4.89 ± 0.31 (4.44 - 5.41)	3.04 ± 0.38 (2.43 - 3.41)	11.5 ± 1.9 (9.3 - 14.3)	10.9 ± 0.7 (10.0 - 12.0)	3.17 ± 2.13 (0.72 - 5.52)
	B	2.15 ± 0.24 (1.43 - 2.43)	4.94 ± 0.49 (3.88 - 5.4)	14.6 ± 1.4 (13.1 - 19.6)	0.92 ± 0.09 (0.79 - 1.03)	5.05 ± 0.48 (4.43 - 6.63)	3.11 ± 0.35 (2.43 - 3.39)	11.9 ± 2.6 (9.2 - 18.7)	11.3 ± 1.1 (10.0 - 14.3)	3.83 ± 2.13 (0.72 - 5.52)
S3b	S	1.9 ± 0.36 (1.03 - 2.26)	4.30 ± 0.88 (2.44 - 5.36)	13.2 ± 1.7 (9.4 - 14.7)	0.88 ± 0.1 (0.71 - 1.04)	4.20 ± 1.07 (1.94 - 5.17)	2.76 ± 0.53 (1.64 - 3.43)	9.3 ± 1.7 (6.5 - 12.4)	10.2 ± 1.9 (6.7 - 12.2)	2.94 ± 1.22 (0.9 - 4.78)
	B	1.91 ± 0.31 (1.19 - 2.28)	4.22 ± 0.79 (2.55 - 5.43)	13.6 ± 1.5 (9.9 - 15.9)	0.91 ± 0.1 (0.70 - 1.08)	4.28 ± 0.92 (2.04 - 5.26)	2.77 ± 0.49 (1.80 - 3.44)	9.9 ± 1.9 (6.8 - 14.3)	11.1 ± 1.5 (7.5 - 14.0)	4.95 ± 1.58 (2.63 - 8.02)
S4	S	1.07 ± 0.02 (1.03 - 1.09)	2.43 ± 0.05 (2.34 - 2.47)	10.6 ± 0.4 (9.8 - 11.0)	0.72 ± 0.07 (0.62 - 0.80)	1.92 ± 0.04 (1.87 - 1.99)	1.63 ± 0.05 (1.57 - 1.70)	5.9 ± 0.4 (5.5 - 6.3)	7.7 ± 0.1 (7.5 - 7.8)	1.48 ± 2.3 (1.28 - 1.69)
	B	1.01 ± 0.09 (0.76 - 1.07)	2.48 ± 0.10 (2.30 - 2.66)	10.9 ± 0.3 (10.4 - 11.6)	0.75 ± 0.04 (0.70 - 0.82)	1.96 ± 0.07 (1.86 - 2.12)	1.61 ± 0.07 (1.50 - 1.74)	5.6 ± 0.6 (5.0 - 6.5)	8.3 ± 0.4 (7.8 - 8.8)	2.43 ± 1.15 (1.37 - 4.8
S5	S	2.18 ± 0.18 (1.9 - 2.77)	4.71 ± 0.32 (4.18 - 5.24)	14.2 ± 1.0 (12.3 - 15.9)	0.91 ± 0.07 (0.73 - 1.05)	4.70 ± 0.30 (4.11 - 5.13)	3.05 ± 0.26 (2.55 - 3.54)	9.7 ± 0.8 (8.5 - 11.3)	11.4 ± 0.7 (10.2 - 12.6)	4.00 ± 0.50 (2.81 - 4.51)
	B	2.2 ± 0.20 (1.92 - 2.73)	4.59 ± 0.41 (3.54 - 5.22)	14.4 ± 1.0 (12.5 - 15.9)	0.93 ± 0.09 (0.74 - 1.19)	4.75 ± 0.29 (4.26 - 5.30)	3.07 ± 0.27 (2.53 - 3.58)	9.5 ± 1.0 (8.0 - 11.3)	12.3 ± 1.2 (10.3 - 15.1)	5.38 ± 2.13 (3.17 - 9.67)
S6	S	2.2 ± 0.2 (2.0 - 2.69)	4.11 ± 0.66 (3.89 - 4.5)	15.0 ± 0.7 (13.9 - 16.8)	1.00 ± 0.06 (0.85 - 1.09)	4.52 ± 0.21 (4.12 - 4.81)	2.90 ± 0.18 (2.59 - 3.17)	8.4 ± 0.6 (7.4 - 9.2)	11.8 ± 0.4 (10.7 - 12.4)	2.98 ± 0.67 (1.94 - 3.89)
	B	2.24 ± 0.21 (2.0 - 2.69)	4.06 ± 0.23 (3.51 - 4.5)	15.0 ± 0.8 (13.8 - 16.6)	1.02 ± 0.08 (0.85 - 1.15)	4.54 ± 0.20 (4.17 - 4.88)	2.94 ± 0.16 (2.62 - 3.20)	8.0 ± 0.7 (7.3 -9.5)	12.5 ± 0.7 (11.6 - 14.2)	3.84 ± 0.84 (2.44 - 5.39)

A4. Concentrations of nutrients at surface (S) and bottom minus two meters (B) in the six hydrological basins of Lake of the Woods from 2012-2014. Mean concentrations are given ± standard deviations, followed by (minimum- maximums). All units are in mg/L. ND is non detect.

Compound		TP	DP	PP	NH3/NH4	NO2/NO3	TN	Chlor a
S1	S	0.029 ± 0.008 (0.020-0.049)	0.010 ± 0.002 (0.007-0.014)	0.019 ± 0.007 (0.010-0.035)	0.028 ± 0.033 (ND - 0.09)	0.017 ± 0.026 (ND – 0.096)	0.58 ± 0.17 (0.37 – 1.02)	10.9 ± 1.7 (2.9 – 32.2)
	B	0.026 ± 0.005 (0.018-0.036)	0.010 ± 0.002 (0.007-0.014)	0.016 ± 0.005 (0.008-0.024)	0.029 ± 0.033 (ND - 0.096)	0.023 ± 0.041 (ND – 0.156)	0.54 ± 0.13 (0.40 – 0.85)	7.1 ± 1.2 (1.2 – 27.4)
S2	S	0.035 ± 0.015 (0.017-0.067)	0.011 ± 0.005 (0.001-0.029)	0.024 ± 0.013 (0.008-0.055)	0.025 ± 0.026 (0.004-0.081)	0.017 ± 0.020 (ND – 0.079)	0.57 ± 0.17 (0.39 – 0.99)	11.2 ± 2.1 (1.3 – 38.6)
	B	0.033 ± 0.011 (0.015-0.061)	0.012 ± 0.005 (0.006-0.029)	0.021 ± 0.009 (0.007-0.049)	0.025 ± 0.025 (ND - 0.093)	0.022 ± 0.024 (ND – 0.111)	0.59 ± 0.15 (0.36 – 0.97)	8.6 ± 1.2 (1.7 – 25.3)
S3a	S	0.035 ± 0.021 (0.014-0.077)	0.012 ± 0.007 (0.006-0.029)	0.023 ± 0.017 (0.007-0.061)	0.024 ± 0.028 (ND - 0.082)	0.008 ± 0.007 (ND – 0.022)	0.64 ± 0.35 (0.39 – 1.39)	14.8 ± 5.4 (0.8 – 61.9)
	B	0.034 ± 0.011 (0.017-0.053)	0.012 ± 0.006 (0.006-0.028)	0.021 ± 0.009 (0.007-0.044)	0.023 ± 0.024 (ND - 0.087)	0.014 ± 0.014 (ND – 0.057)	0.57 ± 0.15 (0.39 – 0.86)	7.6 ± 1.1 (1.2 – 17.8)
S3b	S	0.023 ± 0.01 (0.009-0.046)	0.011 ± 0.008 (0.005-0.032)	0.013 ± 0.005 (0.003-0.023)	0.024 ± 0.026 (ND - 0.078)	0.017 ± 0.022 (ND – 0.063)	0.45 ± 0.10 (0.32 – 0.64)	5.8 ± 0.6 (1.6 – 11.3)
	B	0.046 ± 0.037 (0.013-0.146)	0.024 ± 0.022 (0.006-0.086)	0.022 ± 0.020 (0.005-0.071)	0.052 ± 0.047 (ND - 0.176)	0.032 ± 0.024 (ND – 0.094)	0.57 ± 0.21 (0.34 – 1.33)	5.9 ± 1.4 (0.4 – 23.9)
S4	S	0.009 ± 0.002 (0.007-0.012)	0.004 ± 0.001 (0.003-0.005)	0.006 ± 0.002 (0.003-0.008)	0.019 ± 0.028 (ND - 0.074)	0.041 ± 0.005 (ND- 0.014)	0.29 ± 0.03 (0.27 – 0.34)	2.5 ± 0.8 (0.9 – 5.4)
	B	0.019 ± 0.016 (0.008-0.063)	0.008 ± 0.007 (0.003-0.028)	0.011 ± 0.010 (0.008-0.036)	0.015 ± 0.025 (ND - 0.087)	0.044 ± 0.043 (ND – 0.137)	0.31 ± 0.48 (0.22 – 0.36)	1.5 ± 0.5 (0.2 – 5.5)
S5	S	0.021 ± 0.007 (0.011-0.036)	0.008 ± 0.004 (0.005-0.020)	0.012 ± 0.005 (0.004-0.022)	0.022 ± 0.025 (ND - 0.085)	0.012 ± 0.014 (ND - 0.051)	0.47 ± 0.09 (0.34 – 0.70)	5.5 ± 0.6 (1.4 – 11.9)
	B	0.05 ± 0.067 (0.014-0.337)	0.031 ± 0.057 (0.006-0.258)	0.018 ± 0.014 (0.006-0.091)	0.130 ± 0.245 (ND - 1.000)	0.063 ± 0.071 (ND – 0.241)	0.63 ± 0.34 (0.35 – 1.88)	3.6 ± 0.6 (0.4 – 12.9)
S6	S	0.015 ± 0.005 (0.010-0.029)	0.006 ± 0.001 (0.004-0.011)	0.009 ± 0.004 (0.004-0.018)	0.027 ± 0.05 (ND – 0.204)	0.037 ± 0.13 (ND – 0.567)	0.37 ± 0.35 (0.33 – 0.43)	3.7 ± 0.5 (1.0 – 9.0)
	B	0.027 ± 0.067 (0.010-0.110)	0.013 ± 0.013 (0.005-0.064)	0.014 ± 0.010 (0.004-0.046)	0.030± 0.039 (ND – 0.146)	0.043 ± 0.057 (ND – 0.184)	0.42 ± 0.86 (0.33 – 0.67)	3.4 ± 0.8 (0.3 – 13.7)

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Ontario

November 5, 2015

Michael Goffin
Canadian Co-chair
Environment Canada
Toronto, Ontario

Colonel Daniel C. Koprowski
United States Co-chair
St. Paul District Corps of Engineers
St. Paul, Minnesota

Dear Mr. Goffin and Colonel Koprowski:

Please accept this letter in response to the request from the International Joint Commission's International Rainy Lake of the Woods Watershed Board for water quality data and information collected by the Ministry of the Environment and Climate Change (MOECC).

MOECC monitors nine tributaries to the Lake of the Woods watershed approximately once a week during spring freshet, and every two weeks thereafter, until the end of October (weather dependent). These monitoring data provide annual nutrient loading data from key Canadian tributaries to inform nutrient budget estimates and watershed modelling for Lake of the Woods. In addition to these diffuse watershed contributions, MOECC regulates point source discharges into the Lake of the Woods watershed from municipal and industrial sources.

Lake of the Woods Tributary Monitoring

Table 1 provides a description of sampling locations for the nine tributary monitoring locations in the Lake of the Woods Watershed. Figure 6 provides a map of the monitoring locations.

Table 1. Sampling Locations

Tributary Name	Easting	Northing	Watershed Area (km2)
LaVallee River	452713	5375933	318
Sturgeon River	424889	5390560	213
Pinewood River	412997	5405714	575
Little Grassy River at Highway 600	399807	5422213	334
Log River at Nestor Falls	432421	5440930	437
Atikwa River	430937	5472760	2033
Berry Creek	429303	5477352	1011
Rushing River at Blindfold L Outlet	406608	5502158	395
Deception Creek	369197	5508400	65

Tributaries were sampled for the following parameters:

- Temperature
- Dissolved Oxygen
- Field Conductivity
- Water Level
- Total Suspended Solids
- Total Dissolved Solids
- Conductivity
- pH
- Alkalinity
- Total Ammonia Nitrogen
- Nitrite, Nitrate+nitrite
- Total Phosphorus
- Phosphate
- Total Kjeldahl Nitrogen
- Dissolved Organic Carbon
- Dissolved Inorganic Carbon
- Reactive Silicate

The focus of the summary below is on total phosphorus concentrations, loads and yields.

Figures 1 to 5b below provide interpretative summaries of the Lake of the Woods tributary monitoring data.

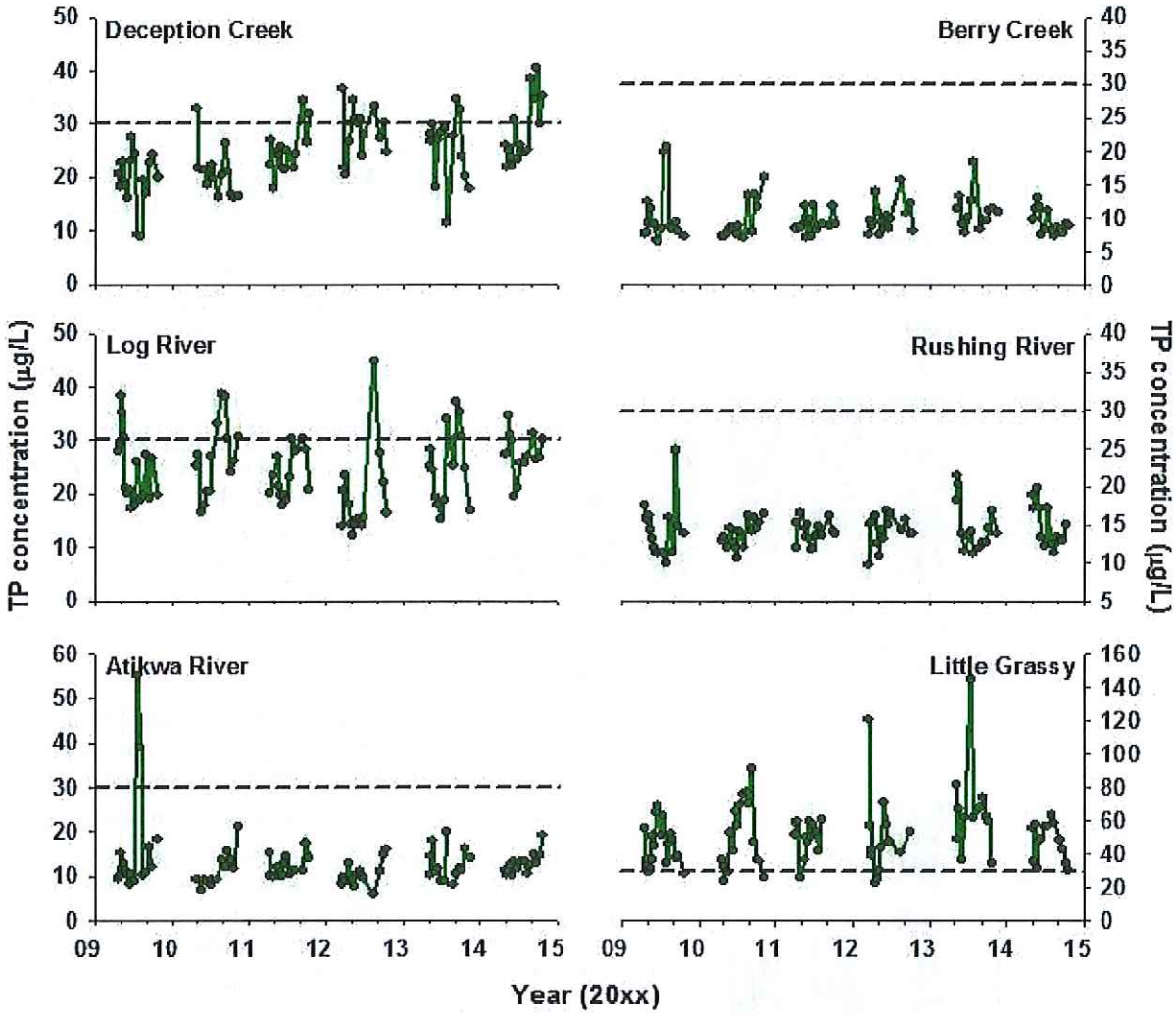


Figure 1: Total phosphorus (TP) concentration data are shown for six Canadian tributaries of the Lake of the Woods, sampled during the ice-free seasons of 2009 to 2014. With the exception of Deception Creek, which shows an increase in TP concentrations ([TP]) from 2009 to 2011, TP levels have changed little over time. The tributaries within the Canadian Shield (Atikwa R, Berry Ck, Rushing R) that have relatively low dissolved organic carbon concentrations (DOC < 10 mg/L) have [TP] consistently below the Ontario Provincial Water Quality Guideline (PWQO) for streams and rivers (i.e., 30 µg/L, below which excessive plant growth in rivers and streams should be eliminated; shown as dashed horizontal lines). The Log River and Deception Creek, also within the Shield but with relatively higher DOC concentrations (DOC between 10 and 20 mg/L), had TP values both above and below the PWQO. The majority of samples collected from the Little Grassy River, the most southerly of the tributaries, were above the PWQO.

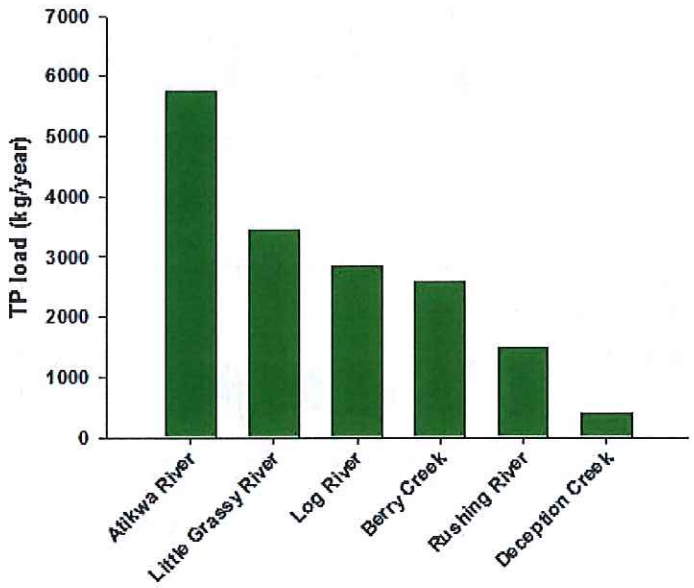


Figure 2a: The five-year (2009-2014) mean TP loads for six Canadian tributaries to the Lake of the Woods varied from under 300 to more than 5500 kg TP per year. The Atikwa River drains the largest area (2033 km^2) and consequently contributed the highest TP load of the measured tributaries. The Little Grassy and Log rivers, which showed the highest TP concentrations contributed ~3000 kg TP per year, on average.

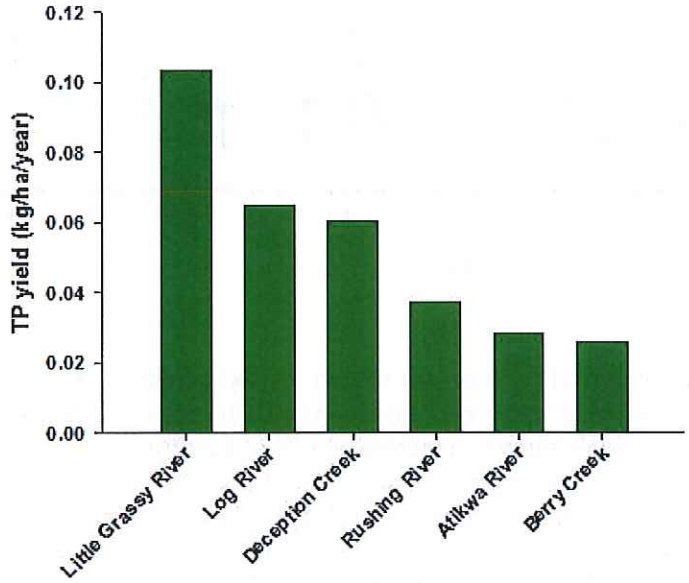


Figure 2b: The five-year (2009-2014) mean TP yield, a measure of the areal TP load, or intensity of loading from each catchment, generally followed the pattern shown for TP concentrations. The Little Grassy River may be an important contributor of TP to the Lake of the Woods, as it shows relatively high TP loads and yields, and drains the southern portion of the Lake of the Woods, where monitoring data have shown the highest TP concentrations.

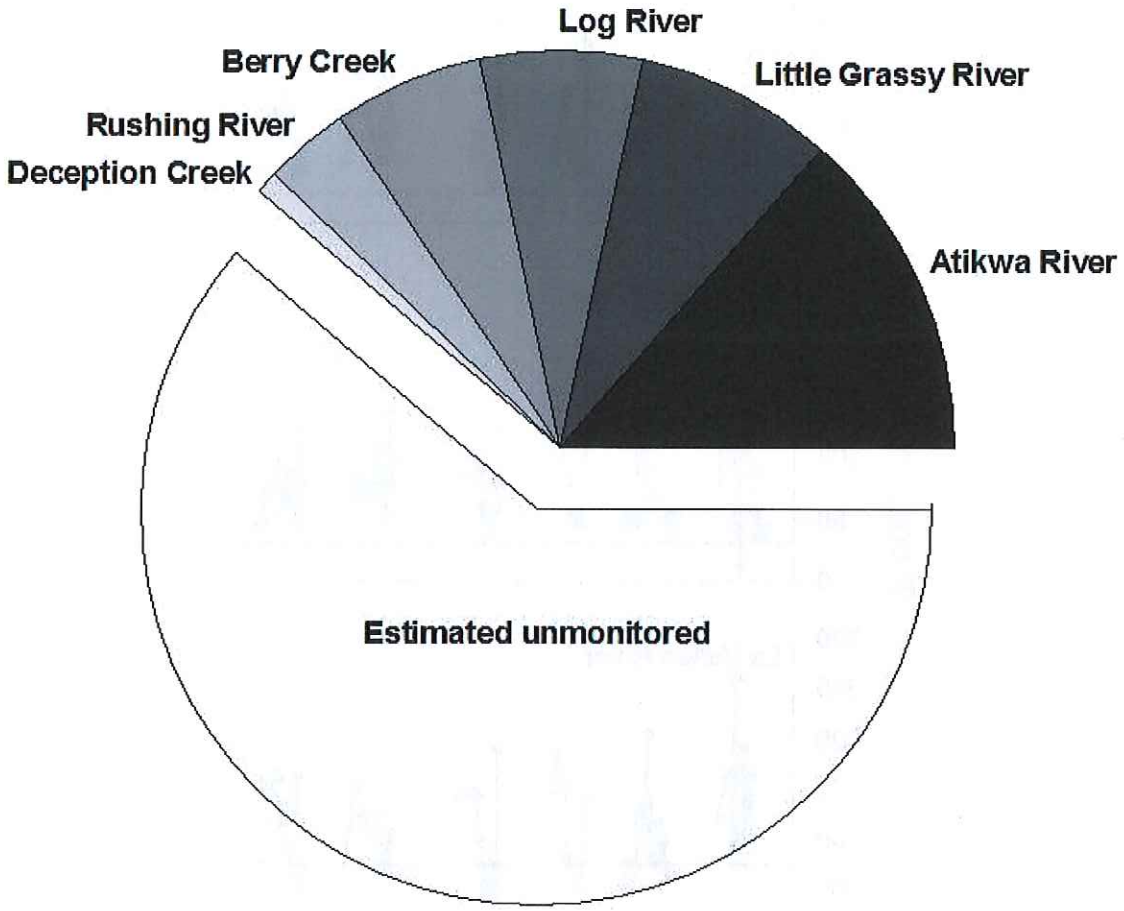


Figure 3: Pie graph showing the relative breakdown of the 5-year mean TP load from the six monitored tributaries to the Lake of the Woods, in comparison to the estimated load from the unmonitored portion of the catchment (prorated from the monitored loads). Approximately 61% of the local catchment area to the Lake of the Woods is currently unmonitored, although this is likely an overestimate as it does not account for monitoring of US tributaries that drain directly to the south end of the lake. Also, TP loading estimates are from measured TP concentration data, but with estimated flow data (prorated from nearby streams, as outlined in Hargan et al. 2011, J. Great Lakes Research, 37: 753-763).

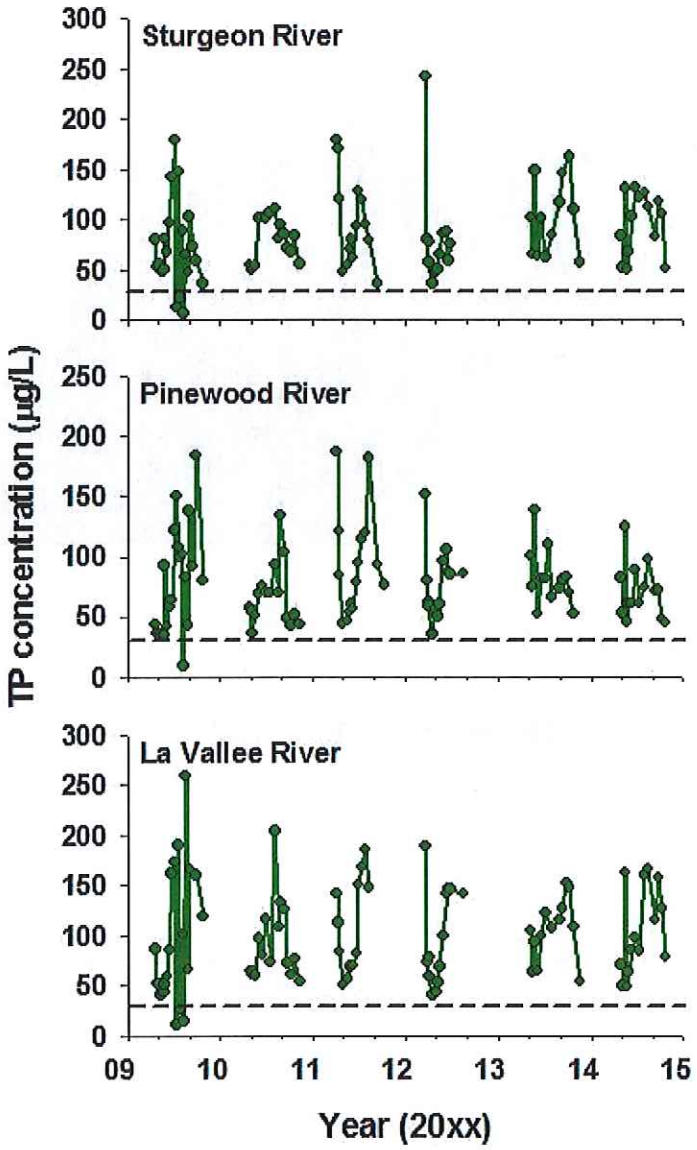


Figure 4: TP concentration data from three Canadian tributaries to the Rainy River, sampled from 2009 to 2014. TP levels were highly variable within years, but were generally similar, on average, across sites. Throughout the sampling season, [TP] commonly exceeded Ontario's PWQO for TP in streams and rivers. Seasonally, concentrations were commonly high in early spring, lower in late spring and early summer, subsequently increasing in late June or July. Seasonal variability from year to year may, in part, reflect variability in flow and precipitation events. Further investigation is required to tease apart this variability.

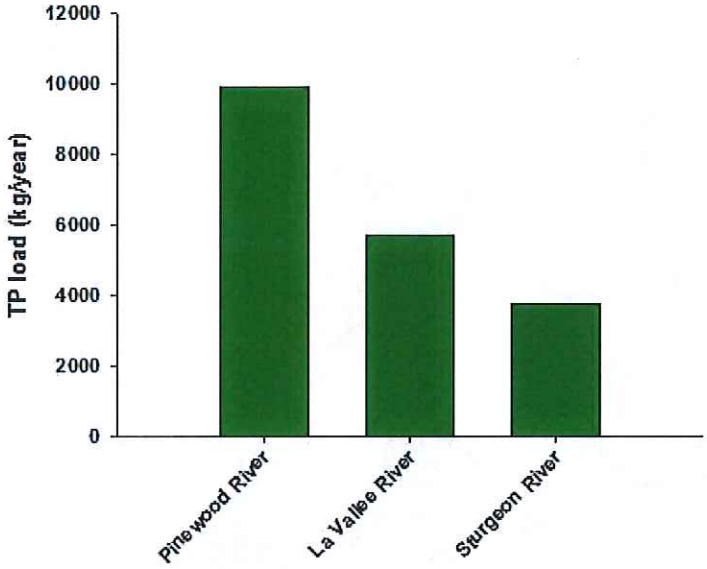


Figure 5a: Variation in the five-year (2009-2014) mean TP loads for three Canadian tributaries to the Rainy River reflect differences in drainage area, from 575 km^2 (Pinewood River) to 213 km^2 (Sturgeon River).

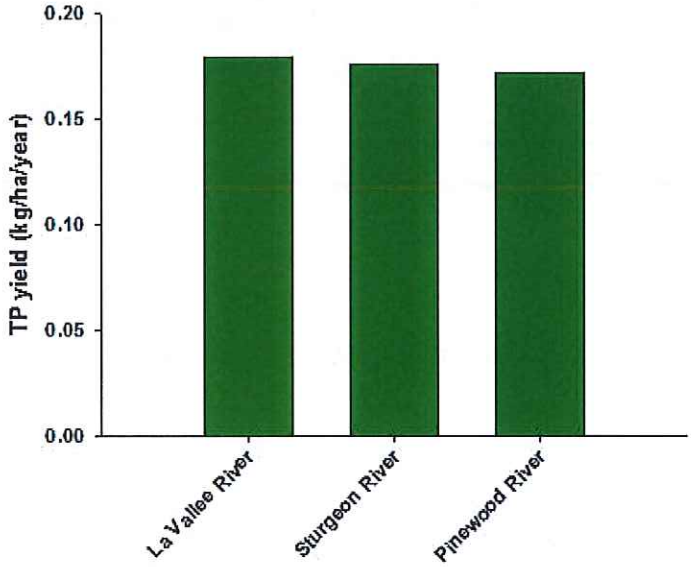
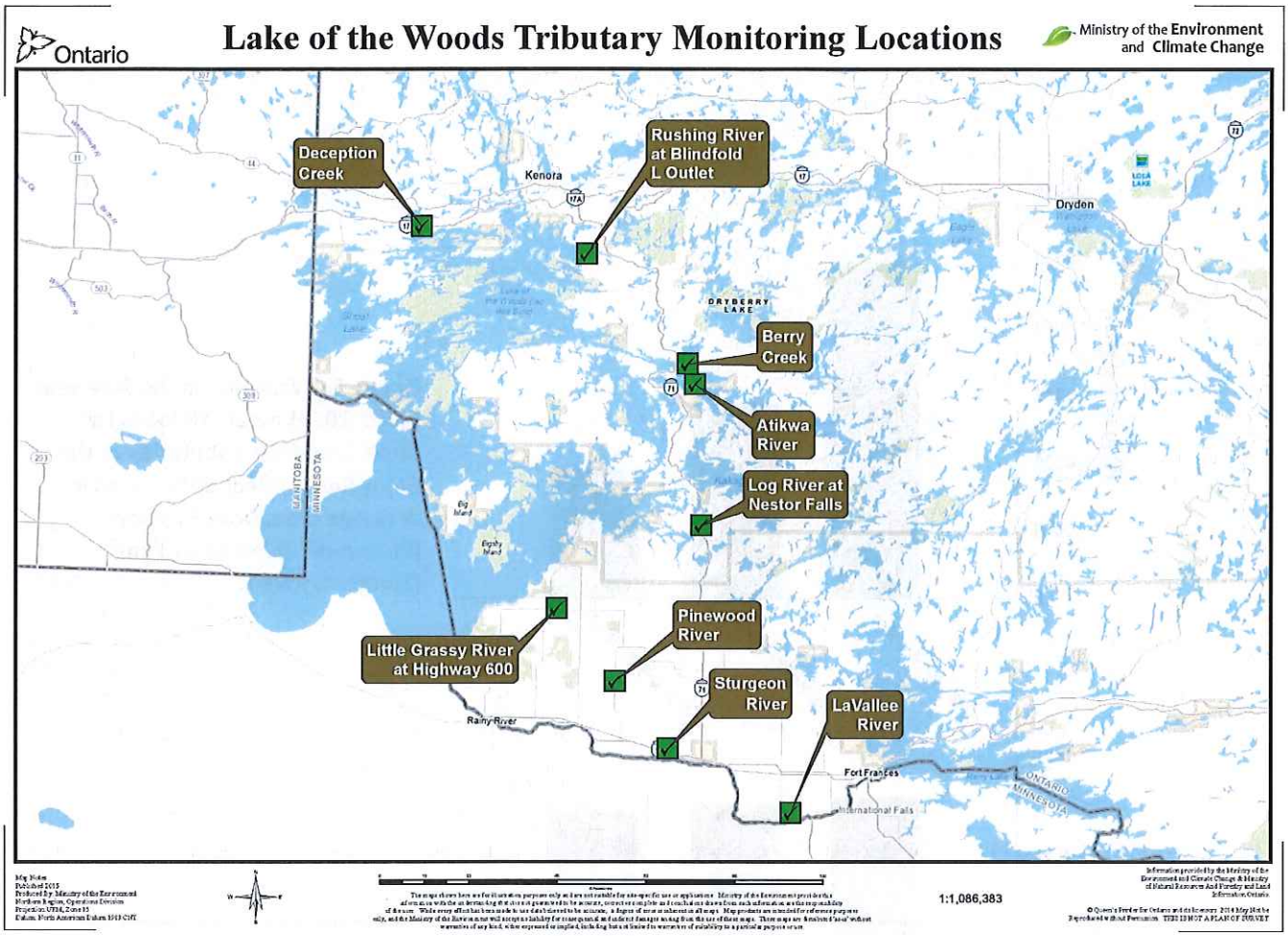


Figure 5b: The 5-year mean TP yields (in kg/ha/year) were similar across the three rivers. Yields from these tributaries were approximately 3-4 times higher than those observed in the monitored streams within the Canadian Shield.

Figure 6. Lake of the Woods Tributary Monitoring Locations



Point Source Discharges

The facilities in Ontario that discharge to the Lake of the Woods Watershed include the following:

Resolute Fort Frances Mill – currently idle
Town of Fort Frances Municipal Sewage Treatment Facility
Town of Emo Municipal Sewage Treatment Facility
Town of Barwick Municipal Sewage Treatment Facility
Town of Rainy River Municipal Sewage Treatment Facility

The New Gold Rainy River Mine is under construction and will begin discharging into the Pinewood River in 2017.

If you require further information, please do not hesitate to contact me by phone at (807) 468-2734 or by email at trina.rawn@ontario.ca.

Sincerely,

Trina Rawn
A/Regional Director

Minnesota Pollution Control Agency

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October 27, 2015

Mr. Michael Goffin
Environment Canada
Regional Director General
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M3H5T4

Colonel Daniel C. Koprowski
St. Paul District, U.S. Army Corps of Engineers
180 5th Street E., Suite 700
St. Paul, Minnesota 55101-1678

Dear Mr. Goffin and Colonel Koprowski:

This letter is in response to your request via the International Joint Commission's International Rainy Lake of the Woods Watershed Board for water quality data and information collected by the Minnesota Pollution Control Agency (MPCA). As you are probably aware, the MPCA has a long history of collecting water quality data in the Lake of the Woods Basin as part of our mission to protect and improve the environment and enhance human health. This letter will summarize MPCA water quality data from three fundamental data sources:

- The MPCA's Intensive Watershed Monitoring Program
- Summaries and trends of lake and stream water quality sites in the Lake of the Woods Basin
- Updated wastewater discharge data from three Minnesota facilities that discharge to the Rainy River

Intensive Watershed Monitoring

The passage of Minnesota's Clean Water Legacy Act in 2006 provided policy framework and money for state and local governments to accelerate efforts to monitor, assess, and restore impaired waters, and to protect unimpaired waters. Following the passage of the Act, the MPCA began implementing what it calls the Watershed Approach. There are 80 major watersheds in Minnesota (Figure 1). Intensive water quality monitoring and assessments will be conducted in each of these watersheds every 10 years. During the 10-year cycle, the MPCA and its partner organizations work on each of the state's watersheds to evaluate water conditions, establish priorities and goals for improvement, and take actions designed to restore or protect water quality. When a watershed's 10-year cycle is completed, a new cycle begins.

Following two years of intensive water quality and biological monitoring, the MPCA has completed lake and stream water quality assessments in three major watersheds within the Lake of the Woods Basin since 2008, Little Fork River, Big Fork River, and Lake of the Woods (see Figure 1). Our assessments were conducted by comparing water quality to state standards based on designated uses, such as protecting aquatic life and aquatic recreation. Other sources of data from partner organizations and citizen volunteers were also incorporated in the assessment process, as long as they met quality assurance measures. Regarding other watersheds within the basin, monitoring is on-going in two watersheds, the Vermilion and Rainy River Headwaters. Due to a funding shortfall, watershed monitoring will be delayed 1-2 years on three watersheds, the Rapid, Rainy Lake, and Lower Rainy River.

Overall, water quality was good to excellent in the Little Fork, Big Fork, and Lake of the Woods watersheds. There were a few stream segments and lakes that were not meeting water quality standards (assessed as non-support), notably Lake of the Woods due to eutrophication/excessive algal blooms, and some segments of the Little Fork River due to high levels of turbidity/suspended sediments. A summary of the assessment results, for protecting aquatic life and aquatic recreation, is shown in Table 1.

Detailed reports on our assessments for these watersheds, and several others within Minnesota, are available here:
http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/watershed-overview-map.html.

Figure 1. The MPCA's Intensive Watershed Monitoring Schedule.

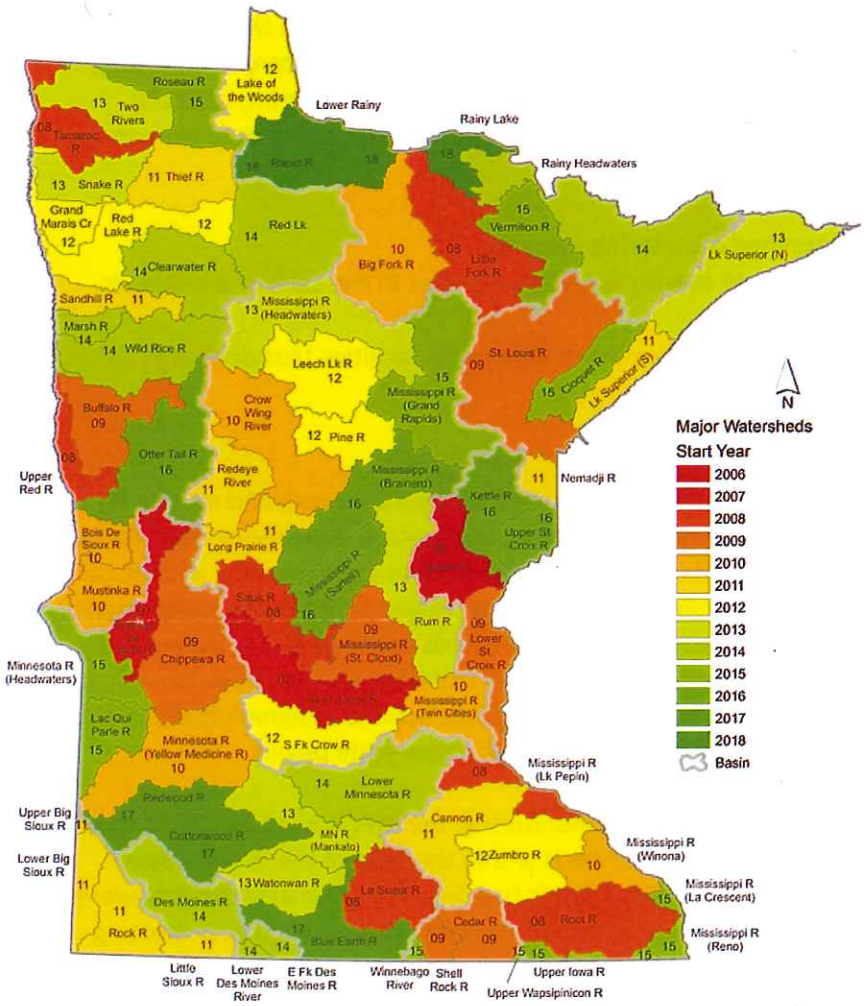


Table 1. MPCA's Assessment Summary for Three Lake of the Woods Basin Watersheds.

Watershed Name	Number of Lakes Meeting Recreational Use Standards	Number of Lakes Not Meeting Recreational Use Standards	Number of Streams Meeting Recreational Use Standards	Number of Streams Not Meeting Recreational Use Standards	Number of Streams Meeting Aquatic Life Standards	Number of Streams Not Meeting Aquatic Life Standards
Little Fork River	15	0	12	0	37	6
Big Fork River	114	6	11	0	33	6
Lake of the Woods [1]	0	1	5	1	10	5

1. This watershed only contains one lake with sufficient data for assessment, Lake of the Woods, which was previously declared impaired by the MPCA in 2008

In summary, the Intensive Watershed Monitoring Program will conduct the following:

- Monitor and assess rivers and lakes in major watersheds to see if they meet water quality standards.
- Identify stressors to water quality and conditions fostering healthy waters.
- Develop Watershed Restoration and Protection Strategies (WRAPS) to restore and protect water bodies; this process is currently underway in the Little Fork, Big Fork, and Lake of the Woods watersheds.
- Implement projects and activities to restore and protect water quality.

Lake and Stream Water Quality Trends

The MPCA has several long-term monitoring programs we use to assess trends in surface water quality. Within the Lake of the Woods Basin, the Citizen Lake Monitoring Program (CLMP), and the Watershed Pollutant Load Monitoring Network (WPLMN) have robust datasets.

The CLMP is a cooperative program that combines the technical resources of the MPCA and the efforts of citizen volunteers statewide that collect water quality data on their lakes. A summary of Secchi transparency (i.e. water clarity) data for lakes within the Lake of the Woods Basin is provided below. In general, lake water quality is good to excellent in the basin, and the northern regions of Minnesota continue to have the highest quality waters. Only a small number of lakes have a documented decreasing trend in water clarity; most lakes have stable clarity.

- Number of lakes with Secchi transparency data – 879
- Number of lakes with no detectable trend in transparency – 124
- Number of lakes with decreasing trends in transparency – 17
- Number of lakes with increasing trends in transparency – 15
- Number of lakes with insufficient data to determine long term trends – 723

More detailed information can be found at the CLMP website:
http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/citizen-lake-monitoring-program/index.html.

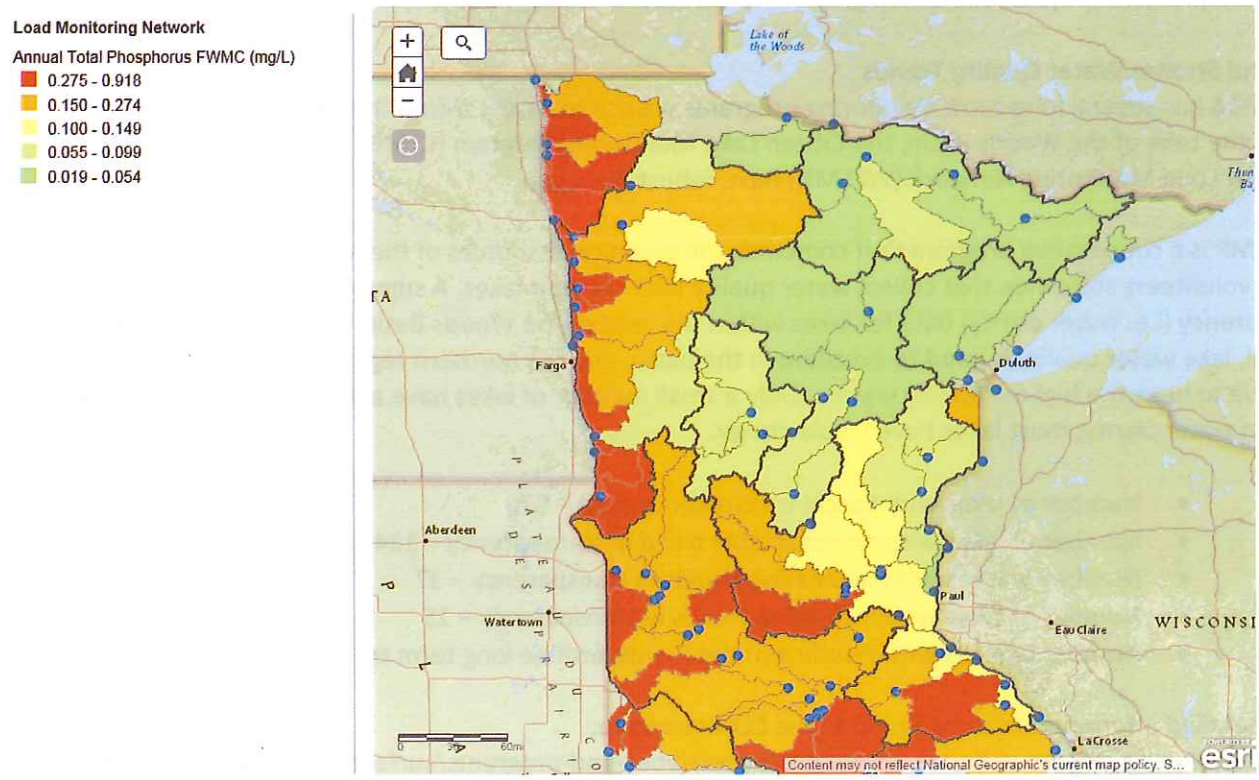
The WPLMN is designed to obtain spatial and temporal pollutant load information from Minnesota's rivers and streams and track water quality trends. This long-term program utilizes state and federal agencies, universities, local partners, and MPCA staff to collect water quality and flow data to calculate pollutant loads. Intensive water quality sampling occurs at all WPLMN sites. Approximately 35 water quality samples are collected annually at basin and major watershed sites and 25 samples collected seasonally at subwatershed sites. There are several large rivers within the Lake of the Woods Basin being monitored as part of the WPLMN:

- Kawishiwi River near Ely, Minnesota
- Vermilion River near Crane Lake, Minnesota
- Little Fork River near Littlefork, Minnesota
- Big Fork River near Big Falls, Minnesota
- Rainy River at Manitou Rapids, Minnesota
- Rapid River at Clementon, Minnesota

Statewide results from the WPLMN indicate that Lake of the Woods Basin sites have low concentrations of nutrients and suspended sediment (Figure 2, showing total phosphorus), likely due to the large percentage of forest and wetlands within the watersheds and comparably low anthropogenic impacts. The Little Fork has the highest concentrations of nutrients and sediment, due to the area's geologic setting and other factors. This watershed is currently being studied by the MPCA and our partners.

Figure 2. 2007-2012 Total Phosphorus Concentrations by Major Watershed.

Total Phosphorus Flow Weighted Mean Concentration by Watershed
Minnesota Pollution Control Agency: Watershed Pollutant Load Monitoring Network



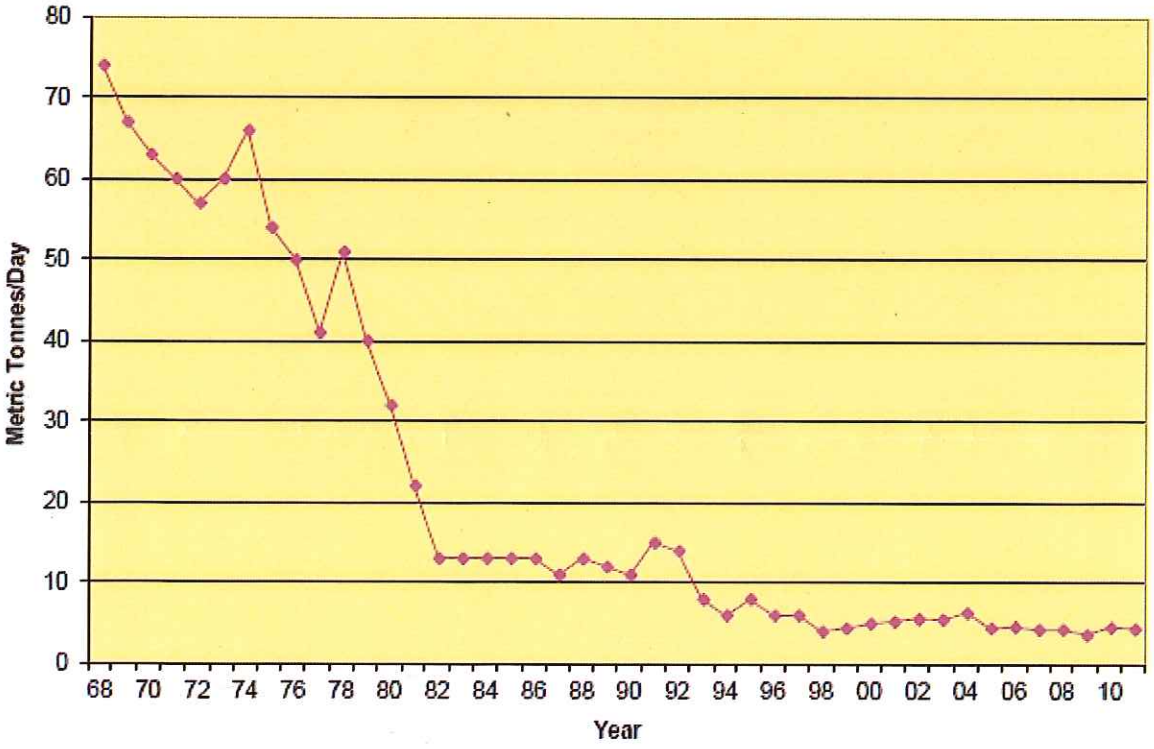
Additional information about the WPLMN can be found on this website: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/streams-and-rivers/watershed-pollutant-load-monitoring-network.html.

Wastewater Dischargers to the Rainy River

The three facilities within Minnesota that discharge treated wastewater to the Rainy River include Boise White Paper LLC in International Falls, North Koochiching Sanitary Sewer District in International Falls, and the City of Baudette, Minnesota. Previous MPCA reporting to the International Joint Commission (IJC) showed the dramatic historical improvement in industrial and municipal wastewater treatment processes, which has resulted in significant water quality improvements in the Rainy River (Figure 3).

A review of wastewater discharge monitoring data reports from 2012-2014 for these facilities continue to show that wastewater loads to the Rainy River are low compared to historical levels, and consistent with the levels shown in Figure 3.

Figure 3. Total Biochemical Oxygen Demand Load to the Rainy River from Continuous Dischargers, 1968-2011 (From 2012 IRRWPB Report to the IJC).

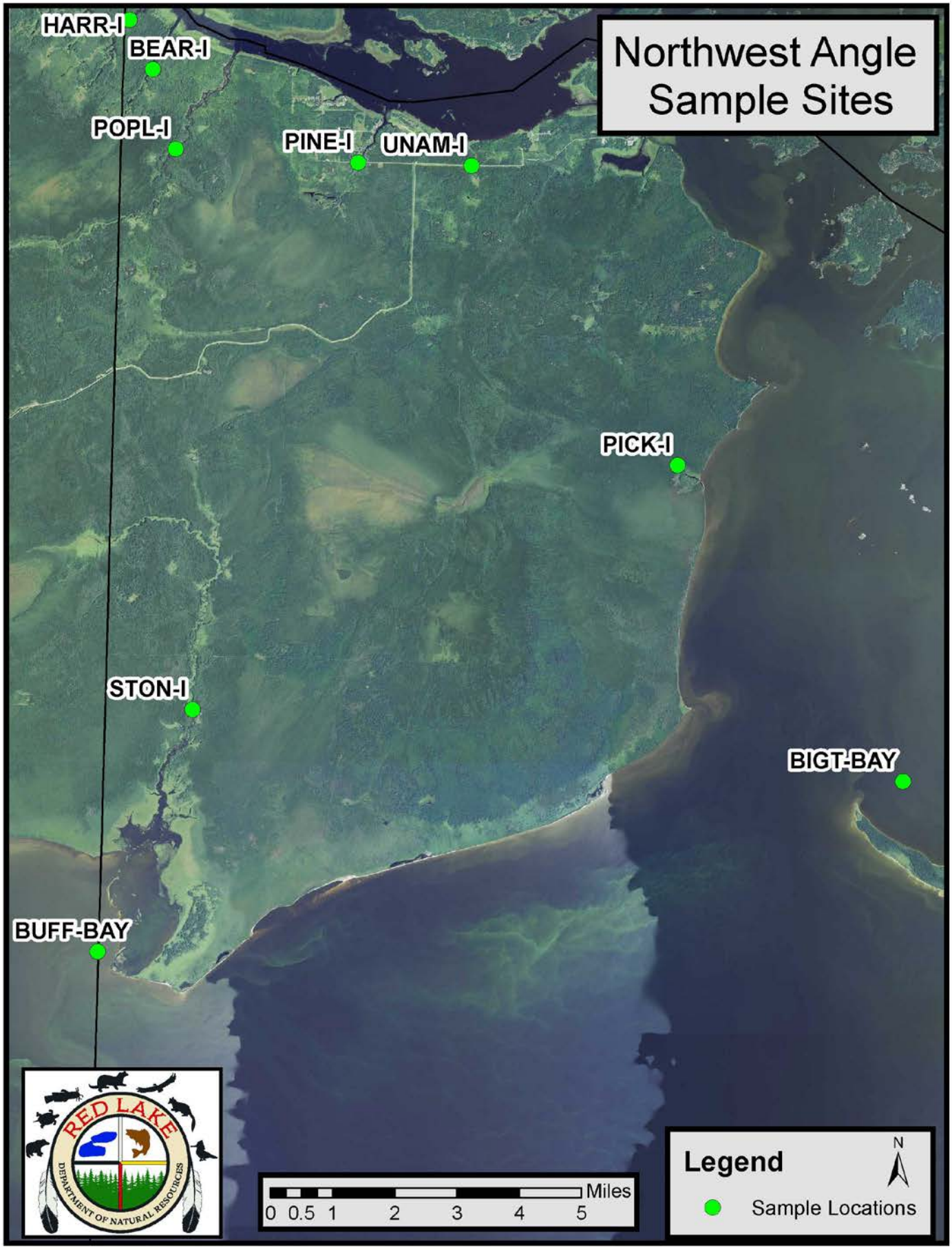


If you have questions or need further information beyond this summary, please contact Jesse Anderson, MPCA Duluth office, at 218-302-6621 or via email at jesse.anderson@state.mn.us.

Sincerely,

John Linc Stine
Commissioner

JLS/PA:je


Northwest Angle
Sample Sites
HARR-I
BEAR-I
POPL-I
PINE-I
UNAM-I
PICK-I
STON-I
BIGT-BAY
BUFF-BAY
RED LAKE
DEPARTMENT OF NATURAL RESOURCES
0 0.5 1 2 3 4 5
Miles
Legend
N
Sample Locations

Stream Name:	**Bear Creek**		
Ecoregion:	Northern Minnesota Wetlands	**Impairments:**	None
Watershed (HUC 8):	09030009	**Habitat Score:**	Not Assessed
Major Watershed:	Rainy River	**Lat/Long:**	49.36532, -95.1404
Location:	Approximately 1,100 meters upstream	**Site:**	BEAR-I

Trend Assessment: Not assessed

Notes: Not enough data points for trend assessments per internal requirements. Ecoregion criteria exceedances: Dissolved oxygen was less than the daily minimum of 5 mg/L 26% of the time. Turbidity exceeded criteria 6%, TSS 5%, inorganic nitrogen 5%, and temperature 37% of the time.

Water Quality Characteristics

Parameter	Unit	Min	Mean	Max	# of samples
Alkalinity, total	mg/l	32	75.58	146	19
Ammonia-nitrogen	mg/l	0	0.000	0.004	21
Chloride	mg/l	1.1	1.89	3.24	21
Conductivity	µS/cm	69	148.85	262	20
Dissolved oxygen (DO)	mg/l	1.18	6.31	12.18	19
Flow	cfs	2.707	14.80	38.344	6
Hardness, carbonate	mg/l	44.4	86.36	148	21
Inorganic nitrogen (nitrate and nitrite)	mg/l	0.029	0.05	0.391	21
Kjeldahl nitrogen	mg/l	0.553	1.23	2.08	21
Nitrogen	mg/l	0.553	1.25	2.19	21
Orthophosphate	mg/l	0.001	0.01	0.061	21
pH	su	6.78	7.32	8.59	20
Phosphorus	mg/l	0.018	0.04	0.09	21
Sulfate	mg/l	3	3	3	21
Temperature, water	°C	4.44	16.56	26.2	20
Total suspended solids	mg/l	1	4.81	31	21
Turbidity	NTU	0	3.63	32.1	35
Volatile suspended solids	mg/l	1	2.35	5	20

Stream Name:	**Harrison Creek**		
Ecoregion:	Northern Minnesota Wetlands	**Impairments:**	None
Watershed (HUC 8):	09030009	**Habitat Score:**	Not Assessed
Major Watershed:	Rainy River	**Lat/Long:**	49.36966, -95.1516
Location:	Approximately 1300 meters upstream	**Site:**	HARR-I

Trend Assessment: Not assessed

Notes: Not enough data points for trend assessments per internal requirements. Ecoregion criteria exceedances: Turbidity 6%, TSS 5%, inorganic nitrogen 5%, and temperature 37% of the time.

Water Quality Characteristics

Parameter	Unit	Min	Mean	Max	# of samples
Alkalinity, total	mg/l	40	86.9	232	20
Ammonia-nitrogen	mg/l	0	0.000	0.002	21
Chloride	mg/l	0.095	1.354	2.03	21
Conductivity	µS/cm	86	155.155	271.4	20
Dissolved oxygen (DO)	mg/l	5.14	8.098	14.1	19
Flow	cfs	1	161.627	322.254	2
Hardness, carbonate	mg/l	49.1	85.276	141	21
Inorganic nitrogen (nitrate and nitrite)	mg/l	0.029	0.034	0.147	21
Kjeldahl nitrogen	mg/l	0.494	1.040	1.87	21
Nitrogen	mg/l	0.494	1.048	1.87	21
Orthophosphate	mg/l	0.001	0.003	0.006	21
pH	su	7.14	7.548	8.29	20
Phosphorus	mg/l	0.017	0.027	0.056	21
Sulfate	mg/l	3	3	3	21
Temperature, water	°C	3.72	17.237	23.8	20
Total suspended solids	mg/l	0.048	4.002	23	21
Turbidity	NTU	0	4.003	35.7	38
Volatile suspended solids	mg/l	0.05	1.553	3	20

Stream Name: Pickerel Creek

Ecoregion:	Northern Minnesota Wetlands	**Impairments:**	None
Watershed (HUC 8):	09030009	**Habitat Score:**	Not Assessed
Major Watershed:	Rainy River	**Lat/Long:**	49.26953, -94.9521
Location:	Approximately 800 meters upstream from lake	**Site:**	PICK-I

Trend Assessment: Not assessed

Notes: Not enough data points for trend assessments per internal requirements. Ecoregion criteria exceedances: Dissolved oxygen was less than the daily minimum of 5 mg/L 32% of the time. TP exceeded criteria 10% of the time and temperature 11%.

Water Quality Characteristics

Parameter	Unit	Min	Mean	Max	# of samples
Alkalinity, total	mg/l	12	71.8	382	20
Ammonia-nitrogen	mg/l	0	0	0	20
Chloride	mg/l	1.27	1.996	2.64	20
Conductivity	µS/cm	35	124.574	336.7	19
Dissolved oxygen (DO)	mg/l	0.55	6.224	11.87	19
Flow	cfs	0.317	11.338	33.074	9
Hardness, carbonate	mg/l	22.7	74.465	185	20
Inorganic nitrogen (nitrate and nitrite)	mg/l	0.027	0.030	0.071	20
Kjeldahl nitrogen	mg/l	0.652	1.509	2.73	20
Nitrogen	mg/l	0.652	1.514	2.73	20
Orthophosphate	mg/l	0.000	0.010	0.033	20
pH	su	6.16	6.909	7.82	19
Phosphorus	mg/l	0.012	0.046	0.11	20
Sulfate	mg/l	2.49	2.832	2.85	20
Temperature, water	°C	2.71	12.784	23.25	19
Total suspended solids	mg/l	0.1	3.41	15	20
Turbidity	NTU	0	2.340	9.7	36
Volatile suspended solids	mg/l	0.158	2.183	7	19

Stream Name: Pine Creek

Ecoregion:	Northern Minnesota Wetlands	**Impairments:**	None
Watershed (HUC 8):	09030009	**Habitat Score:**	Not Assessed
Major Watershed:	Rainy River	**Lat/Long:**	49.33796, -95.0687
Location:	At large box culvert on Dawson Rd NW	**Site:**	PINE-I

Trend Assessment: Not assessed

Notes: Not enough data points for trend assessments per internal requirements. Ecoregion criteria exceedances: Dissolved oxygen was less than the daily minimum of 5 mg/L 39% of the time. Turbidity exceeded ecoregion criteria 3% of the time and temperature 17% of the time.

Water Quality Characteristics

Parameter	Unit	Min	Mean	Max	# of samples
Alkalinity, total	mg/l	36	86.421	172	19
Ammonia-nitrogen	mg/l	0	0.000	0.002	19
Chloride	mg/l	1.79	2.476	3.84	19
Conductivity	µS/cm	80	178.778	341	18
Dissolved oxygen (DO)	mg/l	0.9	6.267	11.18	18
Flow	cfs	-1	12.586	42.07	8
Hardness, carbonate	mg/l	45.8	94.005	171	19
Inorganic nitrogen (nitrate and nitrite)	mg/l	0.03	0.03	0.03	19
Kjeldahl nitrogen	mg/l	0.559	1.043	1.64	19
Nitrogen	mg/l	0.559	1.044	1.64	19
Orthophosphate	mg/l	0.002	0.011	0.057	19
pH	su	6.89	7.338	7.88	18
Phosphorus	mg/l	0.014	0.037	0.083	19
Sulfate	mg/l	3	3	3	19
Temperature, water	°C	4.39	15.329	21.91	18
Total suspended solids	mg/l	0.158	3.025	13	19
Turbidity	NTU	0	1.767	14.9	33
Volatile suspended solids	mg/l	0.167	1.75	3	18

Stream Name:	**Poplar Creek**		
Ecoregion:	Northern Minnesota Wetlands	**Impairments:**	TSS
Watershed (HUC 8):	09030009	**Habitat Score:**	Not Assessed
Major Watershed:	Rainy River	**Lat/Long:**	49.34424, -95.1297
Location:	Approximately 3500 meters upstream	**Site:**	POPL-I

Trend Assessment: Not assessed

Notes: Not enough data points for trend assessments per internal requirements. Ecoregion criteria exceedances: Dissolved oxygen was less than the daily minimum of 5 mg/L 11% of the time. Turbidity exceeded ecoregion criteria 26% of the time, inorganic nitrogen 5%, and temperature 15%. TSS exceeded the state standard of 15 mg/L 19% of the time.

Water Quality Characteristics

Parameter	Unit	Min	Mean	Max	# of samples
Alkalinity, total	mg/l	36	79.619	174	21
Ammonia-nitrogen	mg/l	0	0.000	0.001	21
Chloride	mg/l	1.14	1.75	2.34	21
Conductivity	µS/cm	82.5	160.863	317	19
Dissolved oxygen (DO)	mg/l	1.25	8.018	11.2	19
Flow	cfs	5.861	75.640	326.837	10
Hardness, carbonate	mg/l	52.5	89.371	178	21
Inorganic nitrogen (nitrate and nitrite)	mg/l	0.027	0.032	0.095	21
Kjeldahl nitrogen	mg/l	0.654	1.154	1.45	21
Nitrogen	mg/l	0.654	1.161	1.45	21
Orthophosphate	mg/l	0.001	0.005	0.025	21
pH	su	7.2	7.558	8.28	20
Phosphorus	mg/l	0.013	0.044	0.093	21
Sulfate	mg/l	3	3	3	21
Temperature, water	°C	3.94	15.267	26.3	20
Total suspended solids	mg/l	2	10.857	33	21
Turbidity	NTU	0.3	14.027	68.4	39
Volatile suspended solids	mg/l	0.05	2.503	7	20

Stream Name:	**Stony Creek**		
Ecoregion:	Northern Minnesota Wetlands	**Impairments:**	None
Watershed (HUC 8):	09030009	**Habitat Score:**	Not Assessed
Major Watershed:	Rainy River	**Lat/Long:**	49.20074, -95.1266
Location:	Approximately 2200 meters upstream from lake	**Site:**	STON-I

Trend Assessment: Not assessed

Notes: Not enough data points for trend assessments per internal requirements. Ecoregion criteria exceedances: dissovled oxygen was less than the daily minimum of 5 mg/L 16% of the time. Turbidity exceeded ecoregion criteria 3% of the time and temperature 21% of the time.

Water Quality Characteristics

Parameter	Unit	Min	Mean	Max	# of samples
Alkalinity, total	mg/l	40	90.947	164	19
Ammonia-nitrogen	mg/l	0	0.000	0.001	19
Chloride	mg/l	0.053	1.390	2.32	19
Conductivity	µS/cm	92	180.216	331	19
Dissolved oxygen (DO)	mg/l	0.78	7.344	13.63	19
Flow	cfs	0.858	58.929	209.533	8
Hardness, carbonate	mg/l	54.5	99.237	165	19
Inorganic nitrogen (nitrate and nitrite)	mg/l	0.03	0.030	0.03	19
Kjeldahl nitrogen	mg/l	0.65	1.085	1.47	19
Nitrogen	mg/l	0.65	1.085	1.47	19
Orthophosphate	mg/l	0.000	0.006	0.016	19
pH	su	7.01	7.485	7.94	19
Phosphorus	mg/l	0.017	0.031	0.057	19
Sulfate	mg/l	3	3	3	19
Temperature, water	°C	3.63	15.382	23.84	19
Total suspended solids	mg/l	0.053	3.371	8	19
Turbidity	NTU	0	3.09	13.6	36
Volatile suspended solids	mg/l	0.056	1.559	3	18

Stream Name:	**Unnamed Creek**		
Ecoregion:	Northern Minnesota Wetlands	**Impairments:**	TSS
Watershed (HUC 8):	09030009	**Habitat Score:**	Not Assessed
Major Watershed:	Rainy River	**Lat/Long:**	49.33788, -95.0283
Location:	At culvert on Dawson Rd NW	**Site:**	UNAM-I

Trend Assessment: Not assessed

Notes: Not enough data points for trend assessments per internal requirements. Ecoregion criteria exceedances: Turbidity exceeded ecoregion criteria 9% of the time, TP 17%, and temperature 13% of the time. TSS exceeded the state standard of 15 mg/L 17% of the time.

Water Quality Characteristics

Parameter	Unit	Min	Mean	Max	# of samples
Alkalinity, total	mg/l	72	165.222	334	18
Ammonia-nitrogen	mg/l	0	0.0005	0.002	18
Chloride	mg/l	1.08	6.422	55.6	18
Conductivity	µS/cm	162.9	343.219	639	16
Dissolved oxygen (DO)	mg/l	5.52	8.408	11.59	16
Flow	cfs	0.5	3.083	5	6
Hardness, carbonate	mg/l	80.3	170.461	322	18
Inorganic nitrogen (nitrate and nitrite)	mg/l	0.027	0.032	0.077	18
Kjeldahl nitrogen	mg/l	0.808	1.227	1.97	18
Nitrogen	mg/l	0.808	1.235	2.05	18
Orthophosphate	mg/l	0.003	0.026	0.074	18
pH	su	7.23	7.652	8.41	16
Phosphorus	mg/l	0.02	0.058	0.212	18
Sulfate	mg/l	2.833	3.042	6.59	18
Temperature, water	°C	3.92	14.351	21.57	16
Total suspended solids	mg/l	0.167	8.417	56	18
Turbidity	NTU	0	10.38	123	32
Volatile suspended solids	mg/l	0.176	2.266	9	17

Lake Name: Big Traverse Bay

Ecoregion:	Northern Minnesota Wetlands	Surface Area (acres):	1074560
Watershed:	090300090600	Littoral Area (acres):	
Location:	49.19735 -94.869108	Max depth(m):	5.06
Average TSI:	55.97	Mean depth:	
Trophic Class:	Eutrophic	Site:	BIGT-BAY

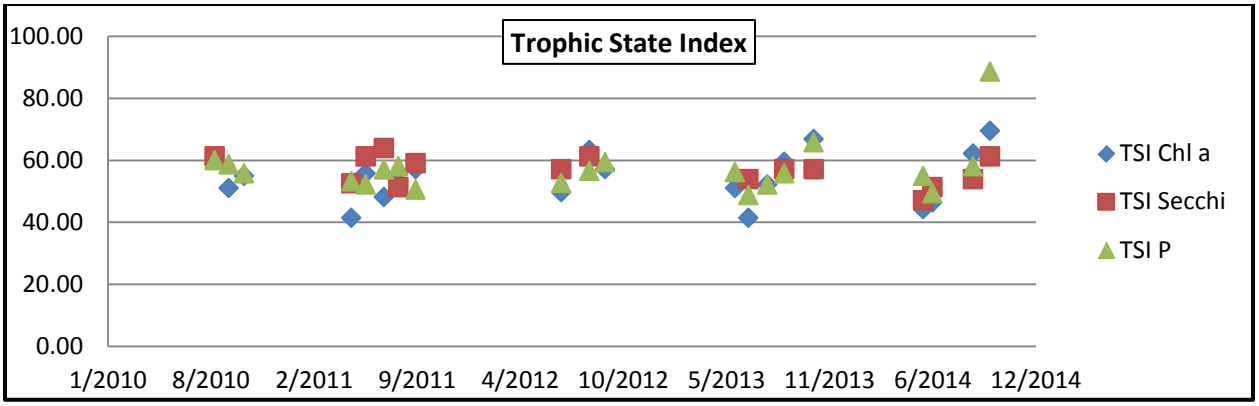
Trend Assessment

Total Phosphorus	Not assessed
Chlorophyll	Not assessed
Secchi Depth	Not assessed

Notes: Not enough data points for trend assessments per internal requirements.

Water Quality Characteristics:

Parameter	Unit	Min	Mean	Max	# of samples
Alkalinity, total	mg/l	36.00	55.00	106.00	20
Chlorophyll a, corrected for pheophytin	µg/l	3.00	15.15	53.00	20
Conductivity	µS/cm	108.00	116.98	134.00	65
Depth, Secchi disk depth	ft	2.50	4.37	8.00	15
Dissolved oxygen (DO)	mg/l	1.18	10.57	17.82	64
pH	pH	7.63	8.23	9.07	65
Phosphorus	mg/l	0.02	0.05	0.35	20
Temperature, water	deg C	3.12	16.26	28.16	65
Turbidity	NTU	0.00	5.48	30.70	70
Orthophosphate	mg/l	0.00	0.01	0.23	20
Kjeldahl nitrogen	mg/l	0.43	0.76	1.72	20
Nitrogen	mg/l	0.00	0.74	1.72	20
Inorganic nitrogen (nitrate and nitrite)	mg/l	0.03	0.03	0.12	20
Ammonia-nitrogen	mg/l	0.00	0.00	0.02	20
Total suspended solids	mg/l	3.00	10.40	32.00	20
Volatile suspended solids	mg/l	0.05	4.21	14.00	19
Sulfate	mg/l	2.25	2.72	5.91	20



Lake Name: Buffalo Bay

Ecoregion:	Northern Minnesota Wetlands	Surface Area (acres):	1074560
Watershed:	090300090600	Littoral Area (acres):	
Location:	49.15283 -95.153402	Max depth(m):	2.84
Average TSI:	56.11	Mean depth:	
Trophic Class:	Eutrophic	Site:	BUFF-BAY

Trend Assessment

Total Phosphorus	Not assessed
Chlorophyll	Not assessed
Secchi Depth	Not assessed

Notes: Not enough data points for trend assessments per internal requirements.

Water Quality Characteristics:

Parameter	Unit	Min	Mean	Max	# of samples
Alkalinity, total	mg/l	44.00	62.60	120.00	20
Chlorophyll a, corrected for pheophytin	µg/l	3.00	10.30	36.00	20
Conductivity	µS/cm	111.20	125.96	141.40	42
Depth, Secchi disk depth	ft	1.50	3.32	6.00	14
Dissolved oxygen (DO)	mg/l	8.61	10.29	17.22	41
pH	pH	7.70	8.13	8.97	42
Phosphorus	mg/l	0.03	0.04	0.08	20
Temperature, water	deg C	6.11	16.18	24.77	42
Turbidity	NTU	0.00	9.63	43.90	53
Orthophosphate	mg/l	0.00	0.00	0.01	20
Kjeldahl nitrogen	mg/l	0.37	0.75	1.30	20
Nitrogen	mg/l	0.37	0.76	1.30	20
Inorganic nitrogen (nitrate and nitrite)	mg/l	0.03	0.03	0.09	20
Ammonia-nitrogen	mg/l	0.00	0.00	0.02	20
Sulfate	mg/l	2.55	2.97	6.74	20
Total suspended solids	mg/l	4.00	18.15	112.00	20
Volatile suspended solids	mg/l	1	5.26	16	19