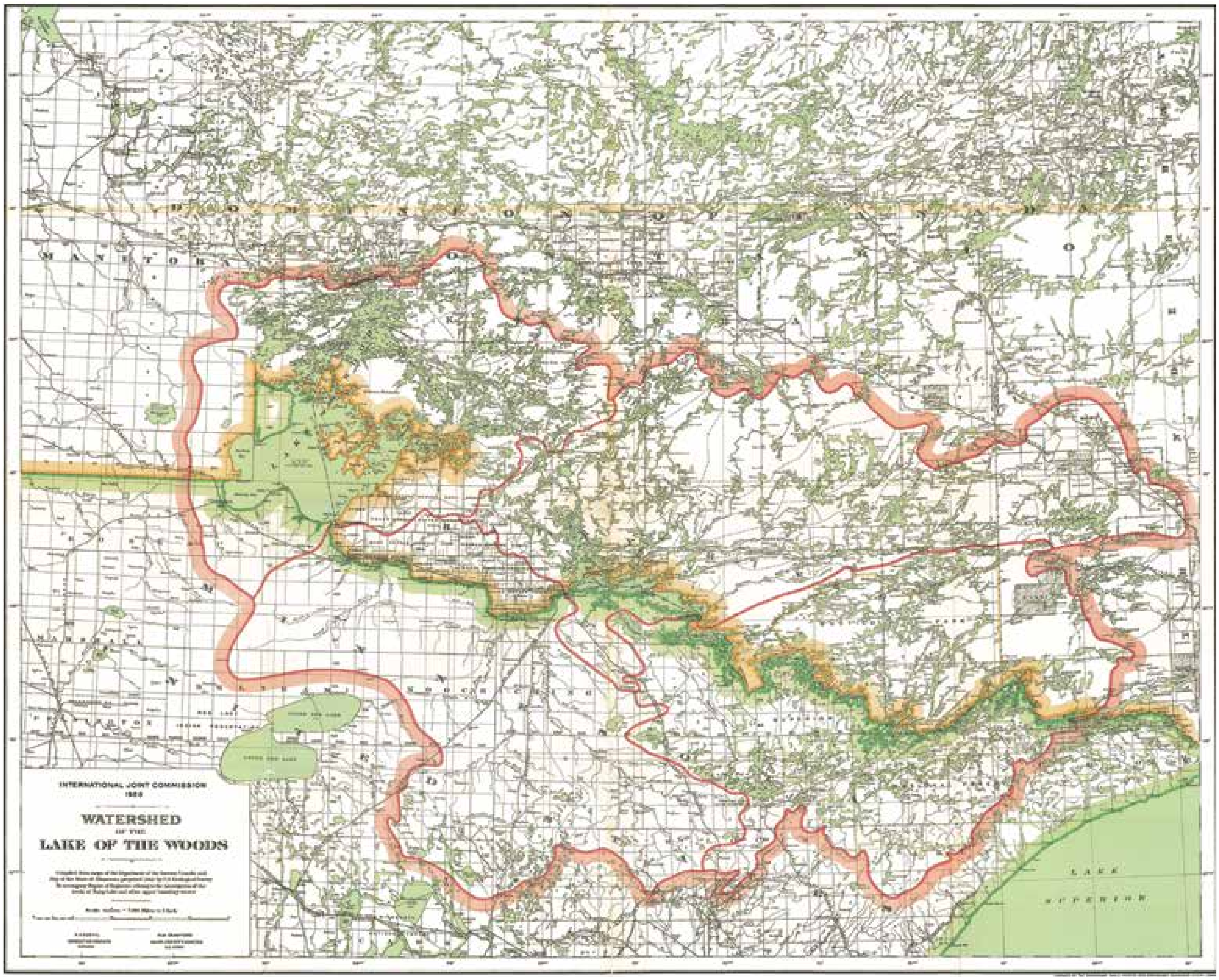
Rainy-Lake of the Woods

State of the Basin Report

2ND EDITION

JULY 2014



Rainy-Lake of the Woods

State of the Basin Report

2ND EDITION – 2014

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The information contained in this State of the Basin Report – 2nd Edition was compiled by the Editors and the Editorial Committee from information in the original 2009 report and from published and unpublished research that has become available since 2009.

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Editors' Note

This report was a collaborative effort and its completion would not have been possible without the contributions of numerous researchers, resource managers and agencies in the basin. We extend special thanks to the Editorial Advisory Committee for their contributions and to the International Joint Commission and the Lake of the Woods Water Sustainability Foundation for providing resources for the preparation and publication of this report. We also thank Patty Nelson, of Kenora, for her excellent graphical design and layout of this report.

Cover

The Watershed of Lake of the Woods
International Joint Commission 1928

(Lee Grim)

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FOREWORD

Bob Sandford

EPCOR Chair
Canadian Partnership Initiative, United Nations Water for Life Decade

The management of water and aquatic ecosystem function on a basin scale is not easy anywhere. It is particularly difficult to manage cascading environmental impacts at the scale of an entire watershed when that level of management has not existed before. Such efforts become even more complicated when the basin is shared by different provinces, states and nations.

Many of the usual suspects that cause problems with lake quality elsewhere have appeared in the Lake of the Woods and Rainy River watershed. These include population shifts from seasonal cottage use to permanent residence; more roads and infrastructure; wetland loss; water regulation and flooding problems; outdated public perceptions relating the state of the health of the watershed and the lake; unresolved and uncharacterized Indigenous water and other rights issues; antiquated governance structures; and heavy investment in a seemingly immovable status quo.

In addition to the usual suspects there are some further challenges including significant nutrient loading and other forms of pollution; industrial and agricultural pressures under changing economic circumstances; concerns related to forestry practices and climate change impacts. What is unique about how this basin has come to be managed is that those who live in the Lake of the Woods and Rainy River watershed have discovered that in the absence of adequate funding and monitoring they have no choice but to cooperate if they want to continue to enjoy the prosperity and quality of life to which residents and visitors have become accustomed. This 2nd Edition of the Rainy-Lake of the Woods State of the Basin Report underscores the depth of that cooperation and the value of coordinated research efforts to solve regional watershed-scale problems through grass roots commitment. In so doing, this report provides an important example, not just for those who live in the basin, but for those who live in basins all over North America that face similarly challenging changes in local eco-hydrological conditions—and there are many.

We find ourselves in an era of significant and rapid hydro-climatic change. One does not have to look far for evidence of how easy it is to give into apathy and hopelessness when confronted with the fact that our political systems are not designed and structured in such a manner that would easily allow them to address issues of the magnitude that currently threaten the ecological and hydrological integrity and economic stability of the Rainy-Lake of the Woods basin. There is no question that the scales are all wrong. While political systems are designed to function within limited often competing jurisdictions over timeframes of four or five years, the problems we have created for ourselves are mismatched both spatially and temporally. The timeframes that must be considered to address these problems span generations and encompass not just states or provinces but the entire globe.

This report demonstrates, however, that meaningfully organized and appropriately funded public participation in important on-going initiatives that address serious environmental cum social cum economic threats allows the public to feel they are not helpless. Whether they work at the municipal, provincial, state or federal level, public interest stakeholder groups like those aligned with the Lake of the Woods Water Sustainability Foundation are the bridge between successive governments. They are the collective memory of society and the conscience of both government and the private sector over time. They are the repositories of knowledge and, as this report demonstrates, they can also be the locus of powerfully effective, scientifically-based collaborative action.

This report recognizes the shortcomings of the existing fragmented approaches to water quality governance. It responds to those shortcomings positively, however, through collaboration that rises above current arrangements but by necessity still respects them. Given the deteriorating water quality in many North American lakes there has never been a time when cross-disciplinary, cross-sectoral, inter-departmental and international integration of water management has been more important. There is much to do. We have to create new language to describe what is happening, fashion new laws that define different liabilities and prescribe more enticing incentives for change. To buy time for that change to occur we have to manage our water resources better than we ever have before. This report demonstrates that there is a major watershed on this continent that can show us how that might be done.

This report is a success story in the making —and I wish the people of the Rainy-Lake of the Woods basin every success in the further telling of that story.

Bob Sandford
EPCOR Chair
Canadian Partnership Initiative
United Nations
Water for Life Decade

EXECUTIVE SUMMARY

Water quality monitoring buoy. (Environment Canada)

Over the past two decades, an impressive amount of research and monitoring has been conducted in the Rainy-Lake of the Woods basin (R-LoW basin). The first State of the Basin Report (SOBR) in 2009 provided details on a wide range of topics, including: drainage basin characteristics, water chemistry and nutrients, biotic communities, emerging threats and an overview of information gaps and monitoring needs that were identified at that time. Many of the information gaps identified in 2009 have been filled in the past five years and this new science is the focus of the 2nd Edition. Furthermore, there have been many steps forward to improve aspects of governance in the basin since the release of the first SOBR. These developments require the 2nd Edition to update science and research initiatives, but also to harmonize the various recommendations and priorities that have materialized following improvements to the governance model.

Governance

In 2009, when the first SOBR was published, there were steps underway to engage the International Joint Commission (IJC) to create a Water Pollution Board for the Rainy-Lake of the Woods basin and to create an ad hoc task force to coordinate complementary research plans in the basin. This goal was fulfilled in 2013 with the establishment of the International Rainy-Lake of the Woods Watershed Board (IRLWWB) and initiation of a Lake of the Woods Basin Water Quality Plan of Study. This Board combines the former International Rainy Lake Board of Control and the International Rainy River Water Pollution Board and extends its water quality mandate to the entire Lake of the Woods basin. The water level and flow regulation functions of the former International Rainy Lake Board of Control remains intact in the directive and membership of the Rainy-Namakan Water Levels Committee of the IRLWWB, to which the IRLWWB delegates its authorities in this matter. The regulation process for Lake of the Woods remains the same, with management by the [Canadian] Lake of the Woods Control Board between normal high and low water levels, with binational oversight and direction by the International Lake of the Woods Control Board, in the rare cases of departures from the normal levels.

The mandate of the International Rainy-Lake of the Woods Watershed Board is to:

- fulfill the obligations of the Rainy Lake convention to manage water levels on Rainy Lake and other boundary waters in the Rainy Lake watershed, and act as technical adviser to the Commission on this matter.
- report on existing water quality objectives in boundary waters
- recommend new water quality and/or aquatic ecosystem health objectives in boundary waters, as required
- establish and report on water quality and aquatic ecosystem health alert levels throughout the basin.

This will require the cooperation of multiple agencies and the review of a great deal of information, the synthesis of which is the focus of this SOBR update. Priority issues are identified as:

- nutrient enrichment
- harmful algal blooms
- invasive species
- surface and groundwater contamination
- cross-cutting factors of climate change indicators and adaptation, and hydrologic regulation.

This board will also support the coordination of research efforts in the basin by developing and implementing the IJC's data harmonization protocols.

The 2009 SOBR recommended *"the creation* *of a technical advisory committee, which will harmonize scientific goals and methodologies through the development of informal and formal agreements among government agencies and other groups working in the basin."* The International Multi Agency Arrangement (IMA) was developed to meet this goal in May 22, 2009. The group includes:

- Environment Canada
- US Environmental Protection Agency
- Red Lake Band of Chippewa Indians
- Lake of the Woods Water Sustainability Foundation
- Minnesota Department of Natural Resources
- Minnesota Pollution Control Agency
- Ontario Ministry of the Environment
- Ontario Ministry of Natural Resources
- Manitoba Water Stewardship
- Koochiching Soil and Water Conservation District

In addition, personnel from other agencies are participating informally on technical committees of the IMA, including those from the Lake of the Woods County Soil and Water Conservation District and the International Joint Commission's transboundary hydrographic data harmonization team.

The purpose of the IMA is to provide trans-jurisdictional coordination on science and management activities that will enhance or restore water quality in the R-LoW basin. This will aid in establishing information exchange and cooperative mechanisms in areas related to transboundary environmental impacts in the jurisdictional areas of Ontario, Manitoba, Canada, Minnesota, the Red Lake Band of Chippewa Indians and the United States. The IMA has developed a Five Year Study Plan to deal with specific information gaps that have been identified.

Research and Monitoring

The 2009 SOBR identified 12 important information gaps, some of which were in the process of being addressed. These were:

1. An assessment of the relative sources of phosphorus to Rainy River and Lake of the Woods (LoW).
2. An assessment of the sensitivity of different regions to shoreline development and long-term changes in climate.
3. Knowledge of the variation in the frequency and intensity of algal blooms and algal toxins and how they are correlated to variation in water quality (especially nutrients) through space and time.
4. Availability of meteorological data at different locations on LoW and the Rainy River.
5. Improvement in spatial coverage of water chemistry from atmospheric deposition.
6. The availability of bathymetric maps and water-circulation patterns.
7. Knowledge of internal loading and release rates of nutrients, especially phosphorus, from lake sediments.
8. Knowledge of the tributary load of nutrients to the Rainy River and LoW.
9. Contributions of non-point source anthropogenic loads to the nutrient budget.
10. Longer-term understanding of the spatial distribution of water quality among monitoring sites.
11. Useful and cross-jurisdictional Geographic Information System (GIS) data.
12. Information regarding long-term variation in algal abundance, composition, and algal toxins.

Clearly, the information gaps listed above would require a huge effort among researchers and stakeholders, yet in the five years since these requirements were listed there have been significant advances made **on all twelve of the unanswered questions**. In addition, and of particular note, there have been further advances in:

- nutrient flux modeling
- temporal and spatial modeling of algal bloom dynamics
- continued identification of the invasion fronts of aquatic invasive species
- improved understanding of lake sediment characteristics
- improved understanding of the effects of water-level controls on chemistry and biota
- research into the potential impacts of

mercury in the environment
- numerous demonstrated impacts of climate change together with other multiple stressors
- harmonization of hydrologic data and digital mapping to create a seamless basin view of drainage systems on both sides of the international boundary.

Drainage basin concerns that have been identified by this synthesis (2nd Edition of the SOBR) as conditions that indicate ongoing problems or areas of research where gaps in understanding exist include: algal blooms; climate change; contaminants; invasive species; nutrients/internal loading and water levels/erosion. This list is mostly unchanged from the set of concerns and information gaps that were identified in the 2009 SOBR. There have been, however, major improvements in the understanding of these issues to the point where the management options are becoming clearer.

Chironomid tube.

Algal blooms

Recent studies have shown that warming trends in the past few decades have led to regional changes in the algal assemblages in lakes. These types of changes in the environment are known to favour cyanobacteria (blue green algae) that bloom in many areas of the basin in the late-summer and fall. These algal blooms and the potential for production of algal toxins are generally the most worrisome problems in the R-LoW basin and there is a perception that the blooms have been increasing in both frequency and severity in recent decades. There is evidence that climate change may exacerbate blooms and there is also recent evidence that is currently being examined that may show that the perception that blooms are worse in recent years is correct. This research is therefore describing a condition whereby blooms are increasing at the same time that nutrient loads have either not increased or have been substantially reduced as in the case of the Rainy River. This is an oversimplification of a complex process where multiple stressors, including climate change, are influencing blooms that have access to nutrients from inflows and internal loads. Algal blooms occur primarily in Lake of the Woods (LoW) and in areas of the Rainy Lake sub-basin.

Satellite imagery has been used in recent years to track the extent and severity of blue green algal blooms in LoW. This has allowed the quantification of algal biomass indicators in an extremely heterogeneous environment. This provides an increased understanding of the drivers that influence algal blooms both between years and seasonally.

Algal blooms are affected by multiple stressors and are themselves an ecosystem stressor which makes it difficult to assess any mitigation strategies that might be proposed to meet management goals. Ongoing work should help to fill the remaining information gaps relating to algal blooms.

Climate change

Climate change is especially evident in the R-LoW basin not only because there are dramatic changes predicted for the future but because measureable changes have occurred in the past few decades. Duration of ice-cover and number of frost-free days have both changed substantially since the 1960s. These changes have exacerbated algal blooms and have been implicated in many other changes that are occurring in the basin. Future predictions see changes in forest cover and shifts in populations of large animals like moose and deer.

Contaminants

The impacts of contaminants have been greatly reduced through reductions of pollutant inputs into the Rainy River. There are generally less contaminants entering the basin than there would be in other areas of North America, e.g. areas in the Great Lakes basin. There are, however, areas that:

- are listed as Federal Contaminated Sites (in Canada)
- may have legacy contamination from historic mining activity
- demonstrate atmospheric contamination of lakes and fish by mercury
- receive point-source discharges from industry and municipalities and
- could be affected by looming potential for mining activities to increase once again in the basin.

The level of threat varies between individual contaminants and their sources but monitoring to assess threats from contaminants is necessary.

Invasive species
The basin has been invaded by many non-native species which have disrupted the biological communities that they have invaded. Invasions have occurred in all trophic levels of the aquatic ecosystem from algae up to fish. There is potential for further invasions which will require ambitious, focused effort to avoid/slow the spread of these species and to better understand their impacts to natural systems.

Nutrients and internal loading
Nutrient load budgets including the use of dynamically linked nutrient/algal biomass models have increased the understanding of the fate of nutrients in the basin. The roles of internal loads especially in the southern portions of LoW have also been studied in recent years and these results will help to identify acceptable Total Maximum Daily Loads (TMDLs) which are being developed for impaired areas in the Minnesota (southern) portion of LoW. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that load among the various sources of that pollutant. For more information regarding TMDLs visit: http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/overviewoftmdl.cfm.

Water levels and erosion
The effects of water level control are currently being studied intensively in the Rainy Lake and Namakan Reservoir system to assess whether the IJC 2000 Rule Curves should be modified. There have also been studies to assess the effects of erosion in the southern areas of LoW.

Recommendations
The 2009 SOBR did not specifically make recommendations but identified basin concerns and the research imperatives that were required at that time to manage outstanding issues and emerging threats. Emerging threats in 2009 were identified as: contaminants, invasive species, water-level fluctuations and climate change.

The following harmonized recommendations and suggested steps forward were formulated based on the state of the basin evaluations summarized in this current report and with further consideration of recommendations provided by the IJC (2012). Some of these, such as the need for continued communication or the necessity for secure funding for critical programs, go almost without saying. Others involve the continued collection of information to answer those clear and compelling scientific questions or objectives that remain. Recommendations are structured under Governance and Research.

Governance
1. Continued support for the IJC and its Rainy-LoW Watershed Board governance model.

2. Ensure continued communication through:
   - support for the International Rainy-Lake of the Woods Watershed Forum
   - continued function of the International Multi-Agency Arrangement and its Technical Advisory Committee
   - function of comprehensive Community and Industry Advisory Committees of the IRLWWB
   - increased involvement of First Nations, Tribes, Métis and local government
   - data harmonization and central data storage strategies.
   - secure funding for monitoring and research.

Research
1. Fill information gaps for basin concerns as listed in Chapter 3.
2. Assess adequacy of current monitoring programs.
3. Assess the need for International Water Quality Objectives.

Note that a non-technical summary of this report is available on the LWWSF website www.lowwsf.com/sobr-summary which will provide a plain language summary of this report to supplement the executive summary provided here.

This report contains a large amount of information and text that has been transferred directly from the 2009 SOBR. Thus, the 2nd Edition is considered to be a standalone document with newer information added to what was understood about the basin in 2009. Some of the basin characteristics which are not expected to undergo change over a short time-frame (e.g., geology, hydrology patterns, etc.) have been summarized in sufficient detail here with reference to the 2009 report (where more detail is available if desired). In some cases, the existing data were examined more closely in the 2009 report, but the findings of any synthesis conducted since then have been included here. In many cases, newer findings have overwritten those that were incomplete or understood to a lesser degree in 2009.

What's New in the Second Edition

The 2009 State of the Basin Report for Lake of the Woods and the Rainy River Basin was produced in response to a growing need for a synthesis document that would summarize the water quality and biological data available at the time. Generally this included data and findings up to the fall of 2007. The purpose of the report was to provide a reference for future monitoring and research and to create benchmarks against which future environmental change could be assessed. Approximately five years have passed since the 2009 report was issued and in many cases there are more than five years of new information to append since the most recent data available in 2009 was often from 2007 or in some cases earlier. Since 2009 there have been advances in the understanding of in-lake processes and further data have been collected to fill gaps and answer questions that were listed as steps forward in the original SOBR. Some of the steps forward described in the 2nd Edition have been significant including:

- improved understanding of nutrient flux and loading in Lake of the Woods
- improved understanding of the impact of internal loads in Lake of the Woods
- improvements to mapping and lake bathymetry
- improved understanding of the effects of climate change on ecological processes
- identification of drivers responsible for algal blooms
- progress to establish TMDLs in Minnesota to address impaired classification of Big Traverse Bay
- improved harmonization of basin hydrologic mapping and watershed boundaries
- improvements to governance — establishment of the IJC International Rainy-Lake of the Woods Watershed Board to encompass the R-LoW basin and initiation of the process to outline a Lake of the Woods Basin Water Quality Plan of Study.

In addition, many individual science projects have been completed in the past four years and these can be reviewed by referring to the proceedings of the annual International Rainy-Lake of the Woods Watershed Forums (formerly known as the International Lake of the Woods Water Quality Forum) that have taken place in International Falls, Minnesota for the past 11 years. Strong attendance and research presented at these forums confirm that substantial progress is being made in the basin even on annual time steps. Proceedings are available at http://lowwsf.com/proceedings-archive.html.

Since 2009, the IJC has expanded its involvement in the R-LoW basin and there have been many steps forward in binational watershed governance and research coordination. In response to a Reference from the Governments of Canada and the United States of America, the IJC appointed a Task Force which conducted a thorough

The IJC Task Force.
(Lee Grim)

review of the conditions, governance structures and priority issues in the basin. The work of the Task Force resulted in a final report with recommendations from the IJC to the Governments of the United States and Canada (IJC 2012), including the establishment of an international watershed board and the development of a water quality plan of study for the basin to address priority issues identified by the Task Force. With the agreement of the two Governments, the IJC established the International Rainy-Lake of the Woods Watershed Board in April 2013. One of the main objectives was to develop a Water Quality Plan of Study for the basin. The IJC's imperative to begin a Plan of Study for the Rainy-Lake of the Woods basin was a primary motivation to complete this Second Edition of the SOBR considering that a comprehensive current review of the state of the basin should provide most of the necessary background material to assemble a Plan of Study.

The first edition of the State of the Basin Report focused mostly on the Lower Rainy River, its tributaries and Lake of the Woods. This 2nd edition of the State of the Basin Report, as indicated by the title, *Rainy-Lake of the Woods Basin*, is expanded in scope to include more information about the entire basin which encompasses large areas upstream of the Lower Rainy River. We have a great deal of data for Rainy Lake, Namakan Reservoir and other lakes in Voyageurs National Park. There is also a great deal of data being collected in the headwaters. Here, when we refer to the Rainy-Lake of the Woods basin (R-LoW basin), we are referring to the catchment or basin that provides runoff water to the outflow at Lake of the Woods. This is more simply the Lake of the Woods basin and it is often referred to here simply as the basin. In some cases the word watershed is used in nomenclature specific cases. Although not technically the same, the words watershed and basin are often used interchangeably by the science community.

PART 1. DRAINAGE BASIN CHARACTERISTICS

The Lake of the Woods and Rainy River basin (R-LoW basin) encompasses approximately 69,750 km^2 (26,930 mi^2) between the outlet from LoW near Kenora to the Rainy River headwaters near Lake Superior (Figure 1). This is a binational basin with approximately 41% in Minnesota, United States (IJC 2012, 2011 Annex) and the remainder in Ontario and Manitoba, Canada. The basin is roughly 400 km (240 miles) east to west and 260 km (156 miles) north to south. It is an important natural, economic and recreational resource. The groundwater and the lakes in the basin are a vital source of drinking water for many communities, such as the City of Baudette MN (which draws groundwater from the Quaternary Buried Artesian aquifer); the City of Fort Frances (which draws its source water from the Upper Rainy River); the City of Kenora (which draws its source water from Lake of the Woods) and the city of Winnipeg (which draws its source water from Shoal Lake).

The basin can be further divided into 10 sub-basins (Figure 1) namely;

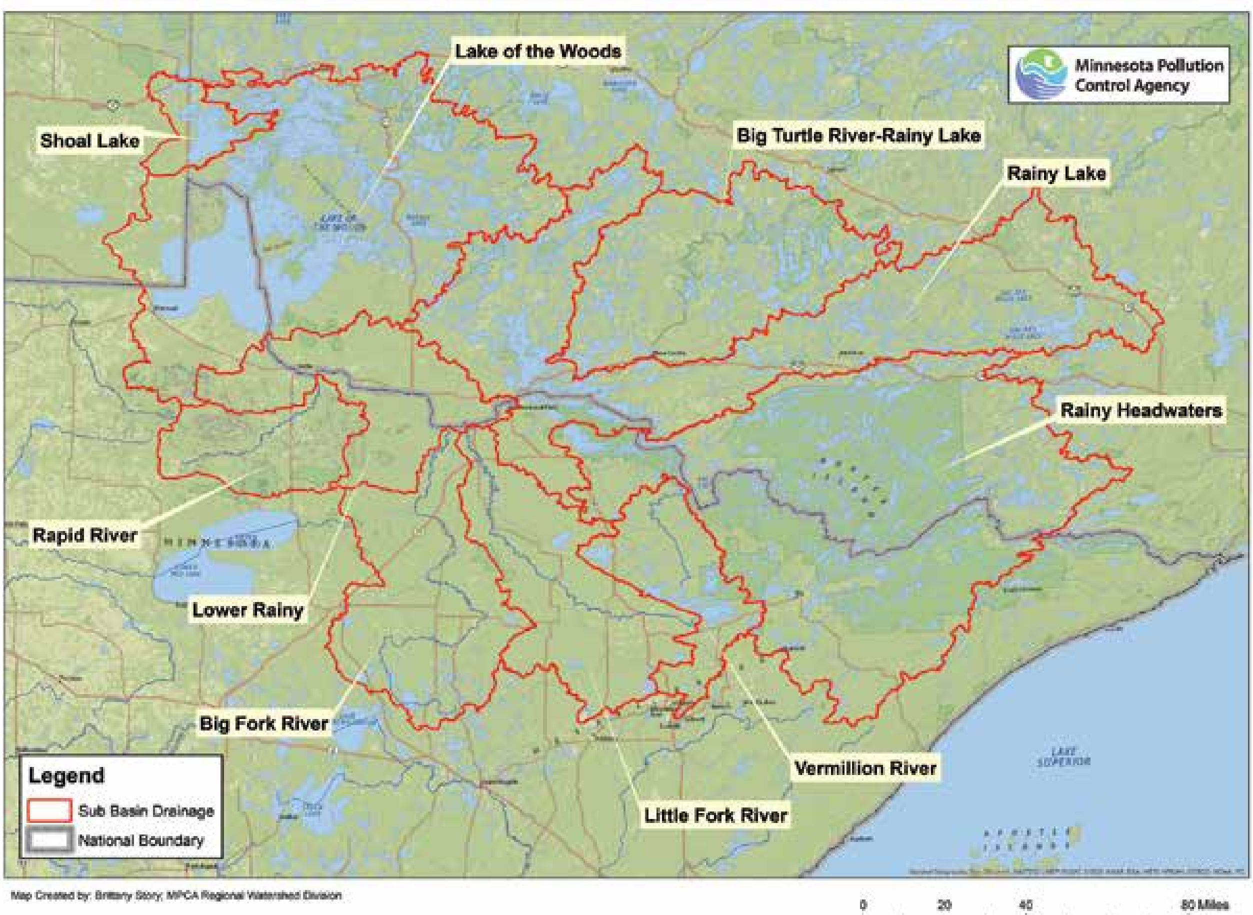


FIGURE 1 - Map showing the major sub-basins of the Rainy-Lake of the Woods Basin (IJC basin harmonization).

- Shoal Lake
- Lake of the Woods
- Big Turtle River-Rainy Lake
- Rainy Lake
- Rainy Headwaters
- Vermilion River
- Little Fork River
- Big Fork River
- Lower Rainy River
- Rapid River.

The 2009 SOBR focused primarily on the Lower Rainy and Lake of the Woods sub-basins. Here we include further information, where possible, on the remaining sub-basins. Many of the lakes in this area lie on the international boundary between Canada and the U.S. and are part of a strong, long lasting cross border partnership (IJC 2012, 2011 Annex). This boundary area, often referred to as the Quetico-Superior, makes up a significant portion of the basin that is managed differently than other local, multiple-use areas due to the presence of large national parks/forests (Quetico, Superior, Voyageurs) and the Boundary Waters Canoe Area Wilderness.

Hydrology, Lake Levels and Flow Regulation
There have been many discharge and water level control activities in the basin since the late 1800s. Figure 2 provides a timeline showing relevant activities between 1890 and 2013.

The Lake of the Woods Control Board (www.lwcb.ca) and the International Rainy Lake Board of Control (http://www.ijc.org/en_/RLWWB/Water_Levels_Data; now a committee of the International Rainy-Lake of the Woods Watershed Board) have collected an enormous amount of data relating to discharge, water levels relative to Rule Curves and precipitation data from many locations throughout the basin (Figure 3). These data are well organized on the websites shown above.

The three key control points in the basin where flow can be regulated are:

- the Lake of the Woods outlets at Kenora
- the Rainy Lake outlet at Fort Frances/International Falls
- the Namakan Lake outlets at Kettle Falls and Squirrel Falls.

These control points separate the basin into three major components namely:

1. Lake of the Woods and the Rainy River
2. Rainy Lake between the outflow from Rainy Lake and the inflow from Namakan Lake
3. The basin upstream of the outflow from Namakan Lake.

Flow and water level characteristics for these three areas are shown in Table 1.

The exact discharge from the Rainy River to Lake of the Woods has not historically been measured at the mouth but was estimated by examining the flow measured at Manitou Rapids which is upstream from the mouth. This is being rectified with the installation of the Wheeler's Point gauge at the mouth of the Rainy River. There are additional problems with estimating flow in the Rainy River due to winter ice damming.

There are many other minor control structures in the watershed such as the run of the river dams on the Seine River and many additional locations where discharge, water level and precipitation are measured.

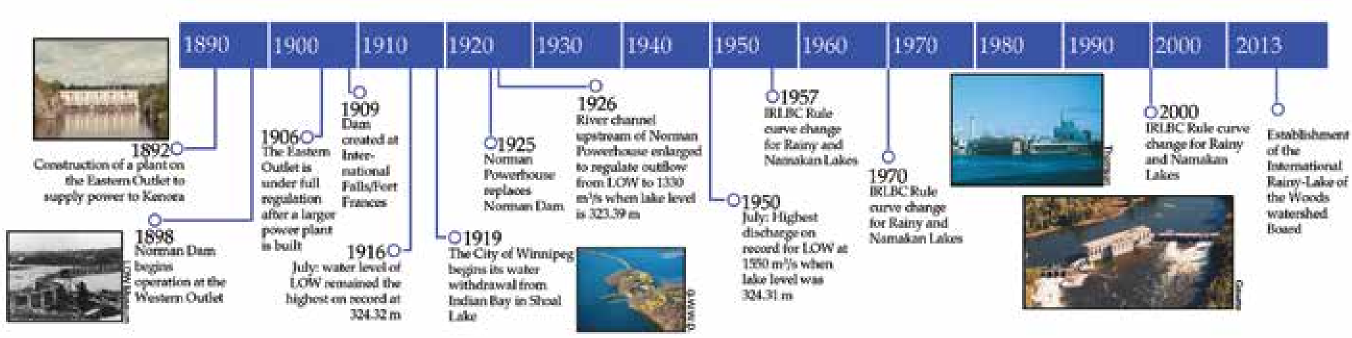


FIGURE 2 – Timeline of water level control activities.

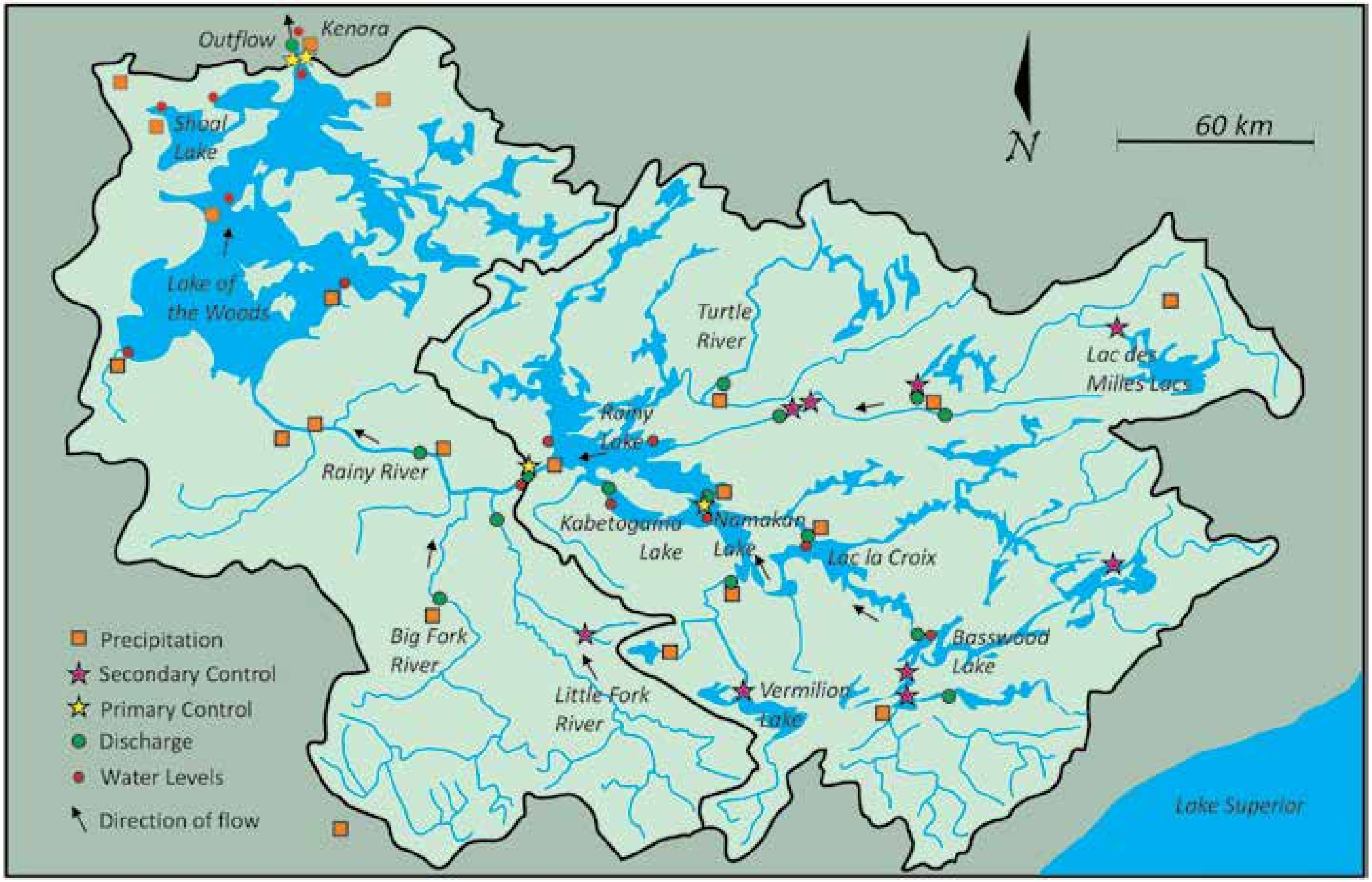


FIGURE 3 – Rainy-Lake of the Woods basin water control points.

TABLE 1 – Flow and water-level characteristics for the three main control points in the Rainy-Lake of the Woods basin.

Outflow	Drainage Area (km^2)	Discharge (m^3/sec)			Water Level (m)		
		min	mean	max	Flood Reserve	Normal max	Normal min
1.Lake of the Woods	70,400	75	460	1580	323.87	323.47	321.87
2.Rainy Lake	38,600	65	290	1350	337.90	337.75	336.70
3.Namakan Lake	19,300	15	160	780	341.10	340.95	338.95

TABLE 2 – Mean annual flows for major discharge gauging locations.

Station ID	Name	Drainage Area (km²)	Mean Annual Flow (m³/s)	Period of Record
05PC018a	Rainy River at Manitou Rapids, ON	50,200	227	1928-2013
05PC019a	Rainy River, Fort Frances, ON	38,600	366	1905-2013
5131500b	Little Fork R. at Little Fork, MN	4,351	30.1	1929-2013
5132000b	Big Fork R. at Big Falls, MN	3,833	20.7	1929-2013
5134200b	Rapid River near Baudette, MN	4,406		1956-1985
05PE020a	Winnipeg River below LoW	70,400	429	1893-2013
05PE011a	LoW western outlet (Norman Dam)		298	1913-2013
05PE006a	LoW eastern outlet (powerhouse)		100	1908-2013
05PE004a	LoW outlet at Mill C (Keewatin)		16.3	1913-1972
05PE003a	LoW outlet at boat lift channel		15.3	1913-1979

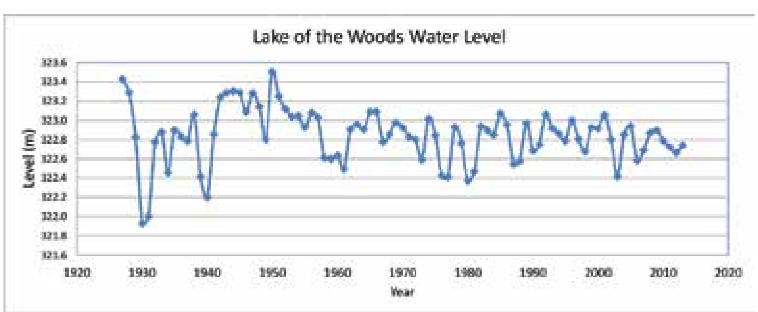
Generally, there is a well-established network of monitoring stations that can adequately describe the hydrology of the basin for most purposes (http://lwcb.ca/waterflowdata.html). Mean annual flows for major discharge gauging locations are shown in Table 2.

The R-LoW basin is the first international watershed to be included in the U.S. Geological Survey (USGS) StreamStats Web application. This is a Web based tool that can be used to generate "click point" basin boundaries and regression-based streamflow statistics. Collaborators on this project include the USGS, the IJC, the R-LoW Board, Ontario Ministry of Natural Resources (OMNR), Environment Canada (EC) and regional stewards of framework datasets. For access to the program visit: http://streamstats.usgs.gov.

Lake levels have been studied in conjunction with research projects examining erosion in the south portions of the LoW. For example, Herb *et al.* (2005) examined lake level data that were collected for Lake of the Woods back to 1913. Over this period, there was no indication of a systematic increase in average lake level. Recent high water events in, for example, 2002, did not stand out as being exceptional when compared to other events in the long-term record. Standard deviations of lake levels from year to year are on the order of 0.5 m (1.6 ft). Lake level, on average, was shown to be highest in July and lowest in March/April with an average difference of 0.5 m. Annual mean levels and outflow discharge are shown in Figure 4.

Rainy Lake Sub-basin

Rainy Lake and Namakan Reservoir are located along the international boundary in portions of the basin that are upstream of Fort Frances and International Falls (Rainy Lake sub-basin). The dams at the outlets of Rainy Lake and Namakan Reservoir are owned and operated by H2O Power LP in Canada and by Boise-Cascade in the U.S. The mandate to ensure compliance by these



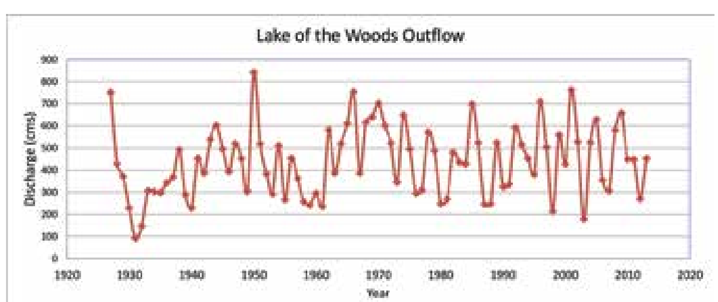


FIGURE 4 – Historic Lake levels and mean annual outflow discharge for Lake of the Woods (LWCB).

In 2007, the IJC began a process to fill gaps in preparation for a review of the 2000 Orders of Approval for the water level regulation of Rainy and Namakan lakes.

companies with the IJC's requirements for the regulation of flows out of Rainy Lake and Namakan Reservoir, and hence inflows to Rainy River and LoW, is now the responsibility of the International Rainy-Lake of the Woods Watershed Board (IRLWWB) Water Levels Control Committee which operates independently from, but reports to, the IRLWWB. Between 1949 and 2013, the International Rainy Lake Board of Control (IRLBC) had this authority.

Outflow from Rainy Lake has been controlled since 1909 at the dam at Fort Frances-International Falls. This dam is several kilometres down the Rainy River from the natural outlet spanning the river between Fort Frances and Ranier. Average inflows to Rainy Lake range from 151 m^3/s (5,332 ft^3/s) in early March to 519 m^3/s (18,328 ft^3/s) in June, although discharge has ranged from 0 to 1,733 m^3/s (LWCB, 2011). Throughout the year, average outflows vary from 167 to 465 m^3/s, with an annual average outflow of 290 m^3/s or 10,240 ft^3/s (LWCB, 2007). Lake level, inflow and outflow statistics are available on the LWCB website, http://www.lwcb.ca/percentiles/PctSite-RainyLake-PdEnding2005.pdf.

The Namakan Reservoir consists of a chain of five lakes with Namakan Lake to the east and Kabetogama Lake to the west. Control of outflow from Namakan Reservoir into Rainy Lake occurs at two stop-log sluice dams at Kettle Falls (which spans the Canada-United States border) and Squirrel Falls (in Canada). Further details on the control structures for both lakes is available at http://www.rlwwb-temp.lwcb.ca/. Of three additional lakes, Sand Point and Little Vermilion are shared between Canada and the U.S. and Crane Lake, is entirely in Minnesota to the south. Average inflows to Namakan Lake range from 73 m^3/s (2,578 ft^3/s) in early March to 342 m^3/s (12,078 ft^3/s) in late May, but inflows can be as low as 8 m^3/s and as high as 677 m^3/s. Average outflows range from 100 to 278 m^3/s, with an annual average outflow of 160 m^3/s (LWCB, 2011). The timing of water release from these lakes has a significant impact on Rainy Lake water level regulation and the effects of water level controls via Rule Curves have been extensively studied in these lakes. Lake level, inflow and outflow statistics are available on the LWCB website, http://www.lwcb.ca/percentiles/PctSite-Namakan-KabetogamaLakes-PdEnding2005.pdf.

To the present date the former IRLBC, followed by the Water Levels Committee of the IRLWWB, have adhered to the IJC-2000-Orders of Approval, Consolidated Order of January 2001, which defines a water level band with upper and lower Rule Curves for Rainy Lake and Namakan Reservoir, minimum outflow requirements and a "drought line", whereby outflows can be further reduced as needed when lake levels fall below a critical minimum level (determined at the discretion of the IRLBC, 2007). The International Falls/Fort Frances dam has been operated to maintain levels preferentially within the middle portion of these bands. In periods of high or low flows, the IJC may sanction the raising or lowering of lake levels outside the Rule Curves. The 2000 Rule Curves have allowed a seasonal variation in water level in Namakan Reservoir of 2.0 m, with a target of 1.5 m. In Rainy Lake a maximum seasonal variation in level of 1.05 m with a target of 0.80 m has been established (LWBC 2007).

In 2007, the IJC began a process to fill data gaps in preparation for a review of the 2000 Orders of Approval for the water level regulation of Rainy and Namakan lakes scheduled to begin in 2015. To support this review, the IJC is executing a Plan of Study to conduct the various monitoring and modeling analyses required to gather the information necessary for the 2015 review. Several research initiatives relating to the review of the 2000 Orders of Approval have been undertaken including the development of a one-dimensional HEC-RAS model of four pinch point channels in the Namakan chain of lakes to improve the understanding of the relationship between water levels and hydraulics in the Namakan Reservoir system, and the development of a hydrologic response model to assess the hydrodynamic changes of the 1970 and 2000 IJC Rule Curves. The later model developed two time series of water levels for Rainy Lake and Namakan Reservoir that researchers who will be conducting the habitat and flooding

Most of the boundary waters are managed as wilderness parkland/forest on both sides of the border.

evaluation work in the next stages of the Plan of Study will use.

Progress updates for the Plan of Study were presented at the International Lake of the Woods Water Quality Forum in 2013. The Rule Curve changes prescribed in the IJC 2000 Order were designed to more closely mimic the natural water level fluctuation in these water bodies with the intent of benefitting the aquatic ecosystems. Eighteen studies have been developed and are in various stages of completion. They encompass a wide range of disciplines, including natural resources investigations such as walleye and northern pike spawning evaluations, Rainy River fish community assessments, habitat and hydrologic modeling projects for the reservoirs and the Rainy River, cultural resources studies, and economic studies that assess the effects of the Rule Curve changes on resorts and property owners. These studies will provide critical input that, along with monitoring and research accomplished by the Canadian and U.S. resources management agencies charged with managing these water bodies, will form the basis for evaluating the effectiveness of the 2000 Rule Curves in achieving the intended ecosystem benefits and their effects on the cultural resources and economics of the region. The studies will be completed in 2015 at which time the IJC will begin a review that will provide a recommendation to either maintain the 2000 Order or to further adjust the Rule Curves. Descriptions of these studies and their status at the time of publication are shown in Table 3.

A U.S. Geological Survey/National Park Service water quality partnership study is currently underway (anticipated completion in 2016) that will assess methylmercury in young-of-year fish as a function of water-level fluctuations. This adds to a prior data set described by Sorensen *et al.*, (2005), http://pubs.acs.org/doi/abs/10.1021/es050471r .

There are currently agreements in place to further adjust water level control in the Rainy/Namakan system. In 2006 the boards and dam owners convened and agreed to suspend hydropower peaking at Rainy Lake from April 15th through to June 30th for 2007 and 2008 to balance hydropower needs with fish habitat requirements during the spring spawning. These were voluntary arrangements which are still in place as of 2014.

Rainy Lake has a large basin which includes the Turtle and Seine Rivers and there are additional control points and gauging stations in these areas. Upstream of Namakan Reservoir there is a vast interconnected international waterway which stretches eastward to within a few kilometres of Lake Superior including Lac la Croix and Basswood Lake. There are water level control structures throughout this area but they exercise minimal impact on flow compared to the structures on Rainy Lake and Namakan Reservoir. Most of the boundary waters are managed as wilderness parkland/forest on both sides of the border.

Lower Rainy River and its main tributaries

The Rainy River between its mouth and the outflow from Rainy Lake (the Lower Rainy sub-basin) is 130 km (81 mi) long and is the primary inflow to LoW. The area above Fort Frances/International Falls (38,600 km^2) which feeds water to this sub-basin represents 55% of the total area of the LoW basin (70,400 km^2) (DeSellas *et al.* 2009). The outlet from Rainy Lake into the Rainy River is controlled by a dam at Fort Frances/International Falls. By the time the Rainy River reaches the gauging station at Manitou Rapids it has accumulated water from the Little Fork River and Big Fork River tributaries and at this point the river is draining approximately 70% of the LoW basin (DeSellas *et al.* 2009). Manitou Rapids provides an estimate of most of the Rainy River flow volumes into LoW but winter discharge measurements are often in error due to ice build-up on the Rainy River (DeSellas *et al.* 2009). The Rainy River itself is predominantly flat and slow moving, with the exception of Manitou and Long Sault Rapids but slope can change considerably with increased flow. The range in water level is about 4.3 m (14 ft) below the Rainy Lake dam, about 5.3 m (17.4 ft) at Manitou Rapids, and about 2.4 m (7.9 ft) near the mouth at the Town of Rainy River. Rainy River flow statistics are available at:

TABLE 3 – Description and status of studies being conducted to assess the effects of the 2000 Rule Curve for Rainy Lake and Namakan Reservoir.

Study	Completion Date	Information Produced
Reservoirs - develop reservoir hydrologic model & reservoir PHABSIM habitat model	Hydrologic model - complete	Model and descriptive text comparing flows and levels for Rainy Lake and Namakan Reservoir under 1970 and 2000 Rule Curve scenarios
	Habitat model anticipated completion: 2015	Models and descriptive text comparing habitat available for selected fish and wildlife species under 1970 and 2000 Rule Curve scenarios
Characterize the natural hydrology of Rainy River (HEC-RAS Model) vs. Rule Curves	Anticipated completion: 2014	Models and descriptive text comparing Rainy River hydrology under 1970 Rule Curve, 2000 Rule Curve, and pre-dam conditions
Measure changes in benthic community in relation to curves, in the reservoirs	Anticipated completion: 2014	Comparison of Rainy Lake and Namakan Reservoir benthic macroinvertebrate communities present under 1970 and 2000 Rule Curves and assessment of aquatic macroinvertebrate communities present in vegetation beds and on coarse woody debris
Aquatic vegetation (replicate Meeker and Harris 2009)	Complete	Comparison of Rainy Lake and Namakan Reservoir aquatic vegetation communities present under 1970 and 2000 Rule Curves
Reservoirs – northern pike spawning habitat and reproductive success	Anticipated completion: 2015	Comparison of Rainy Lake and Namakan Reservoir northern pike spawning and nursery habitat available under 1970 and 2000 Rule Curves
Rainy River – critical spawning and nursery habitats	Anticipated completion: 2015	Comparison of upper Rainy River lake sturgeon, walleye, and log perch spawning habitat available under 1970 and 2000 Rule Curve conditions
Economic survey of impact of Rule Curves on tourist resorts on reservoirs	Anticipated completion: 2015	Assess tourism impacts of 1970 and 2000 Rule Curves on Rainy Lake and Namakan Reservoir resorts
Relate Rule Curve changes to flooding and ice effects on reservoirs	Anticipated completion: 2015	Comparison of Rainy Lake and Namakan Reservoir property damage due to flooding and ice under 1970 and 2000 Rule Curve conditions
Synthesis of four studies	Anticipated completion:2014	Model and descriptive text comparing Rainy Lake and Namakan Reservoir common loon reproductive success under 1970 and 2000 Rule Curve scenarios
Detailed bathymetric mapping of the littoral zone of selected reservoir locations	Anticipated completion: 2014	Detailed bathymetric maps of selected nearshore areas of Rainy Lake and Namakan Reservoir to support assessments of habitat available under the 1970 and 2000 Rule Curves
Assess effects on cultural resources at a small number of sites on the reservoirs	Anticipated completion: 2015	Assessment of which set of Rule Curves (1970 or 2000) produce less damaging hydrologic conditions for cultural resources near Rainy Lake and Namakan Reservoir
Assess effects on cultural resources at benchmark sites on the Rainy River	Anticipated completion: 2015	Assessment of which set of Rule Curves (1970 or 2000) produce less damaging hydrologic conditions for cultural resources near the Rainy River

Study	Completion Date	Information Produced
Assess effects on reservoir habitats for marsh-nesting birds/herps at selected sites	Completed 2011	Comparison of marsh nesting bird and herptile habitat available under 1970 and 2000 Rule Curves
Identify critical river benthic habitats at X-sections; model effects of curve change	Anticipated completion: 2016	Comparison of Rainy River benthic macroinvertebrate communities present under 1970 and 2000 Rule Curves
Measure Unionid (mussel) diversity and abundance in the Rainy River re: effects	Anticipated completion: 2015	Assessment of 1970 and 2000 Rule Curve effects on Rainy River mussel community
Measure changes in fish community health (Index Biotic Integrity) re: effects	Anticipated completion: 2015	Assessment of 1970 and 2000 Rule Curve effects on Rainy River fish community health by using Index of Biotic Integrity
Measure critical spawning habitat for walleye on Namakan Reservoir re: effects	Anticipated completion: 2015	Assessment of effects of 1970 and 2000 Rule Curves on Namakan Reservoir walleye spawning habitat quantity and quality
Examine municipal water treatment and hatchery data for Rainy River re: effects	Anticipated completion: 2015	Assessment of whether the change from the 1970 Rule Curves to the 2000 Rule Curves affected the use of water from the Rainy River for municipal purposes or operation of the fish hatchery located at Manitou Rapids

http://www.lwcb.ca/percentiles/PctSite-RainyRiverBasinFlows-PdEnding2005.pdf.

Flows characteristics at the midpoint of each month at Manitou Rapids on the Rainy River are shown in Figure 5.

The two largest tributary inflows to the Lower Rainy River are the Little Fork and Big Fork Rivers, which together drain 12% of the LoW basin and contribute 10% of the estimated total runoff to LoW (LWCB 2007). This estimate does not include unmonitored areas or groundwater sources. These tributaries empty into the Rainy River upstream of Manitou Rapids. The Little Fork River drains a basin area of 4,773 km^2 (1,843 mi^2) and flows 258 km (160 mi) from its headwaters in northeastern Minnesota to the confluence with the Rainy River. The Big Fork River, to the west, drains 5,343 km^2 (2,063 mi^2). It is 105 km (65 mi) long originating at Dora Lake in Northern Itasca County, Minnesota, and ending at the Rainy River approximately 9 km west of the Little Fork confluence. The USGS has been monitoring streamflow at the cities of Littlefork on the Little Fork River and Big Falls on the Big Fork River continuously since 1929. It is interesting to note that during periods when the upper basin has been relatively dry and the Fork Rivers basin experiences heavy rainfall, the majority of flow in the Rainy River may not come from Rainy Lake but from these tributaries. While the average annual flow from the Fork Rivers is 53 m^3/s (1,872 ft^3/s), their flow has peaked at over 1000 m^3/s (35,315 ft^3/s).

A great deal is known about the hydrology of the Lower Rainy River and its tributaries. McCutcheon *et al.* (2013) have recently used a Hydrological Simulation Program-FORTRAN (HSPF) to develop model applications for the Little Fork and Big Fork sub-basins. HSPF is a primary tool used by the Minnesota Pollution Control Agency (MPCA) for a holistic approach to basin-scale monitoring, assessment, and TMDL development. The HSPF model applications developed for the Little Fork and Big Fork sub-basins have been calibrated to simulate hydrology and water quality and will be used to help address water quality impairments. An HSPF model application is also being used to simulate hydrology (and ultimately

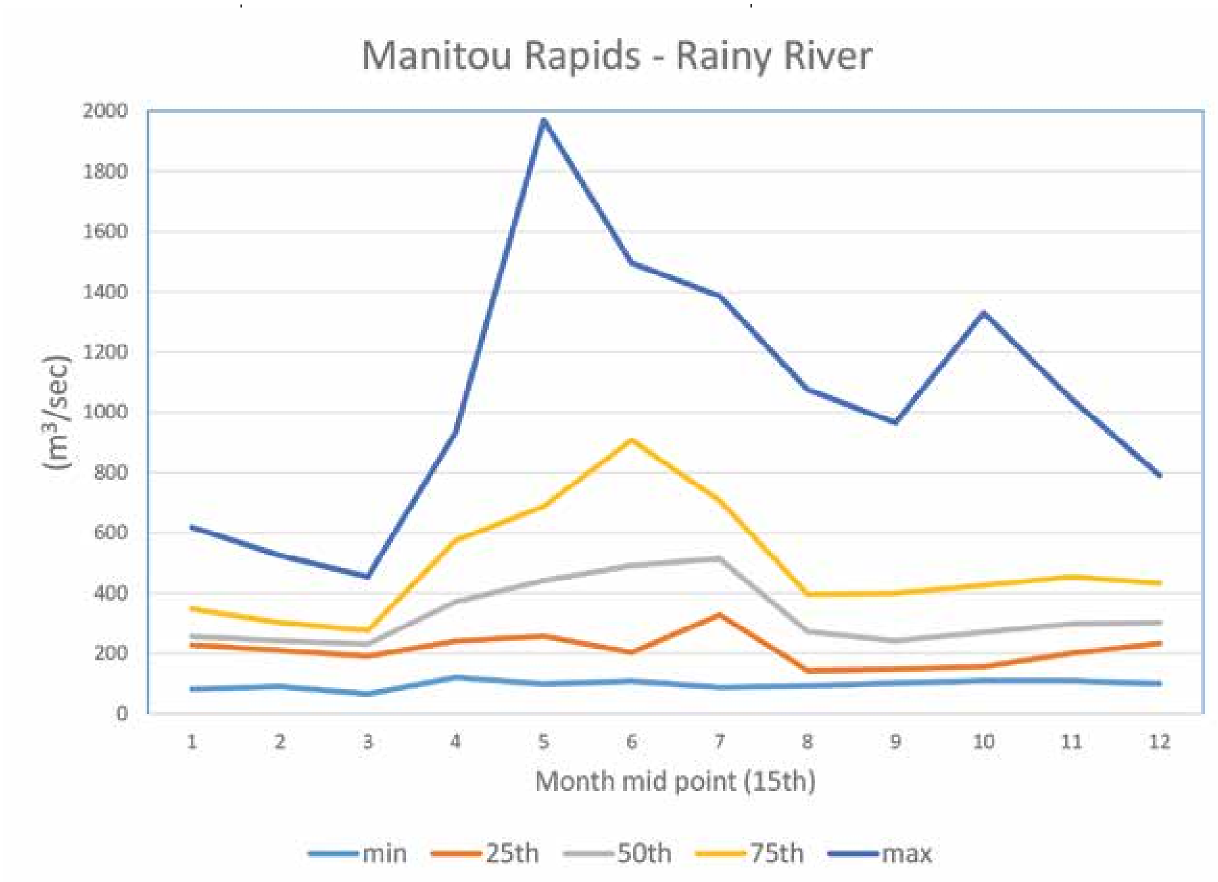


FIGURE 5 – Flow characteristics, percentiles at the midpoint of each month for the Rainy River at Manitou Rapids (LWCB).

water quality) in the entire R-LoW basin. The model results are complete for some sub basins and partly complete for all sub-basins.

Lake of the Woods

Lake of the Woods could be thought of as a very large lake (3,850 km^2, 1,486 mi^2) with a river running through the centre. The main direction of flow is in a northwesterly direction from the Rainy River inflow at Fourmile Bay in the south to the outlet near Kenora, Ontario in the north (Figure 6). While the main direction of hydrological flow is based on a south to north inflow/ outflow gradient, the direction and rate of exchange between sub-basins is strongly modified by wind action, lake morphometry and transient circulation patterns.The south is characterized by Big Traverse Bay which is a shallow, expansive, and open waterbody with a fetch of over 50 km (31 mi). The northern portion of LoW is a convoluted labyrinth with many bays and inlets including approximately 14,500 islands which contribute to its hydrological complexity.

The median (or normal) quarter-month LoW inflow ranges from a low of 155 m^3/s (5,474 ft^3/s) in mid-August to a high of 717 m^3/s (25,321 ft3/s) in June. On a daily basis, inflows have been higher than 3,320 m^3/s (LWCB 2011).

Water exits LoW at two main outlets at Kenora, Ontario, which are separated by Tunnel Island. These outlets have been regulated by the Norman Dam at the western outlet and the Kenora powerhouse dam at the eastern outlet since the mid-1890s. The average discharge from the east and west outlets is 460 m^3/s (16,245 ft^3/s) but in the past they have discharged as much as 1,600 m^3/s (LWCB 2011). Mean outflow generally declines between August and October, and remains stable during the winter months (December to March). Between April and May there is commonly an increase in discharge associated with ice and snow melt, and spring precipitation. A third

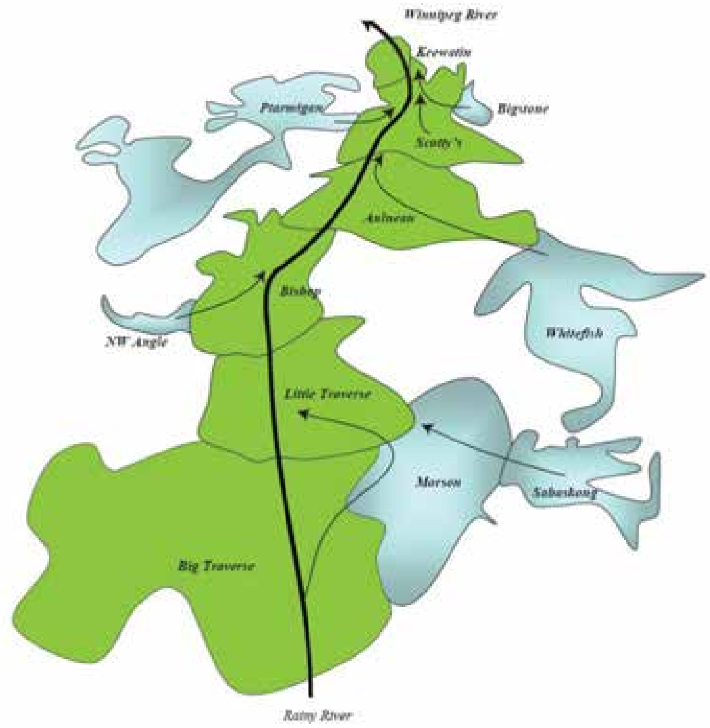


FIGURE 6 – Diagram showing the relationship between major hydrologic areas in LoW relative to the central flow (modified after Malaher 2005, unpublished manuscript).

minor outlet is located at the NW end of Portage Bay in Keewatin, which empties into Darlington Bay on the Winnipeg River.

Two boards are responsible for managing the water levels in LoW. Based on recommendations by the IJC, a treaty between the United States and Canada was signed in 1925 (*Lake of the Woods Convention and Protocol*) which outlines elevation and discharge requirements for regulating water in LoW. As recommended by this treaty, the outflow from LoW through the Norman Dam was enlarged in 1926 so that total outflow from LoW would be 1,330 m^3/s (46,969 ft^3/s) when the lake is at 323.39 m. In anticipation of the treaty requirements, the Canadian LoW Control Board (LWCB) was created under Canada and Ontario legislation in 1919. It was established to implement the recommendations of the IJC 1912-17 reference study of lake levels in LoW. The mandate of the LWCB is to control the outflow from LoW under normal lake levels. The 1925 treaty prescribed the regulation and control of the outflow of Lake of the Woods to the Canadian LWCB and also initiated the International LoW Control Board (ILWCB) whose mandate is to approve the rate of discharge from the lake when water levels rise above elevations of 323.47 m, or fall below 321.87 m. These regulations aim to ensure that water is being used in the best possible way while still protecting diverse interests, including water supply, ecology, agriculture, sewage disposal, electric power generation, fishing, and navigation.

Currently, water level data are obtained from several gauges to guide hydrological decisions in LoW (R. Cousins, LWCB, pers. comm., 2007), including two gauges in Minnesota (Warroad, WSC gauge #05PD001 and Springsteel, USGS gauge #05140521), and four in Canada (Hanson Bay, WSC gauge # 05PD008, Clearwater Bay, WSC gauge # 05PD011, Cyclone Island, WSC gauge # 05P029, and Keewatin, WSC gauge # 05PD014).

As a result of regulation, mean daily levels have been stable over the past ten years, ranging between 321.87 and 323.47 m. During times of high flow, it is not always feasible to maintain this range, and when the lake reaches 323.39 m, regulation focuses on maintaining a height below 323.85 m (LWCB 2002). During drought periods, outflow is adjusted to maintain a balance between upstream and downstream interests. Average annual variation is 0.8 m, and lake levels have been between 322.01 and 323.45 m 98% of the time over the last 30 years (LWCB 2007). Lake-level stabilization in recent years is a result of improved climatic predictive capability and better engineering actions to anticipate and control lake levels.

Shoal Lake

Since 1919, subject to an IJC Order of Approval (IJC 1914) and an Ontario Order in Council, Shoal Lake has supplied drinking water to the city of Winnipeg via a 135 km aqueduct which exits Shoal Lake at the west end of Indian Bay. The aqueduct accounts for about 1% of the average annual outflow from LoW (LWCB 2011). Winnipeg is licensed to take 455 million litres of water per day from Shoal Lake but, in practice, the withdrawals have been approximately 50% of the allowable limit for the past 30 years.

For example, withdrawal in 2000 averaged 227 million litres per day (Shoal Lake Watershed Working Group, 2002).

Prior to the 1890s the natural outflow of Shoal Lake was into LoW via Ash Rapids, located to the southwest of Clearwater Bay. The LoW north end dams were constructed and LoW levels increased in the late 1890s, and Shoal Lake became at times an embayment of LoW. In 1914 when the Canadian government sheared the rock structures forming the rapids, Shoal Lake effectively became part of LoW. Since then, water can flow in both directions through Ash Rapids depending on the net effect of various factors such as withdrawals, rising or dropping LoW levels, and local inflows to Shoal Lake. A water balance study by TetrES (2000) concluded that,

> *"In an average year, there is outflow from Shoal Lake to Lake of the Woods during winter months and vice--versa during summer months, resulting in a small net annual outflow from Shoal Lake. In a dry year, there is inflow from Lake of the Woods to Shoal Lake during most of the year with relatively small outflow from Shoal Lake occurring from mid—winter to early spring. In a wet year, flow is primarily from Shoal Lake to Lake of the Woods during the entire year."*

Lake-level stabilization in recent years is a result of improved climate predictive capability and better engineering actions to anticipate and control lake levels.

One of the key recommendations of the Shoal Lake Water Management Plan (Shoal Lake Watershed Working Group, http://www.gov.mb.ca/waterstewardship/water_quality/quality/shoal_lake/working-group-03.pdf) with respect to hydrology was that data obtained through monitoring programs should be periodically evaluated to monitor the influence that Winnipeg water withdrawals may be having on water levels and water uses of Shoal Lake, over and above the ongoing influences of LoW water level regulation and fluctuations. The Working Group also recommended coordination with the LWCB so that the Board considers the collective interests of Shoal Lake stakeholders with respect to their expectations in water level and flow management.

Stream geomorphology and flood plain characteristics

The soils of the northern and eastern portion of the basin are generally less than 0.3 m (one foot) in depth—overlaying Precambrian Shield rock. The southwest sub-basins lie primarily on the flat lakebed of glacial Lake Agassiz with some of the southern headwaters consisting of glacial till (Waters 1977).

From a fluvial geomorphology perspective the streams and rivers of the northern and eastern portion exhibit relatively stable form and function. Northern/eastern streams are connected to their floodplains, demonstrated during two-year hydrologic events. Channels are also stable, neither aggrading nor degrading. However, due to steep gradients and shallow soils, northern/eastern streams are especially vulnerable to destabilization from increased flows due to wildfire, climate change or land-use activities including forest management practices, residential and recreational development and mining activities (MPCA, unpublished assessment data).

Many of the southwestern streams have experienced erosion, undercutting, and straightening of their streambanks within the last 100 years which may be contributing high sediment loads and hence, phosphorus loads, to the Rainy River (Anderson *et al.*, 2006a). Streams have eroded (downcut) from their original floodplain and while there are limited data, field measurements indicate that many of these streams would require, at a minimum, a 50-yr flood event for water to reach the original 1.5 year event floodplain. Many of the southwestern streams have at least one and sometimes two terraces below the original floodplain. Studies comparing the Little Fork and Big Fork Watersheds point to human activities (clear cutting of the old growth forest, log drives, drainage projects and conversion of forest lands to agriculture) causing the destabilization (Anderson *et al.* 2006a; MPCA unpublished data).

Despite their similar geographical location, there are slight differences between the discharge characteristics of the Little and Big

Land masses are rebounding upward at different rates following the retreat of the Laurentide Ice-sheet which removed an immense weight from the landscape.

Fork rivers. Despite its smaller basin area, the Little Fork River has a higher discharge than the Big Fork River. In addition, the Little Fork River and its tributaries have approximately twice the water yield compared to other area streams. As a result, changes in runoff and precipitation can cause water levels to rise and fall rapidly (Anderson *et al.* 2006a). These differences have been attributed to: (1) a larger area of peatland in the Big Fork basin, which moderates runoff and flow; (2) a higher proportion of pasture land in the Little Fork basin, which generates more runoff than mature forests; (3) a greater number of lakes in the Big Fork basin (420 versus 165 in the Little Fork), which provide storage and regulate streamflow; and (4) geological differences between the two watersheds, including hard, igneous rock in the Little Fork, which yields faster runoff, and softer, fluvial sediments and geology in the Big Fork (Anderson *et al.* 2006a). In 2006, the Little Fork River was added to Minnesota's Impaired Waters List for turbidity. Recovery of the Little Fork River sub-basin from the impacts of historical logging is currently being examined. Potential stressors to the stability of western portion streams include climate change, development and forest management practices (Anderson *et al.* 2006a; St. George 2006).

Lake Levels

Human manipulation of water levels on LoW was initiated with lasting effects with the construction of the Norman Dam between 1893 and 1895 at the outlet near Kenora. The IJC (1917) estimates that this structure raised the level of the lake by approximately 3.5 ft (1.07 m). Water levels on LoW are regulated under a treaty (1925 Lake of the Woods Convention and Protocol) between Canada and the United that prescribes maximum and minimum levels, within which the lake must ordinarily be maintained, to best serve multiple uses.

The Boundary Waters Treaty of 1909 provides for the regulation of water use and water levels by the IJC which appointed the IRLBC to monitor regulation of Rainy and Namakan Reservoirs. The water levels of Namakan, Kabetogama, Sand Point, and Rainy Lakes are controlled by dams at Kettle Falls and International Falls according to Rule Curves established by the IJC.

Although it is a complex undertaking, water levels must be monitored to predict the outcomes of precipitation events (or drought intervals) to provide guidance to human actions through control structures which actively manipulate water levels. Interpretation of water-level data over large areas can be difficult due to variations in levels that are the result of wind action or variations in established sea level datums between monitoring locations. In the case of the LoW basin there is the added difficulty of differential isostatic rebound between the north and south portions of the lake. This occurs because the land masses are rebounding upward at different rates following the retreat of the Laurentide Ice-sheet which removed an immense weight from the landscape. Studies indicate that the north end of the lake will rebound about 10 cm (0.33 ft) more than the south end over the next 200 years and about 28 cm (0.92 ft) more than the south over the next 500 years (Yang and Teller 2005).

The fact that multiple uses exist with respect to water levels guarantees that there will be eternal conflicts whereby higher levels are preferred for some uses at the same time that lower levels would be ideal for others. The potential impact of water-level manipulation is often listed as a concern in any system where water levels are controlled. In the case of the R-LoW basin, many such concerns have been noted.

Water levels and erosion are listed in Chapter 3 as watershed concerns due to the large number of watershed processes that they can potentially influence. Water levels are therefore identified as a basin concern and this is addressed in more detail in Part 6 of Chapter 3.

Climate Impacts on Runoff

Detailed studies of the effects of warming air temperatures and drought on lake properties have been conducted on lakes at the Experimental Lakes Area (ELA) near Kenora, Ontario. During severe drought conditions in the 1980s, ELA scientists reported significant changes to the physical, chemical and biological condition of ELA reference lakes that had been studied intensively for more than three decades (Schindler *et al.* 1996). During the drought, annual air temperatures warmed by approximately 2°C, with declines in mean annual runoff of approximately 50%. Scientists observed an increase in the number of days without flow for many streams, an increase in the water renewal times of lakes, and increases in volume-corrected lake temperatures that were of a similar rate to increases in air temperature (Schindler *et al.* 1996). The increase in air temperature observed at ELA during this time period was less than the increases that are expected in northwestern Ontario over the next half century. Thus, the aquatic changes observed at ELA provide a glimpse of the changes that may be observed in the R-LoW basin over the next few decades.

Flood events that were more commonly associated in the past with spring runoff have shifted to those that are caused by heavy rainfall at other times of the year. Chiotti and Lavender (2008) reported that only 34% of flooding events in the central region of Ontario (including northwestern Ontario) between 1990 and 2003, occurred in the spring (March and April). For example, a series of intense thunderstorms in June of 2002, produced approximately 400 mm of rain in northwestern Ontario and northern Minnesota (Chiotti and Lavender 2008).

Increases in winter temperatures may result in increased runoff and elevated discharge from the lake outflow during the winter months. St. George (2006) reported that increased winter discharge may be responsible for a 58% increase in mean annual flows in the Winnipeg River basin since 1924. However, this record is also punctuated with periods of unusually low discharge, such as the winter of 2006-2007, when average outflow in LoW and Rainy Lake were the lowest in more than 100 years of record-keeping (LWCB 2007), and the period from June, 2006 to mid-March, 2007 when inflow to LoW was the second lowest in 91 years of records (LWCB 2007).

Increased variability in runoff events may describe the new normal condition.

Major Inflows and Tributary Assessment

Rainy River and LoW tributary sampling locations for MPCA, Environment Canada and the Ontario Ministry of the Environment are shown in Figure 7. Data from these locations have been used together in recent modeling efforts to assess nutrient loads to LoW.

In 2010 the MPCA ended the Milestone Monitoring Program and continued with the Intensive Watershed Monitoring Program (IWM, initiated in 2006) which improves the ability to provide basin geographic coverage, year round sampling and capacity to calculate loads. Intensive Watershed Monitoring is based on a 10 year cycle with systematic sampling at the mouth of watersheds of different scales in each of 84 major watersheds. The main IWM objectives are to determine the conditions of all watersheds relative to a variety of indicators, to provide information for the *stressor identification/TMDL process* and to monitor these conditions over time (IRLBC/IRRWPB 2011). For more information about this program please visit www.pca.state.mn.us.

Little Fork River

The lower reach of the Little Fork River mainstream was added to the Impaired Waters List for turbidity in 2006. Sediment loading studies began in 2006 and the TMDL study began in 2012. The IWM Program assessed fish communities, physical habitat, invertebrates, and water chemistry in 2008-09. Flow data can be found in the USGS National Water Information database. The Watershed Assessment Report is available at: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/little-fork-river.html.

A timeline of activities in the Little Fork sub-basin includes:

- 2008 Intensive Watershed Monitoring began, completed in 2010
- 2010 Monitoring and Assessment Report completed
- 2011 Stressor identification began, completion in 2012
- 2012 Watershed modeling complete
- 2012 Little Fork and Big Fork Sediment

Intensive Watershed Monitoring is based on a 10 year cycle with systematic sampling at the mouth of watersheds of different scales.

Transport Study began, completion expected in 2014 (IRLBC/IRRWPB-Fall 2012 Report-September 25, 2012)

Big Fork River

A timeline of activities within the Big Fork River sub-basin as part of the MPCA Major Watershed Restoration and Protection Program (WRAP) includes:

2010 Intensive Watershed Monitoring began, completed in 2011

2011 Assessment completed on 53 stream segments. Among these, 46 segments met all applicable standards and were fully supporting of aquatic life and aquatic recreation, 3 were non-supporting due to low dissolved oxygen (2 due to natural conditions and Popple River between Natures Lake and Dora Lake was determined to be due to anthropogenic activities and will be placed on the 2014 draft 303(d) Report to Congress (Impaired Waters List), 3 were non-supporting due to impaired biota, but these were due to natural conditions, and one was not assessed because it was channelized.

2011 Assessment was completed on 121 lakes of which 114 met all applicable standards and were fully supporting of aquatic life and aquatic recreation. Seven lakes were determined to be non-supporting due to phosphorus levels greater than the 0.03 mg/L standard. These lakes (Bowstring, Dora, Island, Jessie (TMDL completed), Little Spring, Round and Shallow Pond all located in the headwaters of the Big Fork sub-basin) will be placed on the 2014 draft 303(d) Report to Congress.

2012 Watershed modeling and assessment of the Big Fork River sub-basin completed.

2014 Stressor identification will begin with completion expected in 2015.

In December 2013 the Big Fork River Watershed Monitoring and Assessment Report was posted http://www.pca.state.mn.us/index.php/view-document.html?gid=20347. The results of this extensive monitoring indicate that the condition of the lakes and streams is good to very good, with few impairments. The most widespread impairment noted in both streams and lakes was mercury contamination which limits the consumption of fish. Many other impairments were due to natural causes. This report is an excellent example of the benefits of a basin approach to monitoring and illustrates the value of using volunteers in complex monitoring programs. More information is available in Watershed Approach to Condition Monitoring and Assessment at: http://www.pca.state.mn.us/index.php/view-document.html?gid=10230

Rainy River Headwaters

The MPCA's Major Watershed Restoration and Protection Program (WRAP) begins in 2014, with plans to assess the Vermilion basin beginning in 2015, the Rainy River/Rainy Lake basin beginning in 2016, and the Black River, Rapid River and Baudette River watersheds in 2017 (IRLBC/ IRRWPB-Fall 2012 Report-September 25, 2012).

In 2011 the White Iron Chain of Lakes Association (WICOLA) in partnership with the Soil and Water Conservation Districts (SWCDs) implemented the Kawishiwi Watershed Protection Project, a three year project designed to develop a Watershed Management and Protection Plan. The program included lake and stream monitoring, and identification of protection and restoration needs along with the analysis of threats from aquatic invasive species and failing septic systems. The plan was completed in 2013. http://kawishiwiwatershed.com/.

Water quality, sediment quality and streamflow data were collected from 22 sites around Kabetogama Lake in 2008 and 2009 to assess internal and sub-basin nutrient loads. The results were published in two scientific papers (Christensen, *et al.* 2011, 2013).

Information about water quality monitoring in Lake Vermilion may be found at: http://www.sportsmensclublakevermilion.org/htm/waterqualreports.htm.

Ontario Tributaries

The Ontario Ministry of the Environment (OMOE) monitors 11 tributaries to LoW and the Rainy River (2009-2012)

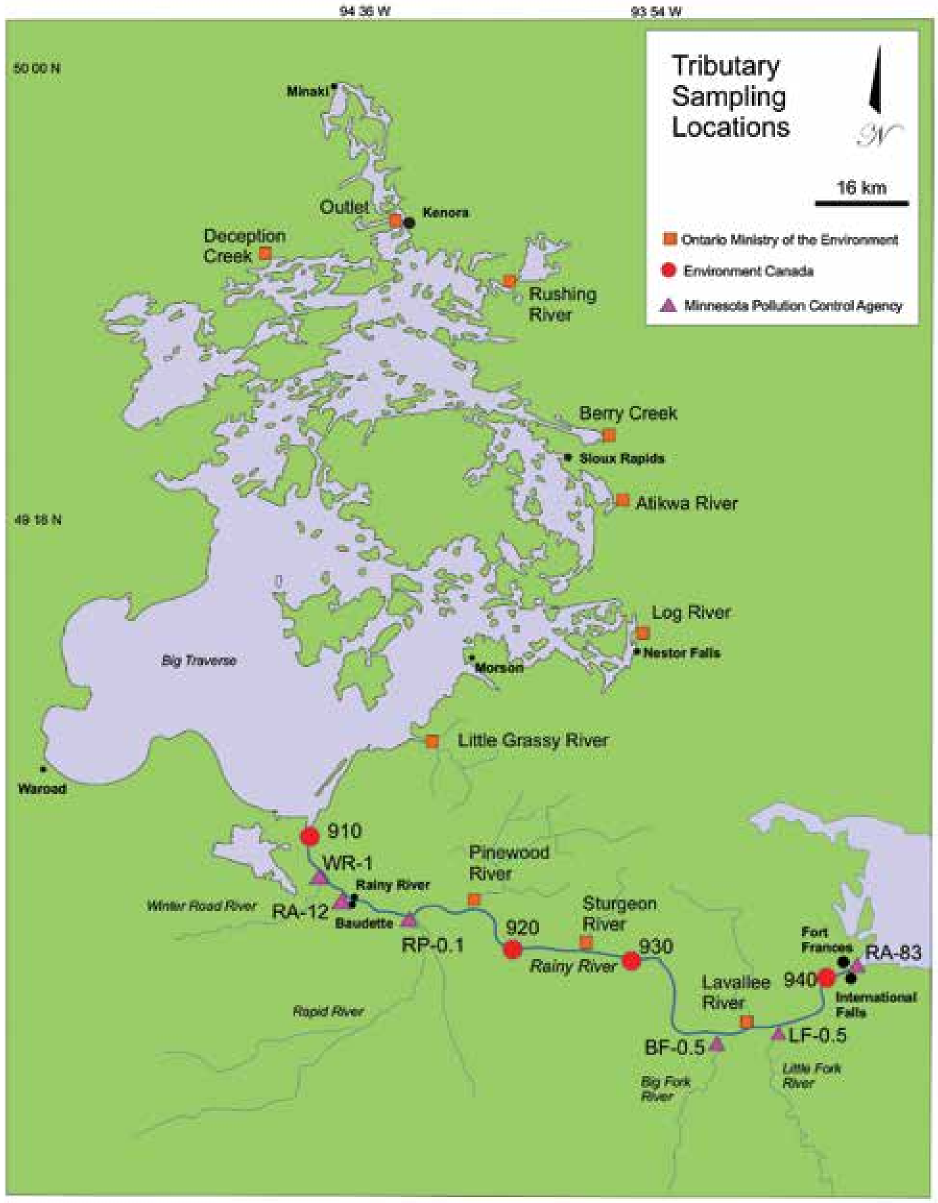


FIGURE 7 – Lake of the Woods and Rainy River tributary monitoring locations.

including the outlet to the Winnipeg River (Table 4; Figure 7). The main objective is to contribute data to nutrient loading estimates. The three tributaries to the Rainy River are the LaVallee River, the Sturgeon River and the Pinewood River (Figure 7). Samples were analyzed for phosphorus, nitrogen, pH, alkalinity, specific conductance, total & dissolved solids, dissolved organic & inorganic carbon, and reactive silicate. Results showed that concentrations in tributaries to the Rainy River are higher than they are in tributaries elsewhere around LoW.

Geology

The basin rests upon bedrock of the Superior Structural Province of the Precambrian Shield. This hard, impermeable bedrock consisting mainly of granitic and metavolcanic rocks, including igneous, metamorphic, and sedimentary rocks was formed approximately 4 billion years ago. A billion years later, crustal rifting in the Lake Superior basin caused lava eruptions that flowed west over the bedrock formed earlier and intruded magma (laden with precious metals) deep into the older continental crust. A band of Archean metasedimentary rock

TABLE 4 – Coordinates for Ontario tributaries monitored weekly during open water from 2009 to 2012. Parameters include TP, temp, DO, Cond, SS, Solids, Dissolved Solids, pH, Alk, NH_4, NO_2+NO3, TKN, DOC, DIC, Silicates

Station Code	Tributary Name	Latitude *Deg min sec*	Longitude *Deg min sec*
99LWTRB0102	LaVallee River	48 32 05	93 38 26
99LWTRB0202	Sturgeon River	49 39 20	94 01 20
99LWTRB0302	Pinewood River	48 47 54	94 11 05
99LWTRB0402	Little Grassy River at Hwy 600	48 56 41	94 22 06
99LWTRB0502	Log River at Nestor Falls	49 07 03	93 55 34
99LWTRB0602	Atikwa River	49 24 13	93 57 07
99LWTRB0702	Berry Creek	49 26 41	93 58 31
99LWTRB0802	Rushing River at Blindfold L. outlet	49 39 53	94 17 39
99LWTRB0902	Deception Creek	49 42 50	94 48 52
99LWTRB1002	Winnipeg River at Kenora	49 46 57	94 29 52
99LWTRB1032	English River at Caribou Falls	50 15 46	94 58 29

transects the upper and lower Rainy River portions of the basin. The Lake of the Woods and Central Rainy River basins as well as the northern portion of the upper Rainy River basin, consist of a veneer of discontinuous glacial till (Fulton 1995). The ground moraine is formed from meta-sediments and greenstone belts and is moderately acidic and relatively rich in nutrients. To the south of the Namakan River and along the eastern edge of the unit adjacent to Quetico Park the ground moraine is derived from granite with soils that are more acidic and nutrient poor. Soil depths throughout are shallow to extremely shallow with large outcroppings of bedrock.

Glacial Lake Agassiz, (Figure 8) formed by a melting continental ice-sheet, covered much of what is now western Minnesota, eastern North Dakota, southern Manitoba, and northwestern Ontario, from approximately 12,500 to 7,500 years ago. The upper and lower portions of the Rainy River basin, including the southern portion of LoW (i.e., Big Traverse Bay), are underlain by sediment (glacial drift and silt, clay, loam, and sand) deposited by Lake Agassiz. These regions are relatively flat with a difference in elevation of 15 m between Rainy Lake and LoW (IJC 1984). Wetlands, peat bogs, and marshes occur in the Agassiz lacustrine plain with beaches of sand and gravel along the northern boundary of the clay plain. When Lake Agassiz retreated, many lakes and rivers remained in the low-lying areas. The rise of the earth's surface which followed the retreat of the glacier (isostatic rebound) greatly shaped the early history of the R-LoW basin (Yang and Teller 2005). Differential rebound that occurred after Lake Agassiz retreated, tilted the land's surface (Tackman *et al.* 1998) such that the lake drains in a northwesterly direction, forming part of the Winnipeg River drainage. Current measurements (e.g., Yang & Teller, 2005) indicate that the land mass in the northern portion of the basin is rising at a faster rate than the southern basin land mass (the north end of the lake will rebound 28 cm more than the south over the next 500 years). As the lake basin gradually tips southward, increased erosion and higher water levels may occur in the south (Lake of the Woods Erosion Working Group, N. Baratono, MPCA, International Falls, MN, pers. comm.)

Land Cover

The 2009 SOBR used 2000 data from various sources to estimate land cover types for the entire basin at relatively low resolution (1 km^2 or 0.39 mi^2). Vegetation and water represent the highest percentages of land cover in all sub-basins with a small

Wetlands perform significant functions which are important to both water quality and quantity.

percentage of cropland. There is a large range in the percent of each sub-basin that is covered by water, i.e. 34% in the LoW basin to 1.5 % in the Lower Rainy River sub-basin. When the water in each area of the basin is factored out to examine percent cover of the land alone, the sub-basins as shown in Table 5 show a higher percentage of vegetated area ranging from 86 % in the Lower Rainy River sub-basin to more than 99% in the Upper Rainy River sub-basin (basin descriptions used in 2009). It is not surprising that the watersheds are covered primarily by vegetation and water. There are however difficulties with separating water from wetland with coarse resolution satellite imagery. This has been a perennial problem with satellite image interpretation in general because wetlands are difficult to define and may change from appearing like a lake in one image to appearing like grassland in the adjacent year's images. The data provided by the USGS Land Management Information Center for Lake of the Woods County (bottom of Table 5) illustrate this problem. At the finer resolution there is a much higher percent of wetland (48%) identified for this county than was shown for the Lower Rainy River Watershed in DeSellas *et al.* (2009) (<0.1%). The 2009 SOBR estimate of 15.9 km^2 (5.79 mi^2) of wetland for the LoW basin is almost certainly a substantial underestimate of wetland area. Wetland area is a difficult attribute to derive for those who require wetland areas for modeling purposes and the main caution here is that land cover estimates, especially for wetland area, must be derived carefully in basins such as these where water covers a large percentage of the basin.

Water and Wetlands

The R-LoW basin contains approximately 14% open water and this percentage is higher in sub-basins such as Lake of the Woods (35%) where there are large areas that are covered by lakes. As previously mentioned there have not been accurate assessments of wetland area determined for most portions of the basin primarily because of the difficulties in differentiating between, or defining, the differences between wetland and water. Some more detailed examination of high resolution images especially in the Lower Rainy River basin suggest that there are substantial wetland areas (LoW County = 48%, Table 5).

FIGURE 8 – The location of glacial Lake Agassiz, 12,500 to 7,500 years ago.

Development has almost certainly resulted in the drainage and alteration of wetlands in some areas but this has not been quantified by sub-basin. Beavers are also responsible for water and wetland alteration throughout the basin (Windels 2013).

Wetlands perform significant functions which are important to both water quality and quantity, including temporal and spatial patterns in the sequestering and discharge of sediment and nutrients from runoff.

Terrestrial Vegetation

The terms used to describe the terrestrial zones of vegetation in the R-LoW basin are different between Canada and the United States. In Canada, the Boreal Shield ecozone stretches 3,800 km (2,361 mi) from Newfoundland to Alberta. The LoW and Rainy River ecoregions (the latter being the Canadian equivalent to the Northern Minnesota Wetlands Ecoregion in the U.S.) are within this ecozone (Environment Canada 2007b). In the U.S., Minnesota is divided into seven terrestrial ecoregions, two of which comprise the R-LoW basin. These are the Northern Minnesota Wetlands Ecoregion and the Northern Lakes and Forests Ecoregion.

Based on data from 2000 for the R-LoW basin, 93.4 % of the land (minus water) is covered by vegetation (forest or grassland) consisting of a mixture of coniferous and deciduous trees, with continuous conifer or deciduous hardwood stands in some sections, such as the drier sites in the south and west, or in wetlands areas. Following fire or logging, succession typically begins with the colonization of pioneer species with higher photosynthetic rates, such as trembling aspen, paper birch, and jack pine, with white spruce, black spruce, and balsam fir developing secondarily. Red pine and eastern white pine occur in warmer regions, while black spruce and tamarack occur in cooler and wetter regions. Some regions support red and sugar maples and eastern white pine. The shrub-level species that occupy the region beneath the forest canopy include beaked hazel, mountain maple, honeysuckle, and dogwood as well as various mosses and herbs. In most regions of the Lake of the Woods and Rainy River basin the soil is sandy and poor in nutrients and forest fires are frequent (Gartner Lee 2007). In the Northern Lakes and Forests ecoregion, coniferous forests dominate except in areas that have been logged or burned where primary forest species occur.

TABLE 5 – Showing area (km^2) of land use type from DeSellas *et al.* 2009 at 1 km resolution together with data from the USGS Land Management Information Center for Lake of the Woods County (bold) which represents a portion of the Lower Rainy sub-basin at a 30 m resolution (Land Management Information Center). Bottom portion of the table shows percent land cover type for the land only portions of each subwatershed.

	Watershed	LoW	Lower RR	LoW County	Central RR	Upper RR	Whole basin
Land plus water	Vegetation/grassland	8770	14044	**1484.7**	16623	16221	55656
	Water	5093	250	**1251.4**	2527	1969	9841
	Crop/shrub/woodland	1085	2316	**248.8**	360	66	3827
	Burnt or sparse veg	2	0		48	14	63
	wetland	16	11	**1613.3**	14	0	41
	Urban	0	1	**1.55**	10	4	15
	Rock/sparse veg	3	2	**4.16**	0	0	6
	total	*14969*	*16624*	***4605***	*19582*	*18274*	*69449*
Land only	Vegetation/grassland (%)	88.8	85.8	**40.0**	97.5	99.5	93.4
	Crop/shrub/woodland (%)	11.0	14.1	**10.0**	2.1	0.4	6.4
	Wetland (%)	0.16	<0.1	**48**	<0.1	0	<0.1
	Other (%)	0.2	0.1	**2.0**	0.4	0.1	0.2

In several scientific papers (Frelich and Reich 2010 and Frelich *et al.* 2012), the authors predicted changes in land cover due to climate change that will cause a north-eastward movement of the prairie forest boundary which is currently near the R-LoW basin to the west. The process of savannification described by Frelich and Reich (2010) is shown in Figure 9. These research efforts estimate that as the climate warms, boreal tree species will be gradually replaced by temperate species in southern boreal forest areas. They predict that warming will result in the replacement of large moose (*Alces alces*) by smaller deer (*Odocoileus virginianus*) and that small detritivores in the soil will be replaced by larger exotic earthworms. These shifts in consumers may induce a cascade of ecological impacts across trophic levels that could alter the boreal to temperate forest transition and lead to the succession of novel plant communities.

St. George *et al.* (2008) examined tree growth through time using tree ring analysis and attempted to establish long-term links to climate in the Lake Winnipeg basin. They noted that high growth was linked to cool/wet summers while low growth was linked to warm/dry summers. The tree-ring record indicated that summer droughts were more persistent in the 19th and late 18th century. It is also interesting to note that no highest or lowest growth years have been observed since 1965, which may indicate that the extremes which may cause differential forest growth are not particular to recent years.

Goldblum and Rigg (2010) reviewed the causes of forest ecotone locations especially between deciduous and boreal forest and pointed out that many of the indicators of deciduous and boreal boundaries such as the minimum temperature, minus 40 degree isotherm are within the LoW basin indicating that this area will likely see forest ecotone movement if climate models are correct. They also point out that an additional worry may be that plant migration rates cannot keep pace with rapid anthropogenic climate change which may lead to "depauperate forest ecotone communities." McLachlan *et al.* (2005) indicate that migration rates may be smaller than originally estimated.

Changes in forest structure in the R-LoW basin may be one of the most tangible effects of climate change with a shift in boundaries between forest types and the succession of novel plant communities.

Forest migration in response to change may not be able to keep pace with a rapidly changing climate.

Land use

Historic and present land uses in this region include agriculture, urbanization, forestry, mining and recreation. In the Rainy River ecoregion, forestry, recreation, tourism, and agriculture are the main land use activities, with 30% of the ecoregion used for mixed farming or grazing (Environment Canada 2007b). In the Lake of the Woods ecoregion, forestry, and recreation are the main land use activities (Environment Canada 2007b). Timber harvesting is the major land use activity within the Northern Minnesota Wetlands ecoregion (Fandrei *et al.* 1988). Agriculture is limited by peatlands, although there is localized farming along the western edge of the ecoregion where grains for livestock, such as hay, are cultivated (MPCA 2001). In the Northern Lakes and Forests ecoregion, agriculture is limited to beef and dairy farms due to thin soil cover over bedrock and reduced levels of soil nutrients (MPCA 2001). The majority of lakes in this ecoregion are used for recreational purposes.

Land use policy is an expansive topic which, for crown land use in Ontario, includes many different uses under a number of land use designations (e.g., Conservation Reserve, Provincial Park, Wilderness Area, Forest Reserve, etc.). OMNR hosts a useful Webpage that includes the Crown Land Use Policy Atlas which has a map browser that will allow the user to locate specific areas and or uses and then locate the policy documents that are relevant for that area. There is a wide range in the policy document dates with many of them being relatively older (1983). Updates in land use policy for many applications should therefore be reviewed or updated with respect to crown land use policy.

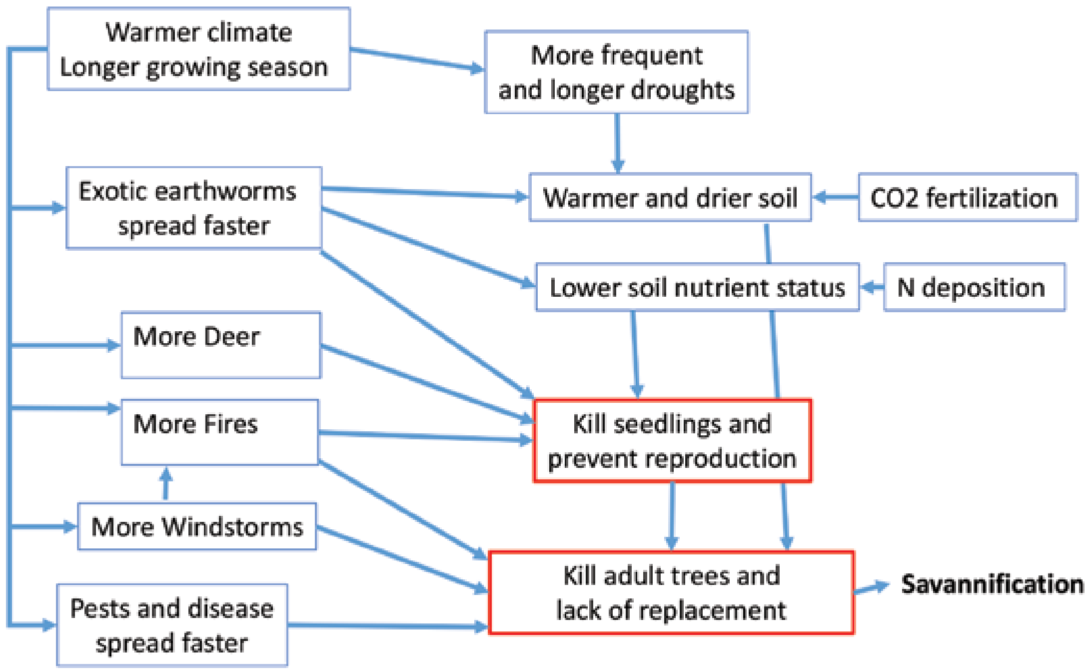


FIGURE 9 – The process of savannification through climate change drivers (following Frelich 2010).

Agriculture

Agriculture covers 6.4 % of the land portion of the basin as cropland or cropland & shrubland/woodland. The Lower Rainy River contains the highest proportion of cropland at approximately 10-15% of the land only portion (minus water). Agricultural activities include crops such as grass seed, small grains, clover, alfalfa, flax, hay, canola, soybeans, and wheat as well as some livestock (beef and milk cows and sheep and lamb). Specific statistics for each are not available. Agricultural activities can influence water quality and quantity, through runoff and tile drainage of nutrient-rich fertilizers and pesticides and consumption and diversion of water for livestock and irrigation. Livestock operations also cause the compaction of land (especially clay-based soils) which reduces the infiltration capacity of the soils.

Forestry

Forestry activities occur within each of the sub-basins and the majority of disturbed forest (DeSellas *et al.* 2009) is located in the central Rainy River portions of the basin (47.6 km^2 or 18.4 mi^2). Forest fires, and forestry-related activities can influence the water quality and quantity of a stream or lake. Decreased vegetation cover on land surfaces decreases the amount of precipitation that is captured before falling on land, increases rates and volumes of runoff, and increases sediment load to aquatic systems. Sediment yields from some drainage basins in other regions of the continent have increased three to tenfold following deforestation (Dearing & Foster 1993).

The University of Maryland shows a world map of forest loss and gain between 2000 and 2012 (http://earthenginepartners.appspot.com/google.com/science-2013-global-forest). The detail is sufficient to allow a clear picture of forestry activity in the basin (Figure 10). Net loss or gain is not calculated for the basin and it is not possible at this point to add watershed boundaries to this figure but it is clear that there is forest harvesting or reforestation activity in most areas of the R-LoW basin.

Mining

Historic Mining

The Canadian portion of the basin has seen extensive gold mining and exploration in the past, primarily between 1879 and approximately 1904 (Davies and Smith 1988). Most of the 143 gold occurrences in the Canadian portion of the basin exist in areas around the north end of LoW. These areas are near High Lake, Shoal Lake, Clearwater Bay, Echo Bay, Ptarmigan Bay, Bigstone Bay, Kenora, and in areas of the lake immediately to the south of these areas (Davies and Smith 1988). There has been mine production with stamp mills and the creation of tailings in a subset of these ore deposits but most of these have been either not developed past the exploration and testing phase or they have been briefly worked and then abandoned. The operational mines have been referenced in many geological survey documents (Bruce ~1925; Davies and Smith 1988; IJC 1917) and in documents that detail history but there are rarely any descriptions of the mining processes that occurred on these sites other than noting that there was a stamping mill on site. The Lake of the Woods Gold and Silver Reduction Company which processed ore was located on the site that is currently Kenora's McLeod Park (J.A. Oblak-IJC 2009). The 3rd Report of the Bureau of Mines (1893) reported in 1893 that the plant, which was to process ore into bullion, was largely unsuccessful.

The Superior Prospects Inc. webpage indicates that there are 27 past producing gold mines in the Kenora area. Most mines were discontinued by the 1930s at the latest (Davies and Smith 1988). Exploration, however, continues today in many of these locations.

Elsewhere in the Canadian portion of the basin, other minerals have been mined, notably iron ore near Atikokan at the Steep Rock Mine which was a huge undertaking to supply iron for the WWII war effort.

In the MN portion of the basin there have been similar, small, and discontinued gold mining activities in the Rainy Lake area in the 1890s and these were probably responsible for the description of iron ore deposits which were subsequently mined extensively in the state including areas around Vermilion Lake. Historic mining in MN include the Dunka iron mine, the Pioneer mine in Ely and the Tower-Soudan mine which is now a Minnesota State Park. Interesting photos of mining in MN are available at: http://www.miningartifacts.org/minnesota-mines.html .

Notable historic mine sites are summarized in Table 6. There is a paucity of detail

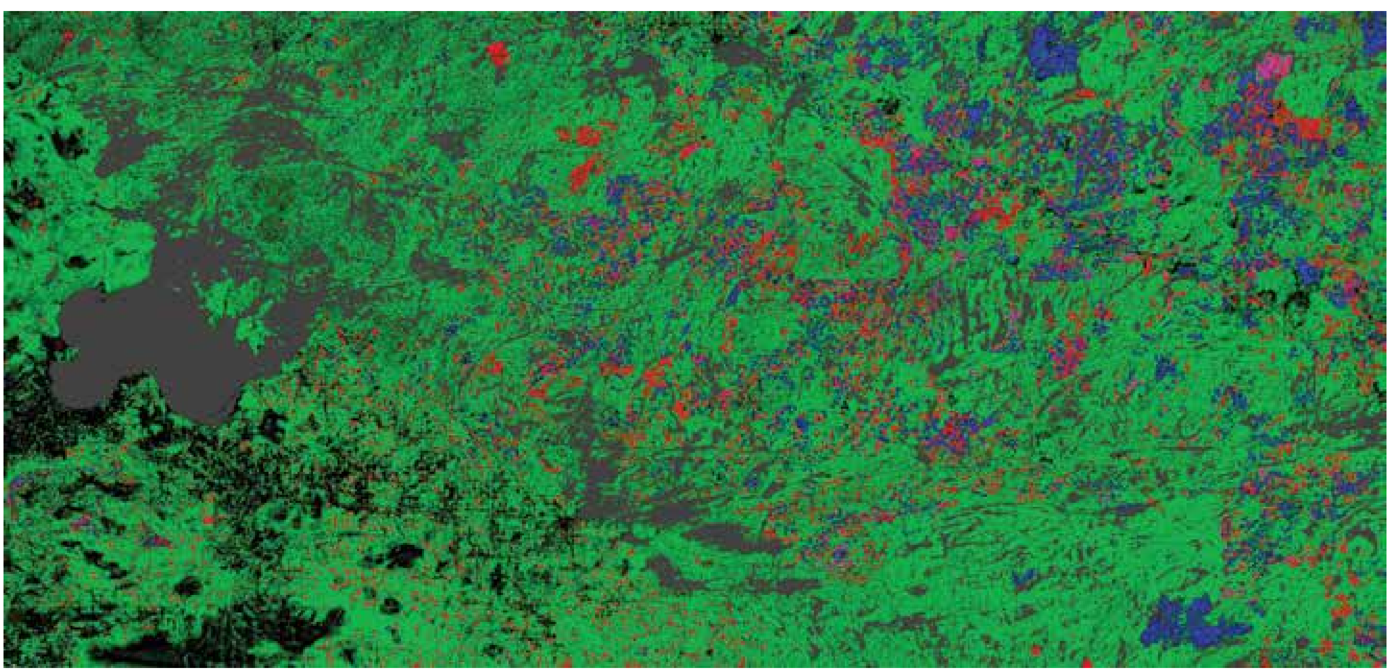


FIGURE 10 – Forest loss and gains in the Rainy-Lake of the Woods watershed between 2000 and 2012. Red = loss, Blue = gain, Magenta = loss and gain and green shows forest extent (University of Maryland).

Shorelunch. (Bev Clark)

regarding the operational procedures of many of these sites but it is important to note their existence for those who are monitoring, especially sediment quality, in the vicinity of the historic mine sites. It should be noted that this is a partial list considering that a full list of historic operational mines for the entire basin has not been compiled.

Present and Future Mining

At present, mining operations in the Canadian portion of the basin are limited to exploration and development. There are current gold exploration properties located to the south (Rainy River) and to the east of LoW (Cameron Lake, Hammond Reef). Josephene Cone is a currently proposed iron mine mid-way between LoW and Lake Superior approximately 285 km NW of Thunder Bay.

The Mesabi Iron Range in Minnesota is near to the southern boundary of the watershed near the Little Fork, Vermilion and Rainy Headwaters sub-basin boundaries (Figure 1). There are several active iron mining operations in this area. A map of current and proposed mines is provided by MNDNR. http://files.dnr.state.mn.us/lands_minerals/mpes_projects/minnesota_mine_sites_and_advanced_minerals_projects_winter2014.pdf . Maps which show taconite and iron mine locations (e.g., http://files.dnr.state.mn.us/lands_minerals/mpes_projects/mn_min_mesabi_map_0214.pdf) relative to the watershed that divides the Superior and LoW basin indicate many mines and plants that are just outside the basin or touching the LoW/Superior watershed divide. Environmental or operational assessments for these mines would need to be reviewed to assess whether or not their impacts might include the R-LoW basin.

The requirement for maps that include mining activity (proposed or ongoing) for the R-LoW basin is one of the gaps identified by the contaminants workgroup at the IJC Lake of the Woods Basin Water Quality Plan of Study workshop in International Falls (March 2014).

A summary of current mining activities or activities proposed for the future are shown in Table 7.

There is increased interest in prospecting for copper, nickel and other sulfide minerals in northeastern Minnesota, including the Superior National Forest (SNF) near the Boundary Waters. In 2013 the Forest Service released a draft EIS regarding 32 applications for permits to conduct exploratory drilling and other activities, much of it centered in the Birch Lake and South Kawishiwi River area (Figure 11). When the Superior National Forest revised its overall Forest Plan in 2004, it provided few details regarding mineral exploration or development in the Forest (IRLBS 2011).

To summarize, current mining in the basin is limited to iron mining activities near the watershed boundary in Minnesota. There have been considerable historic mining activities especially for gold in several areas of the basin with the impacts of these being generally unknown. Potential for future mining activity within the basin is recognised with several mines in the assessment phase. Summaries of mining activities past, present and future (potential) relative to basin boundaries should be more carefully summarized together with more comprehensive mapping of mining activity relative to R-LoW basin boundaries.

Recreation

Hunting, fishing, water-based tourism, ecotourism, shoreline property ownership and a multitude of summer and winter outdoor activities provide recreational opportunities and are important sources of revenue for retail and service related businesses in the basin. Large areas of land outside of the boundaries of the Kenora District, Sioux Narrows-Nestor Falls and Lake of the Woods Township, are designated as provincial and national parks or wilderness areas in addition to large areas of uninhabited Provincial Crown Land (Figure 12). In 1977 Searle wrote,

> *The region known as Quetico-Superior is a matchless section of primeval North America. Encompassing the Boundary Waters Canoe Area of the Superior National Forest, Voyageurs National Park, and the Grand Portage National Monument in Minnesota, and Quetico Provincial Park in Ontario, the Quetico-*

TABLE 6 – Historic gold/silver and iron mines in the Rainy-Lake of the Woods basin.

Mine	Location	Period	Comments
Sultana	Bald Indian Bay	1891-1974	For many years the leading gold producer in ON with activity close to water. The use of quicksilver and the presence of a cyanide plant were noted in the 3rd Report of the Bureau of Mines (1893) "At the Sultana mill quicksilver is added to each mortar at a rate of one third to one half a teaspoon every hour."
Pine Portage	Rat Portage- Pine Portage Bay	1884-	Still considered today as a viable source of gold http://superiorprospects.com/property/view/gold-cross
Scramble	Rossland Station, Black Sturgeon	1894, 1911	
Numerous mines	Rossland Station area	1890s to early 1900s	http://www.rosslandmuseum.ca/history.html
Numerous mines	Rat Portage area	1890s	1893 – 20 gold mines operating within 15 miles of Rat Portage http://www.lakeofthewoodsmuseum.ca/collectionsandresearch/HistoricalTimeline.aspx
Numerous mines	Bigstone Bay area	1890s to 1980s	Keewatin mine described as 'actually worked' Bull dog mine 1889-1984?
Winnipeg Consolidated	Bigstone Bay	1883-1884	Near shore activity – "the refuse runs into the lake, carrying away all the non-free-milling-gold" and "much of the mercury was allowed to run off into the lake also, for if one examines the bottom of the small inlet where the mill stands he will see that it is covered with pellets of mercury."
Minerva	Poplar Bay Island	1880s	Produced 30 ounces of gold from 28 tons of ore http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/afri/data/imaging/52E10NE8995//52E10NE8995.Pdf
Regina	WFB, Regina Bay	1894-1899, 1902, 1905	One of largest in area
Golden Horn	Rush Bay/Echo Bay	~1890s	http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/B085/B085.pdf
Mikado	West Shoal Lake	1893-1903, 1910-1911, 1922 1924	Activity was near to lake
Duport Mine	Shoal Lake Cameron Island	1896-1985	http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/afri/data/imaging/52E11SE8177//52E11SE8177.Pdf
Olympia	Helldiver Bay (S. of Mikado)	1912, 1916	http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/B085/B085.pdf
Cornucopia	Cedar Island (W. of Mikado)	1890s	http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/B085/B085.pdf
Foley	East Shoal Lake, Mine Centre area	1898-1925+	http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/B085/B085.pdf
Golden Star	East Shoal Lake, Mine Centre area between Foley and Bad Vermilion Lake	1894-1900	http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/B085/B085.pdf Largest producer of gold in the area
Olive	South shore of Little Turtle lake west of Mine Centre	1898	http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/B085/B085.pdf 109 tons of ore with $44 per ton of gold

Mine	Location	Period	Comments
Steep Rock	Atikokan, ON	1944-1979	Huge engineering project to support wartime needs for iron - Release of sediment to the Seine River in 1951 (Sowa *et al.* 2001)
Numerous mines	Upper Seine River	1890s	http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/B085/B085.pdf Includes Elizabeth, Harold Lake, Sawbill, Hammond Reef, and Sunbeam mines
Vermilion Iron Range	Vermilion Lake	1880s to ~1960s	Iron - Lake Vermilion (also minor gold rush in 1860s)
Little America Mine, Big American Mine, Lyle Mine, Bushyhead Mine, Soldier Mine?	Rainy Lake Islands	circa 1894	Gold http://www.miningartifacts.org/Minnesota-MInes.html
Dunka	Near Babbitt	1964-1994	Taconite http://www.itrcweb.org/miningwaste-guidance/cs_dunka_mine.htm
Pioneer	Ely	1888-1967	Iron http://www.waymarking.com/waymarks/WMBJZ6_Pioneer_Iron_Mine_Ely_MN
Tower-Soudan	South shore of Lake Vermillion	1882-1962	Iron http://en.wikipedia.org/wiki/Soudan_Underground_Mine_State_Park

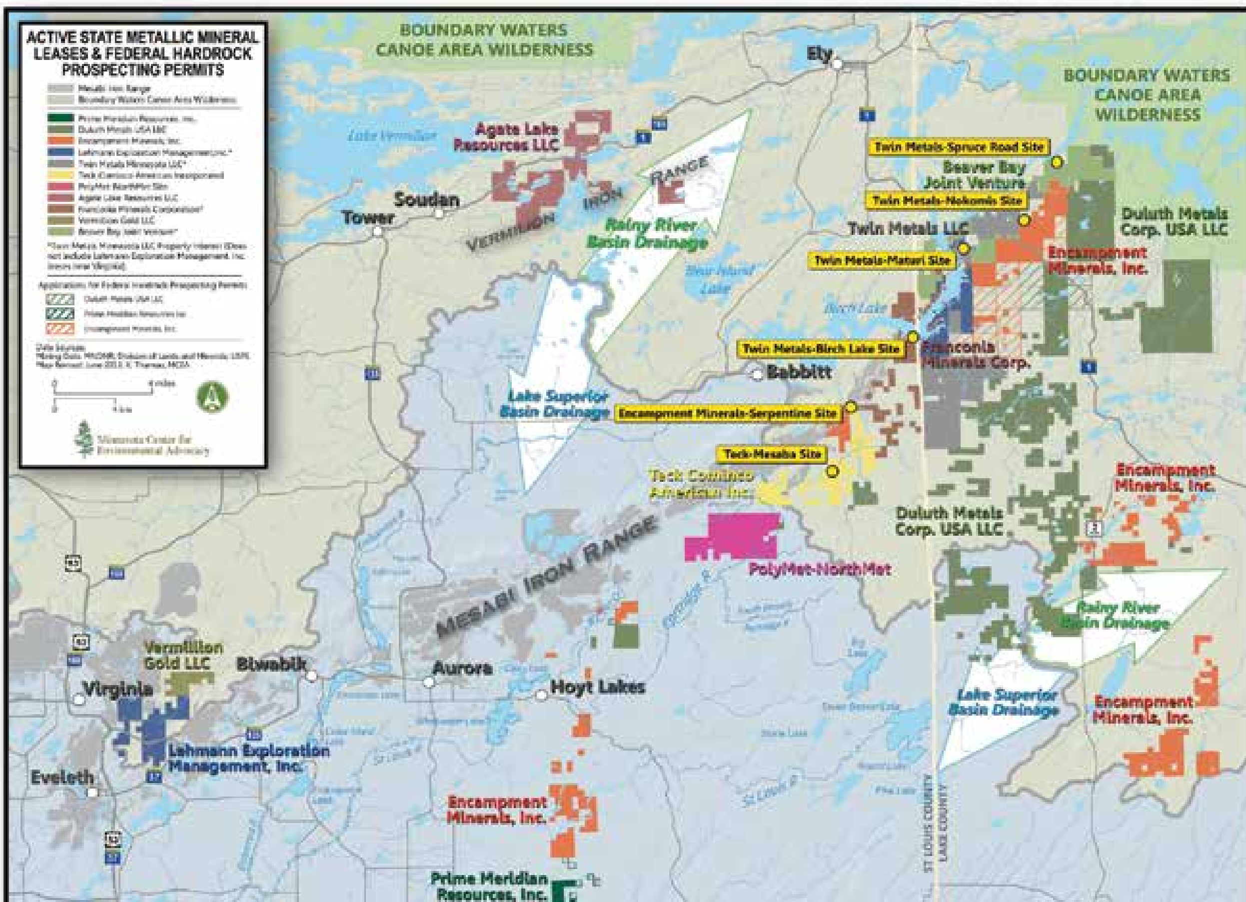


FIGURE 11 – Active Minnesota metallic mineral leases and Federal hardrock prospecting permits (Minnesota Center for Environmental Advocacy).

TABLE 7 – Current and proposed future mining activities in the LoW basin.

Project	Area	Description/Stage of project
Proposed		
Hammond Reef gold deposit (Osisko)	Atikokan http://www.osisko.com/mines-and-projects/hammond-reef/hammond-reef-in-brief/	Open pit mine, an ore processing facility and a tailings management area – in EA process – In early October 2013, EC was responding to the proponent's response to the draft EIS.
New Gold Project	Richardson Twp. www.newgold.com and www.rainyriveresources.com	Potential to become one of Canada's largest open pit mining operations - EA of the proposed gold mine started 4 December 2013 with a 2016 start proposed - includes approval to discharge treated mine effluent to the Pinewood River. The EA report is finished and in a public response period
Twin Metals Minnesota - underground copper-nickel-palladium group metals mine	Near Ely, Minnesota	Would be the largest underground mine in Minnesota if the project proceeds- deposits are located adjacent to the South Kawishiwi River within the Boundary Waters Watershed and are reported as the largest untapped copper deposits in the world. Supplemental Environmental Impact Statement stage.
Josephene Cone - iron	Mid way between LoW and Lake Superior – 285 km NW of Thunder Bay	Proposed extraction and processing 20,000 tonnes/day of ore - also includes a transportation system consisting of a north-south rail line with parallel utilities corridor. Project is in the Environmental Assessment phase.
Gold Resources Ltd.	Mine Centre Ontario	Exploration
For Minnesota mining activity – see Figure 11	Watershed boundary near Babbitt	Active MN metallic mineral leases and Federal hardrock prospecting permits
Operational		
Cliffs Natural Resources Northshore Mine	Near Babbitt	Operational taconite mine
U.S. Steel Minntac	West of Virginia	Taconite mine and plant with operations touching boundary
Hibbing Taconite	North of Hibbing MN	Taconite mine and plant with operations touching boundary

Superior is the only region of its kind in United States and Canada. The forests comprised of boreal spruces and firs, mixed and northern hardwoods and pines, fringe thousands of cold, clear interconnected lakes and free flowing streams. Together they comprise an international wilderness superbly designed by nature for canoeing.

Although these areas are remote they are visited by large numbers of people annually. Ontario Parks noted that 75,502 people visited Quetico Park in 2010. In the U.S., 214,841 people visited Voyageurs National Park in 2012 and there were 1,101,000 visitors on average per year between 2010 and 2014 to the Superior National Forest. Additional information is available on the visitor statistics websites for National and Provincial Park services websites.

Ecological integrity is a first priority for planning and managing Provincial Parks and conservation reserves as part of the 2007 Provincial Parks and Conservation Reserves Act (Ontario) which also initiated the Lands for Life Program. Over 39,000 ha (96,371 acres) have been protected in the basin as conservation reserves and 5,900 ha (14,579 acres) on Rainy Lake have been protected from major industrial uses such as mining or forestry (IJC Task Force Annex 2011).

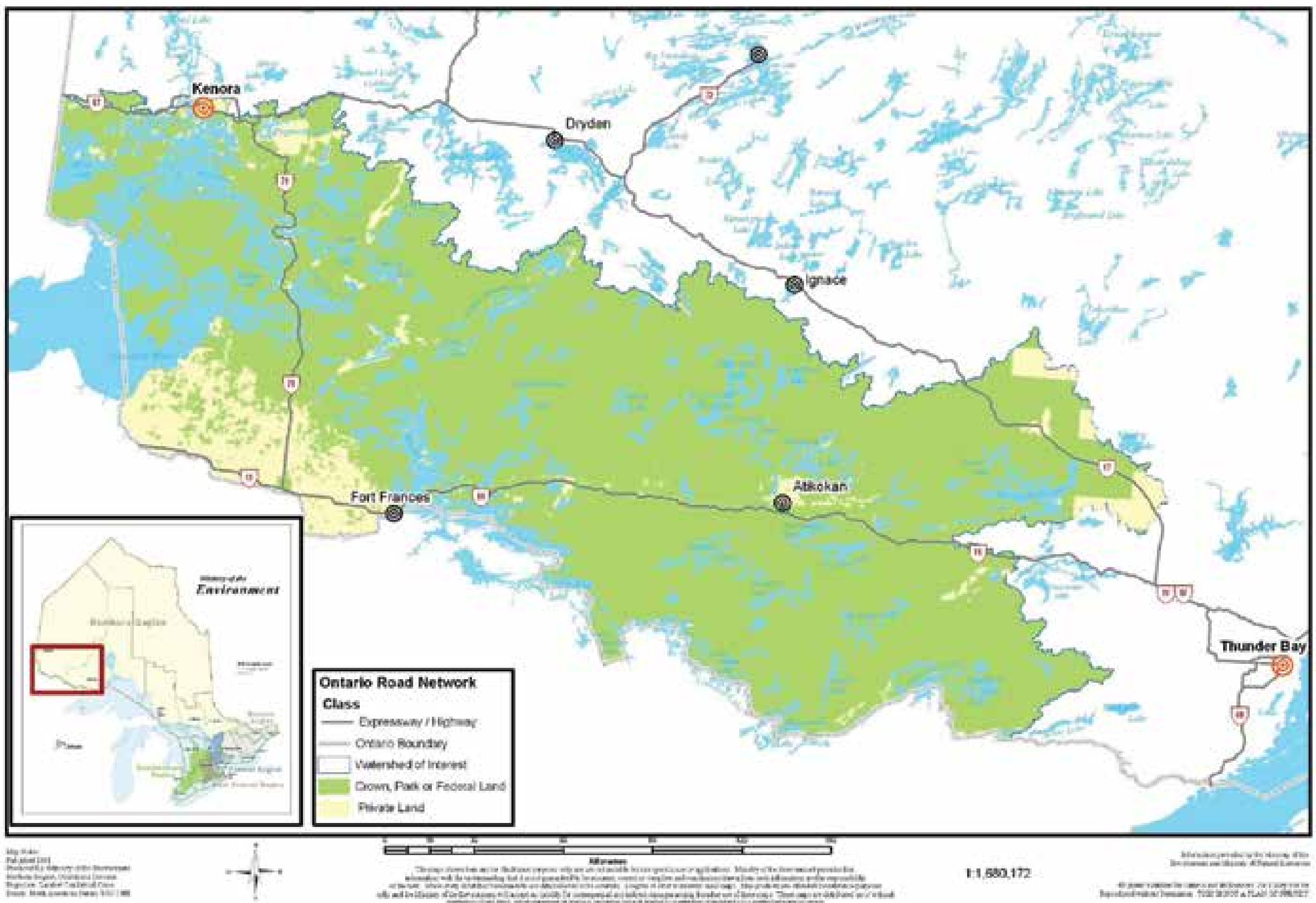


FIGURE 12 – Showing Canadian crown, park or federal lands (green) in the R-LoW basin.

Management plans for Quetico Provincial Park, Voyageurs National Park, the Boundary Waters Canoe Area Wilderness and the Superior National Forest share common management goals for resource protection.

Nature Conservancy

In March 2012, the Nature Conservancy of Canada (NCC) adopted a conservation plan for Rainy Lake and Lake of the Woods. The Rainy Lake Conservancy and NCC have worked in partnership since 1997. By 2013 NCC had conserved almost 400 hectares (1,000 acres) of land on Lake of the Woods. Protected areas include important wetlands and oak savannah, tall grass prairie shoreline, and cobble beaches. As part of the natural areas conservation plan, NCC is also working with the Rainy Lake Conservancy to preserve strategic conservation land on Rainy Lake. Most of Goose Island (approximately 200 acres) is owned by NCC and is managed by Ontario Parks as a Nature Reserve.

For more information visit: http://www.rainylakeconservancy.org/Resources/Documents/Summer2013Newsletter.pdf .

Human population

In the Canadian portion of the R-LoW basin, human populations are sparsely distributed among a few cities and towns and on First Nations lands. Population densities range from 0.15–1.79 people per km^2 on a county and district basis (DeSellas *et al.* 2009). First Nations and Métis communities in Ontario are growing. Aboriginal Affairs and Northern Development Canada projects that the overall aboriginal population in Ontario will grow by 37% between 2001 and 2026. http://www.aadnc-aandc.gc.ca/eng/1309463897584/1309464064861. The IJC Task force report (2011) indicates that there are 28 First Nations and two Tribal Communities in and near the R-LoW basin.

There are seasonal and permanent homes in shoreline areas and along some roadways and shoreline properties cause otherwise sparse populations to swell in many areas during the summer months. Populations in Ontario communities tend to be decreasing while populations in U.S. centres are generally stable or increasing in most counties (Table 8).

It is important to note that the census figures shown in Table 8 do not indicate that many communities have suffered shrinking populations prior to 1996. Decreased labour needs for industries such as logging and pulp and paper have caused towns, e.g. Fort Frances, to shrink in population since the 1970s (Figure 13). Stats Canada notes that:

> *"To a large extent, demographic dynamics at the sub-national level are affected by internal migration and differential migration by age. It has been shown that, in general, rural areas with economies that depend on natural resources and with fewer employment opportunities have seen their populations decline as a result of migration to urban areas and other provinces."*

Tom Mosindy (Ontario Ministry of Natural Resources, pers. comm.) notes that the collapses of the pulp and paper industry and soft North American lumber markets, beginning in 2008 with global recession, have had devastating impacts on North Western Ontario economy and population centres (e.g., Fort Frances, Kenora, Dryden, Atikokan) with indirect repercussions on smaller centres such as Sioux Narrows, Nestor Falls, Rainy River, Morson.

There are many political boundaries in the basin. Minnesota has seven counties whose boundaries lie within the R-LoW basin. From east to west they are Cook County, Lake County, St Louis County, Itasca County, Koochiching County (with the city of International Falls), Lake of the Woods

TABLE 8 – Population census for selected locations for 10 and 15 year census periods. Data are from Appendix H of the Task Force final report (IJC 2012 Annex) and 2011 data are from Statistics Canada.

Location	1996	2011
Alberton, ON	1,055	864
Atikokan, ON	4,010	2,787
Emo, ON	1,350	1,252
Chapple, ON	895	741
Division 1 Unorganized	700	1,130 (2006)
Fort Frances, ON	8,685	7,952
La Vallee, ON	1,130	985
Kenora, ON	16,090	15,348
Kenora Unorganised	7,041 (2006)	7031
Rainy River ON	909 (2006)	842
Rainy River, Unorganized	1,431 (2006)	1,159
Sioux Narrows - Nestor Falls, ON	780	720
	1990	**2010**
Cook County, MN	3,868	5,176
Itasca County, MN	40,863	45,058
Koochiching County, MN	16,299	13,311
Lake County, MN	10,415	10,866
Lake of the Woods County, MN	4,076	4,045
Roseau County, MN	15,026	15,629
St. Louis County, MN	198,213	200,226

County (including the city of Baudette) and Roseau County (which includes the city of Warroad). On the Canadian side, there are the large districts of Rainy River and Kenora. The Rainy River District borders the Rainy River, and includes the town of Fort Frances as well as Lake of the Woods Township (including Morson). To the north the Kenora District includes the city of Kenora, as well as the municipal township of Sioux Narrows-Nestor Falls. Several First Nations and U.S. Tribal communities, as well as members of the Métis Nation of Ontario, are also located in this region.

Climate variables

Excellent, long-term climate data exist for some locations in the R-LoW basin. Among six meteorological stations with long-term climate data, the longest continuous records for temperature (since 1899) and precipitation (since 1916) are from station Kenora A (Table 9). The Kenora A dataset is composed of two shorter records that have been joined here to create a single, long-term climate record. Corrections have been made for missing data and non-homogeneities caused by station alterations, including changes to site exposure, location, instrumentation, observer, observing program, or a combination of the above (for details see Vincent & Gullett 1999 and Mekis & Hogg 1999). These data provide an excellent record of climate normals for the Kenora area which are available on the Environment Canada website. http://climate.weather.gc.ca/climate_normals/results_e.html?stnID=3960&autofwd=1.

Temperature records among stations are strongly correlated, while weaker, but significant correlations exist for precipitation. This is a common characteristic of regional datasets that utilize data from multiple meteorological stations.

There are many ways to utilize climate data depending on the desired outcome. In the following sections, we present climate data to indicate that there have been changes in empirical observations through time without a further, rigorous examination of the data.

Temperature

The R-LoW region experiences a continental climate with variation in temperature among four distinct seasons. Mean summer and winter temperatures at Kenora are 17.8 °C

FIGURE 13 – Historical population census figures for Fort Frances (from Stats Canada).

Examination of air temperatures indicate a measured increase in annual temperatures of 1.19 °C and an increase in winter temperatures of 2.29 °C between 1890 and 2010.

(64.0 °F) and -15.0 °C (5 °F) with maxima occurring in July and January respectively (Chiotti and Lavender 2008). Snow is typically on the ground from November through April.

Observation of mean monthly temperatures may not be valid in cases where the means are changing with time. A comparison of the differences in annual temperatures (anomalies) indicate that warmer than average temperatures have occurred in recent years. This trend is especially apparent in the winter season, with warmer temperatures occurring consistently since 1998 (DeSellas *et al.* 2009). Monthly mean temperatures pre and post 1998 are shown for Kenora in Figure 14. Rühland *et al.* (2010) provide a more rigorous examination of air temperatures and indicate a measured increase in annual temperatures of 1.19 °C and an increase in winter temperatures of 2.29 °C between approximately 1890 and 2010.

Several climate models predict increased mean summer temperatures in the northern temperate zone over the next century. With a higher greenhouse gas scenario considered, winter average air temperatures in northwest Ontario are expected to increase by 1-3 °C over the next three decades and by 5-6 degrees by 2071-2100 (Colombo *et al.* 2007).

DeSellas *et al.* 2009 noted that the length of the frost-free season had increased by 13 days, on average, over the 88 years prior to 2009.

Precipitation

The Kenora area receives a long-term average (1916-2012) of 744 mm (29.3 in) of precipitation per year, with considerable variability between years. There is also variability between months within a given year and for the same month over the period of record. Historical trends in annual precipitation in Kenora show an increased frequency of wet years since the mid-1990s. If the data are examined to align with the same separation of the long-term record as conducted above with temperature data (i.e., pre and post 1998) the annual means increase from 732mm (1916-1997) to 813mm (1998-2012) indicating a trend towards more precipitation in recent years. There is also a strong seasonality to this trend, with lower average precipitation during the winter months and increased precipitation in spring and summer (Figure 15). Again, there are many ways to interpret these data but trends of increasing temperature and precipitation, and declines in winter precipitation, have been recorded throughout the Precambrian Shield and Laurentian Great Lakes regions in previous decades (Magnuson *et al.* 1997).

Although uncommon in this region, heavy rainfall events can cause extreme runoff and flow conditions in streams, rivers, and lakes within the R-LoW basin. For example, a series of thunderstorms caused record one-day rainfalls of 200-400 mm (7.9-15.7 in) in the region of LoW between June 8-11, 2002 (less than 72 hours), resulting in record high river flows and severe flooding (Murphy *et al.* 2003). As a result of this severe rainfall event, Rainy Lake experienced a net 7-day inflow of approximately 1,900 m^3/s (67,099 ft^3/s) on June 13, 2002, the highest on record since monitoring began in 1911 (Murphy *et al.* 2003).

Global circulation models predict increases in total annual precipitation over the next

TABLE 9 – Meteorological stations in the Lake of the Woods region.

Station ID	Name	Prov/ State	Latitude	Longitude	Elevation	Record
6022476	Fort Frances A	ON	48 65	93 43	342	1912-1995
72747	International Falls	MN	48 57	94 37	110	1948-present
6034075	Kenora A	ON	49 78	94 37	406	1899-present
	Lake 239 ELA	ON	49 66	93 72	393	1969-present
6048261	Thunder Bay A	ON	48 37	89 33	199	1895-1993
5023222	Winnipeg Int. A	MB	49 92	97 23	239	1895-present

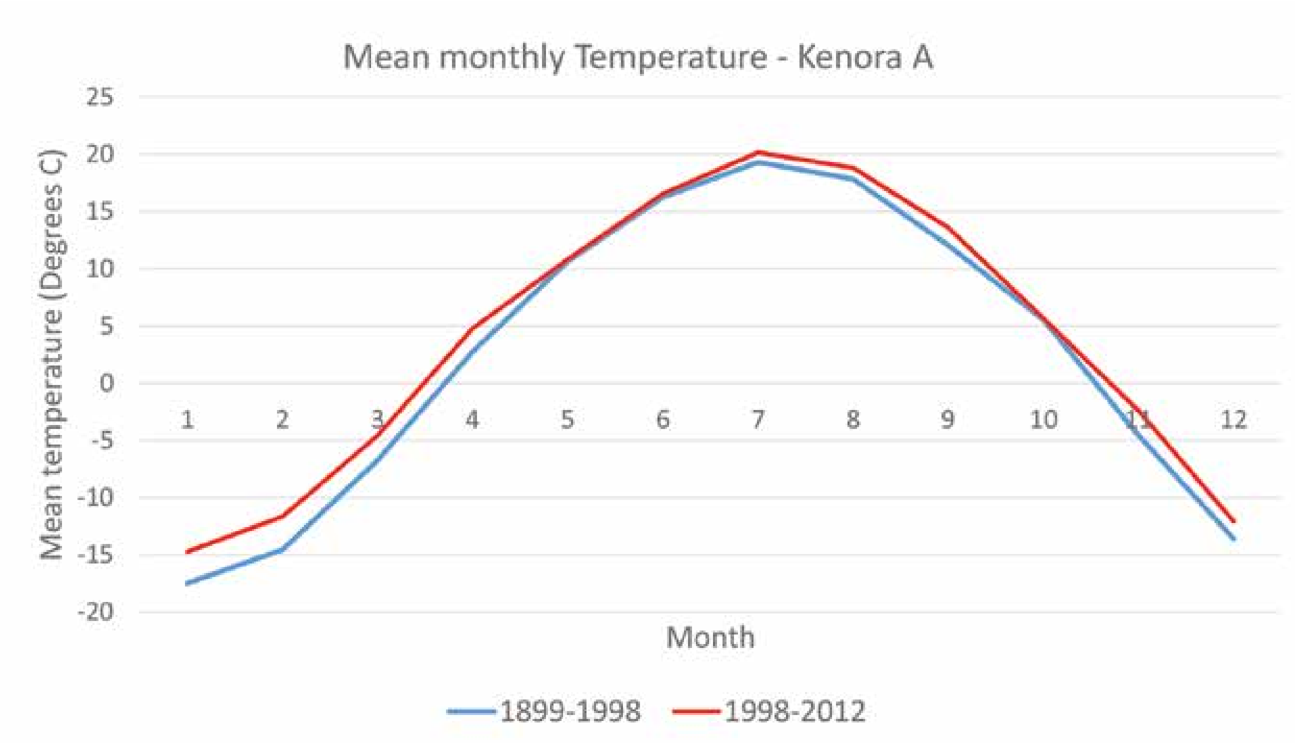


FIGURE 14 – Mean monthly temperatures at Kenora Airport (Kenora A, Government of Canada) for periods 1899 to 1998 and 1998 to 2012.

50 years, although net moisture availability will also be affected by rising temperatures and a lengthening of the growing season which may increase evaporation and evapotranspiration rates. Total annual precipitation in southern Canada has increased by 5 to 35% since 1900, and the number of days with precipitation has increased significantly in Ontario's central region (Chiotti and Lavender 2008). The distribution and nature of precipitation events has switched in recent decades from more frequent, smaller convective storms during the summer to fewer, but larger convective storms. This change in weather patterns will affect the nature of runoff as outlined in previous sections with very high volume runoff events occurring between long periods with very low discharge in streams and rivers.

Wind Climatology

Wind information is necessary for the development of dynamic models that use water movements and for any studies that involve estimating the effects of erosion or erosion rates. Although there is minimal wind and wave data, Herb *et al.* (2005) noted several sources for wind data records that extend back into the middle of the last century, notably International Falls (1948-2004), and Kenora and Winnipeg (1953-2004). These data are available from NOAA National Climatic Data Center (http://www.ncdc.noaa.gov), the State of Minnesota Climatology Office (e.g., http://climate.umn.edu/search/search.asp?qt=wind) and Environment Canada (www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html). In many cases wind data are collected *in situ* to satisfy data requirements for individual studies (Herb *et al.* 2005).

A planned for but never funded Phase II of Lake of the Woods Shoreline Erosion: Analysis of Historical Shorelines, Climate and Lake Level (Herb *et al.* 2005) was to include:

- a wind setup model
- a wave generation model to calculate the characteristics of deep water waves
- a wave transformation model to calculate wave propagation, breaking, and run-up in the near shore environment
- an erosion model to estimate shoreline erosion.

Herb *et al.* (2005) noted that higher resolution (1 hour) lake level and wind data

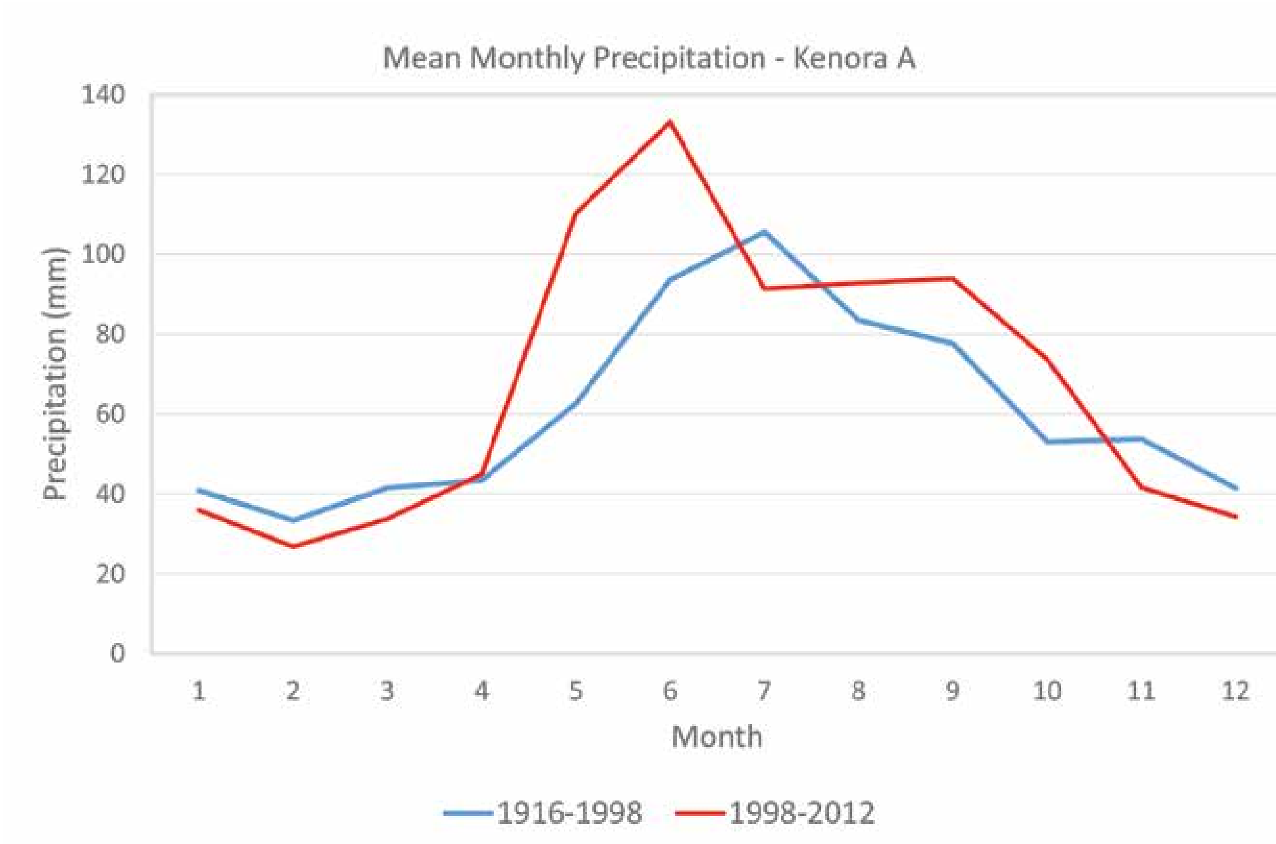


FIGURE 15 – Monthly mean precipitation at Kenora Airport (Kenora A, Government of Canada) for periods 1916 to 1998 and 1998 to 2012.

have been collected to examine wind setup of the water surface on LoW, and to calibrate a simple wind setup model for future applications (Phase II). Wind data were collected from seven local and two regional measurement stations. Among the local stations, Flag Island appears to best represent wind velocity and direction on the southern side of Big Traverse Bay. They further note that local wind stations have insufficient record lengths for historical characterization, but a composite of wind measurements from Winnipeg and International Falls is reasonably well correlated to wind measurements on Big Traverse Bay, with the potential to construct a long-term (50 year) historical record. Examination of the simulated long-term wind record for Big Traverse Bay over a 50 year period does not show any dramatic long-term trends. Preliminary analysis shows that wave height varies with wind velocity and fetch in the expected manner, and that local wave height is well correlated to the local wind velocity. The largest waves are produced by winds coming out of the northwest (the direction of maximum fetch for the Pine Island area).

Information regarding erosion is given in Chapter 3, Part 6.

A Changing Climate

Climate variables reviewed here (i.e., air temperature and precipitation) indicate accelerated climate change in recent decades. These empirical observations are also mirrored in the results of many other research efforts that have been described in other sections of this report including recent paleolimnological studies and others which predict the effects of climate change on terrestrial ecosystems. These observations predict major ecosystem perturbations, some of which are now occurring, and which are anticipated to continue into the future.

There are excellent interactive climate change mapping tools provided on the OMNR website http://www.mnr.gov.on.ca/en/Business/ClimateChange/2ColumnSubPage/STDPROD_090063.html, together with climate adaptation strategies developed by the Province of Ontario. It is important to note that the outcomes predicted by these tools and others rely on a realistic estimation of future greenhouse gas emission scenarios.

There are many additional modeling efforts that have been undertaken to estimate the impacts of climate change in Ontario. All of these predict less than favourable outcomes within this century. An excellent overview of Ontario climate change is presented by McKenney *et al.* (2010) which graphically shows the movement of climate envelopes over wide areas of Ontario in the current century. As existing climate envelopes migrate and new climate envelopes emerge, ecosystem composition, structure, and function will change. In many cases, species distribution and abundance also will change. These changes (McKenney *et al.* 2010) will require adaptive responses by resource managers, which could be enhanced by:

There are many additional modeling efforts that have been undertaken to estimate the impacts of climate change in Ontario. All of these predict less than favourable outcomes within this century.

1. Education: Encourage resource managers to use the time series maps to highlight the extent and speed of potential changes in climate.
2. More green space: To assist natural species migration, increase forest cover, connectivity, and patch size where these ecological elements are lacking.
3. Effective monitoring programs: Develop integrated monitoring programs to help detect and verify change as it occurs. This will help to guide strategic decision making and calibrate future modelling efforts.
4. Ongoing ecoregion assessments: Regularly review the usefulness of Ontario's ecosystem framework to ensure relevance and appropriate use in the context of a rapidly changing climate.

Considering these findings together with the fact that the effects of climate change are noted in many sections of this report, the effects of climate change are therefore categorized as a major concern within the watershed and are futther discussed in Chapter 3.

PART 2: IN-LAKE CHARACTERISTICS

The water quality of the R-LoW basin has been investigated more rigorously in recent years, in part due to the algal blooms that develop in many areas of the basin in the summer and fall. Historical accounts from the 19th century and anecdotal evidence from the early- to mid-1900s suggest that algal blooms have occurred historically in LoW. Also, paleolimnological evidence has demonstrated that the background levels of phosphorus in this lake are naturally elevated compared to lakes elsewhere on the Precambrian Shield, which may contribute to the generally high algal biomass observed in this lake. However, there are concerns that the magnitude and frequency of these blooms may have increased in recent years. The presence of microcystin, a liver toxin produced by some cyanobacteria, in some open-water and shoreline regions of LoW and several other lakes in the basin is also a cause for concern (Kotak *et al.* 2007; Chen *et al.* 2007).

In-lake characteristics of the lakes in the basin, especially in the lakes of Voyageurs National Park have been studied intensively in the past to characterize water quality (Kallemeyn *et al.* 2003) and in more recent years to assess the impacts of water level controls on Rainy Lake and Namakan Reservoir since 2000. There are four Minnesota Pollution Control Agency (MPCA) Sentinel Lakes in the basin and the purpose of these is described in: (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/sentinel-lakes.html).

Many of the Minnesota lakes have had lake assessment reports completed and in 2008 the MPCA expanded their lake monitoring program significantly, see Watershed Approach in: (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/watershed-approach/index.html).

Many lakes throughout the basin and into the headwater areas are being characterized by citizen monitoring groups.

Physical Limnology and Morphometry

Lake morphometry and other physical attributes that control mixing or temperature and oxygen regimes can influence almost all chemical and biological properties of a lake. Physical attributes including depth and volume are often required as input to models that predict hypolimnetic oxygen profiles using only aspects of morphometry

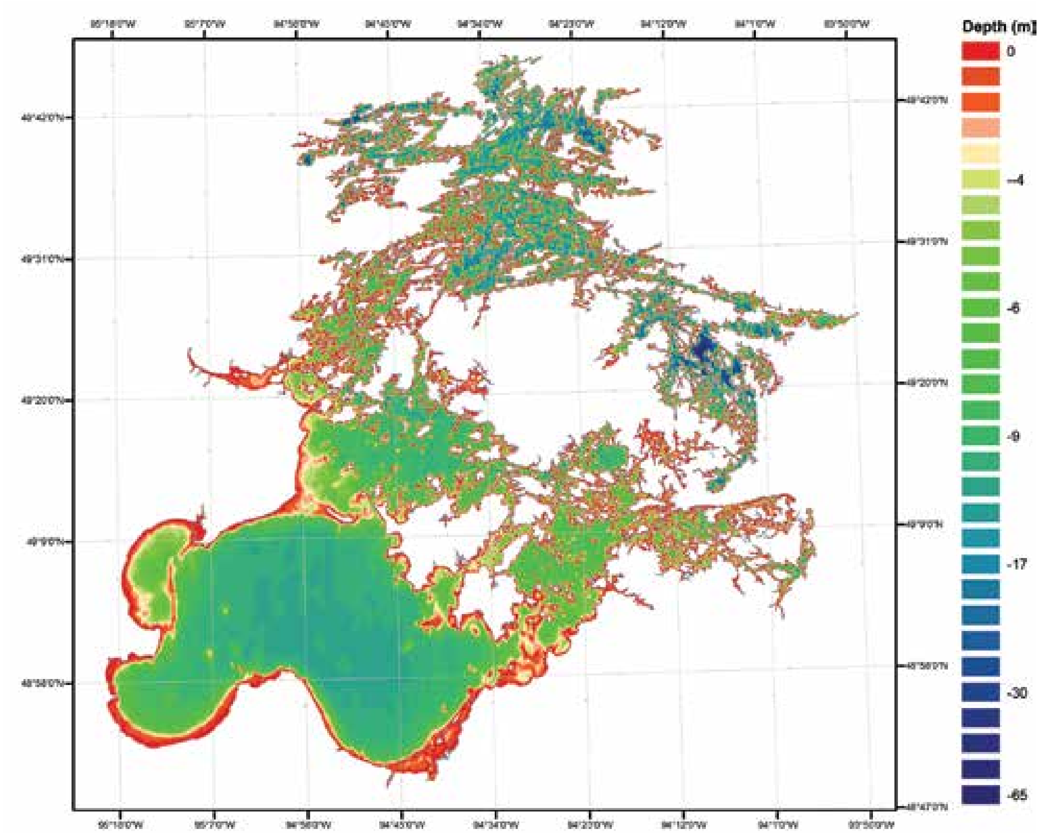


FIGURE 16 – Digital bathymetric map for Lake of the Woods from Zhang *et al.* 2013.

and total phosphorus concentrations (Molot *et al.* 1992). The earliest maps with detailed bathymetric profiles for LoW and the Rainy River can be found in Meyer & White (1915).

The southern regions of LoW, including Big Traverse, Muskeg, Buffalo, and Fourmile bays, the Northwest Angle Inlet, and the western portion of Little Traverse Bay, are shallow with gently sloping shorelines, a flat bottomed lake bed and many peat bogs on the landscape. The more northerly portions of the R-LoW basin are located on Precambrian Shield bedrock with basins and bays that are steep-sided and much deeper. Maximum depths range from 11 m (36 ft) in Big Traverse Bay to 66 m (216 ft) in Whitefish Bay.

Environment Canada has completed digital bathymetry for LoW for use as input to linked hydrodynamic nutrient models (Zhang *et al.* 2013, Figure 16).

Lake surface area is an important factor in the development of wind-induced turbulence which, in turn, affects lake stratification, epilimnion formation, light penetration, and distribution of sediments (Kalff, 2002). For example, Big Traverse has a very large and open surface area with a high fetch. This, combined with its shallow depth, causes the water to be mixed completely such that stable summer stratification does not occur.

Detailed bathymetric maps of the littoral zone for selected locations in Rainy Lake and Namakan Reservoir are being developed to assist research and monitoring studies that are designed to assess the effects of the IJC 2000 Rule Curves on aquatic vegetation, benthos, pike and walleye. Stage-volume relationships for Rainy Lake and Namakan Reservoir were updated using recent bathymetry provided by LakeMaster Inc., a subsidiary of Johnson Outdoor Marine Electronics.

Morphometric characteristics for lakes in Voyageurs National Park are listed in Kallemeyn *et al.* 2003, and shown for the large lakes in Table 10.

Lake Retention Time

Retention time or water residence time

TABLE 10 – Morphometric characteristics of the large lakes in Voyageurs National Park.

Lake	Area (ha)	Max Depth (m)	Mean Depth (m)	Volume (m^3x10^6)	Retention time (y)
Kabetogama	10,425	24.3	9.1	948.7	
Namakan	10,170	45.7	13.6	1383.1	0.6
Rainy	92,100	49.1	9.9	9117.9	1.0
Sand Point	3,580	56.1	12.0	430.7	

completely replace its volume of water. This calculation involves the measurement of all inputs and losses of water to and from the lake. Flushing time, which is derived more easily by dividing lake volume by the outflow discharge volume, is often used when residence time cannot be estimated. These aspects of physical limnology are very important as they moderate the flux of nutrients in the lake and regulate the response of the lake to environmental stressors. As mentioned previously, LoW is characterized by a vast convoluted expanse of water with higher flushing rates in the centre portions that result from the south to north movement of water. As a result, any areas near to the centre of the lake will flush more quickly, while areas in cul de sacs will have very much longer water retention times. Retention time will therefore vary from area to area. Previous estimated mean flushing times for the entire LoW have varied between 4 and 14 years; however, these estimates have been updated in recent years (see Table 11). Estimated flushing times are strongly influenced by hydrology, climate, and water level regulation.

The complex nature of many lakes in the R-LoW basin is such that any estimate of water retention time must be accompanied by details describing how the figure was derived and any use of these figures to describe in lake processes must also recognise spatial variation in retention times. Zhang *et al.* (2013) published a linked hydrodynamic and water quality model that estimated water movement and trophic status measures for LoW using a monthly time step. These model results produced sector based retention times for different areas of the lake which demonstrate variations in retention time that are regulated by proximity to the south to north flow through the central portions of the lake. These are likely the most defensible retention values derived to date and are based on the 3D hydrodynamic Princeton Ocean Model (Table 11). Sectors shown in Table 11 are roughly equivalent to sectors used by other researchers as shown in Table 12.

Water Temperature

All aspects of physical limnology are linked to water temperature. In the

TABLE 11 – Annual sector retention times (2000-2010) from Zhang *et al.* 2013, derived using the 3D Princeton Ocean Model. Units are in years.

Year	S1	S2	S3	S4	S5	S6	Whole Lake
2000	0.88	0.58	0.32	2.83	0.13	2.40	1.66
2001	0.64	0.71	0.25	2.52	0.08	2.24	1.10
2002	0.91	0.72	0.35	2.78	0.13	2.54	1.74
2003	1.45	1.15	0.59	3.46	0.24	3.12	2.83
2004	0.76	0.52	0.28	3.04	0.11	2.83	1.45
2005	0.69	0.52	0.25	2.32	0.09	1.90	1.20
2006	1.08	0.69	0.41	2.36	0.19	2.12	2.33
2007	1.22	0.82	0.45	3.24	0.19	2.59	2.46
2008	0.75	0.57	0.27	2.53	0.10	2.10	1.29
2009	0.69	0.52	0.24	2.71	0.09	2.17	1.12
2010	0.87	0.64	0.30	2.75	0.13	2.19	1.62
11 year	0.90	0.68	0.34	2.76	0.13	2.37	1.71

TABLE 12 – Comparison of sectors described in Table 11 to equivalent sectors used by other researchers on LoW.

Zhang *et al.* model sector 2013	OMNR sector	DeSellas *et al.* sectors 2009
S1 – Big Traverse	5	Parts of 5 & 6
S2 – Sabaskong Bay	4 & 5	Parts of 4 & 5
S3 – Centre, Little Traverse	2 & 6	Parts of 5 & 6
S4 – Whitefish Bay	3	3
S5 – North Central	Part of 1	2
S6 – Clearwater Bay and area	Part of 1	1

case of LoW there are several aspects of water temperature that are crucial to understanding in-lake processes. Most important are the external drivers that have worked to increase the length of the ice-free season in LoW. Although large amounts of water temperature data undoubtedly exist as field data and from the employment of datasonds for various research studies, the formal characterization of water temperatures has not been attempted.

Research that attempts to describe relationships between nutrients and algal production require an estimation of the effects of increasing temperatures. This applies as well to estimates of the processes that contribute to internal loads. Temperature effects are therefore identified in many research efforts as information gaps (Baratono and Paterson pers. comm.).

Evaluation of ice cover patterns on Whitefish Bay indicate an increase in the length of the ice-free period of 27.7 days between 1960 and 2012.

Ice Cover

Recent increases in average temperatures, particularly during the winter season, have caused dramatic changes in ice cover and frost duration. This is evident in the long-term ice records that are available for Clearwater and Whitefish Bays. Ice-on normally occurs in December in Clearwater Bay and in the north end of Whitefish Bay and ice-out between April and May (OMNR-LWFAU, Kenora, ON, 2007, unpublished data; R. Beatty, pers. comm.). Long-term ice-out records from the north end of Lake of the Woods at the OMNR base in Kenora (OMNR-LWFAU, Kenora, ON, 2013, unpublished data) indicate that the length of the ice-free season is increasing in this area with approximately 23 more ice free days in 2013 than in 1966 (Figure 17). These data are somewhat subjective but recent ice on/ice off dates within this record have been confirmed using satellite images. Although the ice on/off records indicate longer open-water seasons in recent years, it is probably as important to recognize that the variability in open water days is also increasing (Figure 17). Higher variability is an expected attribute of climate change in general. It is also interesting to note that the second and third earliest ice out dates in the record (April 16 in both 2010 and 2012) have occurred since the first SOBR was published in 2009.

Rühland *et al.* (2010) present a more rigorous evaluation of ice-cover patterns on Whitefish Bay indicating an increase in the length of the ice-free period by 27.7 days between 1960 and 2010. This includes 13.4 days of later ice-on and 15.1 days earlier ice-out. Similar patterns in ice-duration have been reported in other lakes in the region, including Voyageurs National Park (Kallemeyn *et al.* 2003), Wisconsin (Anderson *et al.* 1996), and the Experimental Lakes Area in northwestern Ontario (Schindler *et al.* 1990; Schindler *et al.* 1996; Department of Fisheries and Oceans, Winnipeg, MB, 2007, unpublished data). Ice phenology records from 1975–2007 for five lakes in the Adirondack Mountains in New York State indicated rapidly decreasing trends of ice-cover duration of up to 21 days (Beier *et al.* 2012).

Water Chemistry

There is presently a substantial quantity of water quality data available for Lake of the Woods, the Rainy River and for Rainy Lake and Namakan Reservoir. Some additional data exists for lakes in the Boundary Water areas, for Inland Lakes in Voyageurs National Park, and for the Little Fork, Big Fork, Lake of the Woods and Rainy

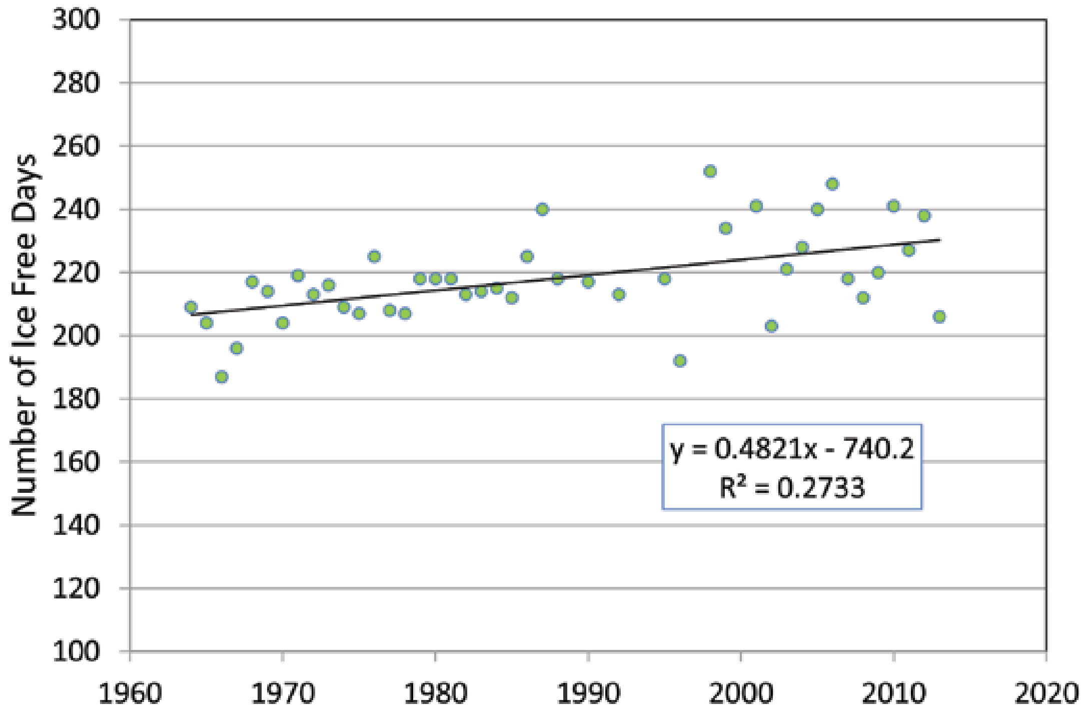


FIGURE 17 – Number of ice-free days in Clearwater Bay.

Headwater sub-basins. The coordinates of these water chemistry data are shown in Table 13.

Where spatial differences in water quality exist it is important to identify the reasons for the differences so that mitigation can be proposed for areas where the water quality is deemed unacceptable. However, seasonal and between-year variability within the datasets can cause difficulties when attempting to characterize water quality in any given area. Managers can generally define what constitutes acceptable water quality but it is unclear whether researchers can measure the system precisely enough to identify the causes in those areas where water quality is impaired. What is most useful, from a state of the basin standpoint, is some sense for whether there have been meaningful changes in water chemistry that have occurred or are occurring in specific areas of the basin. A first step towards this goal is to identify those areas where water quality is unique and then adequately characterize the water quality on a sector by sector basis.

Seasonal variation in water chemistry must be considered before comparing annual means and seasonal and between-year variation must be considered while attempting to observe long-term changes in water chemistry.

It is worthwhile to identify those areas where water chemistry has been examined to address management questions. A partial list (the full list is extensive) is shown in Table 14. Phosphorus data (or trophic state indicator data) are the most widely used, and this to establish links between nutrient loads and algal community responses.

The difficulties encountered with water chemistry analysis in the R-LoW basin can be summarized as follows:

- seasonal variation in some water chemistry parameters makes it difficult to use average annual values to characterize water chemistry
- variability between nearby stations may be extensive which limits the value of sector means
- higher variability exists for some parameters than for others
- there are differences in sample

TABLE 13 – Coordinates of water chemistry data for the Lake of the Woods- Rainy River basin.

Agency	Area	Data
Ontario Ministry of the Environment	Lake of the Woods	http://desc.ca/data
Minnesota Department of Natural Resources	U.S. portion of LoW	http://www.epa.gov/storet/dw_home.html
Environment Canada	Rainy River/Lake of the Woods, tributaries, outflow	Environment Canada 2013 - Not yet available on line.
Voyageurs National Park	Rainy Lake, Namakan Reservoir + lakes upstream	http://www.epa.gov/storet/
Minnesota Pollution Control Agency	Various subwatersheds and lakes throughout the R-LoW basin	http://www.pca.state.mn.us/index.php?option=com_k2&view=item&id=2229

methodologies and analytical methods between monitoring agencies.

For these reasons it is difficult to characterize water quality in a straightforward manner by using annual means in a given location or by combining stations to derive sector means. To examine water chemistry variation between sectors and to examine temporal change we provide separate focus here on three primary areas namely: Lake of the Woods; the Rainy River between Fort Frances/International Falls and the mouth; and the Rainy Lake/Namakan Reservoir basin.

Lake of the Woods
DeSellas *et al.* (2009) clearly showed that there are two defining characteristics of water chemistry in Lake of the Woods. First there is a wide range in water chemistry noted between different sectors of the lake, and second that there is often large seasonal variation in water chemistry at any one location. It is important to note that these observations hold true for the trophic indicator parameters (nutrients, chl a Secchi depth) but are less true for others. For non-trophic-indicator parameters there is relatively lower variability both spatially and temporally.

The most extensively sampled stations in LoW have been monitored by the MPCA/ Minnesota Department of Natural Resources (MDNR) since the early 1950s (with more intensive data collection in recent decades) and by the Lake of the Woods Fisheries Assessment Unit (LWFAU) of the OMNR in Kenora, ON, since 1984 (Mosindy 1987). The OMNR data is collected using a sector based system that has identified areas that are generally considered to share the same water chemistry characteristics.

The 2009 State of the Basin Report tested spatial variability by performing principal components analysis (PCA) on the most recent data from 24 sites throughout LoW (DeSellas *et al.* 2009). This analysis identified two main directions of variation, the primary being a nutrient gradient (axis 1) and a second weaker gradient of ions and alkalinity along axis 2. This is expected because, as shown later, the range in seasonal values and the variation between stations is higher for nutrients and lower for alkalinity, pH and for ions in general. Environment Canada repeated this type of analysis with similar results for slightly different sectors in LoW with data collected between 2009 and 2011 (Pascoe *et al.* 2014).

The DeSellas *et al.* (2009) sectors are shown in Figure 18, and in Table 15 which includes several sample stations that have been recently sampled in each sector. The sectors identified by DeSellas *et al.* (2009) based on the PCA roughly correspond to the sector definitions used by OMNR with the main exception being the division of north sector OMNR-1 into two separate sectors to identify water that is within or isolated from the north south flow of water. The DeSellas *et al.* (2009) sectors are used here to examine sector water chemistry characteristics.

TABLE 14 – Examples of research where water chemistry data have been used to address management questions.

Study Area	Agency	Study
Nutrient loading and flux	Environment Canada (EC), universities, MDNR	Whole lake - LoW
Poplar Bay	Summers *et al.* (2012)	Role of shoreline development as a multiple stressor
Fourmile, Muskeg, Big Traverse and Little Traverse	MPCA	TMDLs
Lakewide – 32 sites	EC - Orihel *et al.* (2012)	N:P ratio relative to microcystins
Lakewide – 28 sites	EC - Binding *et al.* (2010)	Tracking 2009 algal bloom
Lakewide – 28 sites	EC - Binding *et al.* (2011)	Identify bloom drivers – 2003 - 2011.
Zippel Bay	Reavie	Zippel Bay
Namakan Reservoir	Serieyssol (2009)	Logging and water level control impacts on Namakan basin
Lake of the Woods	EC	Linked hydrodynamic nutrient modeling
Lake of the Woods	OMOE, EC, Universities	Nutrient budgets
Lake of the Woods	OMOE, Lake Partner Program data	Calibration of remote sensing data
Lake of the Woods	OMOE, Queens University	Effects of climate change and water level changes on phytoplankton community
Clearwater Bay	OMNR and OMMA	Establishment of 1990-91 restricted area order on development based on TP, chl a, Secchi, DO/temp profiles and available lake trout habitat
Turtle Portage between Whitefish and Sabaskong Bays	Decision based on long-term decline in water quality at stations in south end of Whitefish Bay. OMNR and OMOE.	Closure of man-made navigation channel in 1994-95 to protect water quality and coldwater fish community in Whitefish Bay from Sabaskong bay inflow.
Voyageurs National Park	USGS	Trophic state in Voyageurs National Park lakes before and after implementation of a revised water-level management plan PENDING
Little Fork Watershed	MPCA	Intensive Watershed Monitoring, Major Watershed Loading Program, Fluvial Geomorphology studies
Big Fork Watershed	MPCA	Intensive Watershed Monitoring, Major Watershed Loading Program, Fluvial Geomorphology studies
Lake of the Woods Watershed	MPCA	Intensive Watershed Monitoring
Lake of the Woods Watershed	LOW SWCD, EPA, LOW Schools River Monitoring Project	LOW South Shore Erosion Study, stream monitoring
Headwaters Watershed	MPCA	Major Watershed Loading Program
Headwaters Watershed	WICOLA/Lake SWCD	Kawishiwi Watershed Protection Project
Vermilion Watershed	MPCA	Major Watershed Loading Program
Lower Rainy Watershed	MPCA	Major Watershed Loading Program
Rapid River Watershed	MPCA	Major Watershed Loading Program

TABLE 15 – Sectors in Lake of the Woods that have unique water chemistry.

Sector	Site Name	Map ID	Latitude	Longitude	Agency
North West Bays 1	White Partridge Bay	1	494208	943608	OMNR
	Clearwater Bay East	2	494223	944452	OMNR
	Deception Bay	3	494208	944836	OMNR
	Clearwater Bay West	4	494126	944938	OMNR
	Cul de Sac	5	493737	944953	OMNR
	Echo Bay	6	493833	945453	OMNR
	Poplar Bay East	7	494128	943226	OMOE
	Poplar Bay West	8	494032	943342	OMOE
North Central 2	Bigstone	9	494003	942054	OMNR
	Donald Duck	10	493135	943402	OMNR
	East Allie	11	493510	942709	OMNR
	Rat Portage	12	494323	943221	OMNR
	Outlet at Norman Dam	13	494619	943128	EC
Whitefish 3	Yellow Girl	14	493017	941656	OMNR
	Highrock Island	15	492007	940507	OMNR
	Index Island	16	492408	941100	OMNR
	Turtle Bay	17	491208	940704	OMNR
Sabaskong 4	Hay Island	18	490900	940704	OMNR
	Buff Island	19	490907	941400	OMNR
South 5	Horseshoe	20	491514	942133	OMNR
	Basil Point	21	490431	944329	OMNR
	Mica Point	22	491919	944545	OMNR
	Monkey Rocks Reef	23	492435	945033	OMNR
	Little Traverse	24	491528	994706	MPCA
	NW Angle	25	491911	945451	MPCA
	Tug Channel	26	492142	944215	MPCA
	Canadian Ch.	27	492016	944942	MPCA
	Flag Is.	28	491958	945235	MPCA
	Sturgeon Channel	29	491958	945143	MPCA
Big Traverse 6	Long Point	30	490324	945511	MPCA
	Sable Is.	31	485519	944342	MPCA
	Muskeg Bay	32	485713	951119	MPCA
	Fourmile Bay	33	485106	944143	MPCA

The most recent spring and late-summer data from these long-term monitoring locations are listed in Table 16 and 17 and used here to characterize recent water quality between sectors. We have elected to show the most recent sample dates for spring and late-summer data (May – October) for comparison considering that ice-free means are affected by seasonal variation and between-year variation for some parameters but not for others. By visually comparing the data at the various sample locations within each sector to the sector means it can be observed that the DeSellas *et al.* (2009) PCA has worked well, in most cases, to identify areas that share similar water chemistry.

The between-sector patterns observed by DeSellas *et al.* (2009) remain, in most cases, for the more recent data shown in Tables 16 and 17 but the differences noted here between spring and late-summer data indicates that seasonal variation contributed to the ranges observed in the pooled data that were shown in the 2009 SOBR.

Examination of sector means for each parameter indicates that mean water chemistry values for many parameters fall within a narrow range throughout LoW (Alk, Ca, Cl, Cond, K, Mg, pH, SiO_2, SO_4) with the exception that these are lower in Whitefish Bay. Environment Canada (EC) noted that in its data collected between 2008 and 2010, conductivity was higher in Clearwater Bay and lower in Whitefish Bay (Pascoe *et al.* 2014). This agrees with results shown here but with the exception that, in Tables 16 & 17, the highest conductivity was measured in both spring and fall at the outlet from LoW. EC measured the lowest dissolved organic carbon (DOC) in Whitefish Bay with higher values in more southern areas. Anions and cations varied spatially in the EC dataset and there were no seasonal trends observed which is consistent with seasonal data collected by other agencies. Sulphate concentrations collected by EC were in the same range as those shown here (approximately 2.5-5.5 mg/L) and, although they noted significant differences in spatial concentrations, these concentrations represent a fairly narrow range in values relative to Ontario lakes in general. The distribution of sulphate concentrations (n=5354) measured in Ontario Lakes (OMOE Inland Lakes Database) for approximately 1500 lakes is shown in Figure 19. This illustrates the importance of assessing statistically significant differences relative to meaningful differences. For example, sulphate concentrations in LoW when considered relative to concentrations measured elsewhere could be considered to be below average and within a relatively narrow range (2-5 mg/L) compared to ranges observed elsewhere in Ontario.

There is larger spatial and seasonal variation in trophic indicator parameters (nutrients, chl a, Secchi depth). Spatial variation in TP and the degree to which concentrations overlap from one sector to the next can be

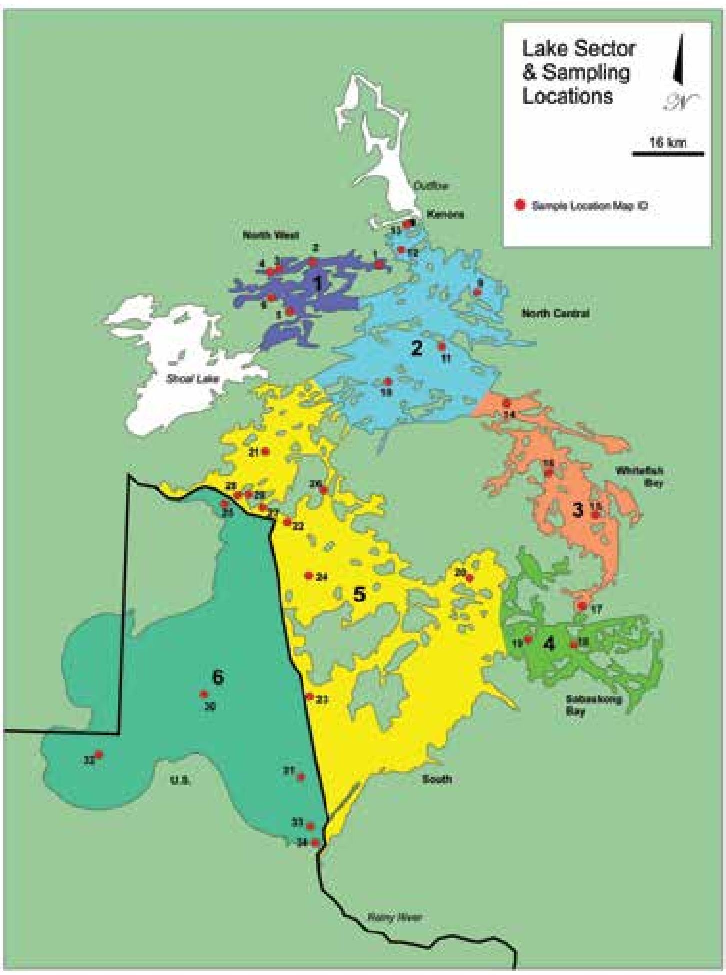


FIGURE 18 – Sectors which have distinct water quality as identified by DeSellas *et al.* (2009) in Lake of the Woods. Sample locations in each sector are shown as small red circles with ID numbers to link map locations to Table 15.

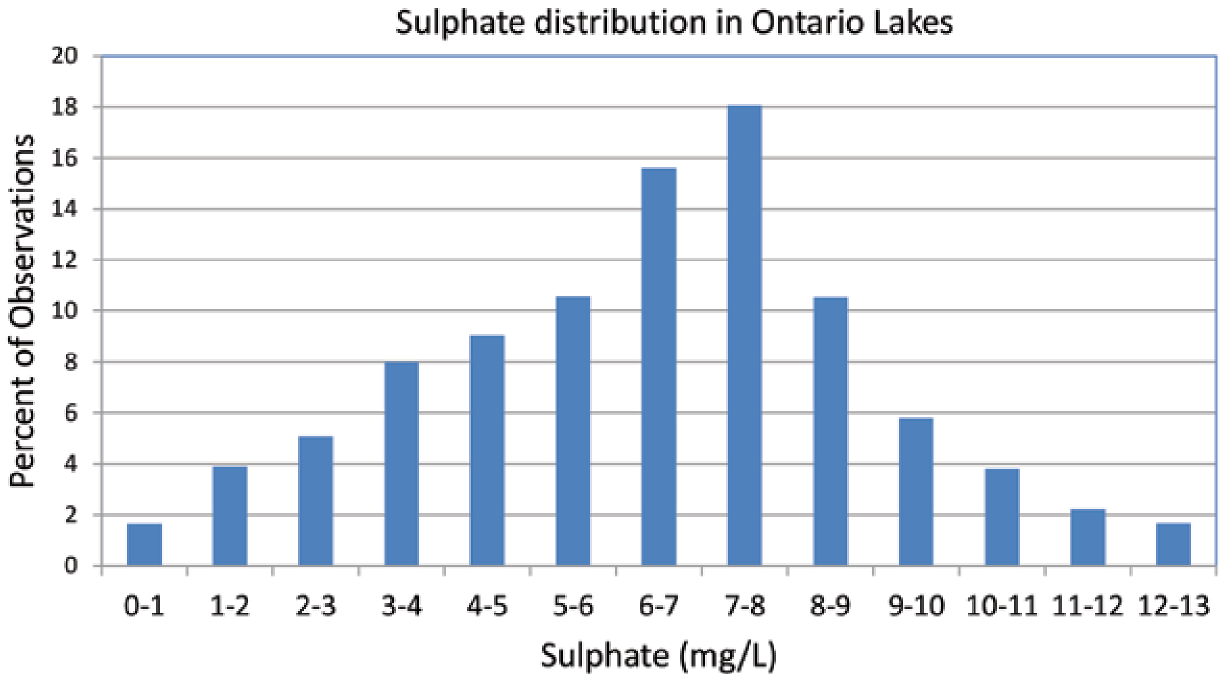


FIGURE 19 – Distribution of sulphate measurements in the OMOE Inland Lakes Database for lakes throughout Ontario. This histogram represents 5354 measurements in 1500 lakes. Measured LoW range is ~2-5 mg/L.

illustrated by observing the monthly, mixed-layer TP envelopes measured by the OMOE Lake Partner Program over time for selected areas in LoW (Figure 20). Lake Partner data are extremely precise (2SD between duplicates = +/- 0.7 µg/L). For information regarding variability in TP in Ontario Lakes see Clark *et al.* (2010).

A bar chart showing mixed-layer (epilimnetic) TP concentrations for the most recent data for sample locations in Lake of the Woods is shown in Figure 21.

Detailed status assessment reports on the trophic status of the U.S. portion of LoW were completed in 1999 (Anderson *et al.* 2000) and 2005 (Anderson *et al.* 2006b), and a summary report was completed in 2006 (Heiskary 2007) through a joint monitoring effort between the MPCA, MN DNR, and the Soil and Water Conservation Districts. These studies concluded that the means of TP, chl a, and Secchi depths for these sites were near to or exceeding the nutrient criteria defined by Minnesota for the Northern Lakes and Forests ecoregion based on section 303(d) of the United States Federal Clean Water Act.

A large body of work followed to assess the nutrient status of these areas and the details are described below in the nutrient sections at the end of Part 2.

Environment Canada collected water quality samples at 29 stations in LoW in 2009, 2010 and 2011. These data were used as input to linked hydrodynamic nutrient and algal biomass models which are discussed later in this chapter in the section on *Nutrient Flux and Budgets*.

It is important to note that there are many mesotrophic to eutrophic TP concentrations in the Voyageurs system upstream of the Lower Rainy River (see Table 21) and many concentrations below 30 µg/L are measured in the Rainy River (see Table 19). It is therefore not entirely accurate to think of Lake of the Woods, in recent years, as being influenced primarily by high concentrations of TP from the Rainy River since mesotrophic to eutrophic concentrations are measured throughout the entire basin. Although a bit of an oversimplification, the Lake of the Woods and Rainy River Watershed, in its entirety,

TABLE 16 – Lake of the Woods spring water chemistry data for the most recent sample date at each location for selected parameters.

	Location	Date	Secchi *(m)*	ALKTI *mg/l*	Ca *mg/l*	Chl a *ug/l*	Cl *mg/l*	Colour *TRUE*	Cond *uS/cm*	DOC *mg/l*	Fe *ug/l*	K *mg/l*	Mg *mg/l*	Mn *ug/l*	Na *mg/l*	NH4 *ug/l*	NO3 *ug/l*	TKN *ug/l*	pH	TP *ug/l*	Sio2 *mg/l*	SO4 *mg/l*
North West Bays 1	White Partridge 1	28/May/13	2.8	46	15.3	4.4	2.00	16.8	120	8.0	20	1.090	4.6	5.0	3.0	36	2	427	7.8	13.5	1.36	3.25
	Clearwater East 2	28/May/13	3.3	46	13.9	3.4	1.90	15.4	121	7.7	20	1.040	4.6	6.3	3.0	14	2	371	7.9	12.2	1.00	2.85
	Deception Bay 3	28/May/13	3.0	46	13.5	3.6	1.85	16.4	118	7.7	30	1.030	4.5	7.3	2.9	18	2	396	7.9	13.3	0.96	2.95
	Clearwater west 4	28/May/13	2.5	44	14.6	3.4	2.38	19.2	116	8.0	40	0.965	4.3	6.4	2.9	26	2	416	7.9	15.1	0.96	3.20
	Cul de Sac 6	28/May/13	2.8	48	14.5	4.6	1.61	15.2	119	7.5	20	0.935	4.2	6.8	2.4	42	2	428	7.9	12.8	1.56	3.35
	Echo Bay 5	28/May/13	2.5	47	14.8	4.8	1.68	13.2	123	7.4	20	0.970	4.6	5.9	2.6	18	10	398	7.9	11.7	1.38	3.30
	Poplar East	28/May/13	3.0	47	14.4	3.0	2.08	16.4	120	8.1	20	0.880	4.5	10.0	2.8	22	2	436	7.9	11.9	1.64	4.00
	Poplar West	28/May/13	2.8	46	14.6	3.6	1.72	16.2	121	8.2	30	0.875	4.5	11.7	2.8	34	2	434	7.9	13.1	1.66	4.05
	mean		***2.8***	***46***	***14.5***	***3.9***	***1.90***	***16.1***	***120***	***7.8***	***25***	***0.973***	***4.5***	***7.4***	***2.8***	***26***	***3***	***413***	***7.9***	***18.0***	***1.32***	***3.37***
North Central 2	Bigstone 8	27/Apr/10	3.1	41	11.8	1.8	2.11	31.2	98	8.8	52	0.930	4.0	22.1	3.3	8	80	439	7.6	27.0	1.96	4.15
	Donald Duck 11	27/Apr/10	2.6	43	12.0	3.0	1.84	41.0	101	10.0	100	0.920	4.2	7.8	2.9	78	22	558	7.9	28.0	1.84	4.35
	East Allie 9	27/Apr/10	3.0	40	11.3	3.4	1.81	32.4	93	8.6	65	0.880	3.7	5.9	2.7	40	24	491	7.8	21.5	1.60	4.35
	Rat Portage Bay	11/May/10	2.0	43	13.7	3.2	2.33	31.2	101	9.7	59	0.927	4.2	6.3	2.8	26	16	480	7.8	20.8	1.40	5.20
	Norman Outlet	28/May/13	2.0	49	14.6	10.4	1.87	23.2	130	9.1	50	0.885	5.2	12.3	3.2	30	2	544	8.0	23.4	1.18	4.15
	mean		***2.5***	***43.0***	***12.7***	***4.4***	***2.0***	***31.8***	***104.7***	***9.2***	***65.0***	***0.9***	***4.3***	***10.9***	***3.0***	***36.4***	***28.8***	***502***	***7.8***	***24.1***	***1.6***	***4.4***
Whitefish 3	Yellowgirl 10	27/Apr/10	3.0	27	9.8	0.6	0.95	13.4	71	5.6	32	0.765	2.0	3.8	1.9	6	2	302	7.1	10.2	0.40	2.30
	Highrock Island 33	25/Apr/12		34	9.8	0.8	1.37	7.6	78	5.7	0	0.720	1.9	3.7	1.5	20	8	309	7.7	11.6	0.60	2.40
	Index Island 32	28/May/12	4.5	31	10.8	1.6	0.94	0.2	80	5.8	10	0.780	2.1	2.9	1.5	10	4	296	7.8	10.1	0.38	2.75
	Turtle Bay 34	28/May/12	6.0	31	12.2	0.8	1.96	0.2	85	6.3	30	0.860	2.1	4.8	1.8	14	4	313	7.9	8.9	0.40	2.55
	mean		***4.5***	***30.9***	***10.6***	***1.0***	***1.3***	***5.4***	***78.6***	***5.9***	***18.0***	***0.8***	***2.0***	***3.8***	***1.7***	***12.5***	***4.5***	***305***	***7.6***	***10.2***	***0.4***	***2.5***
Sabaskong 4	Hay Island 35	22/May/12	2.0	44	11.6	6.0	1.93	27.2	111	8.8	70	0.935	4.3	3.8	2.8	22	10	431	7.9	15.5	2.34	4.55
	Buff Island 36	23/May/12	1.2	46	12.2	4.2	2.13	41.2	118	9.2	230	0.980	4.4	17.5	3.1	12	14	458	7.9	24.9	2.30	4.85
	mean		***1.6***	***45***	***11.9***	***5.1***	***2.03***	***34.2***	***115***	***9.0***	***150***	***0.958***	***4.3***	***10.7***	***2.9***	***17***	***12***	***445***	***7.9***	***20.2***	***2.32***	***4.70***
South 5	Horseshoe Island	27/May/13	2.0	46	14.6	8.8	2.14	34.4	122	9.6	90	0.955	5.1	5.8	3.3	60	20	512	7.9	20.9	2.48	4.60
	Basil Point	27/May/13	1.8	42	14.0	10.4	2.04	37.0	115	9.5	100	0.975	4.9	15.9	3.2	48	68	487	7.8	24.5	1.54	5.00
	Mica Point	27/May/13	1.5	47	16.3	10.4	1.90	28.4	126	9.3	70	0.900	5.3	6.7	3.2	40	2	520	8.0	22.0	0.18	4.40
	Monkey Rocks	27/May/13	2.0	48	14.8	10.0	2.03	29.2	128	9.6	60	0.930	5.4	5.6	3.1	38	2	523	8.0	20.7	0.46	4.45
	Little Traverse 28	22/Apr/10	1.7	43		3.3	1.90	25.0	91							<20	13	350	8.3	18.0	1.70	4.66
	NW Angle 29	24/Apr/10		44		4.6E	1.90	25.0	100							<20	<16	360	8.3	19.0	1.50	4.48
	Tug Channel 30	16/May/10	1.4	44		4.3E	1.89	30.0	96							<20	<16	350	7.9	31.0	1.80	4.72
	Canadian Ch. 31	16/May/10	1.5	44		2.2E	1.95	30.0	97							<20	<16	370	7.7	29.0	0.80	4.79
	Flag Is. 32	24/Apr/10	1.6	44		3.7E	1.97	25.0	100							<20	<16	340	8.4	17.0	1.60	4.46
	Sturgeon Channel 33	25/Apr/10	1.7	44		3.3E	1.88	25.0	100							<20	<16	330	8.2	17.0	1.60	4.54
	mean		***1.7***	***44.6***	***14.9***	***8.6***	***2.0***	***28.9***	***107.5***	***9.5***	***80.0***	***0.9***	***5.2***	***8.5***	***3.2***	***46.5***	***21.0***	***414***	***8.1***	***21.9***	***1.4***	***4.6***
Big Traverse 6	Long Point 23	19/Apr/10	1.9	28.0		4.4	2.10	50.0	100							<20	31	500	8.5	35.0	1.80	4.62
	Sable Is. 25	19/Apr/10	1.1	23.0		4.1	2.20	62.0	87							<20	<16	410	8.7	30.0	1.00	5.36
	Muskeg Bay 24	19/Apr/10	1.7	29.0		5.1	2.00	50.0	102							<20	<16	450	8.6	26.0	1.30	4.52
	Four Mile Bay 26	19/Apr/10	0.9	27.0		7.2	3.20	75.0	111							<20	<16	480	8.0	28.0	2.90	8.14
	Wheelers Point 27	15/Apr/10	0.9	48.0		8.6	3.10	88.0	114							<20	13	580	7.4	35.0	3.40	7.91
	mean		***1.3***	***31.0***		***5.9***	***2.5***	***65.0***	***103***							***<20***	***22.0***	***484***	***8.2***	***30.8***	***2.1***	***6.1***

TABLE 17 – Lake of the Woods, late-summer, epilimnetic water quality data for the most recent sample date for selected parameters.

	Location	Date	Secchi *(m)*	ALKTI *mg/l*	Ca *mg/l*	Chl a *ug/l*	Cl *mg/l*	Colour *TRUE*	Cond *uS/cm*	DOC *mg/l*	Fe *ug/l*	K *mg/l*	Mg *mg/l*	Mn *ug/l*	Na *mg/l*	NH4 *ug/l*	NO3 *ug/l*	TKN *ug/l*	pH	TP *ug/l*	Sio2 *mg/l*	SO4 *mg/l*
North West Bays 1	White Partridge 1	29/Oct/12		48	12.3	8.0	2.3	10.6	120	8.5	30	1.050	4.3	4.9	2.9	24	20	477	7.7	14.2	1.00	3.90
	Clearwater East 2	29/Oct/12	3.0	47	11.9	4.4	2.3	3.0	120	7.6	30	0.980	4.4	9.6	2.9	8	44	382	7.6	17.1	1.48	3.85
	Deception Bay 3	29/Oct/12		47	13.0	4.8	2.3	11.4	119	7.8	20	1.050	4.5	5.8	2.9	4	30	345	7.6	11.8	1.36	3.85
	Clearwater west 4	29/Oct/12	3.5	47	12.9	3.8	2.3	17.6	119	7.5	10	1.020	4.6	4.6	2.9	6	48	359	7.6	15.4	1.52	3.90
	Cul de Sac 6	29/Oct/12	4.0	48	14.4	6.2	1.7	16.2	121	8.4	10	0.980	5.0	5.2	2.5	10	10	399	7.7	9.4	1.24	3.65
	Echo Bay 5	29/Oct/12	3.0	50	13.5	5.8	2.0	12.8	125	8.2	10	1.020	5.1	5.3	2.8	12	16	372	7.7	11.4	1.44	3.80
	Poplar East	29/Oct/12	2.5	48	12.9	7.2	1.9	18.6	122	8.4	50	0.960	4.7	44.4	3.0	12	14	416	7.7	21.4	1.56	4.00
	Poplar West	29/Oct/12	2.5	51	13.1	9.6	1.9	23.4	122	8.7	40	0.940	4.8	17.4	2.9	10	2	426	7.7	19.7	1.40	4.20
	mean		***3.1***	***48***	***13.0***	***6.2***	***2.1***	***14.2***	***121***	***8.1***	***25***	***1.000***	***4.7***	***12.2***	***2.8***	***11***	***23***	***397***	***7.7***	18.0	***1.38***	***3.89***
North Central 2	Bigstone 8	29/Sep/10	3.0	38	10.9	3.4	2.3	23.2	94	8.7	30	0.820	3.6	14.4	2.7	14	138	338	7.4	21.0	1.70	4.00
	Donald Duck 11	29/Sep/10	1.8	41	11.9	5.6	1.9	31.2	99	9.1	70	0.855	3.9	19.7	2.8	24	132	403	7.6	28.8	1.72	4.40
	East Allie 9	29/Sep/10	2.3	40	11.6	9.8	1.7	26.0	96	8.8	50	0.820	3.8	11.9	2.6	16	120	387	7.5	27.4	1.88	4.10
	Rat Portage Bay	29/Sep/10	2.6	41	12.1	8.0	1.9	24.2	101	8.8	40	0.865	3.9	23.3	2.7	78	114	1090	7.6	33.0	1.96	4.20
	Norman Outlet	29/Oct/12	2.5	50	13.2	4.8	2.1	28.2	128	9.6	30	0.955	4.7	11.7	3.0	16	52	423	7.8	33.2	1.96	4.75
			2.4	***42.3***	***11.9***	***6.3***	***2.0***	***26.6***	***103.7***	***9.0***	***44***	***0.9***	***4.0***	***16.2***	***2.7***	***29.6***	***111.2***	***528***	***7.6***	***28.7***	***1.8***	***4.3***
Whitefish 3	Yellowgirl 10	29/Sep/10	2.9	28	8.9	9.8	1.1	17.4	68	6.4	50	0.710	2.0	7.0	1.6	62	4	552	7.5	20.2	0.80	2.75
	Highrock Island 33	22/Oct/12	4.5	27	9.6	3.2	1.0	17.2	79	5.6	0	0.740	2.0	5.4	1.6	12	10	283	7.6	10.9	0.66	2.50
	Index Island 32	22/Oct/12	5.0	26	9.0	2.6	1.0	18.4	78	5.4	20	0.750	2.0	12.5	1.5	14	16	303	7.6	16.1	0.80	2.30
	Turtle Bay 34	22/Oct/12	4.0	28	9.6	7.6	1.4	18.6	82	5.7	50	0.770	2.1	29.1	1.9	38	14	312	7.6	21.1	0.72	2.10
	mean		***4.1***	***27.2***	***9.3***	***5.8***	***1.1***	***17.9***	***77.1***	***5.8***	***30***	***0.7***	***2.0***	***13.5***	***1.6***	***31.5***	***11.0***	***363***	***7.6***	***17.1***	***0.7***	***2.4***
Sabaskong 4	Hay Island 35	31/Oct/12	2.5	50	11.3	9.0	2.0	29.8	117	8.6	30	0.970	4.7	2.7	2.9	46	58	448	7.7	20.4	4.24	4.55
	Buff Island 36	31/Oct/12	2.0	45	11.0	10.2	2.1	34.2	118	8.5	60	0.965	4.5	4.7	3.0	48	40	462	7.8	21.8	4.04	4.25
	mean		***2.3***	***47***	***11.2***	***9.6***	***2.1***	***32.0***	***118***	***8.6***	***45***	***0.968***	***4.6***	***3.7***	***3.0***	***47***	***49***	***455***	***7.7***	21.1	***4.14***	***4.40***
South 5	Horseshoe Island	9/Oct/08	1.2	41	11.6	13.0	2.1	35.6	103	9.9	66	0.890	3.8	12.2	3.1	14	2	507	7.8	25.0	0.20	5.10
	Basil Point	17/Jul/13	1.1	39	10.6		2.5	57.2	102	11.4	160	0.965	4.1	9.3	2.8	60	16	590	7.8	23.1	1.76	5.25
	Mica Point	9/Oct/08	1.1	45	9.7	9.2	2.1	37.2	109	10.2	92	0.940	3.8	9.9	3.4	24	6	485	7.8	23.9	1.44	5.35
	Monkey Rocks	9/Oct/08	1.5	45	9.7	4.6	2.2	38.4	112	10.8	96	0.955	3.3	11.2	3.4	26	10	488	7.8	21.6	1.72	5.60
	Little Traverse 28	24/Oct/10	1.2	49.0		6.1	2.1	40.0	110							11		450	8.0	33.0	4.5	4.97
	NW Angle 29	24/Oct/10		51.0		6.1	2.1	30.0	115							13		470	7.8	41.0	5.2	4.92
	Tug Channel 30	23/Oct/10	1.5	45.0		7.5	2.1	30.0	104							12		440	7.8	33.0	5.1	4.86
	Canadian Ch. 31	23/Oct/10	1.3	47.0		5.4	2.0	30.0	109							21		460	7.8	37.0	5.1	4.85
	Flag Is. 32	24/Oct/10	0.9	51.0		7.3	2.1	30.0	114							10		430	7.8	40.0	5.2	4.94
	Sturgeon Channel 33	23/Oct/10	1.1	48.0		6.8	2.0	30.0	110							14		450	7.8	45.0	5.3	4.83
	mean		***1.2***	***46.0***	***10.4***	***7.3***	***2.1***	***35.8***	***109***	***10.6***	***104***	***0.9***	***3.8***	***10.7***	***3.2***	***21***	***8.5***	***477***	***7.8***	***32.3***	***3.6***	***5.07***
Big Traverse 6	Long Point 23	9/Aug/10	0.9	48.0		19.4	2.2	40.0	108							16.0	13E	420	8.1	58.0	3.5	4.95
	Sable Is. 25	19/Oct/10	0.8	48.0		5.6	2.0	100.0	108							29.0	31.0	570	8.0	44.0	4.6	4.46
	Muskeg Bay 24	21/Oct/10	1.2	53.0		7.0	*2.2*	35.0								17.0	56.0	460	7.7	38.0	2.5	5.16
	Four Mile Bay 26	9/Sep/10	1.0	40.0		5.2	*2.3*	62.0	95							14.0	<16	390	7.7	27.0	3.7	5.31
	Wheelers Point 27																					
	mean		***1.0***	***47.3***		***9.3***	***2.2***	***59.3***	***104***							***19.0***	***43.5***	***460***	***7.9***	***41.8***	***3.6***	***4.97***

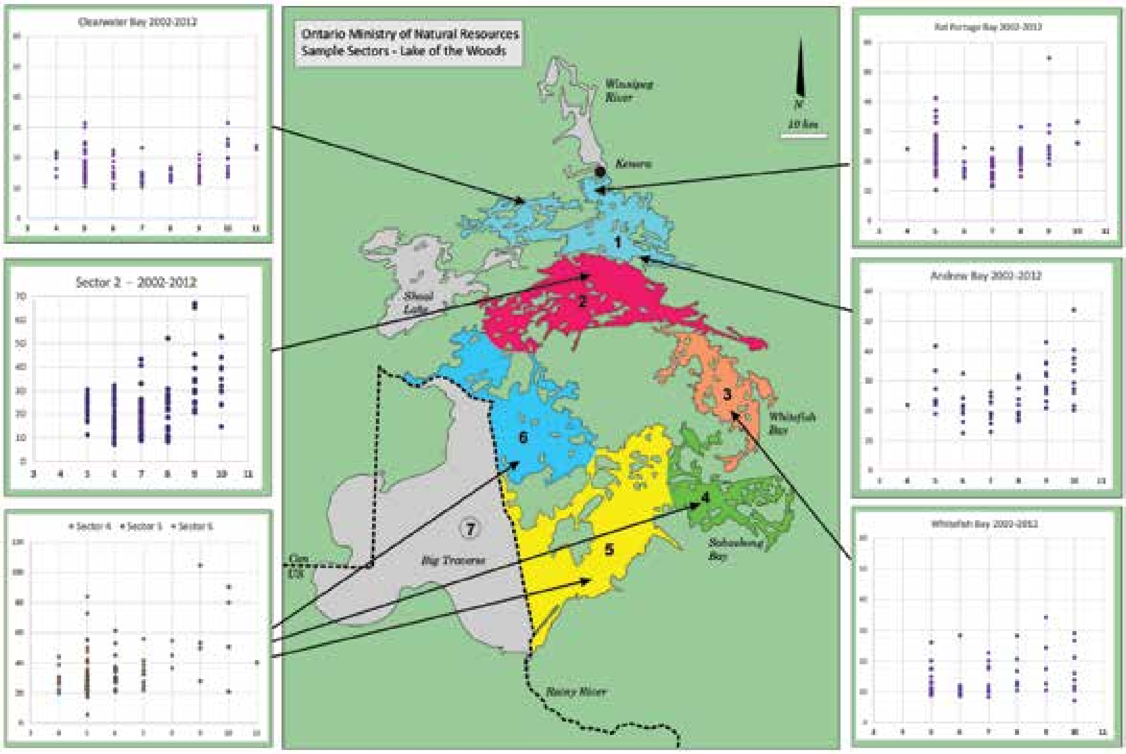


FIGURE 20 – Lake Partner Program seasonal, mixed layer, total phosphorus measurement envelopes between 2002 and 2012.

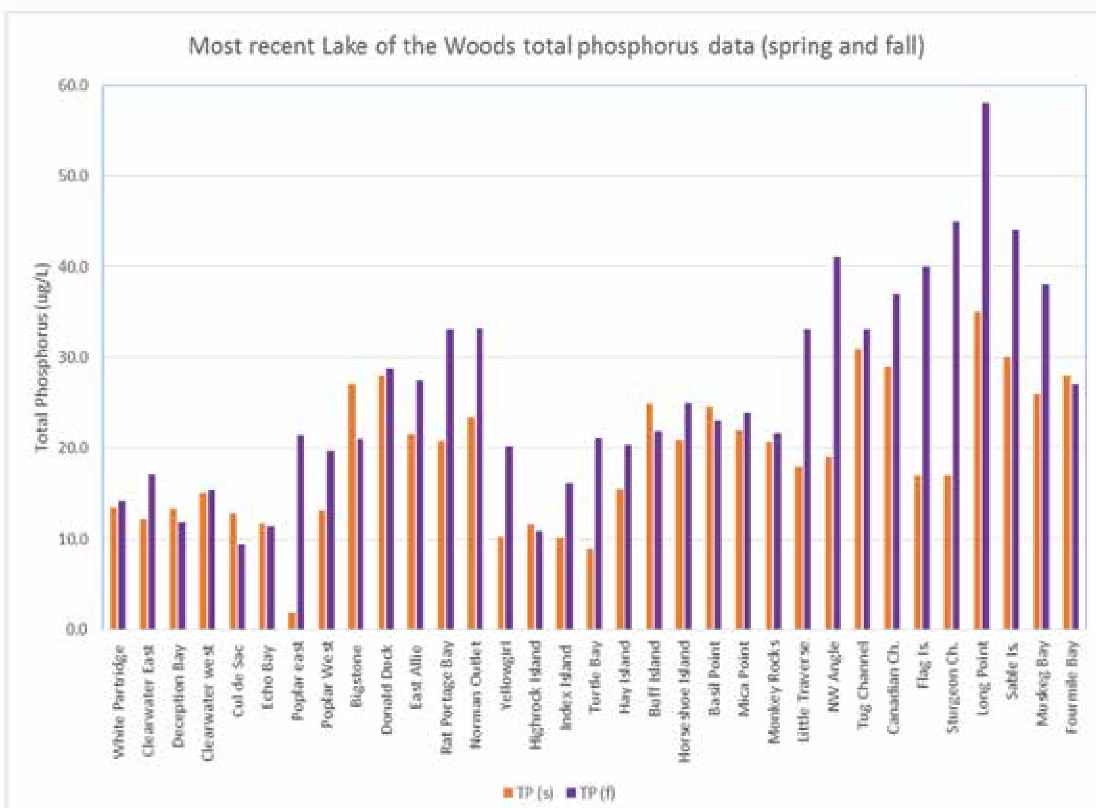


FIGURE 21 – Spring (s) and Late Summer (f) mixed layer TP data observed for the most recent sample dates at each station for Lake of the Woods. Data from OMOE/OMNR and MPCA.

could be characterized as a large, productive, mesotrophic to eutrophic system with more dilute water quality in some areas.

As indicated by DeSellas *et al.* (2009), differences in water chemistry among sectors can be attributed to variations in morphological, geological, geographical, and hydrological patterns. Some considerations include:

1. LoW, the Rainy River, and other tributaries receive water from Minnesota watersheds where timber harvesting, and to a lesser extent agriculture and farming, are common practices. These conditions increase the export of basin materials to the lake and river.
2. Wetlands, which contribute dissolved organic carbon (Dillon & Molot 1997) and nutrients including phosphorus (Paterson *et al.* 2006) represent dominant land cover in the lower Rainy River basin. Sites closer to the mouth of the river have higher DOC and colour compared to more upstream sites (Anderson *et al.* 2006b).
3. Big Traverse Bay may contribute internal P loads and resuspension of sediments into the water column. In addition, erosion increased following the implementation of water level controls. The eroded material that washes into the lake contains phosphorus, which is naturally high in the soils in this region.
4. In the Lake of the Woods, central Rainy River, and the northern portion of the upper Rainy River basins, the area is underlain by impermeable bedrock that is more resistant to erosion thereby exporting less material from the watersheds to the lake. The surrounding basin is mainly forested with little agriculture, many cottages, and a large amount of exposed bedrock.
5. The north/central sectors of LoW receive water primarily from the southern portion of the lake and this may contribute to the water chemistry characteristics of these sectors.
6. Sites within Whitefish Bay are isolated from the main direction of water flow. The same applies to the Clearwater-Echo-Ptarmigan Bay areas at the NW corner of the lake. These sectors are less likely to be influenced by water originating in the south portion of the LoW.

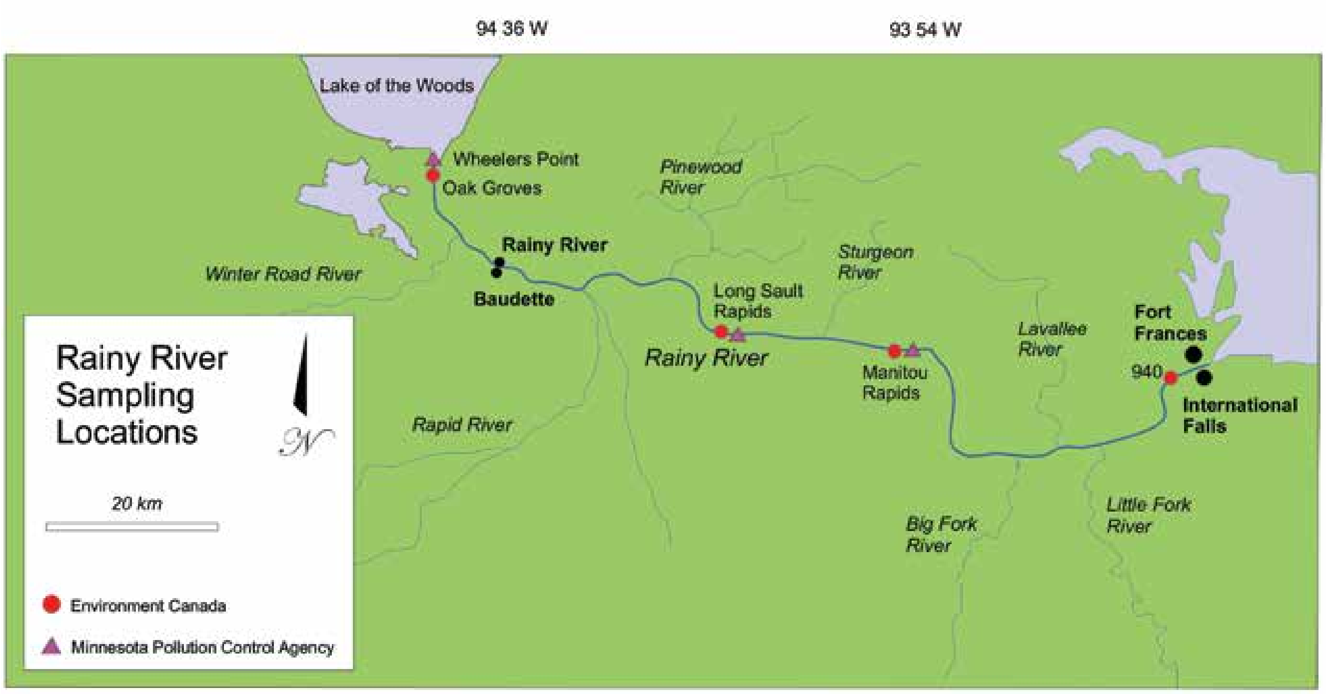


FIGURE 22 – Water quality sampling sites on the Rainy River for Environment Canada and Minnesota Pollution Control Agency. (IRLBC-IRRWPB 2010).

7. There is evidence of internal loading in many areas.

Researchers who must characterize water quality for different sectors to compare relationships between parameters or to track long-term change should consider the degree to which seasonal change influences the data and the degree to which concentrations overlap from one location to the next. Characterizations would be more informative if they indicated seasonal ranges throughout a given sector (box plots or concentration envelopes).

Lower Rainy River

The Rainy River between the mouth and Fort Frances/International Falls (FF/IF) has been sampled in many locations with a number of these locations at the mouth of tributaries to the river (Figure 22). The Minnesota Pollution Control Agency and Environment Canada have collected water quality data in the Rainy River at five locations shown in Table 18 where recent data are available. Water quality data for the most recent sample dates during spring and fall are shown in Table 19.

Environment Canada (Pascoe *et al.* 2014) provide an analysis of data collected between 2009 and 2011 on four stations on the Rainy River. They noted that:

- there was more variability in water quality parameters in 2010 than in other years likely a response to hydrology
- discharge had a significant influence on water quality parameter concentrations likely due to a dilution effect
- total nitrogen (TN) concentrations were highest in the spring
- total Kjeldahl nitrogen (TKN) was lowest in the winter while nitrate and nitrite (NO_2/NO_3) concentrations were higher and made up a larger proportion of TN at this time
- bio-available nutrient concentrations are higher in the winter than in the spring and summer
- ammonia (NH^3) was significantly lower in the winter than in the summer and spring
- TP concentrations were significantly lower in the winter than in the spring or summer
- calcium and magnesium were lower in the winter than in spring or summer
- concentrations for nitrate/nitrite, ammonia, sulphate and TP (annual median) were below all IJC Alert Levels, guidelines or toxicity thresholds. In general, median annual concentrations of water quality parameters in the Rainy River from 2009 to 2011 were below Rainy River Alert Levels (see Chapter 4, Part 3)
- in EC samples collected from 1979-1985, 68% of the samples exceeded the Rainy River Alert Level (IJC) for TP while during the time period from 2009-2011 only 19% of samples exceeded Alert Levels for TP.

Concentrations of many parameters increased between FF/IF and the mouth of the Rainy River on a given sample date (Table 19). Environment Canada noted that, in its dataset, there were increasing concentrations downstream for calcium and magnesium. Concentrations of sodium, chloride and sulphate (and particularly sodium) were highest at the upstream site in Fort Frances where there are anthropogenic sources from road salt and sewage effluent. Environment Canada noted that chloride in the Rainy River ranged from 1.5-3.5 mg/L

TABLE 18 – Location coordinates for sample locations on the Rainy River. Sample locations are shown from upstream (Fort Frances) to downstream (Wheeler's Point).

Site Name	Latitude	Longitude	Agency
Fort Frances EC	483543	932606	EC
Manitou Rapids	483803	935430	EC/MPCA/USGS
Long Sault Rapids	483858	941049	MPCA/EC
Oak Groves	484828	944147	EC
Wheeler's Point	485020	944123	USGS/MPCA

TABLE 19 – Water quality data collected for stations on the Rainy River by MPCA and EC between the mouth and FF/IF. Sample locations are organized from upstream (Fort Frances) to downstream (Wheeler's Point).

Location	Date	Secchi	ALKTI *mg/l*	Ca *mg/l*	Chl a *ug/l*	Cl *mg/l*	Colour *TRUE*	Cond *uS/cm*	K *mg/l*	Mg *mg/l*	Mn *ug/l*	Na *mg/l*	NH4 *ug/l*	NO3 *ug/l*	TKN *ug/l*	pH	TP *ug/l*	Sio2 *mg/l*	SO4 *mg/l*
Fort Frances EC	2009 mean			5.7		1.50			0.610	1.7		3.2	39**	64*	400		17.0		3.69
Fort Frances EC	2010 mean			6.8		2.38			0.690	1.9		4.3	27**	71*	360		22.0		5.38
Fort Frances EC	2011 mean			6.2		1.91			0.670	1.9		3.2	46**	29*	420		14.0		4.00
Fort Frances	29/May/11			6.6		2.05			0.828	1.9		3.0	26	51	392		13.0		4.21
Fort Frances	8/Sep/11			6.4		2.57			0.730	1.0		4.4	39	20	423		11.0		5.73
Manitou Rapids EC	2009 mean			7.3		2.02			0.690	2.2		3.2	26**	73*	400		19.0		4.96
Manitou Rapids EC	2010 mean			12.4		2.80			0.730	4.1		4.3	14**	68*	690		29.0		5.76
Manitou Rapids EC	2011 mean			9.4		2.34			0.870	3.0		3.5	36**	37*	470		17.0		4.67
Manitou Rapids	29/May/11			9.8		2.03			0.910	3.1		3.0	33	37	447		16.0		4.28
Manitou Rapids	8/Sep/11			10.0		2.81			0.810	3.0		5.1	37	12	453		15.0		6.60
Long Sault Rapids EC	2009 mean			7.1		2.00			0.680	2.2		3.1	28**	68*	400				4.85
Long Sault Rapids EC	2010 mean			12.6		2.45			0.780	4.2		3.8	13**	70*	710		29.0		5.35
Long Sault Rapids EC	2011 mean			10.1		2.47			0.870	3.1		3.6	26**	43*	460		17.0		4.66
Long Sault Rapids	29/May/11			10.0		1.98			0.920	3.1		2.9	11	59	432		13.0		4.20
Long Sault Rapids	8/Sep/11			10.2		2.8			0.840	3.2		5.2	25	24	432		15.0		6.70
Oak Groves EC	2009 mean			8.3		2.4			0.730	2.7		3.6	26**	67*	490		21.0		5.46
Oak Groves EC	2010 mean			11.0		2.4			0.810	3.4		3.6	22**	45*	610		29.0		5.25
Oak Groves EC	2011 mean			10.6		2.5			0.840	3.4		4.1	19**	38*	460		22.0		6.21
Oak Groves	25-Oct-11			13.2		3.65			1.250	4.0		5.9	29	7	445		23.0		9.39
Oak Groves	11-Jun-12			7.9		1.99			0.740	2.6		2.6	27	36	448		21.0		4.10
Wheelers Point 27	15/Apr/10	0.9	48.0		8.6	3.10	88.0	114					<20	13	580	7.4	35.0	3.40	7.91
Wheelers Point 27	25/Oct/10	1.2	42		5.1	2.09	88.0	98					10	23	510	7.7	27.0	4.10	4.64

* NO2+NO3
**NH3+NH4

throughout the year and that this was within background levels for surface waters of the Canadian Shield of 1 to 7 mg/L (Evans and Frick 2001). Chloride concentrations from 2009 to 2011 were almost two orders of magnitude lower than Canadian Water Quality Guidelines for the protection of aquatic life, which begins at 120 mg/L for chronic exposure (CCME) and the Rainy River Alert Level for chloride of 100 mg/L (Pascoe *et al.* 2014).

Environment Canada collected mercury samples from four sites on the Rainy River between 2009 and 2011. Concentrations measured during the summer and fall ranged from 0.84–8.40 ng/L, and did not exceed guideline concentrations for the protection of aquatic life (26 ng/L inorganic mercury, CWQG–CCME). Average concentrations fell below the more sensitive IJC Alert Levels for the Rainy River of 6.9 ng/L based on the MPCA criterion for the protection of human health (IRRWPB 1993). They noted that these concentrations were comparable to those measured in the Namakan chain of lakes in Voyageurs National Park (0.45-3.3 ng/L). Average annual concentrations ranged from 1.10 ng/L at the upstream site in Fort Frances in 2010 to 3.16 ng/L at Manitou Rapids in 2011. Environment Canada cautioned that although concentrations were below guideline levels, there is still a general desire for a reduction in mercury concentrations in water and sediments because of its bioaccumulation in the food web, and particularly in sport fish (Pascoe *et al.* 2014).

There has been a large body of work conducted on the tributaries to the Rainy River. These are covered in detail in other sections of this report, e.g. Chapter 1/Part 1 (Hydrology), and Chapter 1/Part 2 (Nutrient Loading).

Rainy Lake-Namakan Reservoir Basin
In the Rainy Lake and Namakan Reservoir sub-basin there has been considerable monitoring by researchers in Voyageurs National Park and this has resulted in the identification of sectors throughout the system that share similar water quality (Maki *et al.* 2013). Four regions of different water quality were identified in Rainy Lake

and each of the five lakes in the Namakan Reservoir was shown to have unique water quality. These sectors are shown in Figure 23.

Sample locations for which recent water quality data exist are shown in Table 20 and results for the most recent spring and fall data are shown in Table 21.

Spatial variation in TP and the degree to which concentrations overlap from one sector to the next can be illustrated by observing the TP envelopes measured by the OMOE Lake Partner Program over time for Rainy Lake (Figure 24).

Spatial variation has been characterized often in the Rainy/Namakan area of the Rainy Lake sub-basin. In benthic invertebrate studies, McEwen and Butler (2008) noted that the greatest similarity between Rainy Lake and Namakan Reservoir, with respect to their sampling sites, was Black Bay in Rainy Lake and Moxie Bay in Kabetogama Lake. They note that both Black Bay and Kabetogama Lake receive inflow from streams that drain watersheds with calcareous glacial drift south and west of Voyageurs National Park, while the main basin of Rainy Lake, along with Namakan and Sand Point Lakes, receives water from the east of the park, largely draining thin, noncalcareous soils. The coupling of more minerals and nutrients from the more fertile watersheds, along with the relatively shallow nature of Black Bay and Kabetogama, can largely explain their generally higher productivity compared with other areas in the Park. Additionally, there is a natural spillway between Kabetogama and Black Bay, and when water levels are high in Namakan Reservoir, water flows from Kabetogama to Black Bay via Gold Portage.

Further examination of spatial variation in water quality in areas upstream of the Lower Rainy River were conducted by Payne (1991) who examined the results of water chemistry data collected in the Rainy and Namakan area between 1977 and 1984. He noted that although water was generally very dilute, it was possible to divide the lakes into three groups based on specific conductance. These groups were:

1. Rainy, Namakan and Sand Point Lakes (44-52 µS/cm)
2. Kabetogama Lake and Black Bay (79-91 µS/cm)
3. Sullivan Bay (157-182 µS/cm).

These areas could be grouped in a similar manner for nutrients, alkalinity, algal productivity and transparency. A full range of water quality parameters including profile data at a large number of stations allowed an excellent baseline examination of water quality and a chance to observe changes in trophic state over the 7 year study. It is rare to have a database that can reach back 50 years with high quality data. Kallemeyn *et al.* (2003) provided a comprehensive aquatic synthesis which provided temporal and spatial analysis of water quality data for the lakes in Voyageurs National Park. As indicated by these studies, the waters of Voyageurs National Park are among the most well characterized in the R-LoW basin.

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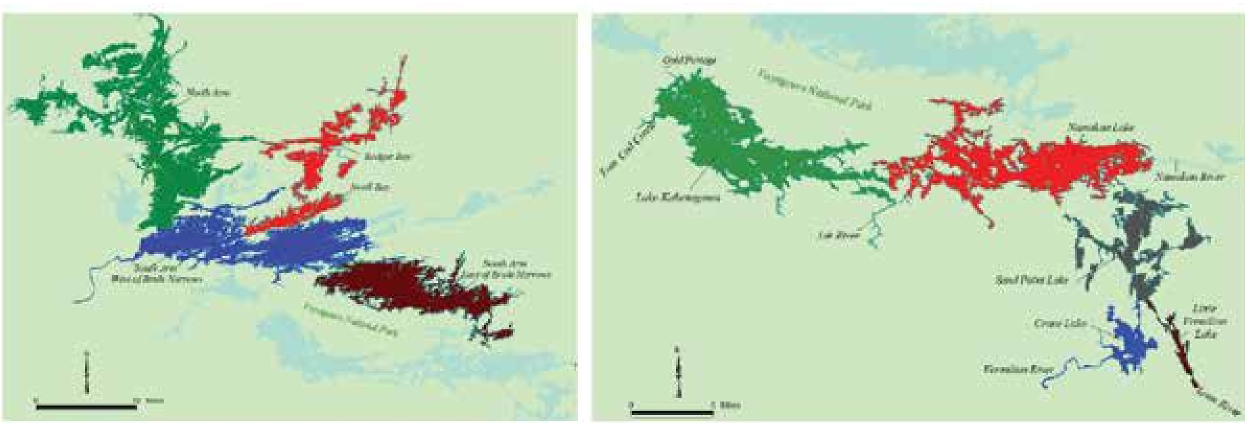

FIGURE 23 – Sectors with unique water chemistry in Rainy Lake (left) and Namakan Reservoir (right) from Maki *et al.* 2013.

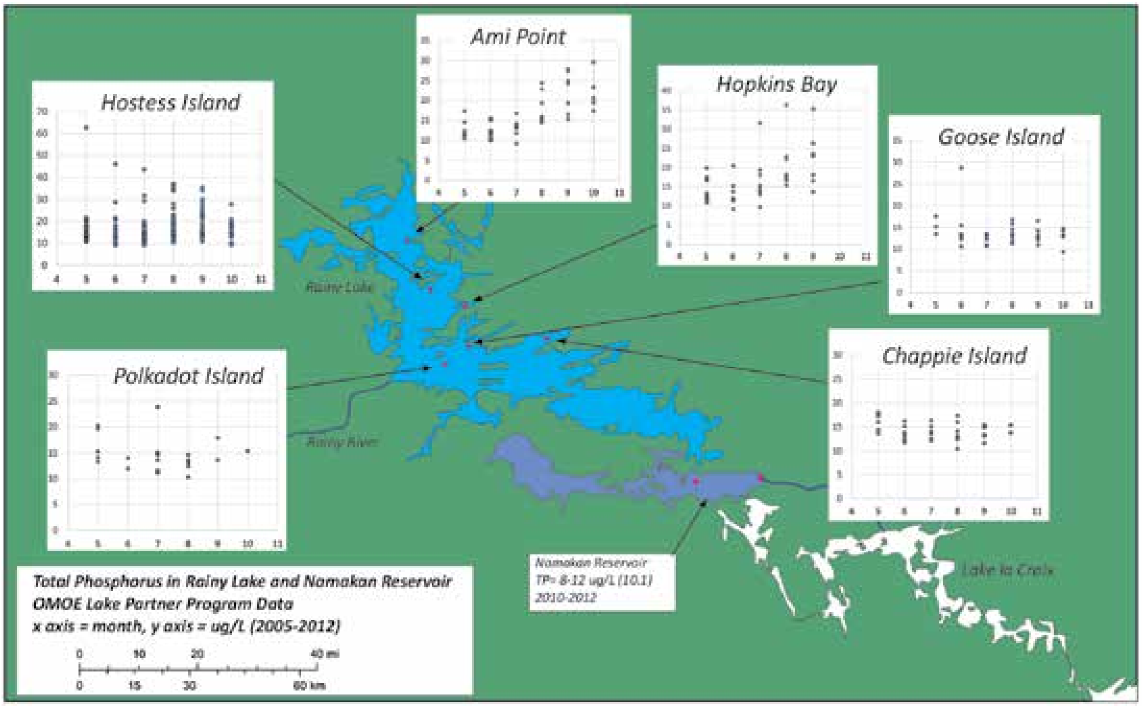

FIGURE 24 – Total phosphorus envelopes from the OMOE - Lake Partner Program for Rainy Lake.

Headwaters

The headwater regions of the basin tend to be more pristine in nature with few point sources of contaminants and little in the way of industrial processes or development of larger population centres. This does not mean that these areas are free from impacts such as the long-range transport of contaminants, pollution from diffuse sources of nutrients such as private septic systems and ecosystem purturbations through the introduction of AIS.

Less impacted areas are often subject to less government agency monitoring especially in a climate where program dollars are scarce. For this reason we often see an increase in citizen monitoring in these areas and there are several well established citizen monitoring programs underway in the R-LoW basin headwater areas. The problem with this arrangement is that the types of data that are collected by citizen monitors such as Secchi depth and nutrient analysis are useful to describe problems that are not as likely to develop in these areas (e.g., eutrophication). On the other hand the problems that are more likely to exist as a result of long range transport (e.g., mercury contamination) are, in most cases, beyond the capabilities of citizen monitoring programs to assess. There are however several comprehensive watershed based programs in place in the U.S. portion of the headwaters notably the Kawishiwi Watershed Protection Project (2011-2013) and the citizen monitoring work of WICOLA (www.kawishiwiwatershed.com; www.wicola.org). It is important to note that citizen monitoring programs provide more than data. They work to foster stewardship and kindle awareness of environmental issues which have a value beyond the data that is collected.

Cititzen water quality monitoring (Roger Sorenson, WICOLA)

In the Rainy Headwaters sub-basin (see Figure 1) there are several sources for water quality data. The data collected with respect to the areas of the sub-basin close to the basin outlet including Voyageurs National Park and the Namakan Reservoir system have been described in the previous section. These areas have been well assessed and many of the findings will be transferable to areas of the headwaters basin further to the east.

In addition there are:

- data collection associated with power licensing,
- subwatershed assessments by MPCA
- EPA, National Lakes Assessment data
- the Kawishiwi Watershed Protection Project data
- data from citizen monitoring by U.S. lake associations (see http://www.minnesotawaters.org/).

It is important to remember that unimpacted areas provide valuable background or reference data for impacted areas that are being assessed elsewhere. The importance of quality reference data should not be underestimated. One of the recommendations that this report will put forward is a request to evaluate current monitoring programs relative to their ability to answer the more important questions.

TABLE 20 – Sample locations in the Rainy River, Namakan Reservoir basin sampled by Voyageurs National Park.

Site Name	Latitude	Longitude
Crane MPCA1	481744	922837
Kabetogama 45	482727	925744
Little Vermilion MPCA4	481649	922422
Namakan Site 14	482636	923621
Rainy RRCC110	483715	930357
Rainy Site 5	483622	925559
Sand Point Site 7	482320	922753

TABLE 21 – Recent water quality data for locations in the Rainy/Namakan (Rainy Lake) sub-basin.

Location	Date	Secchi	Chl a	Cond	pH	TP
Crane MPCA1	31-May-12	1.3	2.9	75	7.3	19.2
Kabetogama 45	31-May-12	2.5	4.5	100	7.9	15.2
Little Vermillion MPCA4	31-May-12	1.8	2.8	30	6.9	18.4
Namakan Site 14	31-May-12	3.1	1.4	46	7.4	8.4
Rainy RRCC110	29-May-12	2.4	2.8	52	7.0	11.6
Rainy Site 5	29-May-12	2.5	1.6	48	7.4	10.4
Sand Point Site 7	31-May-12	2.0	3.8	66	7.4	15.4
mean		***2.2***	***2.8***	***60***	***7.3***	***14.1***
Crane MPCA1	19-Sep-12	2.1	3.9	93	7.4	16.6
Kabetogama 45	20-Sep-12	2.5	8.4	95	7.6	40.6
Little Vermillion MPCA4	19-Sep-12	1.6	3.2	32	6.9	33.8
Namakan Site 14	20-Sep-12	2.8	2.4	48	7.2	7.6
Rainy RRCC110	17-Sep-12	3.2	2.4	50	7.5	9.8
Rainy Site 5	17-Sep-12	3.0	1.3	47	7.4	10.4
Sand Point Site 7	19-Sep-12	2.3	2.2	69	7.3	11.6
mean		***2.5***	***3.4***	***62***	***7.3***	***18.6***

In this case a review of the data collection programs in the headwaters area is required relative to basin concerns that are being assessed by the International Multi-Agency Arrangement (IMA).

Interpreting Change

The 2009 SOBR examined seasonal change for pooled sector data using box plots and provided a summary of change as the difference between two points in time by plotting 1980s data against 2000s data for individual parameters. A summary of temporal (1980s -2000s) changes that were identified in the 2009 report are shown in Table 22a.

There are numerous ways to interpret changes in water chemistry. Attempts to characterize temporal change for a full suite of parameters at many sample locations can be daunting and we therefore limit the extent to which we attempt these characterizations in the following sections. It is, however, reassuring to know that there are sufficient data available to researchers for many applications. Trophic status parameter modeling, for example, is just beginning to include seasonal and multiple station predictions in the results (Zhang *et al*. 2013). In the sections below we discuss seasonal and between year changes for the most recent data.

Seasonal Change

To observe seasonal changes at individual stations, monthly sample visits are required (at the minimum). These data can be difficult to summarize when many years of data at numerous stations are available.

TABLE 22a – Summary of between-year change (1980s to 2000s), observed differences between sectors, and range in ice-free means between sectors (from Figures 4.3 to 4.8, 2009 State of the Basin Report).

Parameter	Temporal change 1980s and 2000s (all sites pooled)	Observed Difference between Sectors	Range in Sector means
Ammonium	Increase	Slightly higher in south sectors	30 µg/L to70 µg/L
TKN	No change	Relatively narrow range - Slightly higher in south sectors	300 µg/L to 600 µg/L
NO2+NO3	No change	Higher in the sectors near to the north south flow	<10 µg/L to 40 µg/L
Colour	No change	Higher in south Sectors	10 to 45
DOC	No change	Narrow range but lower in Whitefish Bay	5 to 6 mg/L in Whitefish 8-10 mg/L elsewhere
TP	No change	Higher in the sectors near to the north south flow & in south	10 µg/L to 45 µg/L
Alkalinity	No change	Narrow range but lower in Whitefish Bay	33 mg/L in Whitefish 43-53 mg/L elsewhere
pH	Decline	Narrow range - Slightly higher in south	7.4 – 8.2
Sulphate	Decline	Narrow range - Higher in the south	2.5 mg/L to 6 mg/L
Silica (SiO2)	No change	Narrow range - Slightly higher in south	<1 mg/L to <3 mg/L
Aluminum	No change	Higher in the south	10 µg/L to120 µg/L
Iron	No change	Higher in the south	20 µg/L to 150 µg/L
Calcium	Decline	Variable within narrow range	10mg/L to15 mg/L
Magnesium	Decline	Variable within narrow range	2-5 mg/L
Chloride	Decline	Variable within narrow range	1-2.5 mg/L
Sodium	Increase	Variable within narrow range	1.5 – 3.5 mg/L
Potassium	No change	Variable within narrow range	0.75 – 1.1 mg/L
Conductivity	No change	Variable within narrow range - Lower in Whitefish Bay	80-120 µS/cm

DeSellas *et al.* (2009) showed seasonal ranges in data observed for each of six sectors in the LoW using box plots. These are an excellent way to visualize data by indicating the range in measurements but they do not show the direction of the seasonal changes. The 2009 data summaries are worth reviewing for researchers who are interested in seasonal variation in water chemistry parameters in LoW.

It is worthwhile identifying which parameters are affected by seasonal change to help identify those parameters that may not be well represented by mean values. In some cases the parameter may vary seasonally in a way that dictates the use of data from a specific season. As an example, production estimates often look closely at late-summer chlorophyll concentrations because these often describe the highest nutrient concentrations encountered throughout the open water season. Phosphorus concentrations in the late summer or in the hypolimnion are more useful to describe their influence on late summer blooms. In these parameters, where there is considerable seasonal variation, the average values or point in time concentrations collected outside the season of interest may be of limited use in answering certain questions.

A casual observation of long-term datasets shows seasonal variation in Secchi depth, chlorophyll, colour, iron, manganese, ammonium, nitrate, total phosphorus and silica. Many other parameters generally do not show the same degree of seasonal change. Some of the parameters that vary seasonally describe production related processes in the lake and others like iron and manganese may be linked to seasonal release of these elements from the sediments. Phosphorus concentrations may vary due to in situ processes but it is possible that supply of this nutrient is also linked to seasonal loading. A good example of seasonal variation is shown for total phosphorus at the outlet from Lake of the Woods between 2008 and 2013 (OMNR data) in Figure 25. It is important to note that seasonal patterns, especially for nutrients, are not often this well-defined.

Further examples of seasonal change can be illustrated by examining variation in concentrations between spring and fall (late summer) for the most recent data for Secchi depth and chl a as shown in Figure 26.

For those parameters that can be confirmed to show minimal seasonal change it should be possible to use sector means of monthly data. It is interesting to note that the LoW

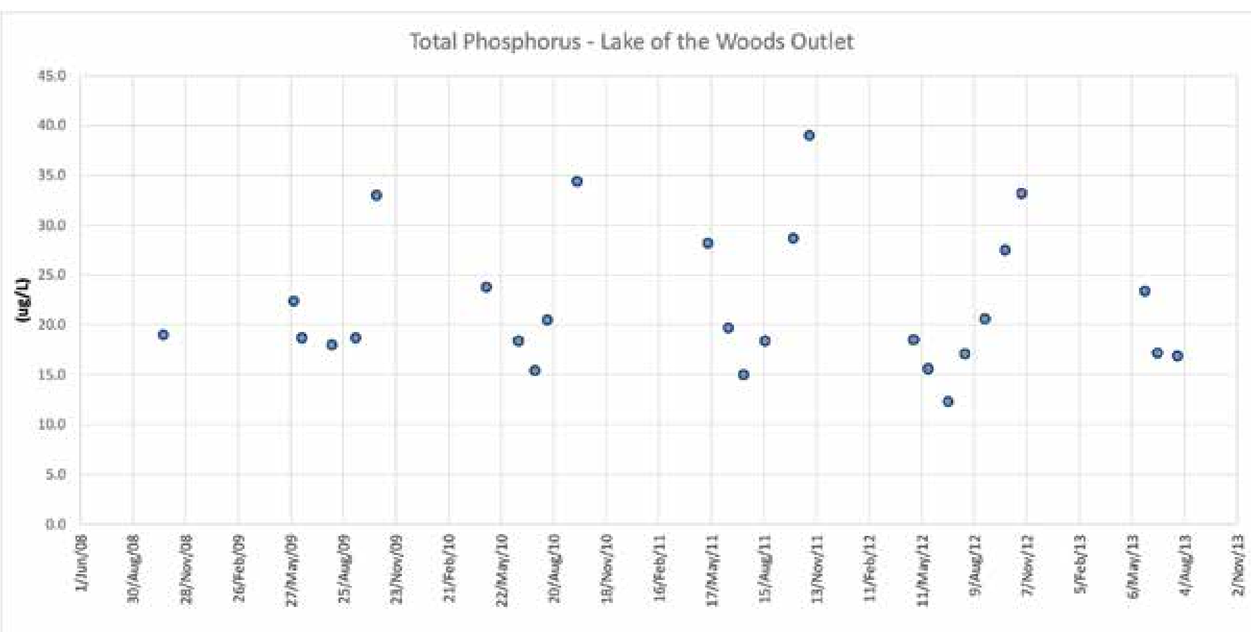

FIGURE 25 – Seasonal total phosphorus concentrations at the Lake of the Woods outlet, 2008-2013 (OMNR data).

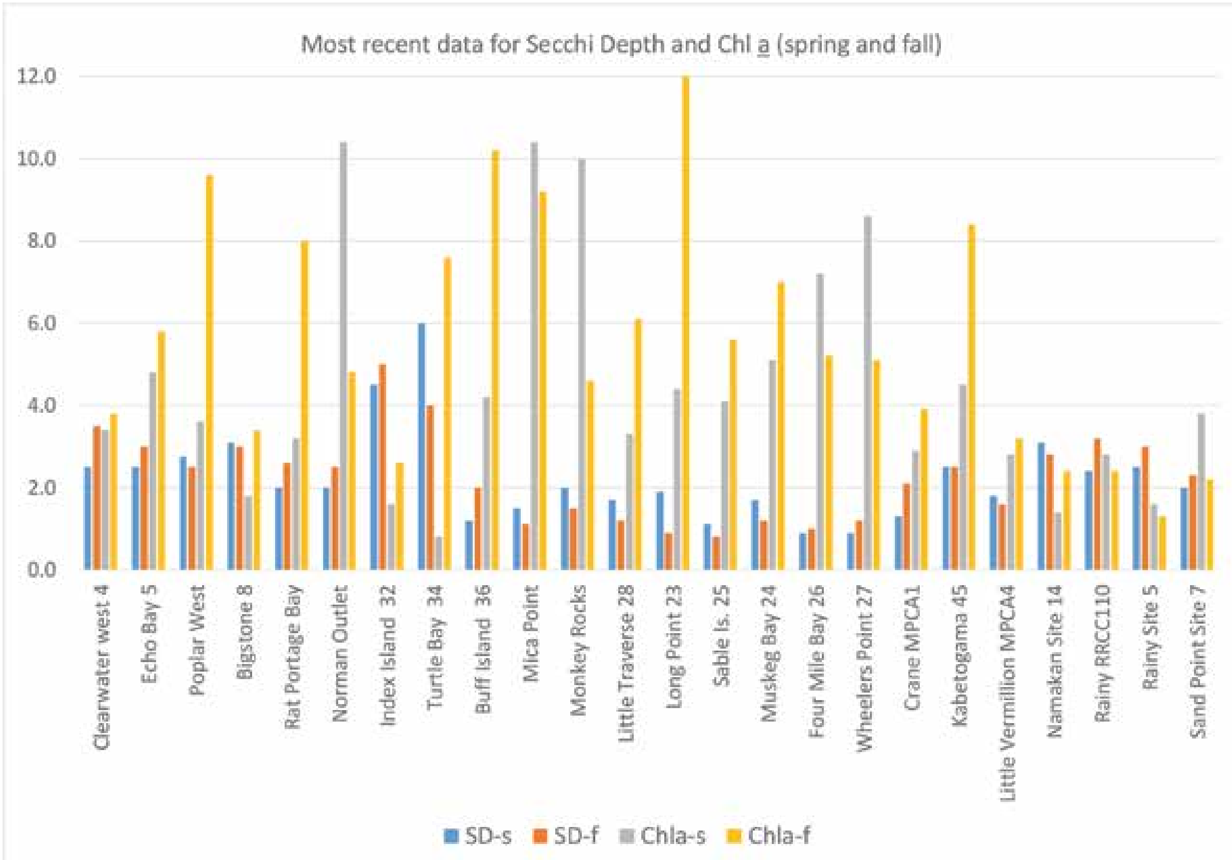

FIGURE 26 – Secchi depth and chl a in spring and fall for the most recent data for locations in the R-LoW basin. Fall chl a at Long Point is 19.4 µg/L. Y axis units are meters for Secchi Depth and µg/L for chl a. Data from OMOE, OMNR and MPCA.

sector means for those parameters that do not show seasonal variation are very similar between all sectors of the lake with the exception of Whitefish and Big Traverse Bays.

Between Year Change

The 2009 report addressed change through time by examining the differences between two points in time (1980s and 2000s) and through the examination of long-term datasets where they existed for individual sample locations. This identified that there were differences in nutrient concentrations and colour between the 2000s and the 1980s data throughout LoW. However, based on a comparison of the mean concentration in 2000s compared to the 1980s, ammonium concentration was the only nutrient variable that demonstrated a statistically significant change. The other measurements of nutrient concentration and colour, including TKN, phosphorus, nitrate-nitrite, colour, and DOC, did not show statistically significant differences between the two time periods.

DeSellas *et al.* (2009) noted that there were statistically significant changes in other chemical variables over time (significance based on Wilcoxon signed-rank test, $P \leq 0.05$). They showed that ionic concentration (i.e., sulfate, calcium, magnesium and chloride) and acidity (pH) have declined significantly, on average, since the 1980s. Other measures of ionic concentration either increased significantly (sodium), or showed no significant change over the time periods (alkalinity, silicate, potassium, conductivity). It is important to note that change was interpreted on a parameter by parameter basis using plots of sample station means between the 1980s and 2000s. This does not allow examination of the nature of the change that has occurred in any one location. These comparisons are useful because they provide a visual representation of the changes in water quality parameters

It seems likely that some areas of the lake are becoming more dilute and it would be important to be able to recognize that LoW has responded to the improvements in water quality in the Rainy River that have occurred in recent decades.

over the past few decades. It should be noted that differences between snapshots in time should be interpreted with caution.

An examination of the entire record for LoW monitoring stations using Mann Kendall analysis of monotonic trends shows similar trends to those noted by the 2009 report with the exception that pH and chloride increased in several locations with no declines observed (Table 22a). In LoW there are many significant changes (Mann Kendall, $p<0.05$) occurring in the water chemistry records, primarily in sectors 1, 2 and 3 (Table 22b, Figure 18). Many anions and cations are declining in these sectors with some increases (Na, Cl) which may be related to road salt applications. Other observations include alkalinity and nitrate which are decreasing in many locations and conductivity which is decreasing in sector three. This scan of between-year trends in the parameter list shown here indicates that there may be relevant changes in the water chemistry at many locations and this should be further explored possibly through a more rigorous ion balance exercise in areas of the lake where data are available. It seems likely that some areas of the lake are becoming more dilute and it would be important to be able to recognize that LoW has responded to the improvements in water quality in the Rainy River that have occurred in recent decades. To date however, there has not been a rigorous examination of data to determine if water chemistry in the lake is changing. Research efforts have been primarily focused on loads and concentrations of phosphorus which generally shows the least evidence of change together with DOC and ammonium.

There have been considerable declines in the concentrations measured for trophic state parameters in the Rainy River in the last several decades. Total phosphorus concentrations have declined from maximum measured annual concentrations often between 100 and 200 µg/L prior to 1985 to concentrations that rarely exceeded 60 µg/L in the past 26 years (DeSellas *et al.* 2009). Environment Canada noted a significant decline in average ammonia concentrations in contemporary samples as compared to those from the late 1970s to mid-1980 but this trend was largely driven by a few spring/summer peaks in historic samples. Ammonia concentrations appear to have increased in the early 1980s from fairly low levels, but have since again declined. Environment Canada notes that MPCA reported a general trend towards decreased concentrations of ammonia in the Rainy River near Baudette in 2001 (Pascoe *et al.* 2014). Trends in the reduction of P and ammonia concentrations may be partially attributed to reductions in point source inputs on the Rainy River. Environment Canada reported no change in the concentration of TKN between the historic and contemporary samples (Pascoe *et al.* 2014).

In the Rainy/Namakan system, there are also indications of long-term changes. In a study of system productivity in August 1999, four months prior to the implementation of the 2000 Rule Curve, Payne (2000) found that the trophic state in both Black Bay and Kabetogama had changed from eutrophic to mesotrophic relative to the period 1979-1983 (as reported by Payne 1991). Payne observed that the main basin of Rainy Lake and both Namakan and Sand Point Lakes had remained meso-oligotrophic over the same period. A subsequent study (Christensen *et al.* 2004) showed similar results and while it is implied in Christensen *et al.* (2004) that the change in the trophic state of Black Bay and Kabetogama correlates with the change in the 2000 Rule Curve, it is likely that these systems had changed prior to the Rule Curve implementation. This is further complicated by the fact that the dam operators changed the operation of the dams in approximately 1987 to a pattern that was intermediate between the 1970 and 2000 Rule Curves. As a result there was a relatively major decrease in annual water level fluctuation between the 1970 and 2000 sets of Rule Curves that was due to the 1987 changes even though it was not formally following an IJC Order (Ryan Maki 2014, pers. comm.). Thus, the changes observed may well be attributed to the changes brought about through the 2000 Rule Curves, but they may have occurred prior to the date of the actual order.

External drivers can act to change water chemistry. In the ELA during periods of

Sector	Location	From	To	Secchi	ALKTI	Ca	Chl a	Cl	Color	Cond	DOC	Fe	K	Mg	Mn	Na	NH4	NO3	TKN	PH	TP	SiO2	SO4
1	CWE	2003	2013		↓		↑		↑									↓		↑			
	CWW	2003	2013		↓		↑		↑				↓			↑		↓					↓
	Cul de Sac	2003	2013		↓			↑										↓		↑			
	Echo Bay	2003	2013		↓		↑	↑	↑				↓					↓					
	Deception B	2003	2013		↓		↑											↓		↑		↑	
	White Partridge	2003	2013		↓		↑											↓					↓
	Poplar East	2009	2013												↑								↓
	Poplar West	2009	2013																				
2	Bigstone 8	1985	2010											↓				↓			↓		
	Donald D	1985	2010										↓						↓				
	East Allie	1985	2010			↓							↓	↓					↓				
	Rat Portage Bay	1985	2010																				
	Norman Outlet	2008	2013			↓								↓								↓	
3	Highrock Is.	1986	2012	↓	↓	↓			↑	↓		↓				↑		↓		↑			↓
	Index Island	1986	2012	↓	↓	↓			↑	↓			↓	↓	↑	↑							↓
	Turtle Bay	1986	2012		↓	↓				↓			↓	↓				↓					↓
	Yellowgirl	1985	2010		↓	↓				↓			↓	↓				↓					↓
4	Hay Island	1986	2012					↑				↓					↑						
	Buff Island	1986	2012													↑			↓				
5	Horseshoe Is.	1988	2013																	↑			
	Basil Point	1988	2013		↓																		
6	Mica Point	1988	2013																				↓
	Monkey Rocks	1988	2013				↑				↑							↓					

TABLE 22b – Between-year changes in water chemistry (Mann Kendall $p<0.05$) noted for monitoring stations in Lake of the Woods (Data from OMOE/OMNR). Parameters where there is a significant increase or decrease over the period noted are indicated with directional arrows. Increases are shown for clarity in shaded cells.

drought it was shown that lakes became more transparent during the drought, a change that was attributed primarily to a decline in dissolved organic carbon (DOC) concentrations in the lakes. Declines in the export of DOC, base cations, phosphorus and nitrogen were reported, resulting in declines in nutrient concentrations in lakes. This was attributed, in part, to declines in water flow from streams, and the reduced weathering of drier soils. Although phytoplankton (free-floating algae) biomass and diversity increased slightly during the drought period, overall there was a significant decline in chlorophyll a concentration in one of the primary reference lakes (Lake 239; Schindler *et al.* 1996).

Change must be interpreted within the context of the temporal scale over which basin perturbations have occurred. Researchers often consider several decades as being too short of a timeframe to identify long term change. In the case of the R-LoW basin there have been many changes, however, over several decades that could produce changes in water chemistry within the timeframe that is covered by recent monitoring. For example, the largest decreases in P loads to the Rainy River occurred just prior to the record observed here. Many of the most dramatic changes relating to climate change have not been over a long timeframe but are limited to more recent decades. These considerations make it possible to assess change as meaningful even within a few decades. A timeframe of several decades is also long enough to link empirical observations to trends noted over longer periods through paleolimnological studies. Figure 27 shows the changes that could potentially affect water chemistry in the basin over the timeframe that recent monitoring has occurred.

Paleolimnological (paleo) examination of cores (top and bottom) can infer change over longer periods. For example, paleo methods indicated an overall small but insignificant decline in TP concentrations since pre industrial times in research conducted by Hyatt *et al.* (2011). This is discussed further in Chapter 2.

It would be important to be able to recognize whether Lake of the Woods has responded to improvements to water quality in the Rainy River in recent decades. These observations would possibly require a more rigorous sampling regime at selected stations throughout the system that could supplement the current long-term records.

Trophic Status

A lake's trophic status, or productivity, can be classified as either oligotrophic (nutrient poor), mesotrophic (moderately productive) or eutrophic (very productive). Lakes can receive nutrients from various external (e.g., fertilizers, wastewater, septic runoff, terrestrial sediments, atmospheric deposition) and internal (e.g., nutrient cycling and resuspension of nutrient-rich lake sediments) sources. Some lakes have

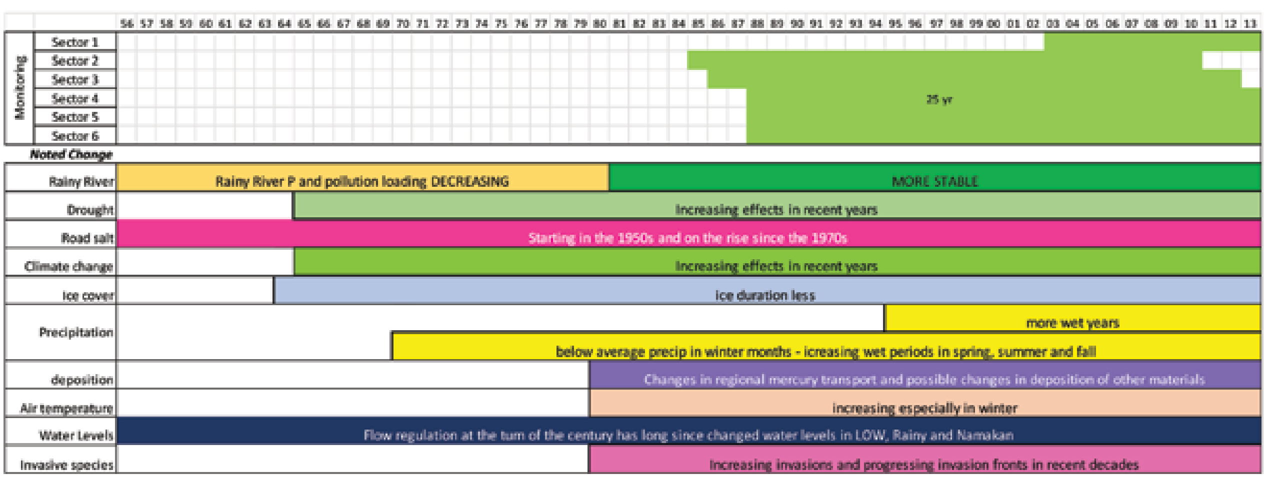

FIGURE 27 – Watershed changes that could potentially change water chemistry in Lake of the Woods within the recent monitoring timeframe.

The trophic status in R-LoW basin lakes is estimated primarily through measurements of total phosphorus.

elevated background levels of nutrients, and thus are naturally mesotrophic or eutrophic, such as a subset of lakes in the Northern Lakes and Forests ecoregion of Minnesota (Heiskary & Walker 1988). Other lakes with low background levels of nutrients can become nutrient enriched over time in a process called *cultural eutrophication*. Under conditions of increased nutrient loading to a lake over time, algal biomass tends to increase. This positive relationship between nutrient loading and lake productivity is well established (Dillon & Rigler 1974; Schindler 1978; Smith 1982).

The cycling, partitioning, and transport of nutrients play a significant role in the productivity of LoW. Long-term monitoring of the lake has shown that LoW experiences significant inter-annual and spatial variability in trophic status and nutrient concentrations (e.g., Mosindy 2005; Anderson *et al.* 2006b). This variability has been observed in the larger lakes in other R-LoW sub-basins.

Trophic Status Indicators
The trophic status in R-LoW basin lakes is estimated primarily through measurements of total phosphorus (TP). Among the major nutrients required for the metabolism, nutrition, and structure of aquatic biota (e.g., phosphorus, carbon, nitrogen, silica), phosphorus is often present in the lowest quantity in oligotrophic, mid-latitude lakes and therefore usually controls biological productivity (Dillon & Rigler 1974; Schindler 1975; Hecky & Kilham 1988). Secchi depth, which is collected routinely, provides an inexpensive estimate of lake productivity but these data are generally not required if TP data are available.

Chlorophyll a (chl a) is commonly used as a surrogate for algal biomass, and across broad nutrient gradients, a strong sigmoidal relationship may exist between TP and algal biomass (Watson *et al.* 1992). The relative importance of phosphorus in structuring algal biomass may vary temporally (annually, monthly, and seasonally) and spatially as demonstrated with LoW data by Pla *et al.* (2005).

Nitrogen (N) can also be an important nutrient in some circumstances in LoW as N concentrations may determine which algal species are dominant in northern lakes. In nutrient poor, oligotrophic systems in temperate regions, many lakes receive much less P than N from their relatively undisturbed watersheds, High N:P ratios suggest a state of P limitation (Downing & McCauley 1992). Alternatively, under mesotrophic or eutrophic conditions, lakes receive nutrients from various sources that may elevate their P concentrations (such as fertilized soils or wastewater). In these circumstances, P concentrations may become sufficient to induce N deficiency in phytoplankton (Downing & McCauley 1992), or result in co-limitation of phytoplankton by P and N. A decoupling of this phosphorus-algal biomass relationship in late summer and early fall has been observed in LoW (Pla *et al.* 2005; Kling 2007). This may be attributed to a seasonal increase in P concentrations that resulted in N limitation or co-limitation of P and N in the phytoplankton over time (Pla *et al.* 2005) or to difficulties in accurately measuring heterogeneous algal biomass. This pattern has been observed in other nutrient-rich lakes (Downing & McCauley 1992; Downing *et al.* 2001), as well as other large remote Precambrian Shield lakes (Guildford *et al.* 1994).

Orihel *et al.* (2012) made further observations with respect to N:P ratios. First, N:P ratios may be at times negatively correlated to particulate microcystin content. Second, N:P ratios may be indicative of the nature of nutrient sources to oligotrophic versus eutrophic ecosystems (Downing and McCauley 1992), and therefore, the association between N:P and microcystin results from the covariation of N:P ratios and lake trophic status. Third, low N:P ratios may be the consequence, rather than the cause, of cyanobacterial blooms. Some planktonic cyanobacteria have a benthic life stage where they assimilate P from sediments (luxury uptake), and consequently, episodes of cyanobacterial recruitment from sediments can dramatically decrease the N:P ratio in the water column (Xie *et al.* 2003).

Scott *et al.* (2013) offered an alternative explanation to the drivers of microcystin

There is a focus on measuring and monitoring trophic status parameters in the basin because much of the research is focused on understanding the drivers that influence the frequency and severity of algal blooms.

concentrations proposed by Orihel *et al. (2012).* Based on an examination of a wider range of N:P ratios, they suggested that elevated microcystin concentrations are more frequent when the N:P ratio is between 15 and 20.

Pla *et al.* (2005) noted that the relationships between phosphorus and algal biomass may not be consistent. Possible contributors to variation in the relationship between phosphorus and chl a in LoW may include variations in light, temperature, mixing regimes, and lake depth among sites. For example, the strength of thermal stratification varies throughout the lake due to differences in depth, wind patterns, and hydrological patterns. This affects the mixing regime and consequently the location of the phytoplankton in the water column, as well as their ability to utilize the nutrient-rich, well-lit epilimnion. This, in turn, influences phytoplankton assemblage composition and biomass (Watson *et al.* 1997). Remote sensing work by Binding *et al.* (2011) indicate large variation in chlorophyll concentrations over short time frames due to vertical wind mixing of pigments. The heterogeneous nature of algal biomass during blooms also makes it almost impossible to collect representative samples which in turn may make it difficult to observe TP-chl a relationships should they exist. Zhang *et al.* (2013) demonstrated that a linked hydrodynamic, phosphorus–algal biomass model, predicted algal biomass and cyanobacterial dominance best in the more eutrophic, southerly regions of LoW. Some of these difficulties may be overcome through the development of remote sensing techniques that can provide better estimates of algal biomass.

Spatial and Temporal Variation in Trophic Status Indicators

It has been demonstrated that there are both spatial and temporal variations in water chemistry throughout the R-LoW basin and that seasonal change is more prevalent with trophic status (TS) indicators. There is a focus on measuring and monitoring TS parameters in the basin because much of the research in the basin is focused on understanding the drivers that influence the frequency and severity of algal blooms. There are also several areas that are considered to be impaired relative to TS indicators. The result is that there has been considerable focus on temporal variation in TS indicators on a sector by sector basis. This focus has resulted in:

- increased frequency of monitoring at individual sample sites
- use of linked models to describe seasonal change on a sector by sector basis
- use of satellite imagery to track seasonal and between-year differences in algal abundance
- use of paleolimnology to track changes over time including pre-monitoring periods
- use of volunteers to collect monthly data at multiple locations throughout the basin
- application recently of fluorescence profiles by EC, using both chl a and phycocyanin probes, to locate subsurface or deep maxima.

Spatial variation in trophic status parameters by sector is described for the most recent data in the water chemistry section of Part 2. These data indicate wide ranges in observed TP concentrations at most locations with much overlap of seasonal concentration envelopes (Figure 28). There have not been significant long-term (between-year) changes noted for TS parameters at most locations in the basin where sufficient records exist with the exception of the reductions that have occurred in the Rainy River.

There has been a focus on measuring seasonal and temporal changes in TS parameters in the southern portions of the lake, i.e. Big Traverse Bay. The MPCA has monitored August water quality at four sites on LoW since 1999, with sampling coinciding with late-summer algal blooms. These four sites in the southern portion of LoW are: Fourmile Bay/Rainy River, Big Traverse Bay, Muskeg Bay, and Long Point. These data are available on the STORET (short for STOrage and RETrieval) Data Warehouse—(http://www.epa.gov/storet/dw_home.html).

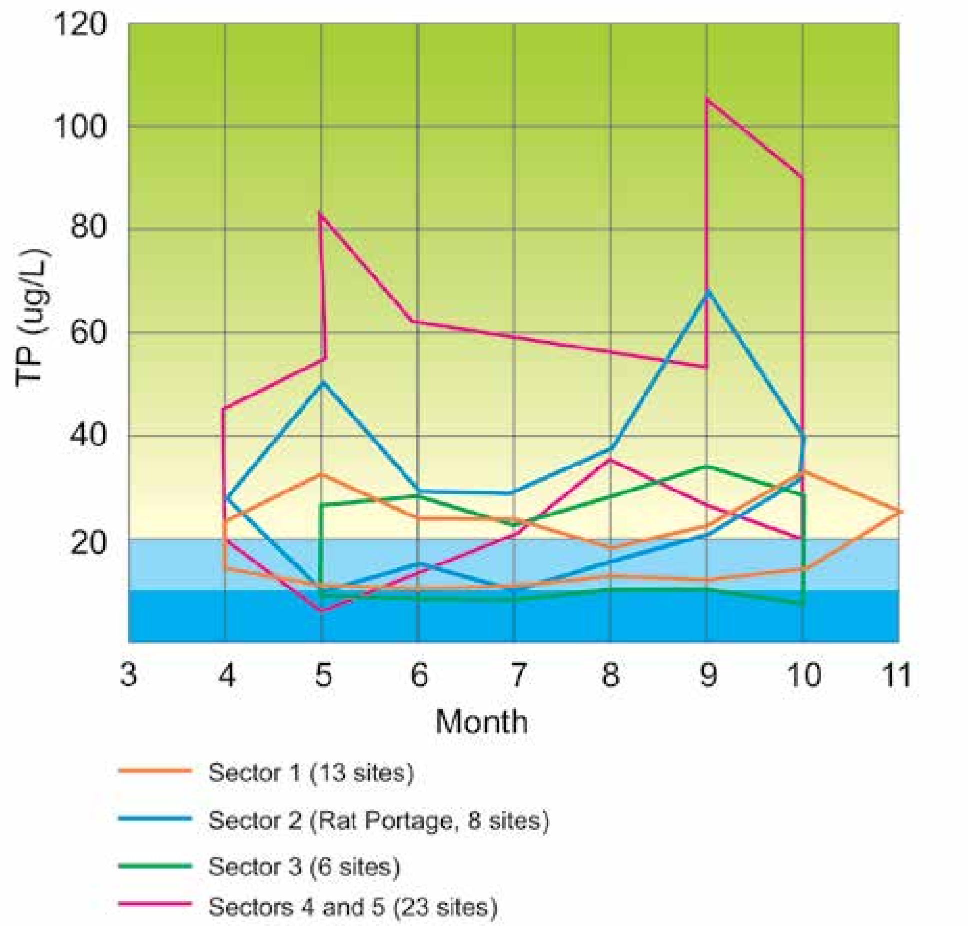

FIGURE 28 – Seasonal P concentration envelopes for sectors 1, 2, 3 and 4/5 in LoW. Dark blue portion of background indicates oligotrophic conditions. Light blue indicates mesotrophic conditions and the green portion indicates a gradient of eutrophic conditions (Data from OMOE/OMNR).

Following the impaired listing of these waters, the MPCA expanded the sampling effort by including an extra site on the Rainy River at Baudette and an additional site has been added at the mouth of the Rainy River at Wheeler's Point. The intention was to define the among-year variability in trophic status between monitoring sites in the Minnesota portion of LoW (Anderson *et al.* 2006b). The 2009 SOBR summarized patterns of temporal and spatial variation in TP and chl a concentrations at these monitoring sites as follows:

- mean TP increased between 1999 and 2006 at Fourmile, Big Traverse, Long Point and Muskeg Bay locations
- mean chl a concentrations across all sites were low in 2005 (4.9 µg/L) compared to 1999 (12.9 µg/L) and 2006 (12.6 µg/L) and this was attributed to late summer severe nuisance algal blooms (Anderson *et al.* 2006)
- there was some temporal variability in Secchi transparency among the four monitoring sites which is in contrast to one MPCA Citizen Lake Monitoring Program (CLMP) site in LoW located near the Rainy River inflow, where no temporal trends in summer transparency were seen from 1993-2006 (MPCA - Environmental Data Access 2007b)
- elevated chl a concentrations at the two sites furthest from Rainy River inflow (Long Point and Muskeg Bay) in 2006 did not have corresponding declines in Secchi depth readings at these sites. This suggests that the low Secchi transparency of Fourmile and Big

Traverse Bays was strongly influenced by turbidity due to suspended solids and DOC from the Rainy River (Anderson *et al.* 2006b)
- slight increases in TP were evident throughout the summer from May to August before declining again in September at all sites.

Environment Canada collected samples for TS indicators from 6 sectors throughout LoW to provide input to a linked hydrodynamic nutrient model which is described in detail in the *Nutrient Flux and Budgets* section below. This model describes spatial, seasonal, and between-year variation in TS parameters for LoW between 2000 and 2010.

The OMOE Lake Partner Program is a volunteer-based monitoring program that engages citizens in monitoring the water quality of hundreds of Ontario's lakes. Since its commencement, there has been ongoing monitoring of many sites in LoW on a monthly basis, allowing examination of spatial and temporal trends in TP and water clarity. TP concentrations at many locations in LoW vary widely within a given year often from concentrations that are nearly oligotrophic to values that are close to being hyper-eutrophic. These wide ranges make it possible to observe strong, seasonal relationships between TP and water clarity. LoW is one of the few places in Ontario where there is a strong relationship between water clarity and TP at individual sample locations. For example, there is a relationship between phosphorus and water clarity for a location near Coney Island in the northern portion of the lake (Figure 29). Seasonal patterns in TP concentrations are pronounced and consistent between years at many locations throughout the lake (Figure 30).

Additional observations of spatial and seasonal trends in TS indicators are possible using the most recent data for sites throughout LoW (Table 16 and 17). TP and chl a concentrations are noticeably higher in the south and comparisons of spring and late-summer TP data demonstrate a general trend of increasing TP throughout the summer at many sites. Anderson *et al.* (2006b) showed that both TP and chl a concentrations increased on a seasonal basis

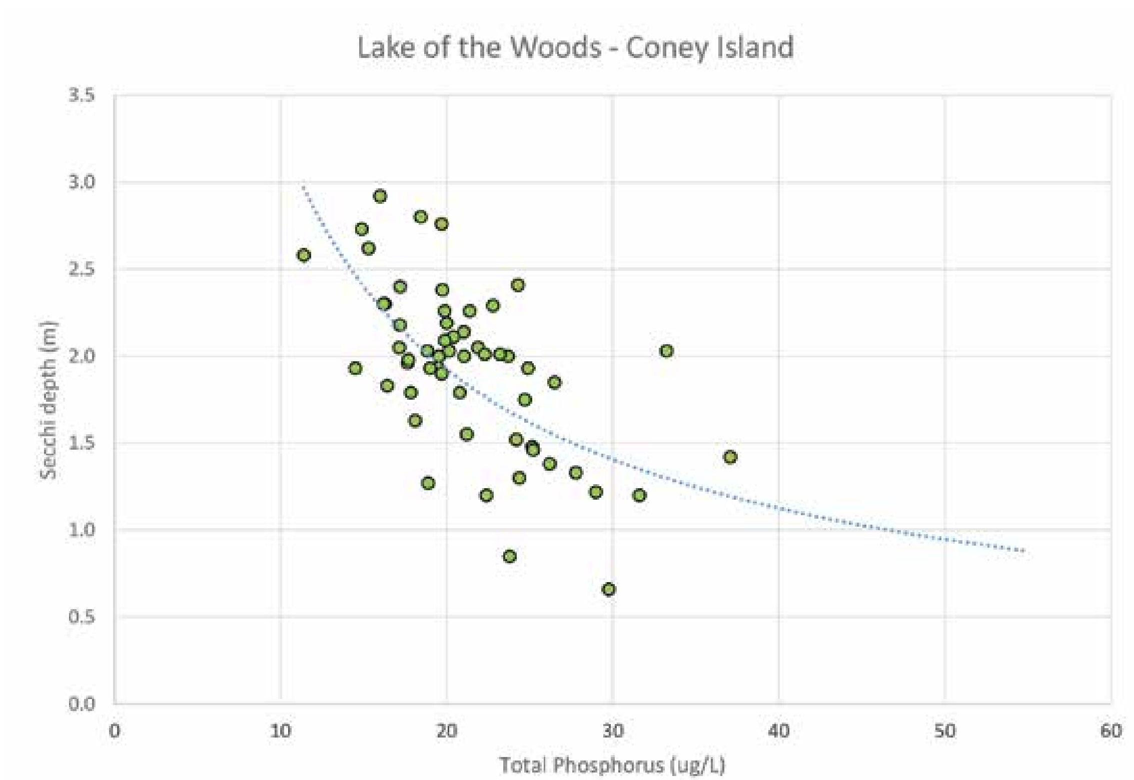

FIGURE 29 – Relationship between TP and Secchi depth at Coney Island in the north end of Lake of the Woods (OMOE, Lake Partner Program data).

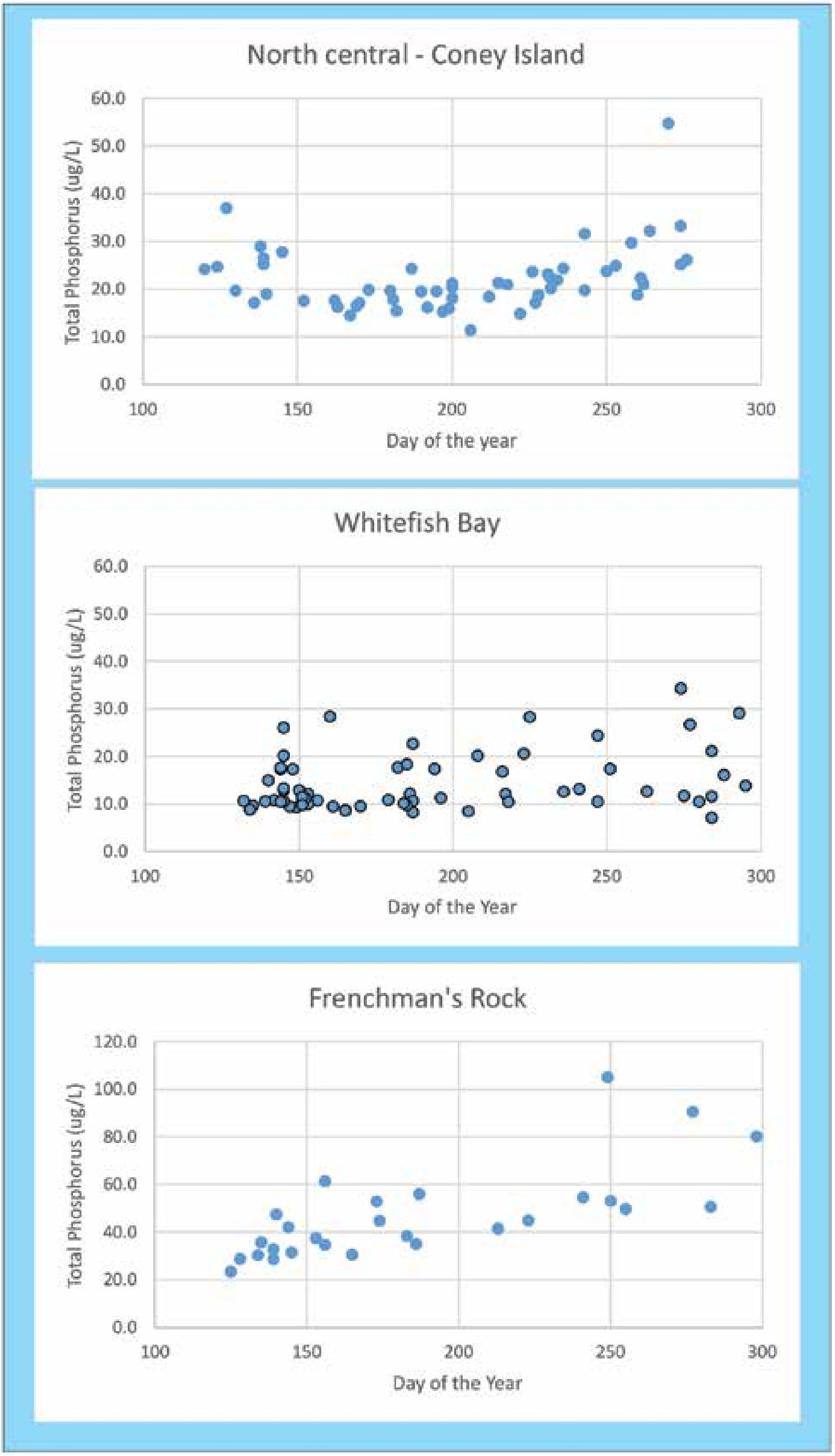

FIGURE 30 – Seasonal changes in TP concentration shown for sites with multiple years of data sufficient to show seasonal distribution in concentrations in; the north central area of the lake (Coney Island), an isolated bay (Whitefish Bay) and the southern portion of the lake (Frenchman's Rock) (OMOE, Lake Partner Program data).

from May to September in 2005 at all four monitoring sites in the Minnesota portion of LoW. Seasonal variation in TP throughout LoW is further examined below in the Section—*Nutrient Flux and Budgets*.

Decreasing TP throughout the summer months in several isolated areas of the basin is typical of Precambrian Shield lakes where nutrient loads are minimal throughout the stratified season and hence, TP is lost as plankton and other material sink from the epilimnion to deeper, colder waters (Kalff, 2002).

The earliest reports of algal blooms in LoW are from over 200 years ago when explorers, fur traders, settlers, and military officials ventured into the area.

Spatial and temporal variation in TS indicators such as algal biomass or chl a are difficult to assess due to extremely heterogeneous distribution of these parameters during bloom conditions. There have been recent advances in the use of satellite images to track algal bloom characteristics seasonally and between years in LoW (Binding 2011) which has led to an improved ability to spatially and temporally analyze phytoplankton biomass. This is discussed further in the following section.

The links between trophic status indicators, algal blooms and internal loads have been investigated in other areas of the basin. Nutrient enrichment has led to excessive algal growth in Kabetogama Lake in northern Minnesota (Christensen *et al.* 2011). Nutrient and algal data were used to determine trophic status and assess the impact of water level changes in 2000. It was determined that internal loads in some areas of Kabetogama Lake may exacerbate algal blooms. Microcystin was detected in 7 of 14 bloom samples. The results noted improvements in chl a and other trophic indicators compared to previous studies.

The USGS and National Park Service partnered on a two year assessment (2011-2012) of trends in streamflow, nutrient concentrations, and cyanobacterial transport in the narrows between Namakan and Kabetogama Lakes in Voyageurs National Park. They note that the 2013 water-quality data will be analyzed, nutrient and microcystin concentrations summarized, and a journal article prepared. The objectives are to (1) determine the timing, direction, and rate of water flow between Namakan and Kabetogama Lakes, (2) assess nutrient and cyanobacterial transport between Namakan and Kabetogama Lakes, and (3) compare nutrient data from this and previous studies to water levels in order to clarify the effects of changes in reservoir operation. Data collection activities include operation and maintenance of an index-velocity stream gauge by the USGS, and water-quality sampling by the National Park Service (NPS). These data will be found at the USGS NWISWeb (National Water Information System). An acoustic doppler velocity meter (ADVM) was installed and operational with visits every 6 weeks during open water of 2012. Data are available on NWIS web at: http://waterdata.usgs.gov/mn/nwis/uv?site_no=482611092483801.

Paleolimnological techniques have been used to describe long-term changes in TS parameters for some areas of the basin and these are described in detail in Chapter 2 - *Historical Conditions*.

Phytoplankton abundance

The most evident result of increased phytoplankton abundance is the occurrence of algal blooms that produce aggregations of aesthetically unappealing material including surface scums. The earliest reports of algal blooms in LoW are from over 200 years ago when explorers, fur traders, settlers, and military officials ventured into the area. The earliest survey of algae in LoW dates back to the early 1900s (Lowe 1924) when many taxa had not yet been described in the scientific literature. In recent decades, there have been increasing concerns about deteriorating water quality and an increased frequency of severe algal blooms on LoW. Not only are these algal blooms aesthetically unpleasant, but some species of cyanobacteria naturally produce and store toxins that are released into the water during cell lysis and death (see *algal toxins* – Part 4). In addition, these toxins can accumulate in the viscera (liver, kidneys) of some fish and in molluscs such as clams, although the levels that accumulate depend on the location and severity of the bloom (Health Canada 2007).

Nuisance algal blooms are often caused by phytoplankton in the group Cyanobacteria.

Uncertainties remain about the drivers that control algal blooms including climate variables and nutrient sources from inflows and from internal loads.

These algae are often blue-green in appearance (hence the common name *blue-greens*), although they can range in colour from green to red. A mass or mat of cyanobacteria is called a bloom, and when this rises to the water surface it is called a *surface scum*. They often occur in warm, still, or slow-moving water during the warm summer months. These blooms invoke ecosystem interactions that have consequences beyond their unaesthetic characteristics.

Surveys to assess phytoplankton abundance have been sparse within the LoW basin. This is partly due to difficulties associated with measuring cell density in extremely heterogeneous concentrations of material which is often the case while blooms are occurring. It is possible to encounter conditions where a sample from one side of an aircraft's pontoon would include thick mats of algal cells while a sample from the opposite side would contain relatively clear water (Clark pers. obs.). This may explain why nutrient correlations with measured chlorophyll are often poor when attempting to develop relationships between trophic status indicators. Satellite imagery is often the only way to assess heterogeneous distributions of algal cells and even then the observed concentrations can change drastically from day to day due to rapid vertical mixing of algal cells following wind events (Binding *et al.* 2011). The difficulty is not with observing the conditions via satellite images but with ground truthing the results by collecting samples that are representative. Representative samples in heterogeneous systems are often difficult to obtain without the collection of unreasonable numbers of samples.

Research by Binding *et al.* (2011) provided some clues as to the external drivers that may control phytoplankton abundance. They showed that bloom intensity was affected by several factors namely:

- more intense blooms were likely to occur earlier rather than later in the season
- January-August cumulative temperatures correlated positively with bloom intensity
- spring precipitation was negatively correlated with bloom intensity.

This supports the ongoing premise that bloom intensity is increased under warmer and drier conditions.

The Binding *et al.* results have shown a time-series of intense algal bloom occurrences on LoW over the last decade, with average monthly bloom extent resulting in eutrophic conditions across as much as 80% of the lake's surface. Peak bloom years were found to be coincident with warm, dry summers. Binding's results suggest that while bloom intensity and extent appear to be strongly associated with lake temperatures, temporal shifts in the timing of the bloom each year are driven more by variations in precipitation events and subsequent nutrient loadings.

Binding *et al.* indicated that evidence to support the occurrence of more intense blooms in recent years was not indicated by their results but it would be premature to make this conclusion based solely on the 2003-2009 record. If intensity of blooms is linked to climate change as suggested by Paerl and Huisman (2008) then it may be safe to conclude that the link between bloom intensity and climate may exist more prominently in systems such as LoW that have seen major changes in physical limnology which can only be linked to climate change (e.g., extended length of the ice free season). This may infer that changes have occurred over a longer timeframe than in the record observed by Binding *et al.* Paterson *et al.* presented evidence at the 2011 Water Quality Forum in International Falls that shows an increase in lake sediment chl a concentrations since the mid-1900s, with larger increases since the early 1980s. This may indicate that blooms have indeed been more severe in recent decades.

Algal blooms are an ongoing concern throughout the basin. Uncertainties remain about the drivers that control algal blooms including climate variables and nutrient sources from inflows and from internal loads. Algal blooms are therefore listed as a basin concern in Chapter 3.

Nutrient Loading

The Rainy River

The Rainy River is the major inflow to LoW, with a mean daily discharge of 365 m^3/s (12,890 ft^3/s). In the past, the pulp and paper companies at International Falls and Fort Frances together with domestic sewage inputs were considered to be the major point sources of nutrients to the Rainy River (LWCB 2002). In recent decades the implementation of regulations for treatment of industrial and domestic waste effluent have led to significant reductions in nutrient loads to the Rainy River. These reductions occurred most substantially in the 1970s and the 1980s (Figure 31).

TP concentrations in the Rainy River at International Falls show a trend of decreased variation in recent years with a slight decline in P after 1985 (DeSellas *et al.* 2009). This trend can be attributed to a combination of improved analytic precision (reduced variability) and reduced impact of large point source loads (lower concentrations). Mean TP concentrations of 30-35 µg/L (1999 and 2005) at Baudette (Anderson *et al.* 2006b) are comparable to in-lake concentrations throughout the U.S. portion of LoW in 1999 and 2005.

MPCA's Major Watershed Load Monitoring Program (MWLMP) initiated in 2007 combines USGS and MDNR flow data with MPCA, Metropolitan Council Environmental Services water quality data to calculate loads for 82 streams in Minnesota. MWLMP sites in the Rainy River basin monitor the Headwaters, Vermilion, Little Fork, Big Fork, Rainy and Rapid rivers. In 2009, the MPCA implemented a loading study for most U.S tributaries to LoW including Manitou Rapids on the Rainy River which is a MWLMP site. The data are available at: http://www.pca.state.mn.us/index.php?option=com_k2&view=item&id=2229.

Basic water quality data and stream flow information from USGS stream gauges, including collection of continuous temperature data from the Rainy River at Manitou Rapids, are retrievable from the USGS National Water Information System data base (NWISWeb): http://mn.water.usgs.gov/index.html.

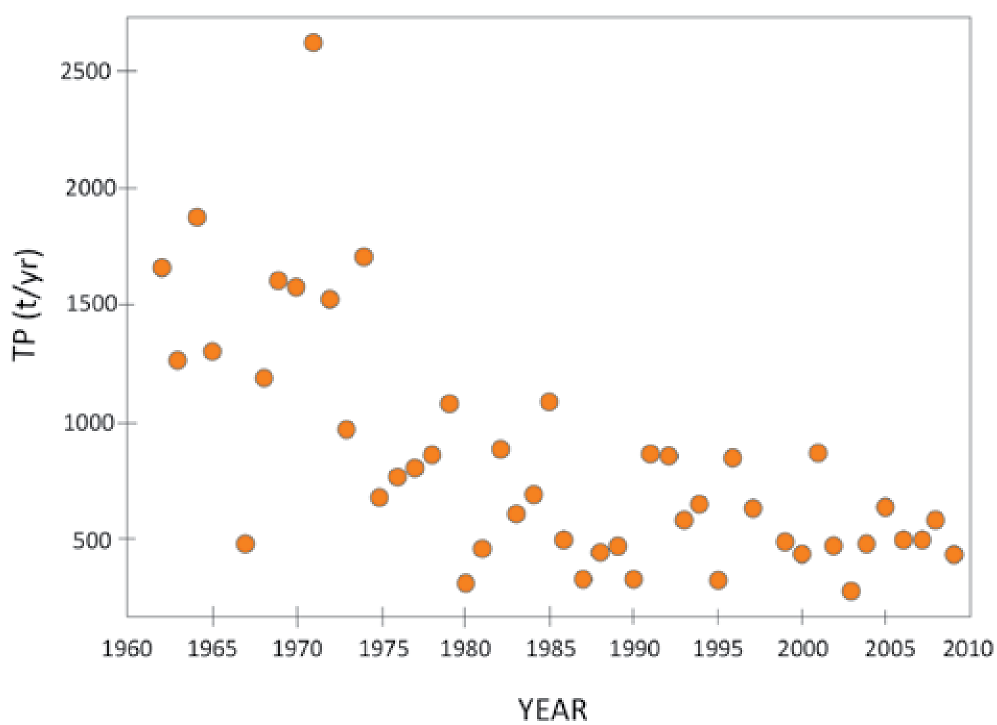

FIGURE 31 – Rainy River total phosphorus loads from Hargan *et al.* (2011).

Fibre mats in the Rainy River downstream of the mills, 1952.

Monthly comparisons of data from two different sites along the Rainy River demonstrate that TP and chl a concentrations in 2005 were significantly higher at the Rainy River at Baudette monitoring site compared to Rainy River at International Falls. Merriman *et al.* (1992) also noted that nutrient concentrations were significantly higher at the outlet of the Rainy River compared to an upstream site at the outlet of Rainy Lake. This is not unexpected but there was a need to calculate Rainy River loads to LoW at the mouth of the river considering that nutrients accumulate downstream. In 2010 the MPCA and USGS installed a flow and stage gauge at Wheelers Point at the mouth of the river to conduct a loading study which is now in the third year. These data are available on the MPCA website: http://www.pca.state.mn.us/index.php?option=com_k2&view=item&id=2229.

The accumulation of nutrients in a downstream direction in the Rainy River is due to the point and non-point sources of nutrients within the basin downstream of International Falls. These include municipal waste water treatment plant effluent, industrial effluent, atmospheric deposition, non-agricultural runoff, and stream bank erosion. Additional potential sources of nutrients to the Rainy River include recreational facilities such as campgrounds, residential and cottage septic systems, hospitality facilities, and cosmetic and industrial fertilizers. Point sources are further discussed in Chapter 3, Part 3.

It is important to note that the proportional contribution of point sources to total loads varies with flow. In 2004, MPCA estimated that of the approximately 400,000 kg/yr (881,849 lb/y) in TP load received by the Rainy River Basin from the U.S. side, 15% was from point sources during low flow, 10% at average flow and 6% at high flow. Values for bioavailable P (BP) were similar with 27% from point sources at low flow, 19% at average flow and 11% at high flow. Atmospheric deposition and non-agricultural rural runoff account for the majority of the P loads to the Rainy River Basin under high, low, and average flow conditions. Stream bank erosion contributed moderate portions of TP and BP loads under all flow conditions. Commercial and industrial processes contributed significantly to both TP and BP loads under low flow conditions and to BP under average flow conditions. Natural, non-point sources of P contributed a higher percentage of loads and were more bioavailable than point sources in the Rainy River Basin (MPCA, 2004). Similar observations have been made for the Little Fork River (2004-06 data) and Zippel Creek (2004 data) (N. Baratono, MPCA, International Falls, MN, 2007, pers. comm.).

In 2009 Environment Canada began monitoring water quality at four locations on the Rainy River (see Figure 7) to estimate nutrient loads. Samples were collected with cooperation of the Rainy River First Nations from transects in the River on a bi-weekly basis. Sampling at sites 920, 930 and 940 occurred between May and October and year round at site 910 at the mouth of the Rainy River. In 2010 mean TP concentrations ranged from 23 µg/L at station 940 to 27.4 µg/L at the mouth of the River (station 910). These concentrations are below the Rainy River Alert Level and the Ontario Provincial Water Quality Objective (PWQO) of 30 µg/L.

More information with respect to loads is provided in the *Nutrient Flux and Budgets* section.

Tributary Loads
The MPCA's Major Watershed Load Monitoring Program (MWLMP) measures and compares regional differences and long-term trends in water quality from Minnesota's major rivers and the outlets of major tributaries. Data will be used:

- in *Total Maximum Daily Load* (TMDL) studies and implementation plans
- to assist basin modeling efforts
- to provide information for research projects.

Beginning in 2007, the MWLMP's multi-agency monitoring approach combined site specific stream flow data from United States Geological Survey (USGS) and Minnesota Department of Natural Resources (MDNR) flow gauging stations with water quality data collected by the Minnesota Pollution Control Agency, and local monitoring organizations to compute annual nutrient and sediment pollutant loads. MWLMP sites in the Rainy River Basin are located on the Headwaters, Vermilion, Little Fork, Big Fork, Rainy and Rapid Rivers. Loading data are currently not available on line, but data will be provided on request.

Ontario Ministry of the Environment has assessed tributary loads from Ontario streams including several that flow into the Rainy River (see Table 23; Figure 7).

Annual mean tributary TP loads are shown for OMOE monitored tributaries in Table 23.

Shoreline Erosion

The southern shoreline of LoW is experiencing significant erosion problems (Johnson and Trask 2013). This erosion threatens habitat that provides refuge for a number of federally threatened and endangered species. The eroding sediments are, in addition, a source of nutrients to the lake. In their study, Johnson and Trask identified areas of major shoreline erosion from 1940 to 2009 and from 2003 to 2009 and estimated the annual rates and overall volumes eroded. They examined eight sets of aerial photos, taken between 1940 and 2009 which showed that some areas have receded by nearly a mile over the past seventy-years, while others (particularly near Rocky Point and Bostic Bay) have seen significant deposition. Final results of the study showed an estimated average erosion rate from the southern shoreline (between Warroad and the Rainy River) of 4.6 million ft^3/yr (130,257 m^3/yr). The estimated total deposition was 400,000 ft^3/yr (11,327 m^3/yr).

Sediment cores were taken to characterize nutrient contents within the shoreline soils. Results of that analysis were combined with the erosion estimates to compute average annual nutrient loadings (to the lake) from shoreline erosion. Final results show an estimated average TP loading of 82 tons/yr but it is unclear what the net load to the water column would be.

Phase 1 of a study of erosion of the Minnesota shoreline of Lake of the Woods

TABLE 23 – Total phosphorus annual average loads from OMOE monitored tributaries. Loads are in metric tonnes.

Tributary	Latitude *Deg min sec*	Longitude *Deg min sec*	Flows To	Annual Mean TP Load (t/yr)	Source
La Vallee River	48 32 05	93 38 26	Rainy River	5.4	OMOE/Hargan *et al. (2011)*
Sturgeon River	49 39 20	94 01 20	Rainy River	3.3	OMOE/Hargan *et al. (2011)*
Pinewood River	48 47 54	94 11 05	Rainy River	7.5	OMOE/Hargan *et al. (2011)*
Little Grassy River at Hwy 600	48 56 41	94 22 06	LoW -south	3.0	Hargan *(2010)*
Log River at Nestor Falls	49 07 03	93 55 34	Sabaskong Bay	2.4	Hargan *(2010)*
Atikwa River	49 24 13	93 57 07	Whitefish Bay	7.2	Hargan *(2010)*
Berry Creek	49 26 41	93 58 31	Whitefish Bay	2.6	Hargan *(2010)*
Rushing River at Blindfold L. outlet	49 39 53	94 17 39	LoW – NE	1.4	Hargan *(2010)*
Deception Creek	49 42 50	94 48 52	LoW - NW	0.32	Hargan *(2010)*
Rapid River	48 41 27	94 25 59	Rainy River	14.1	Hargan *(2010)*
Little Fork River	48 31 17	93 35 12	Rainy River	64.5	Hargan *(2010)*
Big Fork River	48 30 45	93 42 42	Rainy River	33.3	Hargan *(2010)*
Winter Road River	48 45 17	94 39 41	Rainy River	1.8	Hargan *(2010)*

was completed in 2005 (Herb *et al.* 2005). The overall objectives were to determine the causes and to estimate the magnitude of the shoreline recession rates in the US shorelines of Lake of the Woods, and to recommend management practices for shoreline protection against erosion. Historical data were collected on wind and water levels on Lake of the Woods, flow and suspended sediment input from the Rainy River, and information on the shoreline (aerial photos, satellite images, and soil surveys). Analyses of aerial photos from 1940 to 2003 showed rapid erosion of several undeveloped wetland areas of the shoreline and relatively slow erosion of developed areas along Sandy Shores and Birch Beach. Analysis of Pine and Sable Islands show a combination of erosion, rebuilding, and shifting between 1940 and 2003. A synthetic wind record was constructed from regional wind records. Analysis of wind and water level data from the 1950s to 2005 showed a relatively uniform distribution of high wind and high water events. Observed high water events appear as typical events that take place several times per decade. Wind and wave data were also collected at two locations on the southern side of Big Traverse Bay, with record lengths of 4-5 weeks. The on-lake wind data and wave data were collected to develop wave models in a planned Phase 2 of the project; however Phase 2 was never funded.

Sediment subsampling by Environment Canada (Environment Canada).

Herb *et al.* (2005) noted that the suspended sediment data collected for the Rainy and Little Fork rivers show a decreasing trend in suspended sediment concentration over the last 40 years, with relatively constant flow volume. This may indicate a reduction in the sediment supply (and TP loading) to LoW.

A shoreline change model was proposed (Herb *et al.* 2005) to identify the relative importance of controllable and uncontrollable processes in shoreline erosion rates. Based on the results of the historical erosion and model studies, suggested erosion control strategies were planned, including alternative lake level control strategies and shoreline protection strategies.

Ribikawskis *et al.*, presented *Estimating Sediment and Nutrient Loading from Southern Shoreline Erosion in Lake of the Woods* at the 2012 International Lake of the Woods Water Quality Forum. Analyses showed that shoreline areas with bank heights of less than five feet and within mucky soils have a relationship with high erosion. Furthermore, portions of the shoreline were dynamic with recession and deposition occurring between the years 1940 and 2009. Future project goals include: estimating the volume of sediment that has eroded into LoW from the southern shoreline; computing annual erosion rates; conducting nutrient sampling and analysis of near-shore soils to estimate nutrient loads due to erosion; and updating nutrient and sediment budgets for the U.S. portion of LoW.

Internal Loading

Limnologists recognize that shallow and eutrophic lakes with anoxic sediments will be subject to the resuspension of phosphorus from bottom sediments into the water column especially in late summer, a condition that is often concurrent with algal blooms. The extent and consequences of internal loading in LoW has been examined more carefully in recent years within the context of *Nutrient Flux and Budgets* (next Section). The problem with internal loading is that it is difficult to measure directly. It is necessary to retrieve lake sediment cores to measure responses under oxic and anoxic conditions, or infer the net results of an internal load by a mass balance. Neither of these methods are easy to perform nor do they guarantee a firm answer with respect to the internal load, especially in lakes as large as LoW.

Another confounding factor is that Big Traverse Bay, which has the potential to

> The role of internal loads on algal blooms is still unclear at seasonal and shorter time scales, as are mediating factors such a climate.

contribute huge internal loads to the lake, is most often mixed and well oxygenated to the bottom. If it were anoxic, an internal load would be assumed. However, because it is mixed it would normally be considered less likely to contribute internal loads but mixing does not disallow an internal load because conditions at the sediment-water interface can still be such that an internal load can occur. Redox sensitive mobilization is possible from the anoxic zone from a few millimeters below the sediment surface (up to 20cm) in shallow lakes (Søndergaard *et al.* 2003). Søndergaard *et al.* noted that any recovery following a phosphorus loading reduction would depend on past accumulation of phosphorus in the sediment and that, in some lakes, negative phosphorus retention can continue for decades. This may not be the case in Big Traverse where there is demonstrated potential in the sediments for P accumulation. James (2012) collected cores from Big Traverse to answer these questions under laboratory conditions and determined that internal loads to the lake from sediments would be minimal under most conditions encountered in the lake, i.e. surface water mixed to the bottom and plenty of iron binding potential remaining in the sediments.

Metal species play an important role in the cycling of P between the sediment and water column at the sediment water interface and can determine the rate of P loading from the sediment (Pascoe *et al.* 2014). James (2012) found that the sediment Fe:P ratio in Big Traverse sediments exceeded 25 making it likely that P fluxes from the sediments are coupled with iron cycling. In Environment Canada sediment collections (Pascoe *et al.* 2014), the average Fe:P ratio was 22. Under oxygenated conditions some soluble phosphorus will become bound to insoluble iron (Fe) oxides, and precipitate out of the water column to be sequestered to the sediments. This process is reversed when conditions are anoxic at the sediment surface (dissolved oxygen is < 2 mg/L at the sediment water interface). Under these conditions, soluble P is released from the sediments when ferric oxides are reduced to soluble ferrous iron (Kramer *et al.* 1972). In the southern basin of LoW and during the spring and fall circulation period, oxygen concentrations in the sediment surface microzone are likely high enough to prevent this migration.

Increasing P concentrations throughout the open water season, however, indicate that some P may be released from the sediments during the summer and would be available to phytoplankton species during thermal mixing in the fall as is seen in nearby lakes at ELA (Nürnberg 1996). The role of internal loads on algal blooms is still unclear at seasonal and shorter time scales, as are mediating factors such as climate. Work to further describe these processes in more detail is ongoing.

Shoreline Property Loads

The contribution of phosphorus to nearby water bodies from shoreline developments such as permanent homes or vacation properties that are within specified distances of the shoreline have been quantified in many studies and used in lake capacity models for many years (Paterson *et al.* 2006). It is recognized that LoW supports a large number of shoreline properties and an early concern was whether or not these properties were responsible in part for the timing or severity of algal blooms in the lake. An information gap identified by the 2009 SOBR was to further understand the relative impact of phosphorus from these sources. Work by Hargan and others have described the relative inputs from shoreline property sources as being 3% from a whole-lake budget standpoint with the caution that enclosed embayments will be more susceptible to local and diffuse sources of phosphorus (Hargan, 2010; Hargan *et al.* 2011). This caution with respect to enclosed embayments has been underscored by paleolimnological studies conducted in enclosed areas by Summers *et al.* (2012) where shoreline development plays a role as a multiple stressor in Poplar Bay (in the north end of LoW). Modeling indicates that a shift from seasonal to permanent use for the existing properties would increase the P concentrations in the Bay by 12.6 µg/L (Summers *et al.* 2012).

Precipitation

Based on precipitation collector data

measured between 2009 and 2011, Environment Canada estimates TP from wet deposition (to LoW) to be 31 tonnes/yr (Pascoe *et al.* 2014) which is considerably lower than the estimate of total atmospheric phosphorus using deposition estimates from the Experimental Lakes Area (ELA) of 95-129 tonnes/yr (Hargan *et al.* 2011). The phosphorus budget developed by St. Cloud State University estimated a deposition rate of 76 tonnes/yr (Hadash 2010). Differences between these estimates is likely due to the fact that estimates by ELA and St. Cloud are based on total atmospheric deposition while the EC samplers collected wet deposition only. Dry deposition of phosphorus, including that from pollen, may be of similar magnitude to wet deposition. Atmospheric deposition of TP estimated for Southern Ontario lakes is 16.7 – 21.7 mg/m^2/yr (Paterson *et al.* 2006).

More work is required to establish R-LoW basin specific phosphorus loads from precipitation.

Nutrient Flux and Budgets

Since 2009 there have been attempts to refine nutrient loading information to produce nutrient budgets that can:

1. Identify relative total phosphorus (TP) inputs from all sources including internal loads.
2. Examine the effect of nutrient flux within the lake on algal blooms.
3. Determine acceptable loads to the lake.

To develop a phosphorus (P) budget for the lake, it is necessary to quantify the major sources and losses to and from the lake. The amount of P coming in should equal the amount of P that is lost either to the outflow of the lake or to the lake sediments (both considered losses). When the numbers match then the phosphorus budget is considered to be balanced. This is more complex than it seems since there are many sources that are difficult to measure such as the quantity of P that:

- falls onto the surface of the lake via precipitation
- enters the lake through streams and from wetlands
- enters from the basin naturally as overland runoff
- originates from diffuse sources such as from farming or from shoreline septic systems.

Previous discussions with respect to trophic status and algal nutrients emphasize the importance of understanding the relationship between nutrient loading and the temporal flux of nutrients at various locations within LoW. Point source nutrient loads, especially in the Rainy River, have declined but there remains the sense that recent blooms are more intense and more frequent than in the past. The 2009 SOBR identified the need for more comprehensive nutrient budgets and nutrient flux models together with an understanding of the role that nutrients play in algal productivity. These would be required before any potential mitigation measures could be developed.

Since 2009, the listing of the U.S. portion of LoW as an impaired water has required the development of TMDLs which represent the acceptable TP loads to the lake that will maintain water quality within established criteria. In an attempt to meet these goals there have been many recent advances in the understanding of nutrients and nutrient flux within the basin including refined estimates of relative sources of P to the Rainy River and LoW, improved estimates of sediment and internal nutrient loading, improved estimates of tributary loads, and advanced modeling efforts to describe the seasonal flux of nutrients and their impact on algal biomass within LoW. Identifying the components of a P budget together with elements of P flux within the lake will allow managers to assess the relative importance of the individual loads to the lake and provide some guidance as to where the loads could be reduced if necessary. These imperatives have initiated several research and management initiatives within the basin in recent years including:

- Hargan and Hadash phosphorus budget studies
- load and lake mass-balance modeling for TMDL
- gathering data to populate FLUX and BATHTUB models (MPCA)

- Minnesota's Load Based Watershed Monitoring
- Environment Canada tributary load monitoring
- Zhang *et al.* (2013) linked, hydrodynamic trophic status model.

Hargan and Hadash Phosphorus Budget Studies

Kathryn Hargan, as part of her Master of Science Degree at Trent University, assembled the first detailed nutrient budget for Lake of the Woods (Hargan 2010; Hargan *et al.* 2011). The budget was based upon measured flow volumes together with measured P concentrations to calculate loads from the inflows (Figure 32). This budget confirms that the Rainy River is the largest source of P but also shows that more than half of the P that comes into the lake, i.e. 762 metric tonnes (t), stays in the lake and does not exit at the outflow to the Winnipeg River. This P is lost to the sediments through the settling of particles such as algae and bacteria. The budget also illustrated that the contribution of P from shoreline properties is relatively small at a whole lake scale. However, in more enclosed or isolated bays the same contribution from shoreline properties may represent a relatively larger portion of the P budget. Observing the relative contributions of P from different sources allows managers to evaluate the potential that exists to manage P from various sources.

The budget also illustrated that the contribution of P from shoreline properties is relatively small at a whole lake scale.

The nutrient load calculations that were used to construct this budget revealed that although the Rainy River contributes approximately 74% of the P load to LoW, the P loads from the Rainy River have actually declined significantly since the 1960s and 1970s from ~1,500 t/yr to ~500 t/yr due to increased regulation of wastewater treatment plants and pulp mills over the past several decades. This reduction cannot be due to decreased volumes of water since inflow volumes show no trend (Hargan *et al.* 2011). This is a significant observation indicating that algal blooms may be increasing in severity and duration at the same time that P loads are decreasing. Hargan's budget does not include elements of an internal load.

Another way to help visualize or predict nutrient movements in a lake is by using nutrient models. In the case of LoW it would be useful to know the fate of the P that enters the lake from the Rainy River. Joseph Hadash, as part of his Master of Science Degree at St. Cloud State University, used two such models (FLUX and BATHTUB) to examine the fate of P in Big Traverse Bay. He found that the models' predicted P loads

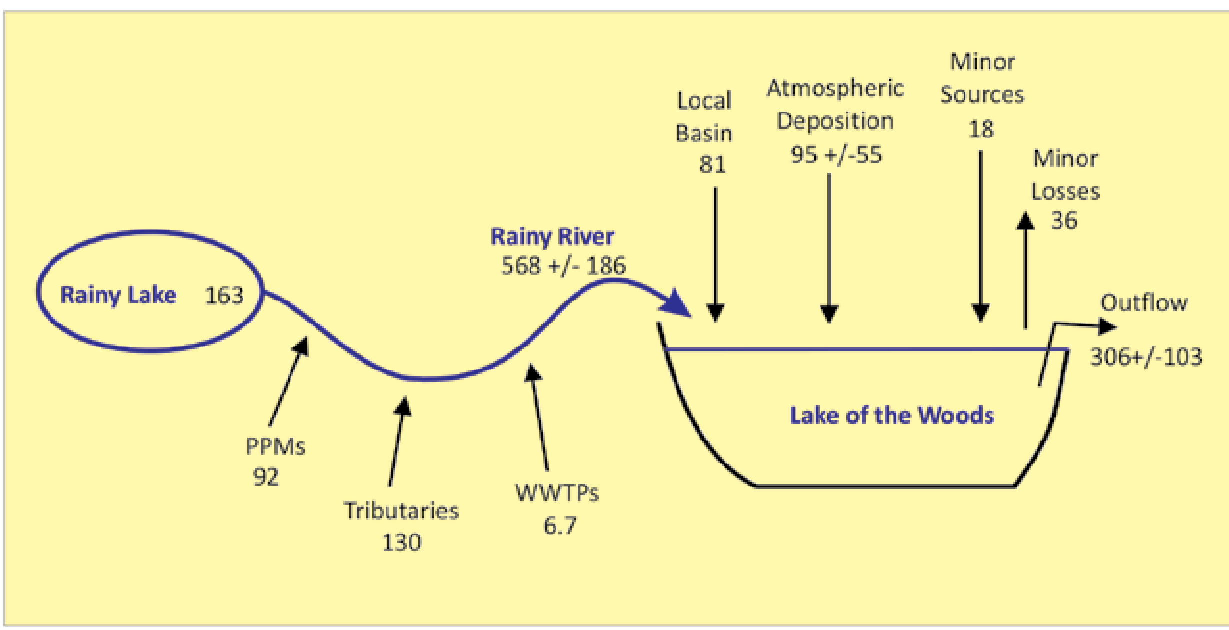

FIGURE 32 – Schematic of summarized annual total phosphorus fluxes to the Rainy River and Lake of the Woods in metric tonnes from Hargan *et al.* 2011. (PPM = pulp and paper mill, WWTP= waste-water treatment plants)

to Big Traverse Bay that were similar to those measured by Hargan. In addition, the BATHTUB model (which combines mass-balances with empirical relations to diagnose and predict trophic responses) estimated an internal load from the sediments and the amount of P that leaves Big Traverse Bay to the north. This indicates that the nutrients available for algal production in Big Traverse also include a rather large internal load from the sediments. Hadash's modeling results showed that if the predicted internal load of 568 t were added to the P budget there would be a total of 1,113 t of P available for algal production in the U.S. portion of the lake. The model also predicted that only 484 t of this 1,113 t would leave the U.S. portion to the north with 629 t remaining in the south portion of the lake. The 484 t that move to the north are further diminished to 306 t at the outflow (Hargan's number) which means that 178 t of the original 484 t that came to the north are lost to the sediments in the northern portions of the lake.

Many internal processes that are linked to hydrology, internal loads, particle settling and wind related currents will have a seasonal impact on in-lake processes including algal blooms.

The budget produced by Hargan *et al.* (2011) and the modeling results shown by Hadash are comparable (within the bounds of error in the estimates) without consideration of the large internal load.

MPCA's Updated Total Phosphorus Budget for Lake of the Woods

In the past several years a significant amount of water quality monitoring, modeling, and research has taken place on LoW which has allowed the MPCA to develop more refined models and predictions of water quality for the southern, eastern, and central basins of LoW using 2010 conditions as a baseline (Anderson *et al.* 2013). Lake of the Woods was divided into 5 segments based on observed differences in water quality and bathymetry—Fourmile Bay, Big Traverse and Buffalo bays, Muskeg Bay, Sabaskong Bay and Northeast Big Traverse and Little Traverse Bay/Northwest Angle. Revised bathymetry data from Environment Canada, measurements of internal phosphorus loading (laboratory aerobic release rates), and revised phosphorus loads from the Rainy River (based on recent event-based sampling) were incorporated into the model. The TP budget was estimated at 1,147 t/y, partitioned into 6 categories (Figure 33):

- tributary inflow (principally the Rainy River) 42%
- internal load 36%
- precipitation 13%
- shoreline erosion 6%
- non-point inflow 2%
- point sources 1%.

BATHTUB estimates that 55% of the phosphorus is retained within the lake. The model's predicted area-weighted mean concentrations of TP, chl a, and Secchi depth were similar to observed values. When excluding internal loading estimates (not modeled previously), results were similar to previous investigations. The model's output will help guide restoration options for the eutrophication impairment and provide a baseline for the TMDL study on the U.S. portion of LoW.

Conclusions from the BATHTUB modeling exercise indicate that we are collectively making progress on the significant data gaps that must be filled to form an accurate TP budget. Present work compares favourably to previous studies with the Rainy River and internal loads remaining as significant sources of P to LoW. Next steps are to assess climate impacts on algal bloom severity, to assess the role of soluble reactive P in algal bloom formation and to complete the TMDL with a start date of January, 2015.

It is important to note that the budgets discussed above are measured as annual totals. Many internal processes that are linked to hydrology, internal loads, particle settling and wind related currents will have a seasonal impact on in-lake processes including algal blooms. One major consideration is the fact that internal loads are usually at their maximum in the late summer when blue green algal blooms are developing in the lake. These processes can be examined through the use of dynamic flux models.

Linked Hydrodynamic Trophic State Model

In 2013, Zhang *et al.* published the results of using a linked hydrodynamic, water quality and algal biomass model on LoW. The model results predicted spatial and seasonal differences in total phosphorus

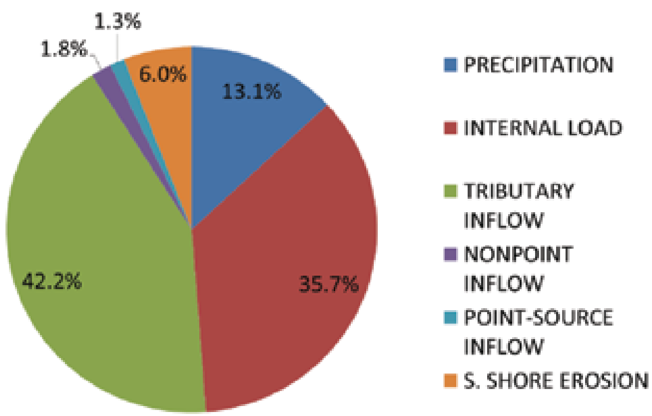

FIGURE 33 – Relative sources of phosphorus to Lake of the Woods (MPCA).

and algal and cyanobacterial standing stock. This modeling exercise recognized the importance of variations in water quality between different sectors in LoW and the influences of seasonal changes within given sectors. Sectors used were either the same as sectors sampled by OMNR or in some cases combinations of those sectors (Table 12). The model results were compared to observed temporal and spatial distribution of TP and chl a. The central and south segments behaved like shallow lakes with strong variability in TP and phytoplankton biomass, whereas two relatively isolated and deeper sectors in the north were characterized by less variability in TP and lower phytoplankton biomass. Algal biomass and cyanobacterial dominance were best predicted in the more eutrophic southern sectors.

The model allows the estimation of seasonal averaged TP fluxes which will benefit researchers who are interested in nutrient phytoplankton relationships. Growing season mean TP fluxes (kg/day) between sectors in 2009 is shown diagrammatically in Figure 34.

Goodness of fit between modeled and observed TP differed among lake segments and years with the side segments showing a greater divergence between predicted and observed values (r=0.3 to 0.33) than for the central segments (r=0.32-0.56). Relative errors suggest the percentage discrepancies between predicted and observed TP were around 30%. This may not be surprising since OMOE Lake Partner Program data, which is comprised of extremely precise low-level TP data were discarded if there was a greater than 5% difference between duplicates. This would have severely limited the use of a robust dataset.

One of the important evaluations of these types of models is the degree to which they can duplicate consistent patterns in empirical datasets as illustrated for the north end of LoW in Figure 35. DeSellas *et al.* (2009) noticed similar patterns at many stations in the north portion of the lake. Model output comparison to these empirically measured patterns should be a next step in model output evaluation.

The results of this modeling exercise reinforce the need to apply a multi segmental model to LoW which cannot be effectively modeled using a single box approach due to spatial differences in hydrodynamics and topography.

Historical Nutrient Loading

A partnership of researchers at the Minnesota Pollution Control Agency, Ontario Ministry of Environment, Minnesota St. Croix River Watershed Research Station and the University of Minnesota at Duluth are undertaking a study of historical nutrient loading from the Rainy River and its effects on current water quality

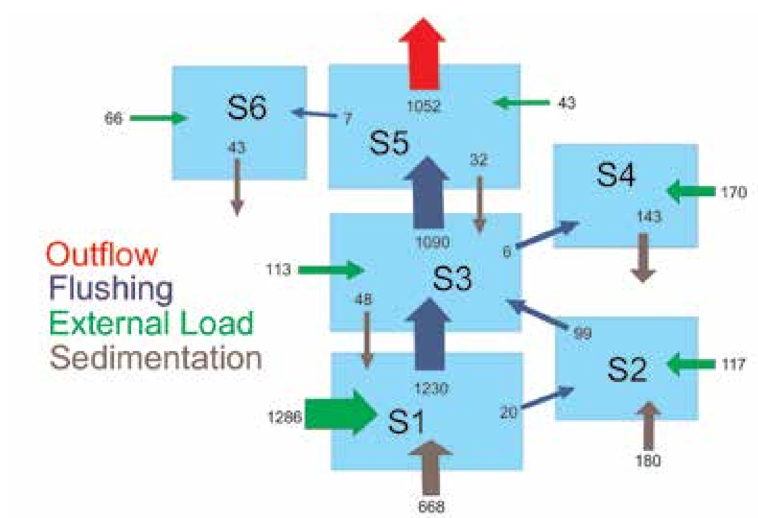

FIGURE 34 – Growing season mean TP fluxes (kg/day) between sectors in 2009 estimated using a linked hydrodynamic, water quality and algal biomass model (Zhang *et al.* 2013)

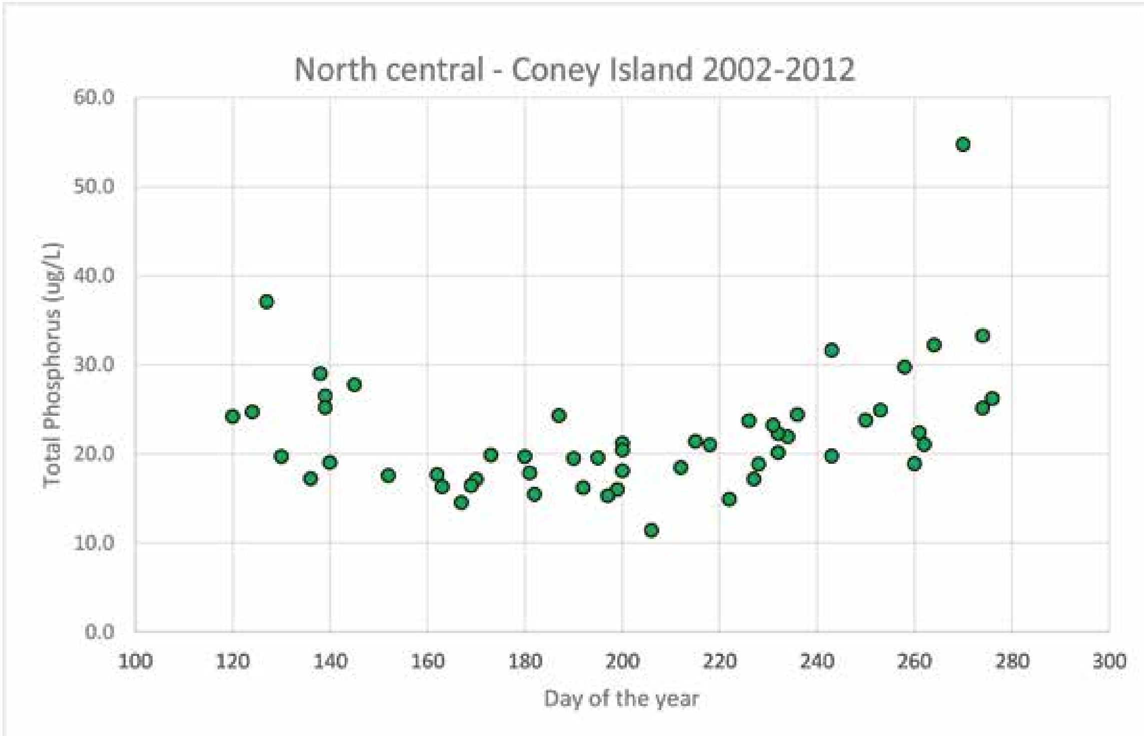

FIGURE 35 – TP seasonal patterns observed for a north central station near Coney Island in Lake of the Woods between 2002 and 2012 (OMOE Lake Partner Program data).

of LoW. This research will determine the effect of decades of uncontrolled pollution from the Rainy River that has built up in the sediments of the Big Traverse basin of Lake of the Woods and explore potential remedial measures. The LOWWSF contributed funds in 2012 to initiate the project and Minnesota has committed $300k to complete the phase 1 (historical nutrient loading) and phase 2 (historical thermal modeling) portions of this project. Edlund *et al.* have presented ongoing efforts to construct this historical phosphorus budget for Lake of the Woods at International Lake of the Woods Water Quality/Watershed Forums in 2012, 2013, and 2014. This project is examined in more detail in Chapter 2–*Historical Conditions*.

Proportion of Loads from Various Sources
Estimates of P loads from various sources have been more precisely estimated in recent years. Phosphorus budgets and Flux modeling described below in Part 4 have derived P loads that are in relatively close agreement (Table 24).

Due to the number of remaining questions that are associated with nutrient loads from inflows and from the sediments, nutrients and internal loading are listed in Chapter 3 as a basin concern.

Contaminants
Water quality monitoring, with respect to contaminants, has been limited to those areas where there is increased concern due to effluent discharges. These locations are usually monitored in association with approved limits associated with the discharges. There are other sections in this report where contaminants are measured in fish or in sediments. Contaminants are being considered as a primary focus area by the IJC, Lake of the Woods Basin Water Quality Plan of Study working group and they are listed in this report as a basin concern in Chapter 3. More detailed information about contaminants in the basin and their sources are given in Chapter 3, Part 3.

TABLE 24 – Comparison of nutrient load estimates from different sources. Due to differences in methods used to derive loads the values shown may not be exactly comparable in some cases. Hargan's total load does not include an internal load.

TP *(tonnes)*	Hargan *et al.* *Whole Lake*	Hadash *Bathtub* *Whole lake*	MPCA *South, Eastern & Central Basins*	Zhang *et al.* *2009 Sector 1*
Internal Load (IL)		568	410	226
Precipitation	95	75	150	469
Tributary Load	469	453	485	
Non-Point Source Inflow	99		20.7	
Point-Source Inflow	98.7		15	
South Shore Erosion			69	
P retained in Lake	60%	57%	55%	63%
Total Load	762	1113	1150	725

PART 3: SEDIMENT CHARACTERISTICS

Sediment History

Hougardy *et al.* (2013) used seismic-reflection data collected from LoW to reveal a detailed sequence of stratigraphy penetrating to depths of as much as 25 m (82 ft) below the present day lake floor. They indicate that stratigraphic changes are likely due to large changes in the water storage dating back as far as the Last Glacial Maximum. They noted that an abrupt change from a thick package of sub-parallel horizons to a relatively thin package of massive sediment occurs at approximately 3-5 m (11.5 ft) depth. This shift is thought to indicate the transition from Lake Agassiz (Figure 8) to LoW derived sediments. Until recently, there have been few studies conducted to characterize the chemistry of the surface sediments in the LoW basin.

Lake Sediments

Lake sediments are composed of inorganic material from the weathering of the basin and of organic matter from biotic production in overlying water and in the sediments themselves. They can function as a sink for both nutrients and contaminants and can, in some cases, contribute these materials back into the water column through physical and chemical resuspension processes. Sediments also provide habitat for important biotic communities.

Environment Canada (EC) conducted surveys in September of 2008-2010 to characterize the physical and chemical characteristics of sediments in LoW (Pascoe *et al.* 2014). They sampled surficial sediments near the centre of each basin at 31 stations throughout LoW (Table 25). Samples were analyzed for physical characteristics, chemistry and benthic invertebrates with a sub-set of 5 stations analyzed for poly-aromatic hydrocarbons (PAHs) and polychlorinated biphenols (PCBs).

The main goal of EC sediment sampling on LoW was the characterization of the benthic macro invertebrate community. Areas with suitable substrates such as mud and silt were targeted since grain size and substrate type are important determinants of the benthic macro-invertebrate community. The results are therefore unable to provide general conclusions about the range of substrate types that are prevalent in LoW.

Silt accounted for 28 to 99% of the sediment particles in samples due to the pre-selection for muddy substrates. Locations with a high percentage of fine particles such as silt likely represent areas of sediment accumulation where water velocity slows and fine suspended sediment particles are deposited to the sediments below. Loss on ignition (LOI) is an indirect measurement of the organic matter in the sediment and ranged from 3.9 % at station 311 in Whitefish Bay to 29% at station 770 in Big Traverse. Another measure of organic matter, total organic carbon (TOC) by weight ranged from 0.8% in station 311 to 8.3% at station 180 (Poplar

TABLE 25 – Environment Canada benthic sampling stations on Lake of the Woods including location, depth and distance to the nearest shoreline.

Station	Name	Latitude	Longitude	Depth (m)	Distance To Shore (m)
111	Town Island	49.7109	-94.4791	12	83
112	Rat Portage Bay- at Treaty Island	49.7312	-94.5115	8	128
120	Bigstone Bay	49.6434	-94.3239	32	243
121	Pipestone Point	49.6337	-94.4170	9	215
142	Safety Bay	49.7501	-94.5670	5.5	172
143	Rheault Bay	49.7378	-94.5682	6	95
150	Ptarmigan Bay	49.6373	-94.7346	13	624
170	Echo Bay	49.6511	-94.8672	13.5	399
180	Poplar Bay	49.6938	-94.5413	27.5	248
181	South Poplar Bay	49.6806	-94.5532	12	149
190	Bird Islands	49.6523	-94.5022	15	1283
191	Wildcat Island	49.6908	-94.4955	9.7	85
210	East Allie Island	49.5857	-94.4545	20	302
213	Bath Island	49.5309	-94.4269	14.2	450
220	Donald Duck Island	49.5295	-94.5633	23.5	271
221	Skeet Island	49.4627	-94.6091	10	458
230	Yellow Girl Bay	49.5033	-94.2750	23.5	552
310	Whitefish Bay	49.3458	-94.1024	30	439
311	Whitefish- south entrance	49.3993	-94.1995	10	228
410	Hay Island	49.1559	-94.1101	8	702
411	Maggie Island	49.1211	-94.2106	6	738
510	South-East Bigsby Island	49.0214	-94.4677	6	2076
530	SplitRock Island	49.2316	-94.4874	10	294
540	Basil Islands	49.1566	-94.4304	6.8	1223
610	Mica Point	49.3248	-94.7695	25.5	300
611	Lambert Island	49.3620	-94.9230	5	467
620	Monkey Rocks	49.4113	-94.8173	10.5	144
710	Rainy River Outlet	48.9218	-94.7282	10	7503
740	Muskeg Bay	48.9537	-95.1885	8.3	7664
770	North Big Traverse	49.1302	-94.9342	10.5	6885
780	Mid-Big Traverse	49.2881	-94.8588	7.5	8697

Bay) and 9% at station 143, which had a large amount of woody material embedded in sediments. Provincial lowest effect levels (LEL) for the protection of aquatic sediments is 1% TOC and severe effect levels (SEL) are 10% TOC (Persaud *et al.* 1993). Total organic carbon concentrations therefore exceeded LEL at all sediment sites but did not exceed SELs. High TOC content in LoW sediments may be reflective of deposition from pulp and papers mills which historically released large quantities of untreated pulp effluent into the Rainy River.

Sediments from five stations were analyzed for PCBs and PAHs and all were below the detection limit for these compounds. This supports work by Donaldson et al (1999) who found low concentrations of PCB in bald eagle populations near LoW.

Concentrations of metals in sediments (Table 26) were above detection limits and in many cases exceeded the Provincial Sediment Quality Guidelines (Persaud *et al.* 1993). The majority of sites exceeded LELs for the protection of the benthic ecosystem for chromium, copper, manganese and nickel. Concentrations of lead and arsenic also exceed LELs for a moderate number of sites. Mercury did not exceed provincial guidelines with fairly uniform concentrations throughout the lake but fish consumption advisories for mercury are in effect for fish in the basin (see Part 3). The main source of mercury for the Rainy Lake sub-basin (and likely elsewhere in the basin) is through atmospheric deposition (Swain *et al.* 1992). Estimates of mercury loadings for Minnesota lakes and streams suggest that 99% of mercury is from atmospheric deposition at a rate of 12.5g/km^2, while waste water accounts for approximately one percent (MPCA 2001, 2007). Slightly higher values near the mouth of the Rainy River at station 710 and 780 may reflect sewage and pulp and paper waste water inputs.

Concentrations of arsenic were spatially heterogeneous, with the majority of sites falling below provincial LELs. A small number of sites exceeded federal sediment quality guideline probable effect levels of 17 mg/kg (CCME), and approached provincial severe effect levels. At these concentrations, arsenic is expected to have a negative impact on the benthic biotic community (Pascoe *et al.* 2014). Concentrations of arsenic, TKN and phosphorus in sediments at LoW stations in relation to Provincial Lowest Effect Level, Federal Probable effect levels and Provincial Severe Effect Levels are shown in Figure 36.

Metals are often associated with organic material in sediments. In LoW, loss on ignition was positively correlated with concentrations of arsenic, barium, beryllium, chromium, copper, iron, lead, nickel, strontium, vanadium, yttrium and zinc. Sites in Whitefish Bay and Poplar Bay stood out has having higher than expected concentrations of arsenic based on the amount of organic matter present, based on the 95% prediction limits of the regression between loss on ignition and arsenic concentrations. Site 180 and 220 had higher than expected concentrations of barium in relation to organic matter.

The source of elevated concentrations of some metals in LoW sediments is unknown but likely partially due to weathering of rocks that are high in metal ores (elevated concentrations can occur in areas where rocks are naturally high in metal ores). Deposits of metal rich ores, particularly gold and sulphite ores, are present throughout the R-LoW basin. Elevated concentrations of metals in lake sediments can originate from anthropogenic sources such as industry, mining and smelting. While there is little industry on LoW, metals in the atmosphere may be transported long distances by air currents. Aerial deposition from industrial processes such as smelting and coal based power generation can disperse elements such as arsenic and mercury over large distances. As noted previously, this is thought to be the main source of mercury to the basin.

While all current mining operations in the Canadian portion of the basin are in the exploratory or development phase, there is an extensive mining history near LoW (see Chapter 1, Part 1, Land Use/ Mining). It is worth noting that the three sites (Whitefish Bay, Bigstone Bay and Poplar Bay) where sediment concentrations of arsenic and barium were higher than expected are adjacent to historic gold mines which are a potential source of arsenic from tailings. Several gold mines were located in the vicinity of Bigstone Bay including Keewatin, Herman, Bull Dog and the largest, the Winnipeg Consolidated, which is immediately adjacent to sampling station 120 in Bigstone Bay. Winnipeg Consolidated had a large gold mill on site and mine effluent was released directly into Bigstone Bay (Beard and Garratt 1984). Poplar Bay Island was the site of the Minerva gold mine and may be the basis of elevated concentrations of arsenic at station 180 and 181 in Poplar Bay (Davies and Smith 1988; Beard and Garratt 1984). These mines had onsite stamping mills, and in some cases mercury was used in extractions. Regina Bay (part of Whitefish Bay) was the location of several gold mines, the largest of which was the Regina mine (Davies and Smith 1988; Beard and Garratt 1984).

Not surprisingly, nutrient concentrations in the surficial sediments of LoW were also elevated in the EC samples. Concentrations of total Kjeldahl nitrogen (TKN) ranged from 550 to 10,287 µg/g exceeding Provincial Aquatic Sediment Quality Guideline LELs at almost all LoW stations. This TKN is largely composed of organic nitrogen which is sequestered from the atmosphere by algal blooms that fix nitrogen from the atmosphere and then settle to the sediments. Concentrations of TKN in the majority of LoW stations (Figure 36) exceeded Provincial Severe Effect Level (SEL) concentrations of 4,800 µg/g. Phosphorus concentrations in surficial sediments in LoW ranged from 652 to 6,420 µg/g. All stations exceeded Provincial LELs for phosphorus of 600 µg/g and three stations: 180 (Poplar Bay), 190 (Bird Island), and 310 (Whitefish Bay) exceeded Provincial SELs. Both Poplar Bay and Whitefish Bay are outside the main flow of water in LoW.

TABLE 26 – Environment Canada surficial sediment chemistry for benthic stations on LoW. Values in µg/g unless otherwise noted. Also shown are Ontario's sediment guidelines for aquatic ecosystems at the Low Effect Level (LEL) and the Severe Effect Level (SEL) in µg/g (mg/kg) dry weight and the CCME guidelines for aquatic life Probable Effect Levels (PEL) and the percentage of sites which exceed these guidelines.

Compound	MDL	Mean	Max	Ont LEL	% over	CWQG PEL	% over	Ont SEL	% over
Metals									
Aluminum	10	13,046	18,400						
Arsenic	1	6.92	30.0	6	32	17	10	33	0
Barium	1	146.2	309.0						
Chromium	1	40.6	54.0	26	93	90	0	110	0
Cobalt	1	15.45	24.0	50					
Copper	1	30.25	50.0	16	93	197	0	110	0
Iron	10	28,590	46,200						
% Fe2O3	1%	5.29	8.40	2	93			4	84
Lead	5	28.13	42.0	31	39	91.3	0	250	0
Mercury	.005	.085	.124	0.2	0	0.486	0	2.0	0
Manganese	1	1,491	6,600	460	84			1,100	52
Nickel	1	33.04	43.0	16	93			75	0
Strontium	1	23.41	32.0						
Titanium	1	317.1	413.0						
Vanadium	1	47.80	66.0						
Yttrium	0.5	11.3	15.6						
Zinc	1	96.03	133.0	120	19	315	0	820	0
Minerals									
Calcium	10	6,285.9	10,100						
Magnesium	10	6,512	9,130						
Potassium	30	2,426	3,740						
Sodium	20	340	890						
Nutrients									
% P	.03%	0.29	2.06						
LOI	.05%	19.0	28.9						
TOC %	0.1%	5.46	9.0	1	97			10	0
TKN	0.05	6,782	10,287	550	100			4,800	87
P- total	0.01	1,319	4,205	600	100			2,000	10

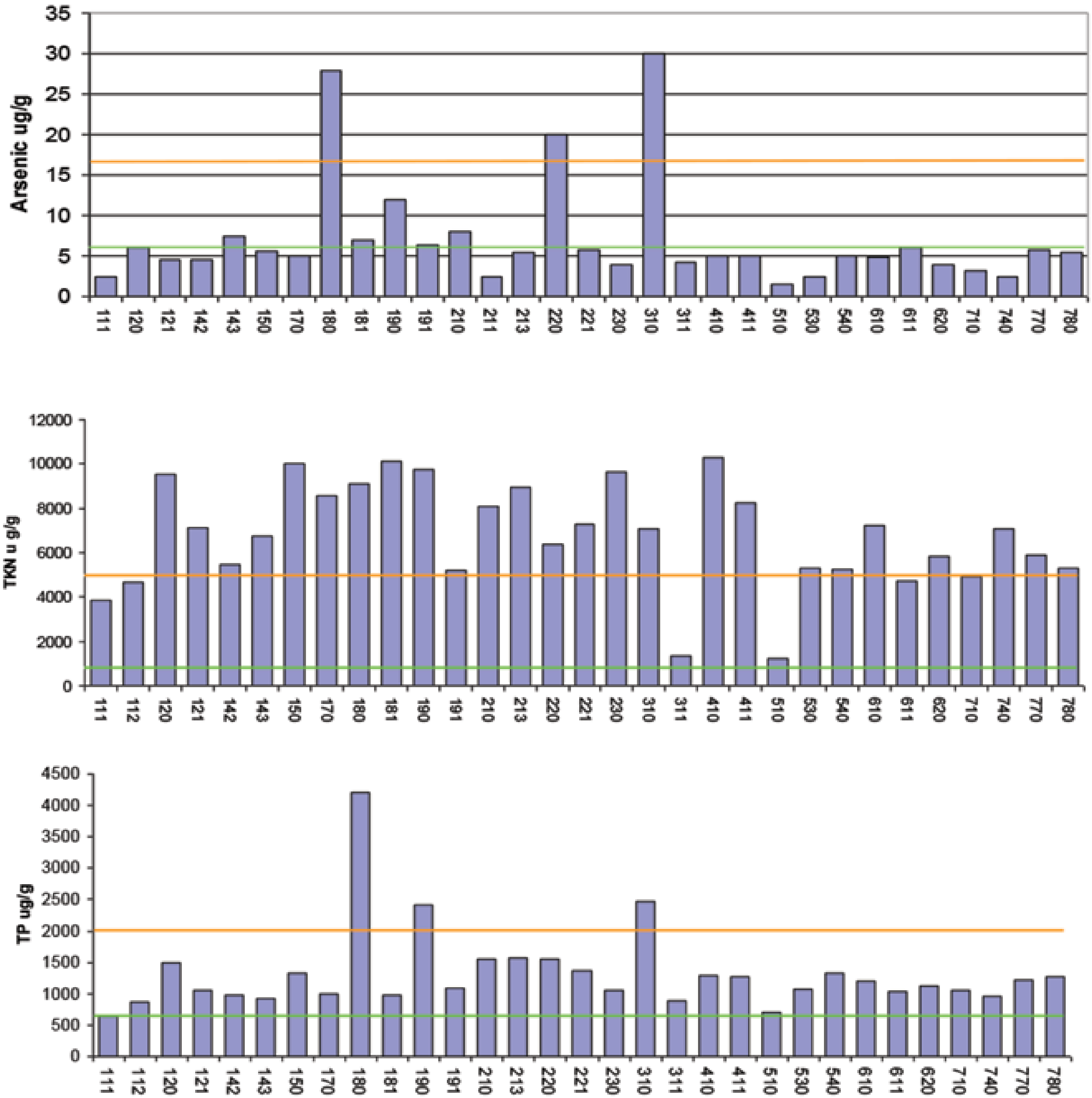

FIGURE 36 – Concentrations of arsenic, total Kjeldahl nitrogen and total phosphorus in sediments at Lake of the Woods stations in relation to provincial Lowest Effect Level (green line) and federal Probable Effects Level (orange line) from Environment Canada. Station locations are given in Table 25.

As LoW phosphorus budgets indicate, considerably more phosphorus enters the lake than leaves via the Winnipeg River, with the remainder sequestered to the sediments (Hargan *et al.* 2011)

Elevated concentrations of nutrients and metal species (i.e., arsenic, iron, manganese and phosphorus) in surficial sediments may be a consequence of their mobility under reducing conditions. The highest concentrations of redox-active metals such as arsenic and iron are typically found in the sediment-water interface, with evidence to suggest that arsenic is most mobile in reduced sediments (Harrington *et al.* 1998; Nicholas *et al.* 2003). Such conditions likely exist in those areas of LoW where bottom waters become anoxic during thermal stratification or under ice cover. Arsenic concentrations in LoW sediments were significantly negatively correlated with dissolved oxygen concentrations in bottom waters in samples collected by Environment Canada (Pascoe *et al.* 2014). Similarly, lake sediments often show an increase in TP near the sediment water interface suggesting phosphorus may move upwards through a redox gradient in the sediment (Carignan and Flett 1981). TP concentrations in the Environment Canada sediment samples were negatively correlated with dissolved oxygen concentrations (of the water overlying the sediment) suggesting that phosphorus may be mobilized towards the surficial sediment layer. This process of mobilization and migration in the sediments has implications for their use in historically tracking nutrients in sediment cores leading to questionable interpretations (Ginn *et al.* 2012). Arsenic and phosphorus concentrations in Environment Canada sediment samples were particularly elevated in Poplar Bay and Whitefish Bay, two of the deepest stations on the lake, both of which experience summer hypoxia.

Elevated concentrations of nutrients and metals in surficial sediments at some sites in LoW may have implications for the health of the benthic community (Pascoe *et al.* 2014). Concentrations above the PEL and SEL levels define concentrations where adverse effects are more likely to occur with frequency (CCME). In Environment Canada sediment samples there were a number of sites in LoW where provincial SEL or federal PEL concentrations were exceeded (most commonly for magnesium, arsenic, phosphorus and nitrogen). These sites were 120 (Bigstone Bay), 180 (Poplar Bay), 190 (Bird Island), 210 (East Allie Island), 220 (Donald Duck Island), 310 (Whitefish Bay), 610 (Mica Point in Little Traverse Bay), 620 (Monkey Rocks in Little Traverse Bay), 710 (outlet of Rainy River). Pascoe *et al.* (2014), noted that concentrations of nutrients and metals at these sites were likely a result of these locations being in areas where there is a decrease in water velocity and a subsequent fall out of suspended sediments to the bottom sediments.

River Sediments

River sediment can be examined as bottom sediment in larger more slowly flowing rivers or commonly as suspended sediments that are transported in the water column by flowing water. Sediment-laden rivers and streams can pose environmental and economic challenges in cases where excessive sediment transport due to erosion can affect aquatic health through eutrophication (nutrient transport) and the transport of harmful organic contaminants. In Minnesota, more than 5,800 miles (9,334 km) of streams are identified as impaired by the MPCA due to elevated levels of suspended sediment (Ellison *et al.* 2014). The U.S. Geological Survey, in cooperation with the MPCA, established a sediment monitoring network in 2007 and began systematic sampling of suspended-sediment concentrations (SSC), total suspended solids (TSS), and turbidity in rivers across Minnesota to improve the understanding of fluvial sediment transport relationships. Suspended sediment concentrations (SSC) measured at 14 sites from 2007 through 2011 indicated a range of 21 to 226 mg/L (Ellison *et al.* 2014). The link to the report is: http://pubs.er.usgs.gov/publication/sir20135205 .

Total suspended solids have been used as a measure of fluvial sediment by the MPCA since the early 1970s but TSS has been determined to under represent SSC. The MPCA was therefore interested in quantifying the differences between SSC and TSS in different parts of MN. Comparisons between concurrently sampled SSC and TSS indicated significant differences between sites, with SSC on average two times higher than TSS concentrations. Seven out of 14 sites had poor or no relationship between SSC and streamflow. Only two sites had strong correlations between SSC and streamflow. In contrast, turbidity had moderate to strong relations with SSC at 10 of 14 sites and was superior to streamflow for estimating SSC at all sites. These results indicate that turbidity may be beneficial as a surrogate for SSC in many of Minnesota's rivers.

Overall, the largest suspended sediment and TSS loads were transported during spring snowmelt runoff, although loads during the fall and summer seasons occasionally exceeded spring runoff at some sites.

The USGS collected suspended sediment and bedload samples in the Rainy River basin at the Little Fork and Big Fork Rivers in 2012 and 2013. These data are being used to evaluate a sediment transport model. The objective is to develop sediment rating curves for Minnesota's various stream types. The report for the initial phase of the project will be completed in 2014.

PART 4: BIOLOGICAL COMMUNITIES

Phytoplankton

Phytoplankton composition and abundance varies both seasonally and spatially in many lakes. In most temperate lakes, including LoW, phytoplankton production, biomass, and seasonality are primarily regulated by phosphorus concentration (Schindler 1978; Hecky & Kilham 1988). To a lesser extent, zooplankton and planktivorous fish grazing, light availability, temperature, and other nutrients (notably, nitrogen, silica, magnesium, calcium, iron, molybdenum, and selenium) are involved in phytoplankton production and regulation, the extent of which is dependent on the phytoplankton group (Wehr & Sheath 2003).

Phytoplankton sampling by Environment Canada. (Environment Canada)

Phytoplankton in the basin have been described in many studies but seasonal variation over wide areas make monitoring difficult. In addition, there are extremely heterogeneous local distributions during peak biomass induced by spatial and vertical wind mixing; conditions that make the collection of representative samples almost impossible. One must bear in mind when assessing reported relative species compositions and phytoplankton biomass that these refer to the sample that was collected and may not be representative of the body of water from which they came. It is therefore not so much that monitoring in the R-LoW basin is poorly developed for phytoplankton but rather that representative sampling is a logistically difficult, if not impossible task.

In recent years, several studies have quantified the dominant groups of phytoplankton (Anderson *et al.* 2006b; Chen *et al.* 2007; Kling 2007). This research has demonstrated that the composition of the phytoplankton community varies throughout the ice-free season in LoW. Chen *et al.* (2007) examined the phytoplankton community through June to August, 2004, at five sites in LoW (Yellow Girl Bay, Donald Duck, East Allie Island, Bigstone Bay, and Rat Portage Bay). They determined that diatoms *Asterionella spp.*, *Fragilaria spp.*, and *Stephanodiscus spp.*, and small flagellates *Cryptomonas spp*. and *Rhodomonas spp.* were relatively important in June with the cyanobacteria *Aphanothece spp.* ranging from 3.5-49% of the total biomass. In July and August, diatoms were replaced by cyanobacteria. The cyanobacteria species present were largely dominated by *Aphanizomenon flos-aquae* with three species of Anabaena (*A. flos-aquae*, *A. lemmermannii*, *A. mendotae*) plus *Aphanothece spp*., *Pseudoanabaena spp.*, and *Woronichinia spp.* These findings were similar

Phytoplankton in the basin have been described in many studies but seasonal variation over wide areas make monitoring difficult.

to those of Kling (2007) who reported that in two northern stations in LoW in 2004, cyanobacteria replaced diatoms at the end of June and continued to dominate throughout July to October, with the recurrence of diatom dominance in November.

A more thorough monitoring effort by Chen *et al.* (2009) sampled 16 sites throughout LoW in July August and September of 2006 and 2007. This study provides a good overview of late summer phytoplankton community metrics. Mean biomass at 16 sites for three months in two consecutive years were determined for total and prominent cyanobacterial genera. Chen also identified areas that were similar to one another with respect to 12 environmental parameters using principal components analysis (PCA). Areas in the north which included Whitefish Bay and Clearwater Bay areas were similar, central and southern areas were clustered with two sites in eastern Sabaskong Bay forming the third cluster. Nutrient concentrations and biomass of specific cyanobacteria contributed most to the scores used in the analysis. It is important to note that the ability to perform this level of analysis with respect to phytoplankton communities is a relatively recent step forward.

Personal communication with Ryan Maki indicates that there has not been recent extensive phytoplankton work done in Voyageurs National Park (VNP) although there has been a fair amount of paleophytoplankton work completed. He indicates that there are phytoplankton data from water column samples taken from the interior lakes (smaller VNP lakes that flow into Namakan Reservoir and Rainy Lake) during three rounds of sampling in 2006 but there is no summary report to assess those data.

The Aquatic Synthesis for Voyageurs National Park (Kallemeyn *et al.* 2003) provides an excellent summary of phytoplankton research in VNP that occurred up to 2003. Additional phytoplankton data are available in several taxonomic identifications from bloom samples for Lake Kabetogama. Kling (2005) published a report on cyanobacteria from a Lake Kabetogama core where there was an increase in numbers of eutrophic indicator taxa deposited since the 1960s and Serieyssol *et al.* (2009) published a paper on diatoms from Namakan Reservoir cores. A draft report by Mark Edlund *et al.* titled, *Determining the Historical Impact of Water-level Management on Lakes in Voyageurs National Park*, will cover the results of Serieyssol *et al.* (2009) as well as info from a Rainy Lake core and an annotated bibliography of the Rainy sub-basin. Readers are encouraged to watch for this report which will follow the publication date of this SOBR 2nd Edition.

It is clear that many aspects of the phytoplankton community in VNP have been characterized although Kallemeyn *et al.* (2003) conclude that a more comprehensive survey of the phytoplankton community is required. In 2014, preparation will begin on a manuscript covering water quality, phytoplankton, and zooplankton in lakes of VNP.

Algal toxins

Toxins produced by certain cyanobacteria can be hepatotoxins (affecting the liver) which are prevalent in Canadian fresh waters or neurotoxins (interfering with the transmission of signals in neurons) which are much less common. Microcystins are prevalent hepatotoxins in Canadian water and microcsystin-LR (MCLR) is among the most common of over 70 microcystin analogues (Kotak & Zurawell 2007). Microcystin-LR is one of the most commonly found toxins in LoW based on spot surveys (H. Kling, Algal Taxonomy and Ecology Inc., Winnipeg, MB, pers. comm.). The three types of neurotoxins are anatoxin-a, anatoxin-a(s), and saxitoxin/neosaxitoxin. The most common algal genera or species that are known to produce toxins are shown in Table 27.

Elevated MCLR concentrations in LoW have been reported during the summer months (Chen *et al.* 2007; Chen *et al.* 2009; Kotak & Zurawell 2007; Orihel *et al.* 2012). MCLR production in blooms in LoW during the summer of 2004 was attributed to *Anabaena spp.* and *Aphanocapsa spp.* (Chen *et al.* 2007). In August and

TABLE 27 – Algal genera or species known to produce toxins from Kotak & Zurawell (2007).

Hepatotoxins (liver)	Neurotoxins (neuromuscular)		
microcystins	**anatoxin-a**	**anatoxin-a(s)**	**Saxitoxin/neosaxitoxin**
Microcystis *Anabaena* *Planktothrix,* *Anabaenopsis* *Nostoc sp.*	*Anabaena flos-aquae* *Ana. spiroides* *Ana. planctonica* *Aphanizomenon flos-aquae* *Microcystis aeruginosa* *Cylindrospermum sp.* *Planktothrix agardhii* *Planktothrix. rubescens*	*Ana. flos-aquae* *Ana. lemmermannii* *P. agardhii*	*Aphanizomenon flos-aquae* *Aph. issatschenkoi* *Ana. circinalis* *Cylindrospermopsis raciborskii* *Lyngbya wollei* *Planktothrix sp.* *Ana. lemmermannii (possible)*

In the presence of a bloom, it is commonly recommended by Health Canada that no recreational activities should take place on the lake, nor should the water be used for drinking, cooking, bathing or washing.

September of 2006, water samples were collected from beaches and off-shore areas in LoW (B. Kotak, unpublished data, sensu Kotak *et al*., 2007). This study found that 60% of the 50 water samples collected along beaches in LoW contained microcystin concentrations <10 µg/L (World Health Organization–WHO Low Risk category), 6% had concentrations of 10-20 µg/L (WHO Moderate Risk category), 8% had concentrations >20 µg/L, and 26% had concentrations >50 µg/L (B. Kotak unpublished data; sensu Kotak *et al.* 2007). Offshore concentrations of microcystin from 2006 exceeded 50 µg/L during a period in August where a severe bloom covered several thousand square kilometres in the southern portion of LoW (B. Kotak, unpublished data, cited in Kotak *et al*., 2007). MCLR has also been detected in clams and leeches in LoW (H. Kling, Algal Taxonomy and Ecology Inc., Winnipeg, MB, unpublished data).

Kotak and Kling (2011) published a preliminary assessment of human exposure risk to microcystin in LoW and the Winnipeg River. The report was produced for the Lake of the Woods District Property Owners Association. Several areas of LoW contained only low microcystin concentrations. Maximum microcystin concentrations in Clearwater Bay and Lobstick Bay were less than 0.50 µg/L and maximum concentrations in Shoal Lake and at Town Island and Channel Island in Lake of the Woods were also low (maximum of 5.36 µg/L near Channel Island). These values are below what the World Health Organization (2003) would consider a risk for recreational contact. In contrast, several other areas of LoW and the Winnipeg River system had much higher shoreline concentrations of microcystin. In increasing order, maximum shoreline concentrations were observed near Frenchman's Rock Road (45 µg/L), Pine Portage Bay (60 µg/L), Sunbath Island (106 µg/L), Nestor Falls (147 µg/L), Gun Lake-Winnipeg River (238 µg/L) and Bigstone Bay (546 µg/L). All of these concentrations would be considered as high risk (WHO 2003) for recreational contact.

The limnological variables that influence the abundance of cyanobacteria and the production of MCLR by these bacteria vary greatly between studies. Several selected observed relationships between environment, cyanobacteria production and production of MCLR or other toxins are shown in Table 28.

It is important to consider that many relationships may not apply specifically to toxin production itself but to the growth of the toxin-producing species, meaning that environmental variables are responsible for controlling the biomass of toxin-producing species, not the toxin itself (Kotak *et al.*, 2000; Giani *et al.* 2005). Kotak (2000) points out that conditions that are optimal for growth of a (toxin producing) species may not be linked to toxin production.

The World Health Organization (WHO, 2003) has developed guidelines for recreational exposure to microcystins. According to the WHO, recreational exposure to microcystin concentrations of less than 10 µg/L (micrograms per litre) represent a low risk to humans, exposure to concentrations of 10 – 20 µg/L represents a moderate risk, and recreational exposure to microcystin concentrations greater than 20 µg/L represent a high health risk to humans. Any contact with water containing more than 20 µg/L of microcystin should be avoided.

Health Canada has a drinking water guideline of 1.5 µg/L of Microcystin-LR (Federal-Provincial-Territorial Committee on Drinking Water 2002). Although conventional water treatment methods may remove low concentrations of Microcystin-LR from drinking water, it may fail to remove higher concentrations. In the presence of a bloom, it is commonly recommended by Health Canada that no recreational activities should take place on the lake, nor should the water be used for drinking, cooking, bathing, or washing. Side effects from ingestion of algal toxins include headaches, fever, diarrhea, abdominal pain, nausea and vomiting, to itchy, irritated eyes and skin if skin contact is made (Health Canada 2007).

Benthic algae

Benthic algae are attached or closely associated with aquatic substrates. Very little

TABLE 28 – Observed relationships between environment, cyanobacteria production and production of MCLR or other toxins in North American Lakes.

Study Area	Variable	Observation	Reference
Twelve naturally eutrophic Boreal Plain lakes in Alberta	Microcystin-LR	Negatively correlated to the N:P ratio in lakes	Kotak *et al.* 2000
In four eutrophic lakes in Quebec's eastern townships	Cellular microcystin	Positively correlated to water column total [N]	Rolland *et al.* 2005
	Increased toxic cyanobacteria biomass	Positively correlated with increased water column stability, higher light extinction coefficient, and low dissolved nutrients	
22 lakes spanning a wide gradient of trophic status	Biomass and toxicity of cyanobacteria	Correlated to total concentrations of phosphorus and nitrogen, as opposed to their ratios	Giani *et al.* 2005
Lake of the Woods 16 sites	Total cyanobacteria biomass	No correlation between MC-LR and biomass of *Anabaena*	Chen *et al.* 2009
	Microcystin-LR	For the pooled data set, total phosphorus and ammonium concentrations were the two parameters most strongly related with MC-LR concentration	
246 water bodies across Canada	Microcystin	The probable risk of microcystin concentrations exceeding water quality guidelines was greatest when the ratio of nitrogen (N) to phosphorus (P) was low and rapidly decreased at higher N:P ratios.	Orihel *et al.* 2012
Wide range of TN:TP ratio lakes (<5 to >50)	TN:TP ratios, microcystin	Elevated microcystin concentrations are most frequent when the N:P ratio is between 15 and 20 which is the range for balanced phytoplankton growth. As a lakes trophic state increases, so does phytoplankton biomass and potential microcystin concentration	Scott *et al*. 2013
Lake of the Woods and Winnipeg River	Abundance and biomass of algal species	Microcystin concentration was positively correlated to the abundance of *Microcystis ichthyoblabe, Anabaena flos-aquae and Anabaena circinalis* in shoreline samples	Kotak & Kling 2011

data exist on the benthic algal communities in the R-LoW basin. In a preliminary study of the benthic algal community in Clearwater Bay, Kling (unpublished data) found that algal mats originating from a bloom had high abundances of cyanobacteria, and that impacted, high nutrient sites were comprised of 98% cyanobacteria, while diatom species dominated (82%) the unimpacted sites. In this study, impacted sites were considered to be those with external nutrient supplies, such as sources of septic system leachate or fertilizers. This demonstrates that benthic algal communities may differ between impacted and unimpacted sites in Clearwater Bay.

Didymo (*Didymosphenia geminata*)
Didymosphenia geminata (commonly referred to as Didymo or "rock snot") is a large golden brown diatom (60-150 μm). Its lengthy mucilaginous stalk allows it to occupy stream environments where it tends to form extensive mats on stream beds. Historically, Didymo has had narrow ecological tolerances and was native to low-nutrient, northern altitude environments, including streams in the region of Lake Superior. However, it has developed a broad distribution throughout North America over the past ten to twenty years occupying higher nutrient, lower altitude environments (Spaulding & Elwell 2007; Lavery *et al.* 2014). Although its trophic interactions are not yet understood, it is known to impact streams in many ways by causing nuisance blooms with shifts in macroinvertebrate communities, including a decline in the *Ephemeroptera-Plectopera-Trichoptera* index (an indicator of water quality) and an increase in oligochaetes and leeches (Edlund *et al.* 2008). Recently, it was detected in the Red River to the west of LoW. Currently, there is an effort to expand outreach and education efforts to inform the public and government agencies and to develop research initiatives to understand the biology and address the impacts of this organism (Spaulding & Elwell 2007).

Zoobenthos

Zoobenthos refers to the community of animals that live in association with the substrate-water interface (Kalff 2002). These may include epifauna which live on the sediment surface or infauna which live in the surficial sediments. Zoobenthos is normally species rich compared to the open-water zooplankton assemblages, with the highest numbers occurring in the littoral zone where the required resources are plentiful (e.g., organic matter, oxygen and nutrients), temperatures are higher, and there is cover for protection from predators. Most research focuses on macrozoobenthos, which are zoobenthic organisms that are large enough to see with the naked eye (<1000-400 μm in length). Macrozoobenthos (macroinvertebrates) include; amphipods, crayfish, molluscs, snails, bivalves, larval insects (including dragonflies, damselflies, stoneflies, mayflies, blackflies, caddisflies, and midges), beetles, and water striders. These benthic organisms are an important part of the diet of many fish species, such as perch and whitefish. Kalff (2002) noted that although the stomach content of lake trout and northern pike is >75% fish, their prey are largely dependent on the zoobenthos. In addition, zoobenthos provide food for other invertebrates, and for birds, such as grebes and ducks (Kalff 2002). Since macroinvertebrate sampling has been sparse and project-specific, baseline or long-term data are inconsistent (T. Mosindy, OMNR, Fisheries Assessment Unit, Kenora, Ontario, pers. comm.; J. Vandenbroeck, OMNR, Fort Frances, Ontario, pers. comm.) especially in the Canadian portion of the R-LoW basin.

MPCA - From 1977-1979, the MPCA conducted invertebrate sampling at upstream (International Falls) and downstream (near the outflow of the Baudette River) biological monitoring stations along the Rainy River (MPCA, unpublished data). Although sample size was small at these locations, the downstream site had a much more diverse assemblage than the upstream site, which was attributed to the presence of the pulp and paper mill in International Falls where wood and other debris was present. This study was followed up by another invertebrate survey of the Rainy River and the southern portion of LoW in 1987 by the MN DNR (MN DNR, 1987, unpublished data). The results demonstrated that the highest densities of invertebrates were in the upper reaches of the Rainy River compared to the lower Rainy River. In addition, sites in the upper Rainy River with gravel, rock, and sand substrate had higher benthic diversity and density compared to sites with finer sediments (clay and silt) in the lower Rainy River (MPCA unpublished data). The heterogeneous substrate in the upper reaches of the river were important in influencing the presence of *Trichoptera* and Ephemeroptera, normally located in gravel, rocky, and sand substrates. The outflows of the Little Fork and Big Fork rivers were included in this study and had lower diversity compared to the Rainy River. In addition, the abundance of different feeding groups (filterers, scrapers, and grazers) varied along with changes in flow throughout the length of the river. For example, there were higher abundances of taxa that are collectors of fine particulate organic matter (e.g., *Sphaeriidae*) in the faster flowing regions as compared to higher abundances of scrapers and coarse particulate collectors (e.g., *Hydropsychidae*) in slow moving regions where detritus tends to accumulate. These results demonstrate that differences in substrate and flow throughout the length of the Rainy River play a major role in determining benthic community structure.

In 2005, the MPCA conducted sampling for benthic macroinvertebrates and chemical/physical variables (conductivity, turbidity, dissolved oxygen, pH, total phosphorus, total suspended solids, nitrogen, and discharge) on one day at streams and wetlands in the basin, including two sites along the Rainy River and many of its tributaries. This effort was part of both the United States Environmental Protection Agency's (USEPA) Environmental Monitoring and Assessment Program (EMAP; McDonald, 2000; McDonald *et al.* 2004) and the MPCA's Biological Criteria Development Program (MPCA 2007c). The sampling protocols followed those outlined in the USEPA's Rapid Biological Assessment Protocol (Barbour 1999). The purpose of this program is to build a database of macroinvertebrate data to better understand the relationship between human disturbances (e.g., point source pollution, toxins) and aquatic biota. These data can be accessed on the MPCA's environmental data access (EDA; http://www.pca.state.mn.us/data/edaWater/index.cfm) and the USEPA's STORET database (http://www.epa.gov/storet/). The data are classified based on:

- richness measures, e.g., number of taxa within the families *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), and *Trichoptera* (caddis flies) (EPT)
- tolerance/intolerance measures, e.g., number of intolerant families, percent abundance of dominant taxon, Hilsenhoff Biotic Index (HBI)
- feeding measures (filterers, gatherers, and scrapers)
- composition measures (e.g., %*Chironomidae*, %*Diptera*).

The HBI estimates overall pollution by weighting abundance using tolerance values. Redundancy analysis (RDA), a constrained ordination method, was run using the benthic metrics and the associated environmental data (including substrate type and HBI) for 26 stream and river locations, obtained from the MPCA's Environmental Data Access (EDA) database. The results show that substrate type and HBI significantly explain the variation in the macroinvertebrate communities between sites (whereas the other environmental variables were not significant). In addition, the sand and gravel sites exhibited significant differences in their HBI and EPT scores, while there were no significant differences between sites with the two substrate types based on the other environmental variables. These results demonstrate that benthic macroinvertebrate communities in the basin exhibit large spatial variation which appears to be related to the differences in stream and river substrates (i.e., gravel, sand, clay, and silt) and HBI. The sites were mainly separated along two meaningful environmental gradients. Axis 1 is a gradient of increasing organic pollution, determined mainly by the HBI score. Axis 2 represents a gradient of substrate type and ion concentration, including conductivity, turbidity, and pH. These results are consistent with other literature demonstrating that substrate composition is important in influencing invertebrate communities (Erman & Erman 1984; Richards *et al.* 1993), although other factors related to stream morphology, flow, macrophytes, and predation are likely important as well (Hawkins *et al.* 1982).

Environment Canada (EC) collected benthic invertebrate samples at 31 stations in LoW in 2008, 2009 and 2010 (Pascoe *et al.* 2014). Seven of these stations were sampled in multiple years for a total of 42 sampling events. The usefulness of this dataset was limited due to the fact that there was too great of a between-year difference in abundance to pool the three years of data with the density of invertebrates being substantially higher in 2010 than either 2008 or 2009. In addition, much of the noted impairment of benthic communities was linked to low oxygen habitats which are a consequence of samples being taken in mid-basin stratified areas. Low oxygen in these areas may be a natural condition, i.e. not linked to anthropogenic activity. Finally, the 25 potential reference sites were not adequate to characterize the diversity of the benthic invertebrate community of LoW. In order to create an adequate reference model a minimum group size of 10 is required and this sample size could not be attained within any of the three reference site groups that were identified through cluster analysis.

Sediment sampling by Environment Canada (Environment Canada)

Benthic invertebrate counts were therefore standardized for abundance to allow spatial analysis of community structure. EC noted that this approach is contrary to that which is normally undertaken by those who examine data generated by the Canadian Benthic Invertebrate Network (CABIN). The alternative was to reject all data from 2010. Other metrics such as Shannon Weiner diversity, Simpson's Evenness and number of EPT taxa did not differ between years, which allowed comparison without adjustments.

The reference condition approach was used to identify three groups of suitable reference sites for comparison with test sites. Potentially impacted sites were identified as those that were near to developed areas (e.g., Kenora harbor), or those that were identified by OMOE as impacted (based on paleoecological evidence). Six stations were identified as potentially impacted:

- station 120 (Bigstone Bay) identified as impacted by OMOE
- stations 142 and 143 near Keewatin due to extensive shoreline development
- station 180 and 181 in highly developed Poplar Bay
- station 191 which is close to OMOE impacted site (PP-1).

Although a suitable number of reference sites could not be identified, EC decided to proceed cautiously using the three identified groups of reference sites. A forward step-wise discriminant function analysis (DFA) habitat model was used to identify the reference sites associated with each test site based on habitat characteristics. Site 120 was classified as belonging to Group 2, site 142, 143, and 191 were classified as belonging to Group 3 and sites 180 and 181 were classified as belonging to Group 1. Although test sites 180 and 181 were classified as having habitat similar to that of Group 1, the sample size of Group 1 was too small to allow an adequate estimates of confidence ellipses. Therefore, test sites 180 and 181 were compared to all reference sites combined. Using these groupings, benthic community structure at the test sites was compared to the appropriate group of reference sites, with values standardized for abundance.

The benthic community at site 180 (Poplar

Bay) and at site 120 (Bigstone Bay) appeared to be impacted, as compared to reference sites. Both sites had low taxonomic diversity; with only *Chaoboridae* and *Tubificidae* present; families tolerant of low oxygen conditions and indicative of pollution. Other potential test sites were not significantly divergent from reference sites. Site 181, also in Poplar Bay, had significantly higher diversity, although still dominated by *Chaoboridae* and *Tubificidae*. Sites 191, 142, and 143 had relatively high diversity, with sites 142 and 143 (see Table 25) containing pollution sensitive EPT taxa. Taking into consideration both the community structure ordination data as well as the benthic metrics they concluded that test sites 142, 143, 181 and 191 were not significantly different from reference sites.

Benthic diversity was positively associated with higher concentrations of dissolved oxygen, chl a, pH and temperatures in bottom waters and negatively associated with TP in bottom waters as well as high nutrient and metals content in the sediment.

Environment Canada was unable to determine precisely which environmental variables in each component were responsible for the variation in benthic metrics as many were highly correlated with each other. For instance dissolved oxygen, and metal concentrations were often negatively correlated. Given that increased biological availability and toxicity of metals is associated with the reducing conditions in anoxic sediments, it is difficult to distinguish which stressors are actually driving changes in the benthic community. Overall however, the environmental variables which were the most important in explaining variation in the PLS model, based on VIP scores, were in order of importance: depth (0.35), water temperature (0.30), DO (0.27), chl a (0.25), total nitrogen in the sediment (0.24), and TP (0.24) in the water. This suggests that the primary factors driving a reduction in benthic metric are water depth and the physical parameters associated with thermal stratification, elevated nutrients and low dissolved oxygen content.

Multivariate analyzes point to impairment of the benthic community in association with deep basins, which are thermally stratified and prone to low dissolved oxygen concentrations. This is not uncommon in eutrophic water bodies where high productivity is linked with hypoxic conditions in the hypolimnion and associated impairment to the benthic community. Nutrient status in LoW ranges from mesotrophic to eutrophic and some deep northern basins, such as Poplar Bay (180) and Bigstone Bay (120) were prone to high nutrient and low dissolved oxygen concentrations in the hypolimnion (see Chapter 2). It should be noted that other deep water sites such as Whitefish Bay (310), Donald Duck (220), Yellow Girl Bay (230) and Mica Point (610) did not show the same degree of hypoxia or impairment to the benthic community, although most of them also undergo some degree of thermal stratification.

EC surveys indicate that benthic invertebrate diversity appears to be most affected at sites which are deep, thermally stratified and with low concentrations of dissolved oxygen in the hypolimnion. Sites in Poplar Bay and Bigstone Bay may be more susceptible to hypoxia because they are more sheltered and outside of the main north to south flow in the lake, leading to longer and more stable periods or stratification.

Both Bays have some degree of cottage development, particularly Poplar Bay, and while nutrient loadings from cottages was considered to be only a minor component of the LoW phosphorus budget local inputs may be an important source of nutrients in isolated bays. Paleolimnological evidence suggests that some of the trends seen in the benthic invertebrate community may be related to changes in climate. Surveys of Chironomid and Chaoborus remains in Poplar Bay and Whitefish Bay suggest that substantial declines in hypolimnetic oxygen in Poplar Bay may have started in the 1970s preceding much of the cottage development, although development may be an additional stressor on the benthic community (Summers *et al.* 2012).

The Canadian Aquatic Biomonitoring Network (CABIN) is a network designed to collect information on the biological condition of benthic aquatic ecosystems in Canada. Typically several years of data are required to generate an adequate reference model for the benthic community. A properly developed CABIN reference model for LoW would allow the assessment of existing and future potential test sites against a known reference model and provide baseline data of the current benthic community structure for future use in the examination of temporal trends.

Voyageurs National Park - Benthos have been collected by McEwen and Butler (2008) in Rainy Lake and Namakan Reservoir mostly to study the effects of water level regulation. Their results agreed with Kraft's suggestion (1988) that benthic invertebrates in Namakan Reservoir were negatively impacted under the more severe 1970 drawdown regime (McEwen & Butler 2010).

Rusty crayfish invasions can pose a threat to native crayfish, fish, invertebrate, and macrophyte populations.

Invasive species – Zoobenthos

Rusty crayfish *(Orconectes rusticus)*
Although the rusty crayfish is native to North America, it has been introduced to many northern lakes and streams outside of its natural range. Rusty crayfish invasions can pose a threat to native crayfish, fish, invertebrate, and macrophyte populations. This omnivorous species competes with native crayfish species for space, and chases them out of their daytime hiding places so they are more likely to be preyed upon by fish and birds. Their high metabolic rate makes them voracious feeders, and they can consume two times more food than similar-sized native crayfish (Jones & Momot 1983). As reviewed by the University of Minnesota's Sea Grant Program (2007), rusty crayfish are omnivores who feed on aquatic plants, benthic invertebrates (including worms, snails, leeches and insects), decaying plants and animals, fish eggs, and small fish. In addition, aquatic macrophyte beds are susceptible to rusty crayfish predation, which can in turn be detrimental to fish and benthic invertebrates who seek refuge in vegetated areas. They may also compete with juvenile game fish and forage fish species for food. The hard carapace of the rusty crayfish makes them a less desirable food item for predators compared to the softer-shelled native species. They are also known to hybridize with the native species which may accelerate the local extinction of native crayfish.

Rusty crayfish (Laureen Parsons, OMNR)

The rusty crayfish was first detected in LoW in 1968 by Crocker and Barr in the Regina Bay/Lobstick Bay area, east of Sioux Narrows (Lake of the Woods 4th International Water Quality Forum Proceedings, 2007). Since then, it has spread through Whitefish Bay and northwards along the eastern shore to Kenora and along the Barrier Islands, and was found along the western shores at Big Narrows near Portage Bay and the southern shore of Hay Island in Sabaskong Bay (Lake of the Woods 4th International Water Quality Forum Proceedings 2007). Geard (2007) noted that water depth and distance from the mainland did not seem to influence the colonization of the rusty crayfish on islands in LoW but Jansen *et al.*, 2009 noted that water depth did play a role in colonization. As of 2013 there are no reports of rusty crayfish in Shoal Lake, but rusty crayfish have moved westwards since 2007 and are now found throughout Ptarmigan and Clearwater Bays. they have also expanded to south of the Aulneau to take in all of Sabaskong Bay, Miles Bay south to Mineral Island and Basil Channel, south from the NW Angle across most of the Little Traverse. They are not yet found south of Bigsby Island, Snake Is.-Windy Pt. to the mouth of the Rainy River. In 2007, the MN DNR (Baudette Office) reported the first sighting of this species in the Minnesota portion of LoW (Lake of the

Many lakes in Minnesota have been infested with zebra mussels and infestations are confirmed in Sand Lake in Itasca County, MN.

Woods 4th International Water Quality Forum Proceedings, 2007). It is currently being monitored by the Ontario Ministry of Natural Resources (OMNR)-LWFAU in Kenora, Ontario. In 2006, they organized and conducted crayfish monitoring in order to target invasion fronts of the rusty crayfish, to determine the relative abundance of each species and their habitat preferences, and identify possible factors influencing their dispersal on LoW (Mosindy *et al.* in prep.; Rosenberg *et al.* 2010; Jansen *et al.* 2009).

There is concern that the Winnipeg River could serve as an access for rusty crayfish to water bodies west of LoW, as it has been reported to occur in the river downstream of the Norman Dam in Kenora (Lake of the Woods 4th International Water Quality Forum Proceedings, 2007) and are prevalent currently in the river at least as far downstream as Minaki (T. Sellers, pers. obs.). Rusty crayfish were reported in Falcon Lake, MB in 2009 (Laureen Janusz, MB Water Stewardship, Winnipeg). The OMNR Invasive Species Monitoring Program, coordinated by the LWFAU in Kenora, is currently assessing the possibility of invasion to the Winnipeg River and an excellent overview with respect to invasion threats by this species is provided as proceedings of a workshop held in Winnipeg, Manitoba, 2006 (Rosenberg *et al.* 2010).

Rusty crayfish were first detected in Voyageurs National Park (Sand Point Lake) in 2006. They also exist in Crane Lake (bordering VNP), and in Johnson Lake which is upstream of but near Namakan Reservoir (Sand Point Lake also flows into Namakan Reservoir) (Maki 2007). The MN DNR does not have any sampling program directed at finding incidences of the rusty crayfish in Minnesota waters (Joe Eisterhold, MN Invasive Species Specialist, MN DNR), though they are documented during annual fisheries assessments for presence and absence. Citizen monitoring programs in the U.S. portion of the Rainy Headwaters sub-basin have detected rusty crayfish in many lakes between Ely and Saganaga Lake in the Boundary Waters Canoe Area (Passe 2014).

Papershell crayfish *(Orconectes immunis)*
This species has been observed in Snake Bay in eastern Whitefish Bay since the late 1960s. They have recently been found in Ptarmigan Bay, SW of Kenora (Jansen *et al.* 2009), areas that are more than 100 km from their last known observation in Whitefish Bay (Lake of the Woods 4th International Water Quality Forum Proceedings 2007).

Northern Clearwater Crayfish *(Orconectes propinquis)*
This species has been observed in Whitefish Bay since the 1960s. It has not been observed elsewhere on LoW (LWFAU). This species of crayfish have also been found in the Kawishiwi watershed (Derrick Passe, Lake County SWCD).

Zebra mussel *(Dreissena polymorpha)*
Zebra mussels have had many impacts on the lakes which they have infested. They alter food webs, outcompete native mussels, and clog water intake pipes. Through significant filter feeding, they alter the phytoplankton and nutrient dynamics within lakes, and the undigested portions (and their associated nutrients) are returned to the lake bottom as pseudofeces. They also consume toxins found in the water, and there is concern that these toxins will be transferred up the food chain through fish, birds, ducks, and crayfish.

Evidence from previous studies suggests that zebra mussels can become established in ambient calcium concentrations >20–28 mg/L (Cohen & Weinstein 2001). Shoal Lake has calcium concentrations that approach 19 mg/L. However, based on this calcium threshold, the majority of LoW is not vulnerable to wide-spread densities, observed in other North American waters since all sectors have ambient calcium concentrations below 20 mg/L, and most are below 15 mg/L (2013 sampling on MN waters yielded Ca concentrations of 12.6 to 22.2 ppm on the main lake and 10.6 ppm in Fourmile Bay). According to other research (Neary & Leach 1992), LoW falls within the appropriate pH (> 7.3), calcium (12->20 mg/L), and temperature ranges (mean annual: >0°C; mean January: >-15°C) to warrant susceptibility to invasion. The vector exists for introduction, as there is good road access to the lake with a high number of tourists visiting the lake each year (Neary & Leach 1992).

Many lakes in Minnesota have been infested with zebra mussels and infestations of mussels are confirmed in Sand Lake in Itasca County, MN. (http://files.dnr.state.mn.us/eco/invasives/infested_waters.pdf) Sand Lake is part of the Bowstring chain of lakes that flow into the Rice and Bigfork Rivers, which flow to the Rainy River.

Zooplankton

Zooplankton records provide another useful tool in the assessment of environmental change. They inhabit most aquatic environments and play an essential role in the function of aquatic ecosystems, as they graze on phytoplankton, detritus and other plankton, serve as food for planktivorous organisms, and recycle nutrients back to primary producers. Previous studies have demonstrated the sensitivity of zooplankton to environmental change, including lake trophic status and nutrient enrichment (Hessen *et al.* 1995; Jeppesen *et al.* 1996), fish predation (Hessen *et al.* 1995; Jeppesen *et al.* 1996; Ramcharan *et al.* 2001; Jeppesen *et al.* 2002), and invasive species (Boudreau & Yan 2003; St. Jacques *et al.* 2005). Along with the combined effects of these multiple stressors, climate change has the potential to affect zooplankton population abundances (Magnuson *et al.* 1997; Rusak *et al.* 2008).

Plankton sampling (U.S. NPS Staff Photo)

Since zooplankton size structure is influenced by size selective predation of planktivorous fish (Brooks & Dodson 1965; Sweetman & Finney 2003), most zooplankton sampling programs have provided some insight into planktivorous fish predation. During the late 1990s, the OMNR-LWFAU sampled zooplankton at various stations on LoW.

From 1992-1999, zooplankton sampling was included in the MN DNR (Baudette) sampling protocol to look at the relationship between zooplankton prey and their fish predators (Heinrich 1990-2006). The sampling locations were 4 km (2.5 mi) northeast of the mouth of Zippel Bay and 2.5 km (1.6 mi) east of Long Point using an 80 µm mesh (for details see Heinrich 1992–99). These data show an increase in crustaceans (including cladocerans and copepods) and a decline in rotifer total mean density with an overall decline in zooplankton species richness between 1992 and1999. In 1999, it was reported that the smallest mean size of crustacean zooplankton consistently occurred in June, suggesting that planktivorous fish are more prevalent in June with a decline in late summer (Heinrich 1999). Their analyzes followed the guidelines set by Mills *et al.* (1987) and Mills (1989) demonstrating that when the dominant piscivores in productive waters are centrarchids or percids, the mean crustacean zooplankton body size is ≥0.8 mm. This would indicate that planktivorous fish are being controlled by piscivores, and piscivores are not being overharvested. These zooplankton data include zooplankton density and size structure and could provide a baseline for future zooplankton research in the southern region of LoW. These data are particularly useful because they provide a record of composition prior to the invasion of the spiny water flea (*Bythotrephes longimanus*), which was discovered in 2007 in the Rainy River.

Following the discovery of the spiny water flea (*Bythotrephes longimanus*) in Rainy Lake in 2006 and the Rainy River in 2007, the MN DNR (Baudette) office reinstated their zooplankton sampling program. Among the zooplankton taxa identified between 1992 and1999 the dominant species included the copepods *Leptodiaptomus minutus*, *Skistodiaptomus oregonensis*, and *Diacyclops sp.*; the cladocerans *Bosmina longirostris* and *Eubosmina coregoni*; and the rotifer *Polyarthra sp.* Shifts and declining densities were observed from 2008 through 2013, with copepod and cladoceran densities declining and with some species no longer being detected during sampling (Heinrich 2014). Continued sampling will help to track the abundances and document seasonal variability and presences of the zooplankton community.

Since 2006, LWFAU has conducted vertical zooplankton hauls at all water quality monitoring sites during monthly water sampling. Samples are preserved and forwarded to Brenda Hann, University of Manitoba for analysis. Changes in the zooplankton community over time and impacts of spiny water flea on resident zooplankton communities are examined in each sector. Despite an increase in zooplankton sampling effort in LoW and the Rainy River in 2007, zooplankton are still relatively understudied in this region. Interannual and long-term variability in zooplankton community structure can often be missed by short-term contemporary sampling programs (Yan *et al.* 1996; Arnott *et al.* 1999; Jeppesen *et al.* 2003). In order to attain a reasonable representation of changes in the zooplankton community, long-term monitoring programs are necessary. The examination of the chitinous remains of cladocerans in lake sediment cores would provide additional insight into shifts in cladoceran assemblage composition and size structure over a significant period of time, such as from the pre-industrial period to present.

Invading Species – Zooplankton

Spiny water flea *(Bythotrephes longimanus)*
The spiny waterflea (SWF) is an invasive predatory zooplankton. They prey upon other zooplankton, including *Daphnia spp.*, which are common food sources for juvenile and small native fish. In lakes in south-central Ontario on the Precambrian Shield, they have been implicated in the decline in some species of zooplankton and the alteration of zooplankton communities (St. Jacques *et al.* 2005; Yan *et al.* 2002; Boudreau & Yan 2003; Strecker *et al.* 2006).

SWF was first observed in Saganagons Lake, near the southeastern boundary of Quetico Provincial Park in 2003, in the South Arm of Rainy Lake in August 2006 and in the Rainy River below the Fort Frances dam during the spring of 2007 (Rob & Van den Broeck 2007). By late summer of 2007, SWF was detected in Wheeler's Point at the outflow of the Rainy River to LoW. In 2007, it was found in other portions of LoW including Zippel Bay to Zippel Creek and the mouths of the Big Fork, Little Fork, and Warroad, and Baudette Rivers (MN DNR 2007c) and in Ontario waters along the eastern shore northwards to Morson and Miles Bay, (Mosindy 2010). SWF were immediately incorporated into diets of cisco, yellow perch, black crappies and juvenile walleye. They spread quickly throughout LoW and by 2009 they were found in Whitefish Bay and in Shoal Lake by 2011 (Mosindy 2013). Spiny water flea were first reported in the Winnipeg River, downstream in Gun Lake at Minaki in September of 2008 (T. Sellers, pers. obs.). Spiny water fleas are also found in Gunflint, Saganaga, Crane, Kabetogama, Lac La Croix, and Little Vermilion lakes.

At the 2013 International Water Quality Forum, Hobmeier *et al.* reported on the impacts of SWF invasions on the zooplankton communities of Voyageurs National Park. Long-term zooplankton surveys in Rainy, Namakan, Kabetogama, Sandpoint and Crane lakes were conducted to investigate whether zooplankton communities have changed after SWF invasion. They found that zooplankton community composition was drastically altered in post-compared to pre-invasion samples (Figure 37). Dominance shifted towards copepods and larger bodied or gelatinous cladoceran species, while overall zooplankton biomass was reduced by 40-60%. Most cladoceran species showed severely decreased populations and changing seasonal abundances, suggesting a gradual and accumulative effect of SWF. Importantly, they noted that SWF also seems to have important non-consumptive effects on native competitor species like *Leptodora kindtii* and predaceous copepods. Food web implications for the affected ecosystems and fisheries are evident.

Eubosmina coregoni
Eubosmina coregoni is a zooplankton that is native to Eurasia. It arrived in North America in the mid-1960s and likely colonized the Laurentian Great Lakes by means of ballast water (Deevy & Deevy

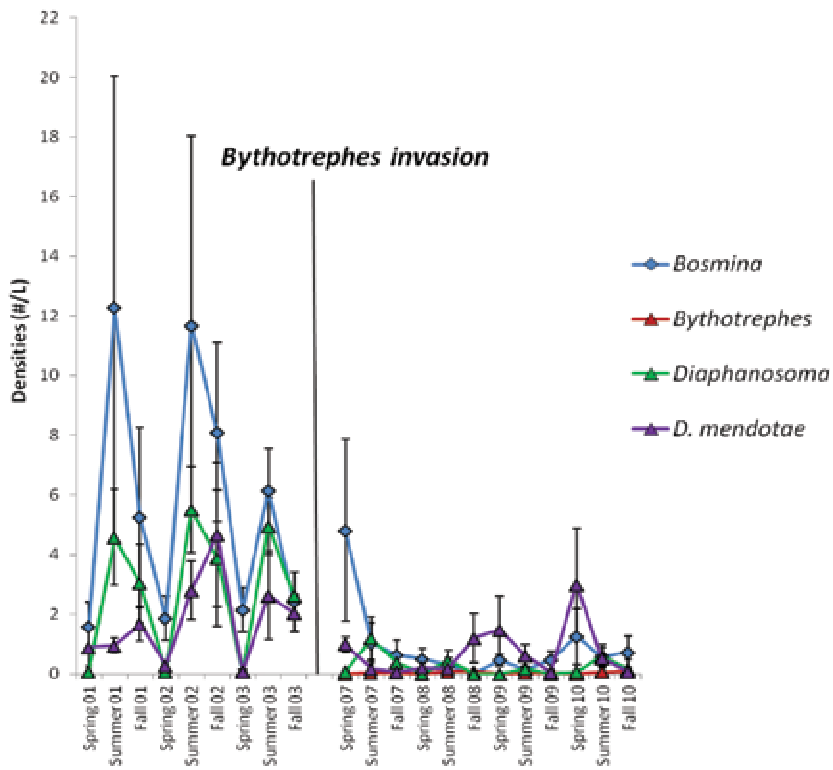

FIGURE 37 – Pre and post spiny water flea invasion zooplankton communities in Voyageurs National Park (Hobmeier *et al.* 2013).

The ecological and economic importance of the R-LoW basin fisheries have made them the core of many research programs in the region.

1971). It was observed in Lake Winnipeg in 1994 (Salki 1996).

Suchy & Hann (2007) used paleo-limnological techniques to investigate the early invasion timeline and present distribution of *E. coregoni* in LoW. They determined that this species first arrived in LoW in the early 1990s either by way of the Rainy River via the Laurentian Great Lakes or through the Winnipeg River. Its highest abundances occurred in the northern and eastern regions of LoW with modest numbers in the southern basin, which may have been due to unsuitable preservation conditions (such as wind-induced turbulence) in that region. Their results highlight the possible temporal and spatial invasion pathways for this and other invasive species.

Fish

A number of agencies are responsible for monitoring and reporting on fisheries in the R-LoW basin, including the Ontario Ministry of Natural Resources (OMNR), Minnesota Department of Natural Resources (MN DNR), Ontario Ministry of the Environment (OMOE), Minnesota Pollution Control Agency (MPCA), Environment Canada (EC), and United States Environmental Protection Agency (USEPA). Many of these agencies work together through regional and international partnerships and collaborations to monitor fish in the basin.

The ecological and economic importance of the R-LoW basin fisheries have made them the core of many research programs in the region. The area manager at the OMNR, in Kenora, Ontario is responsible for fisheries management in the Ontario portion of LoW. The LoW Fisheries Assessment Unit (LWFAU), Biodiversity and Monitoring Section, OMNR, has been conducting ongoing, long-term monitoring on LoW since 1978, the results of which are used in local fisheries management programs and to assist with managing other similar fish communities in Ontario. For monitoring purposes the Ontario portion of LoW has been divided into sectors (see Table 12 and Part 2) based on differences in water chemistry, limnology, fish communities, and user group patterns (OMNR/MN DNR 2004). The LWFAU monitors these sectors for two consecutive years on a rotation of every six years.

The Rainy River/Manitou area managers at the OMNR Fort Frances, Ontario office are responsible for fisheries within the Rainy River.

Fisheries management for the Minnesota portion of LoW and the lower extent of the Rainy River are under jurisdiction of the Area Fisheries Managers at the MN DNR office in Baudette, Minnesota, while the upper reach of the Rainy River is the responsibility of the MN DNR office in International Falls, Minnesota. Fisheries assessment in Minnesota follows the Large Lake Sampling Guide methodology (Wingate & Schupp 1984). This program was designed to standardize walleye sampling on Minnesota's large walleye lakes and has been in effect since 1983.

Details of the assessment and monitoring programs, sampling methodologies, fish stocks, and socio-economic data from the 1997-2004 surveys are provided in the Ontario-Minnesota Boundary Waters Fisheries Atlas (OMNR/MN DNR 2004). This document was historically published every six years and provides detailed information and statistics on fisheries resources and related socio-economic data for LoW, Rainy River, Rainy Lake, Namakan Lake, and Sand Point Lake. Its purpose is to facilitate fisheries resource management and the development of long-term solutions in these water bodies. The data provided from the fish surveys include abundance, size and age structure of populations, growth rates, condition indices, sex ratios, and for some species, maturity schedules (Kallemeyn *et al.* 2003). Further details can be obtained in the Fisheries Atlas (OMNR/MN DNR, 2004) and more recent reports can be obtained from the aforementioned fisheries offices.

Sturgeon - a recovery success story in the making (OMNR Fort Frances)

Since the 1800s, the commercial fisheries industry in the R-LoW basin was intense and grew rapidly on both the U.S. and Canadian sides of the border (Schupp & Macins 1977). For many years, the theoretical yields of some commercially harvested fish (including walleye, cisco, white fish, sucker, and lake sturgeon) were exceeded, with sportfishing increasing this pressure. Exploitation of fisheries, especially walleye, was the primary influence on percid yields through 1888-1973, and the continuation of selective fishing was concluded to be very detrimental to walleye populations (Schupp & Macins 1977). Restrictions and regulations governing commercial and sport fishery were then imposed, and the last commercial fishing licenses were bought out from Minnesotan (1985) and Ontario fisherman (1991).

Through the early 1970s, pollution from pulp and paper mills at International Falls and Fort Frances were likely impacting critical spawning and nursery habitat on the Rainy River.

Lake Sturgeon *(Acipenser fulvescens)*
Lake sturgeon is the largest fish found in both Ontario and Minnesota waters. Their mean age at maturity in this area for males is 16.8 years and 25.8 years for females (Mosindy & Rusak 1991). Sturgeon are generally restricted to the southern half of LoW in the Big Traverse Bay and the Rainy River (Rusak & Mosindy 1997) but they are also found upstream in Rainy Lake, the

Sampling fish in Voyageurs National Park. (U.S. NPS Staff Photo)

Overharvesting for meat and caviar during the late 1800s and early 1900s resulted in drastic declines in lake sturgeon on LoW, the Rainy River and Rainy Lake.

Seine River, Turtle Lake and River, Namakan Reservoir, Namakan River, Quetico River and Lac la Croix (OMNR/MN DNR 2004; McLeod & Debruyne 2009; Shaw *et al.* 2012; Adams *et al.* 2006) These fish are specialized bottom feeders and use their long snouts to stir up the lake and river bottoms where their barbells are used to detect and capture small fish, crustaceans, mollusks, and other benthic organisms.

Lake sturgeon was once the central focus of both a native subsistence fishery and a non-native commercial fishery (Mosindy & Rusak 1991). Overharvesting for meat and caviar during the late 1800s and early 1900s resulted in drastic declines in lake sturgeon on LoW, the Rainy River and Rainy Lake. Pollution from pulp and paper mills at International Falls and Fort Frances in addition to municipal discharges during the late 1800s to mid-1900s caused water quality and nursing and spawning habitats in the Rainy River to deteriorate. This led to further declines in fish populations. Since the passage of the Clean Water Act in 1972, and subsequent legislation in Ontario and legislation involving limits on lake sturgeon harvest, water quality in the Rainy River has improved and sturgeon recovery has been slow and gradual (Mosindy & Rusak, 1991; Stewig 2005).

A management plan for lake sturgeon has been developed by Ontario, Minnesota, and Rainy River First Nations biologists (OMNR and MN DNR, 1995). Both short and long-term goals of this program are outlined in the Ontario - Minnesota Boundary Waters Fisheries Atlas (OMNR/MN DNR, 2004). The objective of this plan is to re-establish and maintain the sturgeon populations in a self-sustaining manner in suitable habitats within Ontario and Minnesota, while providing subsistence, recreational and commercial fisheries along with some trophy fishing for fish greater than 183 cm in length (OMNR/MN DNR, 2004). A fully recovered population would include fish with age, size, abundance, and brood stock characteristics that are similar to those of unexploited or lightly exploited populations (OMNR/MN DNR, 2004). Today, harvest in Ontario is minimal, restricted to subsistence fishing only (<1000 kg/yr) since both commercial and sport fishing for lake sturgeon were closed in 2010 when they were classified as a threatened species under the Ontario Endangered Species Act. Minnesota released their own lake sturgeon management plan (Talmage *et al.* 2009) for the U.S. portion of the Rainy River and LoW which further defines sturgeon management objectives and strategies around assessment, habitat, enforcement, and public involvement.

In Minnesota, where lake sturgeon are currently listed as a species of special concern, harvest pressure is through sport-angling, with controls that allow only one sturgeon per license year between 45 and 50 inches or over 75 inches total length. As well, the season closure date was recently moved to protect spawning fish. Average annual sturgeon harvest in Minnesota averaged 5,400 kg from 1997 to 2000, but increased to over 6,100 kg between 2001 and 2003. Mean annual harvest decreased to 3,062 kg (6,751 lb) in 2004 and 2005 (Topp & Stewig 2005). Beginning in 2006, anglers were required to buy a sturgeon tag and report their harvest within 48 hours. Sturgeon harvest from 2006 through 2013 has averaged 2,955 kg (ranging from 1,554 to 4,150) based on angler harvest reports (P. Talmage, MN DNR, Baudette, MN, pers. comm.). Open season for lake sturgeon in the border waters is April 24 – May 7 and July 1 – September 30. Minimum size limits during this time is 114-127 cm (45-50 inches) inclusive or over 190.5 cm (75 inches). Anglers may catch and release lake sturgeon from July 1st through May 14th.

To assess recovery of the sturgeon population, an intensive tagging survey was performed in 2004 and 2005 in a collaborative project between the MN DNR, OMNR, and the Rainy River First Nations (RRFN). The purpose was to generate a more accurate description of size and age structure of sturgeon longer than 1,000 mm. From this study, it was estimated that the population size of lake sturgeon over 1,000 mm in total length was 59,050 (+/- 30,736-121,372). This was higher than the estimate made in 1991 of 16,910 sturgeon (Mosindy & Rusak 1991). Based on the Peterson Mark Recapture method, sturgeon abundance estimates for individuals longer than 1,000 mm in 2003 and 2004 were 47,054 and 62,875, respectively (Heinrich 2006). Another population estimate, again involving MN DNR, OMNR and RRFN is planned for 2014.

Total lake sturgeon abundance has increased, and there are more sexually mature female fish in the population such that natural reproduction and recruitment have improved.

Total lake sturgeon abundance has increased, and there are more sexually mature female fish in the population such that natural reproduction and recruitment have improved (based on Heinrich 1990-2006; Topp & Stewig 2005-2006). The reason for this was because the sturgeon population in the Rainy River and the southeast corner of LoW was growing and recruitment was consistent over the last 30 years. In 2005, Stewig recommended that the short-term goal level of harvest (0.025 kg/ha) be maintained for at least 5-10 years (Stewig 2005) to allow the sturgeon population to continue to expand. Short-range goals were achieved in 2013; management is now under the context of the long-range goals (outlined in OMNR/MN DNR 2004) with a harvest level of 0.04 kg/ha.

There are currently at least two discrete populations of sturgeon in LoW and the Rainy River: one that remains within the lake and the other that migrates to the river in the winter months (Rusak & Mosindy 1997). These two populations use the same spawning grounds located at Long Sault Rapids, Manitou Rapids, just below International Falls on the Rainy River, and additional sites upstream on major tributaries such as the Big and Little Fork Rivers in Minnesota (Rusak & Mosindy 1997). However, population differences appear to be related to their preference for particular winter habitat, which was linked to foraging behaviour (Rusak & Mosindy 1997). The return of sturgeon from their winter spawning grounds was related to a trend of increasing flow and temperature (Rusak & Mosindy 1997). Because river temperatures begin to increase sooner than lake temperatures, the river population spawns earlier based on the different spring warming cue which could have allowed for population segregation over evolutionary time (Rusak & Mosindy 1997). Overall, it is important to consider the possibility of the existence of more than one population when managing and protecting sturgeon populations. Furthermore, their widespread movements, particularly in the spring and summer months, mean that it is important to take their entire ranges into account when protecting and managing the populations (Rusak & Mosindy 1997).

Sturgeon populations in Namakan Reservoir have been intensively studied in recent years (Shaw *et al.* 2012). Since the early 1900s, dams at the outlets of Rainy and Namakan lakes have prevented the upstream movement of lake sturgeon thus isolating these fish into three populations: Namakan Reservoir, Rainy Lake, and Rainy River/LoW (Mosindy and Rusak 1991; Adams *et al.* 2006). Previous lake sturgeon research in northern Minnesota and Ontario has been conducted in Rainy Lake (Adams *et al.* 2006), the Rainy River (Mosindy and Rusak 1991; Stewig 2005), and the lower Seine River, which is a tributary of Rainy Lake in Ontario. Little is known about the lake sturgeon population of the large and complex Namakan Reservoir where future hydropower development has been proposed (McLeod 2008).

In 2011, the Seine River First Nation, in conjunction with the OMNR, monitored water temperatures and levels at two locations downstream of the Crilly Dam and inserted transmitters in 12 sturgeon as part of a pilot project. Study objectives have been set with the assistance of fisheries consultant Ryan Haines, as submitted in a report to the Boards (IRLBC-IRRWPB). The Seine River

Releasing fish in Voyageurs National Park (U.S. NPS Staff Photo)

First Nation hopes to determine:

- how peaking and ponding influences on water levels and flows affect the sturgeon spawning
- how timing of the spawn may be determined by temperature and other surrogate parameters
- the effects of backwater from Rainy Lake on the Seine River.

The Manitou Fish Hatchery began sturgeon aquaculture with support from Ontario Hydro in the early 1990s. Other than the release of several thousand fry into the Rainy River for ceremonial purposes, the majority of sturgeon fry produced at the hatchery are sold to MN DNR, OMNR and Manitoba Hydro for research and stocking elsewhere. For more information contact Joe Hunter, hatchery manager, Rainy River First Nations, Emo, ON.

Walleye / Sauger
(Sander vitreus / Sander canadensis)
Walleye and sauger are commercially important piscivorous fish, although their diet will include invertebrates (copepods and crustaceans) during the first few months of their life. Swenson (1977) determined that walleye food consumption is influenced by macrophytes, light conditions, prey availability, and season; while sauger food consumption rates (which were lower than those of walleye) are influenced by wave activity and prey density. Walleye that were tagged at several spawning sites in LoW and the Rainy River revealed that most walleye travel within 10-15 km (6-9 mi) of their spawning area (OMNR/MN DNR 2004).

Shoal Lake - Both commercial and sport fishing for walleye on Shoal Lake were closed in the spring of 1983, following a drastic population decline from over fishing. As late as 2006, regular monitoring indicated that a protracted recovery was occurring but adult biomass and survival have remained low, partly attributable to continuing fishing mortality from a subsistence fishery. Increases in northern pike (*Esox lucius*), lake whitefish (*Coregonus clupeaformis*) and smallmouth bass (*Micropterus dolomieu*) abundance have been observed. Rainbow smelt (*Osmerus mordax*), an anadromous marine fish species native to Atlantic Canada, were first detected in 1999. Recent fish community changes involving declines in native coregonid populations, especially cisco (*Coregonus artedii*), and improvements in recruitment and survival of walleye since 2005 which are finally leading to a recovery; three decades after the fishery closure (Mosindy 2013). Characteristics of the 2011 Fall Walleye Index Netting (FWIN) indicated substantial improvements in population status when compared to results from previous FWINs. Walleye age class structure has broadened to include representation of 16 year-classes, up from 13 in 2001 and 2006. While age structure continued to be largely restricted to fish age six and younger, the geometric mean number of walleyes age 6 and older had increased significantly from 0.43 walleye per lift in 2006 to 1.21 walleye per lift in 2011. Mean age of the catch had also increased from 3.3 to four years old between 2006 and 2011. Mosindy cautions that continuing high exploitation will offset recent gains, especially since strong 2005-2007 year-classes are fully vulnerable to 4.25 to 5 inch stretched mesh gill nets commonly used on LoW. Immediate controls on harvesting are vital to ensuring survival of four and five year old fish, otherwise recovery will return to where it was during previous assessments (Mosindy 2011).

Lake of the Woods - In 2010 Mosindy published the results of the status of walleye

Nearshore fish sampling.
(U.S. NPS Staff Photo)

in LoW South Sector 5, based on the 2007 Fall Walleye Index Netting (FWIN) results and compared them to previous FWIN results from 1997 and 2002. Overall walleye abundance, estimated at 8.6 fish per lift (geometric mean), had declined from 1997 and 2002 FWIN catches (Mosindy and Mucha 2006). McLeod and Rob (2009) noted a similar declining trend in walleye abundance from FWIN catches in the North Arm of Rainy Lake during the same time series (1997–2007). They also observed the same variability in recent recruitment patterns, including an absence of walleyes from the 2000 year-class, followed by an unusually large 2001 year-class. The population age class structure in Sector 5 was shown to broaden to include older age groups while the representation of older, mature fish had more than doubled from previous estimates. This reflected a long-term decline in total annual mortality rates, a direct result of lower exploitation by both commercial and sport fisheries since the late 1990s. A continuing decline in walleye growth rates and an increase in age at maturity since 1997 were indicative of decreased fishing pressure on walleye stocks in this area.

Results from MN DNR annual monitoring show healthy walleye and sauger populations in Minnesota waters.

Minnesota - Spring walleye electrofishing is conducted by the MN DNR to assess whether the walleye population is becoming stressed from overharvesting. This is accomplished by monitoring the abundance of large walleye and the size distribution of the spawning stock in the Rainy River (Heinrich 2013). Catch and possession limits for walleye and sauger are set by OMNR and MN DNR to protect and maintain the fishery. Results from MN DNR annual monitoring show healthy walleye and sauger populations in the Minnesota waters (Heinrich 2013). The walleye population is currently at the long-term mean abundance, up from lower relative abundances observed in the mid- to late-2000s. The declined abundance observed in the mid-to late-2000s was driven by two weak year classes (2002, 2004). Moderate to strong year class production in 2009, 2010, 2011, and 2012 should result in above average net catches in the next few years. Biological performance indicators indicate that the resource is not over-exploited (Heinrich 2013). Sauger is also within the normal range of abundance for MN waters. During the late 2000s abundance was at record highs, as a result of three consecutive strong year classes produced in 2005-2007. With the exception of 2011, no strong year classes have been produced since 2007. Creel information is also available from the MN DNR Office in Baudette.

Seasons and limits may vary and details should be checked at:
http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@letsfish/documents/document/mnr_e001325.pdf, and
http://files.dnr.state.mn.us/rlp/regulations/fishing/fishing2014.pdf#view=fit&pagemode=bookmarks

Lake Trout *(Salvelinus namaycush)*
Whitefish Bay and Clearwater Bay, located in the northeastern and northwestern regions of LoW respectively, have deep, cold, and clear waters that are ideal lake trout habitat. These regions of LoW have been known for their trophy lake trout fisheries.

In the 1980s, it was discovered that the lake trout in the main basins of Clearwater and Echo Bays were being negatively impacted by overharvesting by the winter fishery, reduced hypolimnetic oxygen, and above average levels of TP and chl a (Mosindy 1987). More specifically, declining hypolimnetic (deep water) dissolved oxygen levels and deteriorating spawning sites due to shoreline residential development and increased nearshore macrophytes and algal material were suspected as the main causes of lake trout decline.

Clearwater Bay has been developed for cottages, residences, and other tourism-related properties since the early 1900s. Development increased substantially beginning in the late 1940s (Hargan 2010), with the construction of roads and subsequently the Trans-Canada Highway in the late 1950s / early 1960s. This development went unchecked until the early 1990s when guidelines outlined by the Clearwater Bay Restricted Area Order (RAO) were instituted by the OMNR to restrict development of the Clearwater Bay region and to preserve lake trout habitat and other important ecosystems. In addition, a Clearwater Bay Lake Trout Strategy was developed by the OMNR in consultation with a Clearwater Bay Fisheries Advisory Committee and stakeholders in late 1980s.

Based on the results of Mosindy (1987) and the recommendation of the OMNR and the Clearwater Bay Fisheries Advisory Committee, the winter lake trout fishery on Clearwater Bay, Echo Bay, and Cul de Sac in LoW was closed in 1988, and a tag system was adopted for controlling harvest. This tag system limits the catch to one lake trout per angler per tag, with tags awarded by a lottery system. Baitfish cannot be used and only single, barbless hooks are permitted to minimize mortality from catch-and-release angling. In addition, a cottage evaluation program was recommended to assess the condition of septic facilities of regional cottages in an attempt to minimize nutrient inputs to the Bay. Changes to Ontario regulations in 2010 made angling for lake trout outside of Clearwater and Whitefish Bays catch and release only with no possession allowed. Lake trout are known to move into areas such as Ptarmigan Bay, nearby the closed winter fisheries, once surface water temperatures cool at which point they become vulnerable to harvest by winter anglers (Mosindy 2011).

In 1984, the OMNR began a long-term monitoring program in Clearwater Bay that focused on fisheries and associated water chemistry parameters. Because there were no previous long-term monitoring data from this region, the 1984 data would serve as a baseline for future studies. Clearwater Bay East, Clearwater Bay West, Deception Bay, and Echo Bay were monitored every 5 years from 1984-2007. In 2002, sampling locations were added in White Partridge Bay and Cul de Sac.

Although there is spatial and temporal variation in water quality in Clearwater Bay and Echo Bay, there were no significant trends in nutrients or chl a concentrations at sites in this region (DeSellas *et al.* 2009). However, studies have demonstrated that there is considerable variation in optimal lake trout habitat (based on hypolimnetic dissolved oxygen concentrations) between sites and years in LoW (Mosindy, 2006). Mosindy (2006) determined the amount of optimal lake trout habitat for each of the six OMNR sampling sites within Clearwater Bay with habitat quality based on mean volume weighted hypolimnetic dissolved oxygen concentrations (MVWHDO) > 7 ppm as defined by Evans (2007). End of summer is a bottleneck period for lake trout because the mixed surface water is unsuitable, i.e. >15°C, and oxygen conditions in the hypolimnion are near to their lowest concentrations before fall turnover. Although there was considerable temporal and spatial variation among sites, the deepest site, Clearwater Bay (50 m) and Deception Bay (32 m) had the highest volume of optimal habitat and two other deep sites, Clearwater Bay East (32 m) and Echo Bay (37 m) had the least amount of MVWHDO >7 ppm (Mosindy 2006). Overall, there was a general long-term trend showing an increasing amount of desirable lake trout habitat at most sites in Clearwater Bay from 1984 to 2004 (Mosindy 2006).

Ten years after the implementation of the Clearwater Bay Lake Trout Strategy and the RAO, lake trout habitat quality had improved in Clearwater Bay and Cul de Sac, and this was reflected by an increase in lake trout populations with increases in spawning and recruitment (Mosindy 2006). Declines in lake trout mortality to less than or equal to 20% in Echo Bay, Clearwater Bays, and Cul de Sac indicated success of the tag system. The health of lake trout populations in Echo Bay were still a concern at that time (Mosindy 2006). The low abundance and large fork lengths of lake trout in Echo Bay and Clearwater Bay sampling locations indicated that the fishery was dominated by a small number of older adults (Mosindy 2006). Slow recruitment was attributed to the continued exploitation of the fish population or to other habitat problems, such as low hypolimnetic oxygen (Mosindy 2006).

Rainbow smelt were accidentally introduced into upper reaches of the LoW drainage basin from Lake Superior in the 1960s. They have since spread throughout the R-LoW basin.

Shortjaw Cisco *(Coregonus zenithicus)*
Shortjaw cisco are listed as threatened on both the provincial Committee on the Status of Species at Risk in Ontario (COSARRO) and federal Committee on the Status of Endangered Wildlife in Canada (COSEWIC) species at risk lists (Fisheries and Oceans Canada 2013). Shortjaw cisco was originally reported to occur in Lake of the Woods during the early 1960s but had not been observed in recent years. Concerted netting by the LWFAU during 2010–2012 confirmed the presence of this species in Cul de Sac, Echo, Clearwater and Whitefish bays (COSEWIC 2013). Similar in size and shape to the common shallow water cisco (*C. artedii*), it has a slightly subterminal mouth, and fewer, shorter and coarser gill rakers. It was found only at depths >30 m (98 ft) in coldwater basins of LoW, where as a deepwater planktivore, it is vulnerable to eutrophication, changes in the zooplankton community and competition/predation by aquatic invasive species, such as rainbow smelt.

Invasive Species – Fish

Rainbow Smelt *(Osmerus mordax)*
Rainbow smelt were accidentally introduced into upper reaches of the LoW drainage basin from Lake Superior in the 1960s. They have since spread throughout the R-LoW basin where stratified basins allow adults to seek refuge below the thermocline in summer. Smelt were first detected in Namakan Reservoir and Rainy Lake in 1990 and LoW in 1991 (Franzin *et al.* 1994). They were likely introduced by anglers, and through downstream migrations in the Rainy River (Franzin *et al.* 1994). Rainbow smelt populations peaked in 1996 in Rainy Lake and by the 2002-03 sampling season, only one smelt per net on average were detected in Rainy Lake (Kallemeyn *et al.* 2008). Smelt are targeted by predatory fish such as walleye, northern pike and lake trout which may result in a corresponding increase in growth rate of these piscivores. Walleye numbers, for example, increased significantly during the 1990s following the invasion of rainbow smelt (Kallemeyn *et al.* 2008). However, they were known to displace some members of the whitefish family such as cisco and lake whitefish in Shoal Lake (Mosindy 2013). Invasions can causes shifts in fish community structure through competition and by predation on other young fish. Invasions in Shoal Lake were shown to have no impact on yellow perch, northern pike, smallmouth bass or white sucker populations (Mosindy 2013).

Despite its elevated position in the food web relative to other forage fish, the inclusion of rainbow smelt in trophic food webs of northwestern Ontario lakes does not lead to observed increases in mercury in other predatory fish (Swanson *et al.* 2003; Swanson *et al.* 2006).

Maintaining healthy predator populations appears to be key to controlling impacts of smelt on the fish community (Mosindy 2013).

Macrophytes and Emergent Plants
Macrophytes play an important role in aquatic ecosystems. They stabilize lake and river sediment, influence the chemical conditions of the sediment and water, cycle nutrients and organic matter, and they provide structured habitat for fish and their prey (Carpenter & Lodge 1986).

The LWFAU conducted extensive surveys during the early 1990s to map critical fish habitat on island and mainland shorelines around Clearwater, Ptarmigan, Rat Portage and Bigstone Bays at the north end of LoW, and around Whitefish and Sabaskong Bays on the eastern side of the lake. Surveys focused on nearshore habitats and included physical characteristics such as shoreline vegetation, slope, existing development, nearshore substrate and aquatic vegetation present. Aquatic macrophytes were classified according to submergent, emergent and floating categories with estimates of percent cover by type.

Several additional macrophyte surveys have been conducted on Shoal Lake (Pip *et al.* 1984; Pip & Simmons 1985; Guy 1988; Sutherland 1985; Pip & Simmons 1986; Pip & Sutherland-Guy 1987; Pip 1987; Pip & Sutherland-Guy 1989; Sutherland-Guy & Pip 1989; Pip 1990) and as part of the Rainy Namakan Rule Curve studies (see Table 3).

For additional information regarding aquatic macrophytes in Minnesota lakes see Neuman (2008).

Invasive Species – Emergent plants

Cattail *(Typha xglauca)*
Hybridization of two cattail species, *Typha latifolia* and *T. angustifolia* is quite common throughout northeastern and central North America, including the Great Lakes Region. The hybrid species, *T. xglauca*, can tolerate wider ranges in water level fluctuations, disturbances (such as eutrophication), salinity, and pH compared to the parent species (Smith 1987). In addition, water management practices in recent decades have decreased drought and flooding events, which historically minimized cattail expansion in this region. These characteristics and conditions have led to the rapid spread and colonization of cattails in wetland habitats of many areas in North America, including the Great Lakes region and Voyageurs National Park (Windels *et al.* 2007a,b). The resulting monocultures pose a threat to biodiversity and ecosystem function, as they often outcompete and shade out native plants. They may also be allelopathic, producing chemicals that discourage the growth of other plant species (e.g., Lee & Fairbrothers 1973).

The resulting monocultures pose a threat to biodiversity and ecosystem function, as cattail often outcompete and shade out native plants.

Due to an overlap of the morphological characteristics of both the hybrid and parental species, taxonomic identification is difficult without the use of genetic markers (Kuehn & White, 1999). Researchers with the National Park Service and USGS are using genetic techniques to investigate the role of hybridization in the spread of *Typha* in Voyageurs National Park (Windels *et al.* 2007a). These researchers are also examining management options for the hybrid *Typha* species in wetlands in this region, including water level modification, cutting and/or removal of plants, prescribed burning in early spring, and chemical control (Windels *et al.* 2007b).

It is clear from the examination of biological communities that there are invasive species present at most trophic levels and that invaders are inhabiting both aquatic and terrestrial environments. Invasive species are therefore a watershed concern and are examined in more detail in Chapter 3.

Mammals

Beavers
Recent studies in Voyageurs National Park have shown that hyrologically connected systems facilitate long distance dispersal in beavers (Windels 2013). Beavers typically disperse from natal areas between 2-3 years of age. Mean dispersal distances reported in the literature have generally not exceeded 10 km in northern systems, as predation risk from wolves and bears limit overland travel. Six-hundred-thirty-five beavers were ear-tagged from 2006-2012 in VNP. Trapping is not allowed in VNP and beaver densities exceed 1.0 lodges/km^2. Fifty-five ear-tagged beavers were reported legally trapped outside of the park between 2008 and 2012, of which 48 were determined to be dispersal events. Mean estimated dispersal distance by water was 31.4 km (19.5 mi). Maximum dispersal distance was 99.9 km (62 mi), with 10 others also exceeding 50 km. Dispersal was female-biased (62.5% of events), and females also dispersed farther than males (35.0 ±5.0

Muskrat (Kathleen Rühland)

km vs. 24.2 ±5.0 km). These results suggest that long-distance dispersal by beavers is facilitated in hydrologically-connected systems.

Muskrats

Environment Canada used digital elevation data to assess muskrat house sustainability with respect to water level fluctuations in the Rainy-Namakan system. They determined that muskrat houses were not sustainable in the system. This can have consequences considering that muskrats may be a factor in controlling hybrid cattail growth (Morin *et al.* 2014).

Deer and Moose

Recent studies suggest that deer and moose population dynamics will change throughout the basin in response to future climate change scenarios (Frelich and Reich 2010 and Frelich *et al.* 2012). The authors predict that warming will result in the replacement of moose (*Alces alces*) by deer (*Odocoileus virginianus*). This shift and others in consumers (see Part 1, Land Cover-Terrestrial Vegetation) may induce a cascade of ecological impacts across trophic levels that could alter the boreal to temperate forest transition and lead to the succession of novel plant communities.

Minnestoa's moose population, which is concentrated in the NE corner of the state, has been in decline for reasons that are poorly understood. Population declines in the NW population in the 1980s-2000s were correlated with increasing summer temperatures. In 2008, the MN State Legislature directed the DNR to establish a Moose Advisory Committee that would recommend elements of a Moose Management and Research Plan which was approved in 2011. It is recognized that this will be a lengthy and costly, but necessary process. The Minnesota Moose Research and Management Plan is available at: http://files.dnr.state.mn.us/fish_wildlife/wildlife/moose/management/mooseplan-final.pdf.

American White Pelicans (Patty Nelson)

Waterbirds

A variety of waterbirds are present in the R-LoW basin including waterfowl, wading birds, and shorebirds. Some birds are present year-round, while others are migratory with breeding grounds or stopovers in the basin. Species richness, composition, abundance and biomass of water birds are influenced by many factors, including littoral macrophytes, lake trophic status, and morphometry (Kalff 2002). Water birds usually occupy riparian zones and thus alterations to shorelines may add pressure to waterbird populations. For example, rising water levels may decrease available breeding habitat for ground-nesting birds who utilize aquatic shorelines.

The Important Bird Area (IBA) program is part of an international effort organized by BirdLife International to identify, conserve and preserve private and public lands that contain important bird habitats in Canada (IBA Canada 2004). There are two areas in LoW that host a large number of migratory birds each year, but are sensitive to environmental changes. These two regions have been designated as Important Birds Areas (IBAs) in Canada (http://www.ibacanada.com). The first is Three Sisters Island, which is a nesting colony for the American white pelican. The second is the Lake of the Woods Sand Spit Archipelago, which includes the LoW shoreline from Rainy River to Windy Point and areas inland (Harris *et al.* 2001). The Ontario portion of the Sandspit Archipelago IBA consists of the Sable Islands, Windy Point, and Burton Island, which are located approximately 25 km (15.5 mi) northwest of the town of Rainy River (IBA Canada 2004). The Minnesota portion contains Pine and Curry Islands, Tern Island, Morris and Rocky Points, and Zipple Spit (IBA Canada 2004). These sites contain exceptional wetlands and sandbars at the mouth of the Rainy River, and cattail and bulrush marshes, mud flats, sand barrier islands, sand beaches and points, rocky shorelines, bur oak woodlands, and other unique habitats that are available for breeding and staging birds (Harris *et al.* 2001). A total of 256 bird species are known to congregate on this IBA, 137 of them breeding (18 of which are year-round residents), 90 migrants, 29 non-breeding vagrants, and 17 considered rare in Ontario (Harris *et al.* 2001). These include the endangered piping plover as well as other waterbirds, land birds, and waterfowl (Harris *et al.* 2001).

The Ontario Ministry of Natural Resources (Kenora District, Fort Frances District, Thunder Bay, Ontario and the LWFAU) and the Minnesota Department of Natural Resources (Wetland Wildlife Populations and Research Group and Nongame Program, Bemidjii, Minnesota) have performed various surveys and studies regarding the population status and reproductive success of several bird populations in various regions of LoW, including the American white pelican (*Pelecanus erythrorhynchos*), double-crested cormorant (*Phalacrocorax auritus*), common tern (*Sterna hirundo*), bald eagle (*Haliaeetus leucocephalus*), and piping plover (*Charadrius melodus*). A list of MN DNR Bird Reports is available at: http://www.dnr.state.mn.us/eco/nongame/projects/research_reports/birds.html.

***American White Pelican** (Pelecanus erythrorhynchos)*

The American white pelican (AWP) was assessed by the Committee on the Status of Species at Risk in Ontario (COSSARO) as threatened in 2009 which is a re-assessment that reflects the species' expanding range and population in Ontario. AWP were formerly classified as endangered. In Minnesota, the AWP is listed as a species of Special Concern by the MN DNR (i.e., not endangered or threatened but extremely uncommon and/or has unique and specific habitat requirements). AWPs are protected in Ontario under the Fish and Wildlife Conservation Act as a *Specially Protected Bird*. Its conservation status is ranked as secure globally and nationally and imperiled provincially. AWPs are not listed under the Migratory Bird Convention Act (1994) and designated as Not at Risk federally by the Committee on the Status of Endangered Wildlife in Canada (American White Pelican Recovery Team 2011). In 2011 the Ontario Ministry of Natural Resources published *A Recovery Strategy for the American White Pelican in Ontario* (American White Pelican Recovery Team 2011).

Pelicans and cormorants together on an island in the south portion of Lake of the Woods. (Bev Clark)

The AWP is the largest colonial nesting bird in Ontario with a body length of approximately 1.3 m (4.3 ft) and a wing span of 2.4-3.0 m (Ratcliff 2005). AWPs breed in various locations in Canada and the U.S. and overwinter in the Gulf of Mexico. Their preferred breeding sites are on islands that are remote from mammalian predators and human disturbances (Ratcliff 2005). LoW is home to the oldest (since 1938) AWP nesting site in Ontario and is considered to be one of the largest in Canada. Most of the occurrences of AWP populations in Ontario are on Crown Land, with the exception of portions of Big Island (5 km north of the Three Sisters Island colonies) that have Indian Reserve Status (Ratcliff, 2005). In the Ontario portion of LoW, AWPs historically inhabited Dream Island, but this site was abandoned in the 1960s and the largest colonies are currently located on the Three Sisters Islands, to the west of Bigsby Island. These sites are less accessible to humans due to the presence of submerged rocks and the islands' deep soils support trees and vegetation that shelter young birds (Trottier *et al.* 1980). In the MN portion of LoW, AWP s nest on Crowduck Island, and they historically occupied Odell Island (Macins, 1991).

AWPs have been known to forage up to 300 km (186 mi) away in search of abundant food supplies (Ratcliff 2005). The feeding ranges of LoW AWPs extend to Rainy Lake in the east; Red Lake, Minnesota to the south; Whitemouth Lake, Manitoba to the west; and Separation Lake, Ontario to the

White pelicans target schooling fish such as yellow perch, shiners and bullheads. Occasionally sauger, pike, walleye and bass are consumed but in very small quantities.

north (Macins 1991). Since they do not dive to forage for food, AWPs tend to forage in small groups, and in deeper water they feed in association with double-crested cormorants. They target schooling fish such as yellow perch, shiners, and bullheads. Occasionally, sauger, pike, walleye, and bass are consumed but in very small quantities (Lockhart & Macins 2001). They consume an estimated average of 1.4 kg (3.1 lb) of fish per day. AWP s are known to dramatically alter the landscape through their nesting and colonial behaviour with vegetation and trees in the colony location becoming degraded over time (Lockhart & Macins 2001; Ratcliff 2005). There has also been concern in recent years over their effects on recreation, aquaculture, and fisheries (Wires & Cuthbert 2001a).

Populations of the AWP have increased dramatically since the 1960s in many areas of their range. The Ontario portion of LoW was estimated to have 5,595 breeding pairs in 2009 (American White Pelican Recovery Team 2011). In 2010 a new nesting island was discovered that may support a few hundred additional nesting pairs. In Ontario, nesting records from LoW have been collected consistently since 1965 (Ratcliff 2005). Over this period, the breeding population of the AWP gradually increased, stabilized, and has since declined. In all cases, the estimates for LoW, and elsewhere, reflect the number of nesting attempts with very limited information on the number of young fledged. At least for 2009, there is reason to believe that there was low recruitment based on observations reported from the adjacent Minnesota colony (American White Pelican Recovery Team 2011).

In the Minnesota portion of LoW, populations increased from 29 breeding pairs in 1973 to 832 pairs in 1997 (Macins 1991; K. Haws, MN DNR, Bemidji, MN, unpublished data). Since historical data on breeding pairs is not available in MN, it is not possible to determine if populations are continuing to increase in this state. Previous studies recommended that colonies (> 100 pairs) in MN, including those on LoW, be monitored at regular intervals of every three years (Wires *et al.* 2005). In 2004-05, the first statewide breeding census for cormorants and pelicans in MN was undertaken (Wires *et al.* 2006) and in 2010 a second complete census was conducted (Wires *et al.* 2011). In LoW, numbers nearly doubled since 2004 with increases occurring on two of the islands that were active in the first survey, and an additional site, Red Lake Rock, was used for nesting by a large number of AWPs in 2010.

American white pelican populations are influenced by disease, persecution, disturbance, predation, water levels and pollution/contaminants (American White Pelican Recovery Team 2011). For example, an increase in LoW water levels of 30 cm in 1989 caused a large reduction in available nesting habitat and may have contributed to a decline in nesting AWP count from 6,454 in mid-May to 4,046 in late June (Macins, 1991). Alternatively, when water levels are low, the normally isolated locations of the breeding colonies may become accessible to mainland predators such as coyote, raccoon, red fox, and striped skunk (Ratcliff 2005). In 2003, the West Nile Virus was identified as the cause of up to 90% mortalities in several U.S. states (Minnesota, Montana, North Dakota, South Dakota, Kansas, Missouri, and Iowa; Ratcliff 2005). Outbreaks of avian botulism have also been implicated in mortalities (Hendricks & Johnson 2002). Human presence near the breeding colonies may cause the adults to abandon their nests. AWPs nest in association with double-crested cormorants (see next section), and thus the control of cormorants in regions where they cohabitate will directly affect AWP breeding success (Ratcliff 2005). Given their sensitivity to human disturbance and their fish-foraging behaviour, they may become targets of illegal control efforts by local citizens.

***Double-crested Cormorant** (Phalacrocorax auritus)*

Double-crested cormorants (DCC) are large, fish-eating birds whose populations have experienced many changes over the past 100 years. DCCs occur in inland lakes and coastal areas of North America, and have been observed to nest on islands in LoW for hundreds of years (Environment

> Heinrich concluded that it is highly improbable that the present level of cormorant abundance has negatively impacted the walleye, sauger or yellow perch populations on Lake of the Woods.

Canada 2005) with reports dating back to 1798 (Peck & James 1983; Wires *et al.* 2005). DCCs nesting in islands in LoW from about mid-April to late August or early September tend to form large ground colonies, although they are known to nest in trees as well (Wires *et al.* 2005). As with white pelicans, with which they cohabitate, DCC nesting behaviour is known to impact vegetation communities on nesting islands (Hebert *et al.* 2005, S. Lockhart, OMNR, Kenora, ON, pers. comm.).

DCC's average weight is 2.0 kg (4.4 lbs) and they can consume approximately 25% of their weight in fish each day (Dunn 1975; Schramm 1984; Glahn & Brugger 1995; Hatch & Weseloh 1999). The presence of large numbers of DCCs has caused hostility among commercial and recreational anglers who believed that they threaten economically important fish stocks and aquaculture (Glahn & Brugger 1995). However, studies have demonstrated that DCCs feed primarily on small, largely non-commercial, shallow-water fish (Environment Canada 2005). In addition, cormorants in Lake Ontario have been shown to consume only about 0.5% of the prey fish, which is insignificant when compared to about 13% consumed by sport fish (Environment Canada 2005). Heinrich (MNDR 2008) in a review of cormorant-walleye interactions concluded that it is highly improbable that the present level of cormorant abundance has negatively impacted the walleye, sauger or yellow perch populations on LoW.

By the 1920s, LoW harboured some of the last known breeding colonies of DCCs in North America. In 1932 it was noted that cormorant numbers were declining steadily, mainly due to hunting by humans (Roberts 1932) and loss of ideal breeding and foraging habitat (Environment Canada 2005). In addition, between the 1950s and 1970s, DCCs were experiencing reproductive failure due to eggshell thinning and reproductive and growth impairments caused by organochlorine contaminants (such as DDT) (Environment Canada 2005, Bishop *et al.* 1992). Events over the past 30 years have led to the resurgence of DCC populations in North America. These include:

1. a ban on DDT (1972 in U.S., 1974 in Canada) and other pesticide reduction regulations
2. the addition of this species to the U.S. Migratory Bird Treaty Act protected bird list
3. reduction in human harassment/ overfishing
4. the introduction of alewife in the Great Lakes regions

Mallards and Canada Goose (Patty Nelson)

5. creation of additional nesting and foraging habitat (Environment Canada 2005).

In Minnesota, accurate historical data are not available and historical numbers are mostly based on qualitative descriptions of flocks of cormorants (Wires *et al.* 2001b). The majority of MN breeding pairs (75%) are located at ten sites (Wires *et al*. 2011) with colonies currently on Crowduck Island, Gull Rock, Little Massacre Island, Red Lake Rock, and Techout Island (Wires *et al.* 2011). In 2004, LoW was reported to have an estimated 4,370 cormorant nests but Wires *et al.* (2011) noted that significant change occurred in DCC numbers between 2004 and 2011, where nest numbers declined by 62%. Most of this decline was attributable to the abandonment of O'Dell Island, where nearly 2,000 pairs were recorded in 2004, but substantial declines occurred at other LoW colonies as well.

Currently, the DCC populations that nest on the Ontario portion of LoW are considered to be stable or slightly decreasing with increases over the past several decades attributed to bans on organochlorines (in the early 1970s) and an increased tolerance towards the birds. There are currently no management plans or monitoring programs in place for DCCs in the Ontario waters of LoW.

The concentration of cormorants at a small number of sites in LoW makes them extremely vulnerable to extreme weather, disease, human disturbances, and hydrological changes. It has been recommended that large colonies of DCCs be monitored at intervals of at least once every three years (Wires *et al.* 2005). Similar to white pelicans, cormorants are sensitive to human disturbance, and thus careful sampling methodologies must be employed when doing population studies. Cormorants often nest in the same trees and islands as other bird species that are sensitive to human disturbance, including white pelicans, common terns, and herons (Wires *et al.* 2005). Entering nesting sites to control cormorant populations would have direct effects on the breeding success of these birds (Ratcliff 2005).

An excellent overview of cormorant interactions with its environment and insights into management actions directed towards this species is contained in *Cormorant—Plight of a Feathered Pariah* by Linda R. Wires (2014).

Common Tern *(Sterna hirundo)*
Common terns (terns) are medium-sized birds with wingspans of 70-80 cm. Terns make their nests on rocks near the water's edge and forage by plunge-diving for fish. Terns are known to nest in the MN portion of LoW at Pine/Curry Islands, the Northwest Angle, and Zipple Bay (Haws 2005). They are uncommon in the Ontario waters of LoW but sometimes nest on Windy Point and are more frequent during migration months (Harris *et al.* 2001).

Terns are listed as threatened in MN: (http://www.dnr.state.mn.us/rsg/profile.html?action=elementDetail&selectedElement=ABNNM08070T). They are highly susceptible to shoreline and island erosion, and habitat loss that is associated with rising water levels, such as in areas of Pine/Curry Island, the south shore of Fourmile Bay, Sandy Shores (east of Rocky Point), and the shoreline between Rocky Point and Long Point (Cuthburt & McKearnan 1985; Herb *et al.* 2004; Haws 2005). In 2003, more than 200 adults were observed with 40-50 nests in July and 140 young fledged and this success was attributed to unusually low water levels (Haws 2005). High water years, such as 2002, tend to result in lower numbers of fledged young (Haws 2005). In 2003, a new nesting site was observed west of Crowduck Island, at a site named Joshua's Reef where 153 tern nests were observed in July (Haws 2005).

Predation and competition for breeding space have negative effects on tern success (e.g., Haws 2005). Terns compete with ring-billed gulls for breeding space, and gulls may prey on tern chicks and eggs. A federal permit has been obtained by the MN DNR to remove gulls when they are present in common tern and plover nesting sites. Trapping of mammalian predators in the regions of nesting sites has been attempted in the past, but this is ineffective in low water years where land bridges are formed. In 2004, a colony located on Morris Point on Pine/Curry Island had 109 tern nests, but there was complete nest failure due to predation (Haws 2005). Monitoring and management plans for common terns on Pine and Curry Island have been recommended.

Piping Plover *(Charadrius melodus circumcinctus)*

Piping plovers (plovers) are small migratory shorebirds that live along shorelines and make their nests on sparsely vegetated sand or gravel beaches. They are predominately monogamous and tend to return to the same natal and/or adult breeding site each year. There are currently less than 6,000 piping plovers left in the world (Environment Canada 2007c). There are two subspecies of piping plover in Canada: an Atlantic coast subspecies (*C. m. melodus*), which occurs in the Maritimes, Québec, Newfoundland and Saint-Pierre-et-Miquelon and an inland subspecies (*C. m. circumcinctus*), which is found in Alberta, Saskatchewan, Manitoba and in North Western Ontario. The LoW subpopulation in Ontario and Minnesota is considered to be part of the Great Plains population. This subspecies is listed as either threatened or endangered throughout its entire range in North America.

There are currently less than 6,000 piping plovers left in the world.

In 2013 the Ontario Ministry of Natural Resources published a recovery strategy for the piping plover in Ontario (Kirk 2013). This is a comprehensive document with an ambitious strategy to aid in plover recovery. There are numerous references to the LoW plover population. Kirk notes that the number of breeding pairs on LoW has been sporadic. At Windy Point, no birds were confirmed nesting from 1987 to 1991, or in 2001. However, single pairs nested (nests with more than one egg) in 1979, 1995 to 1997, 1999, 2000, 2009 and 2010. Two pairs nested in 1998, 2002, and 2007. The last successful nesting at Windy Point was in 2009 when one chick was reported to have fledged. While nesting was initiated in 2010 and again in 2011, these nests were not successful. No successful nesting was recorded in 2012 on the Ontario side of Lake of the Woods (Kirk 2013). At Sable Islands Provincial Nature Reserve, no confirmed nesting took place between 1992 and 2006. Single pairs nested in 1979, 1986 to 1988, 1990, 1991 and 2007, and two pairs in 1989. The last nesting attempt (unsuccessful) at Sable Islands was in 2007.

Piping plover numbers on the U.S. side of LoW in Minnesota reached a peak of 47 to 50 adults in 1984 and have declined steadily to only two adults in 2010. In 2012, two chicks were reported to have fledged from the Minnesota side of the lake on Pine and Curry Islands (Kirk 2013).

Like the common tern, piping plover are particularly vulnerable to annual shifts in water levels and erosion (e.g., Maxson & Haws 1992; Haws 2005; Environment Canada 2007). In drought years, landbridges can form between the nesting islands and the mainland, allowing predators to enter the breeding areas. In addition, nests are destroyed when floods occur. During high water years, not only are there fewer nesting locations available, but shoreline erosion decreases available nesting habitat for future years. Erosion of the soft, organic sediments of parts of the LoW shoreline has been occurring at four areas of LoW over the last 40 years, including Pine and Curry Island, the south shore of Fourmile Bay, Sandy Shores (east of Rocky Point), and the shoreline between Rocky and Long Points (Herb *et al.* 2005). In addition, inundation of certain areas by high waters has irreversibly damaged the plover and tern nesting habitat (Haws 2005). In LoW, the primary predation threats come from loafing gulls (Kirk 2013). These include ring-billed gulls, herring gulls and Franklin's gull (*Leucophaeus pipixcan*), which has a more westerly distribution and does not breed in the eastern Great Lakes. After gulls, the American crow is thought to be the most important predator. Human disturbance probably has much less of an effect on piping plovers in the LoW subpopulation than in the Great Lakes subpopulation (Kirk 2013). Egg and chick losses also result from predation by mammalian predators (Wiens & Cuthbert 1984; Maxson & Haws 2000). Additional threats to survival and recovery noted by Kirk (2013) are:

- habitat loss and degradation
- watershed level habitat change

- ice-scouring, storms and other natural events
- habitat loss in wintering areas
- climate change
- disease and pollution
- energy development.

Despite intensive management efforts since the 1980s, the reproductive success of piping plovers is low in LoW, and its populations have been declining steadily since 1988 (Maxson & Haws 2000; Heyens 2006). In the 1980s, approximately 50 birds were recorded at one location on the MN portion of LoW (Maxson & Haws 2000) but in the MN and ON portions of LoW, piping plover numbers declined from 18 adults in 1991 to 13 adults in 1996 to 8 adults in 2001 (Environment Canada 2006; Heyens, 2006). This is concerning because this remnant plover population at LoW in Ontario and Minnesota serves as a possible link between the populations of the Northern Great Plains/ Prairies and the Great Lakes. Kirk (2013) shows no breeding birds in the MN/LoW sub-population and only a couple of birds in the Ontario LoW population as at 2011.

In the past, a number of management strategies have been employed in an attempt to increase plover populations. For example, potential crow/raptor perch trees were cut down, herbaceous vegetation was hand-pulled at various plover nesting sites, elevated string gull deterrents were set, predator exclosures around nests were used, American crow (*Corvus brachyrhynchos*) and ring-billed gull nests were destroyed, mammalian predators were trapped, and sanctuaries were signed (Maxson & Haws 2000). In addition plover chicks were banded when possible to monitor the return of adult birds to each site (Maxson & Haws 1992; Haws 2005). Wire mesh exclosures will continue to be placed around plover nests once one egg has been laid and nests in imminent danger of rising water levels moved to higher ground (Haws 2005; Heyens 2006). Due to suspected egg predation by Franklin's gulls in 2007, it has been suggested that the exclosure design be changed to one used by the Province of Alberta that is smaller, stackable, and less likely to be used as a predator perching location (Heyens 2007). Public outreach and education on the sensitive habitat areas of these birds, the rules associated with them, and the justification of these rules will continue to be administered by the MN DNR Nongame Wildlife Program and Wetland Wildlife Populations and Research Group and OMNR (Haws 2005; Heyens 2006). In Ontario the protection and recovery objectives are ambitious and well documented in the Piping Plover Recovery Strategy (Kirk 2013).

Immature bald eagles. (Patty Nelson)

***Bald Eagle** (Haliaeetus leucocephalus)*
The bald eagle is assessed by the Committee on the Status of Species at Risk in Ontario (COSSARO) as a species of Special Concern. The Special Concern classification withdraws bald eagles from Endangered Species Act legislation and regulations, but they remain a Species at Risk under Ontario policy and receive protection through the Province's Fish and Wildlife Conservation Act. In the U.S., bald eagles were removed from Endangered Species Act classifications in 2007. However, they continue to be protected under the Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act.

Bald eagles are large, strong, predatory birds that occur near large bodies of open water where fish are plentiful and where there are tall trees for nesting and roosting. In addition to fish, they prey on waterfowl, shorebirds, and small mammals, and are also scavengers of the shoreline areas. They occur across North America, including LoW and are considered to be an ambassador species for other species in the ecosystem, indicators of environmental health, part of traditional First Nations' culture, and popular with the general public including tourists (Grier *et al.* 2003).

Across most of their North American range, bald eagles were once considered to be on the brink of extinction. Habitat loss, persecution, and presence of persistent organic pollutants and other organochlorines (DDT, PCB, dioxins) throughout the 1900s severely depleted their numbers. Federal, Provincial, and State legislation in both Canada and the U.S. regarding hunting and disturbance of bald eagles and their nests, education and law enforcement, and the reduction of toxic pollutants has led to the recovery of bald eagles in many areas. In fact, the density of bald eagles in LoW is considered to be saturated and unlikely to increase due to natural and inter-population pressures and territorial behaviour (Grier *et al.* 2003).

Bald eagle populations in northwestern Ontario are successful in part because most human activity near nests occurs after the young have hatched, which is unlike southern Ontario where human presence is constant and where successful nests are normally 1 km removed from human activity (Grier *et al.* 2003). Bald eagles in LoW have been relatively well studied and populations at LoW and Red Lake/Lac Seul Areas, Ontario, have steadily increased based on a 1966-1998 study (Grier *et al.* 2003). In 1998 (the most recent data on record), the Kenora District OMNR reported 300 bald eagle nests on LoW, 40 on Shoal Lake, and 378 elsewhere (total=718), and the Fort Frances District OMNR office reported 357 nests in total. Future monitoring of bald eagles in LoW has been suggested to track their status since there are a number of factors that may be threatening populations, including human disturbance and destruction of nesting habitat, the possibility of personal capture of eagles, toxic pollutants, and diseases such as avian vacuolar myelinopathy and West Nile Virus (Grier *et al.* 2003).

In MN, the bald eagle is listed as a species of special concern. The Northern States Bald Eagle Recovery Plan established a goal of 300 occupied breeding territories in Minnesota. This goal was surpassed in 1987 when 350 occupied breeding areas were documented. Numbers and range of bald eagles have continued to expand and by 1994 there were 615 (known) occupied territories in the state. Consequently, the status of bald eagles under the state endangered species law was changed from threatened to special concern in 1996. (http://www.dnr.state.mn.us/rsg/profile.html?action=elementDetail&selectedElement=ABNKC10010).

Other Waterbirds

A number of waterbirds nest on or near the shores of the R-LoW basin and forage for food in its waters. Since 1980, a number of northern or prairie shorebirds have been present in late May and early June, such as the marbled godwit (*Limosa fedoa*), ruddy turnstone (*Arenaria interpres*), semi-palmated plover (*Charadrius semipalmatus*), red-necked phalarope, (*Phalaropus lobatus*) black-bellied plover (*Pluvialis squatarola*), sandhill crane (*Grus canadensis*), Bonaparte's gull (*Larus philadelphia*), and Franklin gull (*Larus pipixcan*) (L. Heyens, OMNR, Kenora, ON, pers. comm.). Most of these species only spend a short time on the lakes as they migrate to their feeding and/or breeding grounds. However, some individuals may stay longer if the spring is cooler or wetter than normal (L. Heyens, OMNR, Kenora, ON, pers. comm.). The waterfowl species continue to be healthy, including the ring-necked duck (*Aythya collaris*), mallard (*Anas platyrhynchos*), Eurasian widgeon (*Anas penelope*), Canada goose (*Branta canadensis*), green-winged teal (*Anas crecca*), common goldeneye (*Bucephala clangula*), and merganser (*Mergus sp.*) (L. Heyens, OMNR, Kenora, ON, pers. comm.).

A list of waterbirds spotted at Loon Lake Lodge, MN in 2010 include: common loon, American white pelican, great blue heron, Canada goose, tundra swan, wood duck, American black duck, mallard, blue-winged teal, ring-necked duck, lesser scaup, bufflehead, common goldeneye, hooded merganser, common merganser, and red-breasted merganser (http://www.visitloonlake.com/minnesota-vacations-rentals-drivedirections.htm).

Reptiles and Amphibians

Because many reptiles (e.g., turtles) and amphibians (e.g., frogs, toads, salamanders) are sensitive to pollution and terrestrial and aquatic habitat alterations, understanding their populations and distributions may provide insight into the status of the wetland habitats of the R-LoW basin. Despite their value as indicator species, studies of herpetofauna in the basin have been very limited. The OMNR Natural Heritage Information Centre documents sightings of amphibians and reptiles in a database that is available online (http://nhic.mnr.gov.on.ca/nhic_.cfm).

Minnesota's Frog and Toad Calling Survey (MFTCS) has been ongoing since 1993 to assess potential population declines of Minnesota's fourteen frog and toad species (Anderson & Baker 2002). This is a volunteer-based program that uses the methods established by the U.S. Geological Survey Biological Resources Division's North American Amphibian Monitoring Program (NAAMP). These methods are used to identify trends in Minnesota's frog and toad populations over time and each volunteer is certified prior to contributing data to the program. Frog and toad calls are counted and scored three times per year in the early spring, late spring, and summer. Frogs and toads surveyed at 10 sites along one route near Peppermint Creek near Baudette in Lake of the Woods County, have been studied almost annually since 1998. Frog and toad species at this site include: American toad (*Bufo americanus*), gray treefrog (*Hyla versicolor*), spring peeper (*Pseudacris crucifer*), western chorus frog (*Pseudacris triseriata*), northern leopard frog (*Rana pipiens*), and wood frog (*Rana sylvatica*) (Anderson & Baker 2002). Many of these species continue to receive a call rating where calls are constant, continuous, and overlapping, suggesting that species numbers are relatively high. In 2005, another route in the region was established near the Northwest Angle Inlet in MN and has been included in subsequent surveys. These data are included in NAAMP's eastern U.S. regional monitoring program (MN DNR, 2007).

Painted turtle (Bev Clark)

The MN DNR *Minnesota County Biological Survey* enlists volunteers to contribute data on a scheduled basis, and includes information on amphibians and reptiles. Surveys for most counties are completed with Lake of the Woods, Koochiching, Beltrami, Clearwater and St. Louis county surveys in progress for 2014 (http://www.dnr.state.mn.us/eco/mcbs/outcomes/map.html).

Amphibian research has been minimal in the R-LoW basin in Ontario. Canada, in the past, has had a community-based volunteer monitoring effort as part of their FrogWatch Program, which was a partnership between Environment Canada's Ecological Monitoring and Assessment Network (EMAN), Nature Canada, the Ontario Trillium Foundation, and the University of Guelph. Starting in April and May of each year in Northern Ontario, volunteer observers monitored their local wetlands for frogs and toads via sightings and calls and submit their results to FrogWatch. This program is currently housed at Naturewatch (www.naturewatch.ca).

Species at Risk

The Ontario Ministry of Natural Resources website lists the species at risk for different parts of Ontario. The most relevant area listed is the Rainy River area which encompasses much of the R-LoW basin. There are adjacent areas listed e.g., Kenora and Thunder Bay, but these regions stretch far to the north and east such that they contain species at risk that are not within the R-LoW basin. http://www.mnr.gov.on.ca/en/Business/Species/index.html?CSB_ic-name=specialInitiatives&CSB_ic-info=speciesAtRisk_Eng.

Species at risk in Ontario are divided into five categories as follows:

- extinct: no longer lives anywhere in the world
- extirpated: lives somewhere in the world, and at one time lived in the wild in Ontario, but no longer lives in the wild in Ontario
- endangered: lives in the wild in Ontario but is facing imminent extinction or extirpation
- threatened: lives in the wild in Ontario, is not endangered, but is likely to become endangered if steps are not taken to address factors threatening it
- special concern: lives in the wild in Ontario, is not endangered or threatened, but may become threatened or endangered due to a combination of biological characteristics and identified threats.

Ontario species at risk noted for the Rainy River are noted below. Endangered species are shown in bold.

Birds	American White Pelican (*Pelecanus erythrorhynchos*) threatened Bald Eagle (*Haliaeetus leucocephalus*) special concern Barn Swallow (*Hirundo rustica*) threatened Black Tern (*Chlidonias niger*) special concern Bobolink (*Dolichonyx oryzivorus*) threatened Eastern Meadowlark (*Sturnella magna*) threatened **Golden Eagle** (*Aquila chrysaetos*) endangered **Piping Plover** (*Charadrius melodus*) endangered Short-eared Owl (*Asio flammeus*) special concern Yellow Rail (*Coturnicops noveboracensis*) special concern
Fish	Lake Sturgeon (*Acipenser fulvescens*) special concern (Southern Hudson Bay/James Bay population), threatened (Northwestern Ontario and Great Lakes-Upper St. Lawrence River populations) Shortjaw cisco (*Coregonus zenithicus*) threatened
Insects	**Pygmy Snaketail** (*Ophiogomphus howei*) endangered
Mammals	**American Badger** (*Taxidea taxus*) endangered
Plants	Small-flowered Lipocarpha (*Lipocarpha micrantha*) threatened **Western Silvery Aster** (*Symphyotrichum sericeum*) endangered
Turtles	Snapping Turtle (*Chelydra serpentina*) special concern

Ontario's Biodiversity Council lists threats to biodiversity as: habitat loss, invasive species, population growth, pollution, unsustainable use, climate change, and cumulative impacts of threats. http://viewer.zmags.com/publication/c527c66f#/c527c66f/22

The Minnesota Department of Natural Resources website lists the endangered, threatened and special concerned species for Minnesota (http://www.dnr.state.mn.us/ets/index.html). These are listed below. Minnesota also has a State Wildlife Action Plan: Tomorrow's Habitat for the Wild and Rare (http://www.dnr.state.mn.us/cwcs/index.html) that lists the animal species of greatest conservation need (SGCN).

Bird	Boreal Owl (*Aegolium funereus*) special concern Nelson's Sparrow (*Ammodramus nelsoni*) special concern Short-eared Owl (*Asio flammeus*) special concern **Piping Plover** (*Charadrius melodus*) endangered Yellow Rail (*Coturnicops noveboracensis*) special concern Peregrine Falcon (*Falco peregrinus*) special concern Franklin's Gull (*Leucophaeus pipixcan*) special concern American White Pelican (*Pelecanus erythrorhynchos*) special concern Wilson's Phalarope (*Phalaropus tricolor*) threatened Common Tern (*Sterna hirundo*) threatened
Fish	Lake Sturgeon (*Acipenser fulvescens*) special concern Nipigon Cisco (*Coregonus nipigon*) special concern Shortjaw Cisco (*Coregonus zenithicus*) special concern Lake Chub (*Couesius plumbeus*) special concern Northern Brook Lamprey (*Ichthyomyzon fossor*) special concern Northern Longear Sunfish (*Lepomis peltastes*) special concern Redfin Shiner (*Lythrurus umbratilis*) special concern
Insect	Laurentian Tiger Beetle (*Cicindela denikei*) special concern Taiga Alpine (*Erebia mancinus*) special concern Leonard's Skipper (*Hesperia leonardus*) special concern A Caddisfly (*Hydroptila tortosa*) special concern Nabokov's Blue (*Lycaeides idas nabokovi*) special concern A Caddisfly (*Oxyethira itascae*) special concern
Lichen	Eastern candlewax lichen (*Ahtiana aurescens*) special concern **A Species of Lichen** (*Caloplaca parvula*) endangered A Species of Lichen (*Cladonia pseudorangiformis*) special concern **Yellow specklebelly** (*Pseudocyphellaria crocata*) endangered Peppered moon lichen (*Sticta fuliginosa*) special concern
Mammal	Least Weasel (*Mustela nivalis*) special concern Eastern Heather Vole (*Phenacomys ungava*) special concern Smoky Shrew (*Sorex fumeus*) special concern Northern Bog Lemming (*Synaptomys borealis*) special concern
Moss	**Luminous Moss** (*Schistostega pennata*) endangered
Mussel	Creek Heelsplitter (*Lasmigona compressa*) special concern Black Sandshell (*Ligumia recta*) special concern
Reptile	Blanding's Turtle (*Emydoidea blandingii*) threatened
Vascular Plant	Siberian Yarrow (*Achillea alpina*) threatened Maidenhair Spleenwort (*Asplenium trichomanes ssp. trichomanes*) threatened **Alpine Milk-vetch** (*Astragalus alpinus var. alpinus*) endangered Holboell's Rock-cress (*Boechera retrofracta*) threatened Common Moonwort (*Botrychium lunaria*) threatened Mingan Moonwort (*Botrychium minganense*) special concern Blunt-lobed Grapefern (*Botrychium oneidense*) threatened Pale Moonwort (*Botrychium pallidum*) special concern St. Lawrence Grapefern (*Botrychium rugulosum*) special concern Least Moonwort (*Botrychium simplex*) special concern Marsh Reedgrass (*Calamagrostis lacustris*) special concern

Larger Water-starwort (*Callitriche heterophylla*) threatened
Floating Marsh-marigold (*Caltha natans*) endangered
Coastal Sedge (*Carex exilis*) special concern
Yellow Sedge (*Carex flava*) special concern
Michaux's Sedge (*Carex michauxiana*) special concern
Prairie Sedge (*Carex praticola*) special concern
Twig-rush (*Cladium mariscoides*) special concern
Pigmyweed (*Crassula aquatica*) threatened
Ram's-head Lady's-slipper (*Cypripedium arietinum*) threatened
Rock Whitlow-grass (*Draba arabisans*) special concern
English Sundew (*Drosera anglica*) special concern
Linear-leaved Sundew (*Drosera linearis*) special concern
Neat Spike-rush (*Eleocharis nitida*) special concern
Few-flowered Spike-rush (*Eleocharis quinqueflora*) special concern
Autumn Fimbristylis (*Fimbristylis autumnalis*) special concern
Blanket-flower (*Gaillardia aristata*) special concern
Felwort (*Gentianella amarella*) special concern
Nuttall's Sunflower (*Helianthus nuttallii ssp. rydbergii*) special concern
Rock Clubmoss (*Huperzia porophila*) threatened
Bog Rush *(Juncus stygius var. americanus*) special concern
Creeping Juniper (*Juniperus horizontalis*) special concern
Auricled Twayblade (*Listera auriculata*) endangered
American Shore-plantain (*Littorella americana*) special concern
Small-flowered Woodrush (*Luzula parviflora*) threatened
White Adder's-mouth (*Malaxis monophyllos var. brachypoda*) special concern
Rock Sandwort (*Minuartia dawsonensis*) threatened
Large-leaved Sandwort (*Moehringia macrophylla*) threatened
One Flowered Muhly (*Muhlenbergia uniflora*) special concern
Thread-like Naiad (*Najas gracillima*) special concern
Small White Water-lily (*Nymphaea leibergii*) threatened
Blunt-fruited Sweet Cicely (*Osmorhiza depauperata*) special concern
Elegant Groundsel (*Packera indecora*) endangered
Franklin's Phacelia (*Phacelia franklinii*) threatened
Club-spur Orchid (*Platanthera clavellata*) special concern
Small Shinleaf (*Pyrola minor*) special concern
Lapland Buttercup (*Ranunculus lapponicus*) special concern
Sooty-colored Beak-rush (*Rhynchospora fusca*) special concern
Cloudberry (*Rubus chamaemorus*) threatened
Satiny Willow (*Salix pellita*) threatened
Encrusted Saxifrage (*Saxifraga paniculata*) special concern
Awlwort (*Subularia aquatica ssp. americana*) threatened
Torrey's Manna-grass (*Torreyochloa pallida*) special concern
Lavendar Bladderwort (*Utricularia resupinata*) threatened
Lance-leaved Violet (*Viola lanceolata var. lanceolata*) threatened
Barren Strawberry (*Waldsteinia fragarioides var. fragarioides*) special concern
Montane Yellow-eyed Grass (*Xyris montana*) special concern

2 HISTORICAL CONDITIONS

PALEOLIMNOLOGICAL APPROACH

Knowledge of background or pre-impact conditions is important for environmental research, as it can assist in the establishment of realistic reference conditions or mitigation goals (Smol 2008). Paleolimnology is a science that uses chemical, biotic, and physical indicators preserved in lake sediment profiles to reconstruct past environmental conditions in aquatic systems. Paleolimnology can help define the extent of change in a lake by extending the monitoring record to a time period that is prior to major anthropogenic disturbances. These techniques can be used to infer the range of natural variability of an ecosystem over time, as well as determine the point in time that a lake has changed (Smol 2008). Furthermore, because one centimetre of surficial sediment often represents two or more years of lake history, paleoecological records are integrative, thus reducing inter-annual variability (Glew 1988).

Paleolimnological studies that examine full length sediment cores provide large amounts of detailed information on ecological and environmental trends over long time scales. These detailed analyses can track environmental changes over time and, because they can be accurately dated, pinpoint the timing of a given change. However, if a regional assessment is desired, this approach is very time-consuming, and is often not practical from a management perspective (Smol 2008). As an economical alternative (and often in conjunction with a detailed core analysis), paleolimnologists may use the "top-bottom" or "before-after" method which examines two discrete time intervals—the top portion of the core (modern environment) and a bottom portion which is usually taken from a pre-industrial or background level in the sediments. This approach is useful because it provides a snapshot of present-day and pre-disturbance conditions and can be applied to multiple lakes across a region in a time-efficient manner.

Water quality and biota

Although paleolimnological-based diatom reconstructions have shown minimal limnological changes in lakes in the Northern Lakes and Forest (NLF) ecoregion since 1970 (Ramstack *et al.* 2003), agriculture and other land use practices (e.g., timber harvesting, urbanization) are present in the LoW and lower Rainy River watersheds which may indicate the potential for change. A paleolimnological study examining shifts in the diatom assemblages of Zippel Bay in southern LoW demonstrated that, although Zippel Bay is naturally eutrophic, TP levels have doubled in the past approximately 150 years (Reavie & Baratono 2007). This indicates that land use practices are being reflected by Zippel Bay's algal (diatom) record but there may also be a step change that is coincident with damming.

As a first step in assessing the spatial patterns in water quality across LoW, Pla *et al.*, (2005) examined the surface sediment, present-day, diatom assemblages in multiple cores from the LoW basin. Pla confirmed that there are significant spatial trends in water chemistry across LoW which was indicated by the sedimentary diatom assemblages. TP concentration explained 43% of this variation. The diatom assemblages also decreased in diversity with increasing TP concentrations. This was attributed to a decreased importance of diatom taxa and increasing importance of other algal taxa under eutrophic conditions (e.g., chlorophytes and filamentous cyanobacteria including *Anabaena sp.*, *Aphanizomenon sp.*). This variability was also partially explained by potential differences in sedimentation rates between sites, where the top 1 cm of sediment represents a longer period of

A sediment core is retrieved from a deep location in Lake of the Woods. (Kathleen Rühland)

Diatom-inferred water quality reconstructions show that there has been minimal long-term change in water quality of Voyageurs National Park inland lakes.

deposition at sites with lower sedimentation rates, and thus more diverse assemblages are possible (after Smol 1981).

Hyatt *et al.* (2011) used top/bottom methods to examine cores from 17 northern locations in LoW (including 12 Pla *et al.* sites plus 5 additional sites). Diatom-inferred TP reconstructions revealed that 88% of the sites showed either no change or a slight (but not significant) decline in TP between pre-industrial times and the present. The results showed that there were consistent changes in the diatom communities between pre- and post-industrial times and that the magnitude of these changes varied along a trophic gradient. These notable changes in diatom assemblages were among taxa that share similar preferences for nutrient concentrations, suggesting that TP was not responsible for the diatom shifts. The authors suggest that these results indicate that increases in temperature over the last few decades, and the associated changes to ice-cover and water column properties were key factors influencing a lake-wide restructuring of the diatom communities over the past approximately 150 years. This top-bottom assessment was consistent with diatom analysis from detailed, dated sediment cores from the LoW where the timing and nature of these lake-wide changes were in agreement with recent regional warming (Rühland *et al.* 2010). Similar results based on sediment records were observed for lakes in Voyageurs National Park where diatom communities changed in all lakes around the time of logging and settlement with some lakes showing more recent changes in diatom communities that may be linked to climate warming or other land-use changes. Diatom-inferred water quality reconstructions show that there has been minimal long-term change in water quality of Voyageurs National Park inland lakes (Edlund *et al.* 2010; Serieyssol *et al.* 2009).

Based on the high correlation between TP and diatom assemblages in LoW established by Pla *et al.* (2005), Paterson *et al.* (2007) expanded on this surface sediment calibration set by developing two different paleoecological models to reconstruct variation in TP concentration through time in LoW. They determined that the 'Reduced Model', which was based on similarities in chemistry of LoW sites and lakes in the Northern Lakes and Forests ecoregion of Minnesota (includes 55 lakes in the NLF ecoregion and 16 sites in LoW for a total of 71 sites), was superior to the 'Full Model' (which included 112 lakes from all Minnesota ecoregions and 16 sites in LoW for a total of 128 sites) in predicting TP in LoW. Rühland *et al.* (2010) used diatom-inferred TP reconstructions based on the Paterson *et al.* expanded calibration set for 4 locations (1 reference and 3 impacted). The results indicate that diatom assemblages in the four LoW sediment cores have undergone two pronounced and synchronous shifts over the last 200 yr. The first shift in the early 1900s corresponds with dam construction and logging activities within the LoW basin. This lake-wide response represents the first substantial change from pre-1900 diatom

Measuring water quality with a Secchi disk. (U.S. NPS Staff Photo)

assemblages. However, damming (and perhaps logging) do not appear to have had long-term effects on phosphorus concentrations, particularly at the disturbed sites. The second shift occurred in the last few decades and is consistent with the warmest temperatures on record for the LoW region. Recent changes in diatom inferred TP were observed at all sites, with modest decreases at the disturbed sites and a larger decrease at the reference site. The algae that Rühland *et al.* studied are diatoms and although these are not the same as blue green algae they showed that the types of conditions that are favoured by the more recent diatom communities are also those that are favoured by the blue green algae.

Stainton *et al.* (2007) collected six short sediment cores in 2002 (representing the last 150 years of sediment accumulation) from various regions in LoW, including Grassy Reserve, Whitefish Bay, White Partridge Bay, Clearwater Bay, and Monkey Rocks. Sediment sections from these cores were analyzed for carbon, nitrogen, phosphorous, chlorophyll and deposition rate. Quantification of siliceous and non-siliceous biological remains was performed on various sediment intervals from the cores from Grassy Reserve, Whitefish Bay, White Partridge Bay, Clearwater Bay and Monkey Rocks. Biological remains examined included phytoplankton microfossils (cyanophytes including akinetes, chlorophytes, diatoms, and chrysophytes), zooplankton remains (Cladocera, fecal pellets of copepods) and other invertebrates (thecate protozoa and sponge spicules) using methods presented in Kling (1998). Stainton concluded that phosphorus concentrations increased significantly in lake sediments starting in approximately the mid 1950s, with this trend being more prominent in the areas of the lake subject to main basin flow than in the more isolated Clearwater, Echo, and Whitefish Bays. These results may not indicate changes in historical P concentrations in the water column considering cautions that exist with respect to the movement of P in the sediments (Zhang *et al.* 2013; Ginn *et al.* 2012).

In 2012, Summers *et al.* examined chironomid and chaoborus (midge) remains preserved in a dated sediment core from Poplar Bay, LoW, Ontario, to assess the effects of multiple stressors (e.g., recent warming and shoreline development) on water quality over the past approximately 200 years. The effects of recent warming and shoreline development on Poplar Bay water quality were examined using an index of hypolimnetic oxygen status based on the ratio of chaoborus to chironomid remains (chaob:chir) and a midge-inferred volume-weighted hypolimnetic oxygen (VWHO) model. The results indicate that hypolimnetic oxygen concentrations in Poplar Bay have been historically hypoxic (1-4 mg/L) but have declined further to generally <2 mg/L over the last few decades. Significant relationships between air temperature and midge data indicate that substantial warming starting in the late-1970s has triggered a marked response in the midge assemblages that pre-dates the onset of cottage development (mid-1990s). These findings complement the Hyatt *et al.* (2011) diatom-based study on the same sediment core, likewise suggesting that recent warming has played a prominent role in structuring limnetic communities. Summers *et al.* (2012) cautions that it is likely that the full, compounded effects of recent warming and shoreline development have not yet been realized.

Agreement between several paleolimnological studies indicate that there has not likely been large changes over time in lakewide TP concentrations in the northern areas of LoW aside from evidence that concentrations may have declined in recent years in unimpacted areas. Evidence exists for changes in diatom community structure in recent decades due to aspects of climate change.

Crystal Hyatt taking a core of Bigstone Bay with OMNR support. (Todd Sellers)

Paleolimnological techniques have also been used to track the arrival and occurrence of the invasive cladoceran, *Eubosmina coregoni*, as well as *Bosmina sp.* in LoW (Suchy & Hann 2007). It was determined that *E. coregoni* arrived in LoW in the early 1990s. These results also show that *E. coregoni* and *Bosmina sp.* relative and absolute abundances were higher in the deeper northern (i.e., Cul de Sac, Echo Bay, Portage Bay, Clearwater Bay West, Ptarmigan Bay) sites and in some eastern portions of the lake (Sabaskong Bay, Regina Bay) compared to shallow, more isolated (Long Bay, Whitefish Bay south) or macrophyte-rich (Turtle Lake) areas (Suchy & Hann 2007).

Additional paleolimnological research provides good evidence that the blue green algal blooms are worse in recent years, based on the historical deposition of algal chlorophyll pigments in the sediments (Paterson *et al.* 2011). There are more pigments deposited in recent years in a way that lines up exactly with the increasing trend in the number of ice-free days over the last 20 years. These pigments are likely the result of blue green algal growth. So it is not just the diatom communities that are changing. If algal blooms have increased in occurrence or severity in response to climate change—then which aspects of the change are they responding to? Are the conditions which favour increased blooms related to the longer growing season or to some other factors (often related) such as increased water temperature, decreased vertical mixing (i.e., changes in wind strength), increased thermal stability, or increases in the number of wet years?

There are several reports and papers dealing with paleo results from the small interior lakes in Voyageurs National Park (small lakes upstream of Rainy Lake and Namakan Reservoir that are within Park boundaries). Many of these can be accessed via the NPS Great Lake Inventory and Monitoring website (http://science.nature.nps.gov/im/units/glkn/publications.cfm).

Morphology, Geology, and Hydrological Control

Differences in morphology, geology and hydrology throughout LoW are reflected in the sedimentary diatom assemblages (Pla *et al.* 2005). Sediment cores from regions on the Precambrian Shield (east and northwest) had diatom assemblages that are more typical of lakes elsewhere on the Precambrian Shield. In sites within the narrow channels of LoW, including Big Narrows and Tranquil Channel, flow is minimal and at the sites just north of these channels there was a decline in the importance of heavily silicified *Aulacoseira taxa* and an increase in the relative abundance of *Stephanodiscus* species, perhaps indicative of increased water column stability (Pla *et al.* 2005). In general, the well mixed conditions of the southern sections were dominated by *Aulacoseira* species (>40%) which are normally found in turbulent or well-mixed waters that reduce sinking rates for these relatively heavy diatoms (Pla *et al.* 2005). Alternatively, planktonic species with slower sinking rates (e.g., *Cyclotella sp.*, *Asterionella formosa*, *Tabellaria flocculosa*) are more abundant at the northwestern and eastern sites that are deeper and provide more stable water column conditions due to stronger late-summer stratification (Pla *et al.* 2005).

The initiation of hydrological control (including flooding and damming) on LoW had marked effects on the lake's phytoplankton communities (Rühland *et al.* 2010). Reavie & Baratono (2007) showed a decline in benthic and increase in planktonic taxa in the early 1900s that was coincident with hydrological control of LoW and subsequent flooding of Zippel Bay starting in the 1880s. The increased water levels and water column stability in Zippel Bay following flooding created a more favourable environment for plankton (Reavie & Baratono 2007). Serieyssol *et al.* (2009) found that damming, hydrological management, and settlement in the Namakan Reservoir area have had impacts that have increased sedimentation rates, decreased species richness, and increased total phosphorus and conductivity.

The initiation of hydrological control (including flooding and damming) on LoW had marked effects on the lake's phytoplankton communities.

Nutrient Loading / Erosion

Reavie & Baratono (2007) examined the sources and rates of sedimentation in Zippel Bay, a region of LoW that is experiencing rapid sedimentation and increased nutrient concentrations due to farm runoff and stream bank erosion. They determined that the majority of fluvial sediments to Zippel Bay are originating in the South Arm and have drastically increased since 1990. Despite the increased disturbance in the West Arm of Zippel Bay, contributions from the West Arm of Zippel Bay were found to be significantly less than the South Arm.

Edlund *et al.* presented ongoing efforts to construct a historical phosphorus budget for Lake of the Woods at the International Rainy-Lake of the Woods Watershed Forums in 2012, 2013 and 2014 (known as the International Lake of the Woods Water Quality Forum prior to 2014). They noted that efforts to reconstruct a historical P budget for LoW require two pieces of information—the amount of P historically lost from outflow and the amount of P buried in the sediment. The sum of these two quantities over time provides the historical record of P loading to the lake, which is a key piece of information needed by resource managers to address water quality and cyanobacterial issues currently impacting LoW. They conducted seismic profiling and sediment coring throughout the basin with short gravity cores used to define depositional zones and ground truth seismic data. Index cores (approximately 1 m) were also collected from Big Traverse, Little Traverse, Sabaskong, Muskeg, Buffalo Bay, and Big Narrows and these were analyzed for a suite of characteristics including dating, geochemistry (loss on ignition, phosphorus, silica), diatom communities, and fossil pigments. Results show that much of the southern basin of LoW is a depositional environment. Most cores show decreasing inorganics and increasing organics and carbonates during the last 200 years. Sedimentation rates across the southern basin generally increase two-fold between pre-1900 and modern times, with the cores from Big Traverse Bay showing three- to five-fold increases in sedimentation rates. Muskeg and Sabaskong Bays have the highest sedimentation rates among the southern bays. Two areas of the lake with unusual sedimentation patterns include Muskeg Bay, where much of the lake bottom appears non-depositional (lined with exposed Agassiz clays), and Buffalo Bay, where sediment accumulation may not have begun until water levels were raised at Kenora. Additional observations (Edlund *et al.* 2014) made possible with this work include:

- diatom species have shifted to eutrophic indicators post 1980s
- diatom productivity has increased since the 1960s
- northern areas show a weak P signal with a strong post-1980s climate signal
- southern areas show movement of legacy phosphorus upcore and potential climate influences on internal loading.

The proportion of total P loads that are represented by internal loads is unclear and the seasonal role that internal loads play with respect to fueling algal blooms is also unclear. Work to describe these processes is ongoing.

Climate Variables

Yang & Teller (2005) examined the changing depth and size of LoW since the retreat of the Laurentide Ice Sheet in northwestern Ontario. After separation of the lake from Lake Agassiz, LoW has expanded and deepened resulting from isostatic rebound. However, increased evaporation and reduced precipitation during the mid-Holocene likely stopped outflow and decreased lake levels and size. Using their modern hydrological budget for LoW, they demonstrated that a reduction in runoff and precipitation by 65% and an increase in lake evaporation by 40% would cause lake levels to drop below the outlet at Kenora. This has implications for climate change because the mid-Holocene has been considered a good analogue for recent climatic warming, since the change in temperature throughout the mid-Holocene was similar to that expected under a two fold increase in CO_2 (MacDonald *et al.* 1993).

(Patty Nelson)

Rühland *et al.* (2008) investigated the impacts of more recent climatic changes on LoW and other north-temperate lakes. They examined the sedimentary diatom assemblages from Whitefish Bay, (considered to be an unimpacted region of LoW) and found strong relationships ($p<0.005$) between sedimentary diatom data from this location and long-term changes in air temperature and ice-out records. The results indicate that recent warming and extensive increases in the length of the ice-free season on LoW have caused a taxon-specific reorganization of diatom community composition that is remarkably similar to diatom shifts observed in paleolimnological records from over 200 non-enriched, non-acidified lakes throughout the Northern Hemisphere including temperate, alpine and Arctic regions (see also the findings by Rühland *et al.*, 2010 in the previous Water Quality and Biota Section).

Serieyssol *et al.* (2009) found evidence of climate warming impacts in the sedimentary diatom communities in both Namakan Reservoir and Lac La Croix.

Enache *et al.* (2011) provided evidence that changes in diatom community structure since pre-industrial times are not limited to impacted areas. They studied 40 relatively undisturbed lakes in the Experimental Lakes Area of northwestern Ontario and found that changes in diatom assemblages are consistent with taxa that would benefit from enhanced stratification and a longer ice-free season.

Evidence that climate change is acting as a multiple stressor in many watershed processes identifies it as a watershed concern and is examined as such more closely in Chapter 3.

3 BASIN CONCERNS

The International Multi-Agency Arrangement (IMA) Technical Advisory Committee (TAC) has produced a five-year workplan (2014-2019) with the goal to produce the necessary materials required to establish initiatives (including restoration programs) that will address: water quality, severity of nuisance cyanobacteria blooms, shoreline erosion, aquatic invasive species, and the impact of climatic change on aquatic resources. This workplan will assist IMA member agencies to determine appropriate activities for LoW as they develop their internal work plans.

Overall objectives of the IMA workplan are as follows:

1. Determine if existing monitoring sites and protocols provide adequate information for the R-LoW basin.
2. Quantify the TP load from Rainy River to LoW with the installation of a United States Geological Survey (USGS) gauge at Wheeler's Point.
3. Continue to refine internal loading estimates and modeling for LoW (whole lake and southern basin upstream of the Little Traverse outlets).
4. Using the Basin Model (which will be completed in 2014), determine point and non-point source anthropogenic contributions to the nutrient budget for LoW and complete load and lake mass-balance modeling needed for the TMDL.
5. Complete the Total Maximum Daily Load (TMDL) study in U.S. waters, and develop nutrient and chlorophyll a reduction targets for the south end of LoW.
6. Partner with local, provincial/state and federal agencies to develop a historical nutrient budget for LoW that will determine how historical nutrient loads from the Rainy River Basin are affecting current water quality conditions.
7. Develop land use maps for the R-LoW basin.
8. Assess and map phytoplankton abundance, distribution, composition, using remote sensing
9. Compile a Landsat imagery database and water clarity maps.
10. Develop a monitoring/modeling program for assessing impacts of climate change on basin water resources
11. Complete/obtain detailed bathymetric maps and water circulation/internal water movement data for advanced lake modeling.
12. Assess and develop a GIS database of aquatic invasive species abundance and distribution.
13. Track projects and activities that are not continuous.

There are four management objectives:

1. Develop and implement a set of management strategies, focused on mitigation of effects of excess nutrients on water quality, based on preliminary identification of the most significant sources of nutrient loading to LoW.
2. Reduce nutrient loading to the Rainy River and its tributaries from permitted facilities.
3. Begin implementation of communications and public outreach strategies.
4. Update the 2009 State of the Basin Report (i.e., this current SOBR 2nd Edition).

The IMA workplan and its objectives are consistent with the topics identified in this report as being either basin concerns or issues by nature of the fact that more information is required. These same concerns are echoed in almost all summaries that have been developed throughout the basin. General concerns include, algal blooms, climate change, contaminants, invasive species, nutrients and internal loading, water levels and erosion. It should be noted here that the IMA five-year workplan is prescriptive with respect to the processes required to address each of these issues with strategies, timelines and project leads.

Algal bloom in nearshore area. (Environment Canada)

PART 1: ALGAL BLOOMS

Algal bloom characteristics are better understood in recent years due to the developing ability to track temporal and spatial changes in bloom extent using satellite imagery. More precise nutrient flux modeling that can predict seasonal changes in nutrient concentrations for specific sectors within the basin may also allow a better understanding of algal bloom responses to nutrient loads. These are recent developments that will eventually allow managers to assess the potential for bloom mitigation. Although much research indicates that climate change has altered algal communities and provides conditions which generally favour the cyanobacteria, it remains largely unclear whether recent blooms have increased in frequency or severity.

Gaps and next steps

There are several unanswered questions with respect to algal blooms:

1. The influence of P loads both from the Rainy River and from internal loads from the sediments on bloom frequency and severity have not been quantified.
2. Phosphorus loading from the Rainy River has decreased in recent years and at the same time algal blooms may be getting worse (possibly in response to climate change) but the bloom intensity over time and the drivers associated with between year differences in bloom intensity have not been clearly demonstrated. This makes it difficult to determine what the results of further phosphorus reductions from the basin would be since the reductions that have occurred to date do not seem to have helped to decrease the blooms.
3. Historical phosphorus in the sediments of Big Traverse Bay that was deposited during periods of higher loads may be available for algal production through the process of internal loading. It is uncertain whether or not the lake will eventually respond to recent phosphorus reductions from the Rainy River and how long this might take.
4. Nutrients and climate may not be the only factors influencing blooms. There is additional information from other science studies that can shed some light on the “multiple stressors” aspect of the blooms. Molot *et al.* (2010, 2014) have indicated that iron in lake sediments may play a role in the dynamics of blue green algal blooms.
5. The degree to which temperature increases may control nutrient supply from sediments is unknown.
6. The effect of water circulation and thermal stability on the transfer of nutrients and spatial extent of algal blooms is poorly understood.

Next steps can be identified relative to the IMA TAC objectives listed at the beginning of this chapter. Algal bloom concerns and gaps listed here are aligned with the IMA, TAC overall objectives #1 through 6, 8, 11 and 13. They are further aligned with management goals 1 and 2. In addition to these, there should be a focus on identifying the effects of multiple stressors on the dynamics of cyanobacteria blooms and an answer to the question of whether blooms have been more severe in recent decades. Paterson *et al.* presented evidence at the 2011 International Lake of the Woods Water Quality Forum in International Falls that may support the premise that blooms have been increasing concurrently with temperature changes in recent decades. They showed increases in lake sediment chl a concentrations since the mid-1900s, with more marked increases since the early 1980s at multiple sites in the Lake of the Woods. These results are, as of yet, unpublished.

PART 2: CLIMATE CHANGE

It is important to understand that changes in the climate have the potential to impact every state of the basin that we are attempting to describe.

It is important to understand that changes in the climate have the potential to impact every state of the basin that we are attempting to describe. Changes in the duration of ice-cover, for example, which are directly linked to climate will have compounding effects relating to other basin concerns noted here including Algal Blooms (Part 1), Invasive Species (Part 4) and with Water Levels, Waves and Erosion (Part 6).

Beier, in 2012, noted that:

> *"Scientific understanding of global climate change has largely outpaced knowledge of climate influences on ecosystems and human communities at the local and regional scales. Local studies of climate change impacts on ecosystem functions and services are needed for informing management, conservation and adaptation efforts, as well as fostering public awareness of the nature of climate change and its consequences for human well-being."*

Recent studies have found that warming temperatures may exacerbate the severity of blue-green (cyanobacteria) blooms in enriched lakes, because some cyanobacteria may have a competitive advantage at higher water temperatures (e.g., > 25°C) (Paerl and Huisman 2008). Warming also strengthens vertical stratification and the thermal stability of lakes, thus reducing water column mixing. Because many cyanobacteria can form intracellular gas vesicles that alter their buoyancy in water, they can float to the surface during periods of water column stability. When dense surface blooms form, they shade and severely limit the light available to other algae for photosynthesis, providing blue-greens a further advantage over other algal groups (Paerl and Huisman 2008). Algal assemblages in LoW may already be responding to recent increases in air temperature. In an examination of diatom algal fossils preserved in lake sediment cores from Whitefish Bay, LoW, Rühland *et al.* (2008, 2010) reported significant changes in species composition since pre-industrial times (pre-1850), with marked changes occurring over the past three decades. The timing of these changes was concurrent with recent increases in air temperature and increases in the duration of the ice-free period. Strikingly similar biological changes were also reported for more than a hundred lakes across vast regions of the Northern Hemisphere (Rühland *et al.* 2008) and for unimpacted lakes in adjacent areas of the basin (Enache *et al.* 2011). Some of these changes in climate may directly influence the inputs of P through the Rainy River through the effects of drought.

Climate change is expected to have a profound impact on coldwater fish in North American lakes. Jacobson *et al.* (2012) employed the oxythermal index to model the availability of coldwater thermal habitat in the Big Traverse and Whitefish Bay under increased mean annual temperatures scenarios. Greatest declines in thermal habitat during summer stratification were predicted to occur in Whitefish Bay, especially for lake trout, followed by whitefish, and to a lesser degree for burbot and cisco.

The terrestrial ecosystems are also predicted to change dramatically in response to changes in climate. Frelich *et al.* (2012) predict sweeping changes in forest cover from boreal to temperate species together with major changes in the major types of animals on the landscape including shifts from moose to deer and from below

Satellite photo of Lake of the Woods still covered with ice on April 29, 2014. (MODIS)

ground dominance of the types of worms present which will in turn affect the species of vegetation present. These changes will produce what he refers to as *novel ecosystems* which may be different from anything that we are currently familiar with. It is simply impossible to predict changes to the basin that could have effects that are as consequential as these would be.

In particular there should be increased action and awareness surrounding the importance of modifying human activities that contribute to climate change.

There have been many recent attempts to understand the impacts of regional climate change through basin research, and through the organization of climate change synthesis workshops. There are also provincial initiatives in place notably the Ontario Ministry of the Environment's Climate Change Progress Reports, http://www.ene.gov.on.ca/environment/en/category/climate_change/STDPROD_078898.html and the OMOE Climate Action Report – Adapting to Change, Protecting the Future (2011) http://www.ene.gov.on.ca/environment/en/resources/STDPROD_081658.html.

Gaps and next steps

Climate change concerns are being addressed to a great extent in the R-LoW basin where many aspects of regional climate change have been linked to physical and ecological processes. In planned future research, Phase II of the Historical Nutrient Loading study (Edlund *et al.*, in progress) will involve the building, calibrating and testing of a thermodynamic model to help understand the effects of temperature and water column stability on algal blooms. Additional future modeling will help to understand the role of hydrological control, and the effects of internal loads under a changing climate.

The ways in which climate change will affect the R-LoW basin should continue to be considered in all aspects of research, monitoring and management within the basin. Consideration of impacts linked to climate change and the role of climate change as a multiple stressor should be included in all future Environmental Assessments that take place in the basin. In particular there should be increased action and awareness surrounding the importance of modifying human activities that contribute to climate change. Regrettably there seems to be increasing focus on adapting to climate change (http://www.bbc.com/news/science-environment-26814742) with less discussion around addressing its causes (http://www.bbc.com/news/science-environment-26824943).

Next steps can be identified relative to the IMA, TAC objectives listed at the beginning of this chapter. Climate change concerns and gaps listed here are aligned with the IMA, TAC overall objective #10.

PART 3: CONTAMINANTS

Although there is not a complete inventory that can be examined, there are likely many fewer contaminants entering the R-LoW basin now than in the past. The International Joint Commission listed improvements in water quality in the Rainy River as one of the major accomplishments to date in the basin, in its final report to the governments of Canada and the United States on the work of the IJC's International Lake of the Woods and Rainy River Watershed Task Force (IJC 2012). They noted that by the 1950s the Rainy River was extremely polluted with human waste, bark, lime and sulphite solutions from municipal discharges and from the two pulp and paper mills at Fort Frances and International Falls. In the early 1960s the IJC conducted a study to recommend water quality objectives and remediation strategies for the river, pursuant to a 1959 Reference to the IJC from the United States and Canada. Following the initiation of the IRRWPB in 1966, conditions continued to improve with the establishment of international water quality objectives and subsequently alert levels recommended by the IJC. Sewage treatment and pulp and paper process improvements and more stringent regulations led to improved water quality by the end of the 1960s and continuing through the 1980s. They note that BOD levels in the river dropped from 74 metric tonnes /day in 1968 to the 2009 levels of 3.6 metric tonnes/day. The IRRWPB posted biannual reports relating to water quality on their website (most recent is 2011).

The Government of Canada maintains a list of federal responsibility contaminated sites within Canada on their website at: http://www.tbs-sct.gc.ca/fcsi-rscf/home-accueil-eng.aspx

There are six high priority, active contaminated sites in the Canadian portion of the LoW basin and ten medium priority active sites. These are shown in Table 29. There are an additional 6 low priority sites

TABLE 29 – The high and medium priority active contaminated sites listed by the Government of Canada in the Canadian portion of the basin.

Identifier	Location	Media	Contaminants	Priority	Status
33984001	Kenora Marina	Sediment 5,200 m^3	PHC, PAH, metals, organics	High	Develop Remediation/Risk Management Strategy
05178001	Rainy Whitehorse R.	Soil - 1 m^3	PHC and PAH	High	Additional assessment
05152002	Rainy River	Soil - 3,670 m^3 Groundwater	PHC, BTEX	High	Remediation/risk management planned
05152001	Fort Frances Sand Bay	Soil - 8,000 m^3	PHC and PAH BTEX, other	High	Detailed testing underway
05171004	Namakan Twenty Four Is.	Soil – 1 m^3	PHC and PAH	High	Remedial action plan under development
05184001	Seine River	Soil – 2,600m^3	PHC	Medium	Detailed testing underway
00014198	Namakan Brule Island	Soil	Metal, metalloid and organometallic	Medium	Detailed testing underway
00000609	Near Mica Point	Soil – 1 m^3	PHC	Medium	Detailed testing underway
00014256	Near Mica Point	Soil	Metal, metalloid and organometallic	Medium	Detailed testing underway
00014186	Near Mica Point	Soil – 4 m^3 7 ha	Metal, metalloid and organometallic	Medium	Detailed testing underway
00014691	Falcon Islands	Soil	Metal, metalloid and organometallic	Medium	Detailed testing underway
00014177	Bishop Bay	Soil – 3 m^3 5 ha	Metal, metalloid and organometallic	Medium	Detailed testing underway
00014251	Near Wiley Bay Crow Rock Ch.	Soil –		Medium	Detailed testing underway
00014574	Near Wiley Bay Micrometer Is.	Soil	Metal, metalloid and organometallic	Medium	Detailed testing underway
00014407	Bigstone Bay Heenan Point	Soil	Metal, metalloid and organometallic	Medium	Detailed testing underway

(not shown). Many of these sites represent relatively minor volumes of contaminated soil such as at the base of a navigation light. The Kenora Marina is the only site listed as being in water (sediments). Work to study and remediate these sites is ongoing. A listing of non federal responsibility U.S. and Canadian contaminated sites is not available.

A more detailed review of the potential for contaminants to enter groundwater from diffuse and point sources in the basin is required.

Point Sources

Several point sources of contaminants to the basin are shown in Table 30.

The Environmental Effects Monitoring Program (EEM) in Canada requires effluent producers, including pulp and paper mills, to monitor the effects of their effluent discharges on surface water receivers. Monitoring requirements include fish and benthos surveys and effluent toxicity testing. A series of monitoring cycles are required and the Canadian pulp and paper mills on the Rainy River have been through several cycles since the regulations came into effect. Effluent discharge of BOD, TSS, absorbable organic halogens (AOX) and TP from the Abitibi-Bowater mill at Fort Frances are normally well below compliance levels. In 2010, a Director's Order issued to Abitibi (Resolute) required the company to assess all sources of Total Reduced Sulphur (TRS) atmospheric emissions, submit a TRS reduction plan and a Technical Benchmarking Report (TBR). The TBR included an assessment of the best available technology to reduce the amount of TRS emissions. As a result of the order, the mill identified the wastewater treatment system as the highest source of TRS. Optimization of the wastewater system included removal of the initial settling ponds, incorporating a modified aeration system and construction of a nutrient addition facility. As a result, the company has significantly reduced the number of times that TRS has been exceeded and improved effluent quality (IRLBC/ IRRWPB - Fall 2012 Report - September 25, 2012).

The Fort Frances wastewater treatment plant was upgraded to secondary treatment in 1998. Average annual discharge in 2011 was 20 kg/d BOD, 47 kg/d TSS and 1.7 kg/d TP. The average TP concentration in the discharge was 0.2 mg/L, resulting in an annual loading of 697 kg. Bypass events have been recorded.

On the U.S. side the National Pollutant Discharge Elimination System (NPDES) permits industrial discharges of BOD, TSS, AOX, and TP from Boise Inc. to the Rainy River. The discharges of these effluent parameters have all been reduced substantially between 1996 and 2011 (IRLBC/IRRWPB, 2012). The current permit will expire in 2015.

The North Koochiching Sanitary Sewer District includes International Falls, which discharges sewage effluent to the Rainy River. The NPDES permit for the discharge, which will expire in 2016, sets limits for effluent parameters (BOD, TSS) which have shown steady improvement for the past few decades (IRLBC/IRRWPB, 2012). BOD was halved from 89.7 kg/d in 1996 to 41.6 kg/day in 2011. TSS was reduced from 50.4 kg/d in 1996 to 28 kg/d in 2011. The District has added an enhanced solids removal module, which will further reduce BOD and TSS discharges and provide for significant effluent reductions in phosphorus and mercury.

The Baudette wastewater treatment facility utilizes a lagoon with seasonal discharges to the Rainy River in spring and fall. NPDES permits levels of BOD and TSS in the discharge. The NPDES Permit limits phosphorus discharge for the Baudette facility to 367 kg/yr and the 2011 permit was modified to allow the facility to obtain equipment (by September 2012) for phosphorus treatment which reduces concentrations to 1.0 mg/L in the discharge.

Additional point sources include seasonal discharge from sewage lagoons at Emo, Rainy River First Nations at Manitou Rapids, Barwick and the Town of Rainy River.

IRLBC/IRRWPB board reports indicate that loads from point source discharges to the Rainy River from municipal and industrial sources have remained relatively constant

TABLE 30 – Point sources including waste water treatment plants (WWTP) and lagoons, and pulp and paper mills (PPM) located within the Lake of the Woods (LoW) catchment.

Name	Station Code	Water chemistry	Date Operational	Discharge Location
U.S.				
Williams WWTP, MN	MN0021679-SD-2	2000-2008	6/27/74	Williams Creek S. Branch Zippel Creek ? LoW
Baudette WWTP, MN	MN0029599-SD-1	1998-2004	7/28/74	Rainy River
Boise Cascade Corp. PPM, MN	MN0001643-SD-1	1999-2008	10/19/78	Rainy River
North Koochiching WWTP	MN0020257-SD-2	1999-2008	11/9/84	Rainy River
Warroad WWTP	MN MN0025194-SD-3		4/7/75	Ditch - Sprague Creek -Roseau River
ISD 363 – Indus Public School	MNG550009-SD-1		18/25/77	Ditch - Rainy River
Cook WTF			1988	Upgrades to ponds initiated in 2013
Ely WTF				
Canada				
Emo lagoon/WWTP, ON		2001-2007	1970s (40-60 d/yr)	Rainy River, immediately downstream of Emo
Barwick lagoon/WWTP, ON		No P data; 2005-07	1970s (48-72 h/yr)	Rainy River, upstream of Barwick
Rainy River Lagoon, ON		1996-2005	1970s (40-60 d/yr)	Rainy River, immediately downstream of the town of Rainy River
Abitibi Fort Frances (PPM), ON		1995-2005; 2008	1905	Rainy River
Abitibi Kenora			1905; Closed 2006	Near to LoW's Winnipeg River outlet
Manitou Rapids Lagoon		monitored		Rainy River
Fort Frances WWTP	MOE Certificate of Approval #3-0049-96-006	1996-present	Rebuild in 1998 to include secondary treatment and P removal	Rainy River
Kenora WWTP				Near LoW's outlet on Winnipeg River - east side of Old Fort Island
Atikokan WWTP	Ontario Clean Water Agency MOE C of A #3419-8C8LFJ	OCWA process data collection		Seine River
Lac La Croix lagoons				Outflow from Lac la Croix

and should remain at current levels for the foreseeable future.

Diffuse Sources

There are likely diffuse sources of contaminants associated with road salt in areas of the basin that are near to major roads and highways. These have not been specifically assessed or quantified.

There are diffuse sources of nutrients from shoreline property septic systems and it has been noted that the impact of these systems is likely more important in more enclosed embayments.

Diffuse sources of nutrients and other contaminants from agricultural areas have also not been assessed or quantified.

An effort should be made to complete an inventory of diffuse sources of contaminants in the basin to establish the level of concern that should be attributed to these sources, i.e. whether or not mitigation measures or management initiatives are required. This may be important with respect to historic mine site contamination of sediments (see below).

Mining

There is some evidence of effects on the environment as a result of mining. For example, the former Steep Rock Mine, an iron ore mine which operated from 1944 to 1979 was responsible for the release of dredged and stored suspended sediments to the Seine River during the spring freshet of 1951 (Sowa *et al.* 2001). The Steep Rock Mine was one of the largest undertakings of its kind with many water diversions and perturbations to the aquatic ecosystem to achieve war time extraction of iron ore. Water management of the former site continues today. Rat Portage, Bigstone Bay and Whitefish Bay were historical gold mining sites and Environment Canada (2013) noted that three of their sediment monitoring sites (Whitefish Bay, Bigstone Bay and Poplar Bay) where sediment concentrations of arsenic and barium were higher than expected were adjacent to historic gold mines. Aside from these observations, there is nothing of substance that is known about the effects of historic mining in the Canadian portion of the basin.

In Minnesota there are effects from leaching metals from sulfide waste rock stockpiles at the historic Dunka taconite mine near Babbitt. Contaminants enter Birch Lake which is near to Boundary Waters (http://www.environmentminnesota.org/media/mne/runoff-old-mines-raises-fears).

Atmospheric Sources

The long-range transport of contaminants via the atmosphere has been assessed for many metals and for effects associated with acid deposition for areas throughout North America. The R-LoW basin has not been impacted by acid deposition to the same extent as other areas in North America but there is evidence of contamination by atmospheric deposition especially with mercury which has contaminated fish in many lakes with the sources identified as being primarily from the atmosphere.

Mercury

Mercury is a contaminant of concern in the R-LOW basin. Mercury concentrations in fish have resulted in fish consumption restrictions in both Ontario and Minnesota (MDNR 2010, OMOE 2011). Two thirds of surface waters in Minnesota's Impaired Waters list are impaired due to mercury levels in fish or water. A map of impaired waters is available at: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/rainy-river-headwaters.html. Elevated mercury concentrations have been found in the fish and sediments of Voyageurs National Park (Weeks and Andrascik 1998, Wiener *et al.* 2006) with atmospheric deposition being the primary source of mercury in the basin (Wiener *et al.* 2006, MPCA 2001).

Mercury in the aquatic environment will bioaccumulate in aquatic biota and biomagnify in aquatic food webs. Mercury concentrations in fish are positively correlated with body size so that larger fish, and especially older fish, have higher concentrations of mercury due to their higher trophic position in the food web and a longer time spent accumulating mercury (Scott & Armstrong 1972). In an examination of forage fish in 25 central

The presence of mercury in the aquatic food webs in this region continues to be the main concern in food consumption advisories in both Ontario and Minnesota.

Canadian lakes (including rainbow smelt in Lake of the Woods), Swanson *et al.* (2006) found that fish growth rate and water chemistry were more important than the traditional indices of trophic position. Johnston *et al.* (2003) examined temporal effects associated with mercury bioaccumulation in piscivorous fish in northwestern Ontario lakes (including LoW) following invasion by the rainbow smelt. They determined that the effects of rainbow smelt invasion on mercury bioaccumulation in piscivores in lakes in this region has been minimal despite the importance of smelt as a prey item in piscivore diets and considering that smelt occupy a higher trophic level than other forage fish.

The presence of mercury in the aquatic food webs in this region continues to be the main concern in food consumption advisories in both Ontario and Minnesota (OMOE 2014; Minnesota Department of Health 2013). Mercury is present in aquatic environments and fish throughout the world, including remote lakes in northwestern Ontario (Schindler *et al.* 1996) and northern Minnesota (i.e., Voyageurs National Park, reviewed in Kallemeyn *et al.* 2003). Mercury is a naturally occurring element that is present in rocks and soil, and drainage basins and their watersheds store and transform mercury into methylmercury, the biologically available form of mercury that bioaccumulates in biota (Rudd, 1995; Harris *et al.* 2007). However, the geological contribution of mercury to lakes is negligible compared to atmospheric sources (Swain *et al.* 1992; Wiener *et al.* 2006). In Canada, the major contribution of atmospheric anthropogenic mercury until the 1980s was the chloralkali industry but all chloralkali plants are now closed in Ontario. The resulting decline in emissions combined with reductions from mining and smelting industries throughout the 1990s has resulted in an overall decline in the amount of mercury emitted to the atmosphere from anthropogenic sources (Figure 38). In 2011, Canada emitted under 3.7 tonnes of mercury, 27% of which was attributed to electricity generation and 26% to incineration. Ontario was responsible for 27% of the total Canadian emissions. U.S. mercury emissions are also declining (from approximately 250 tons/yr in 1990 to 100 tons/yr in 2005).

Fish mercury levels have been found to be elevated in biota in Minnesota's Voyageurs National Park, including Rainy Lake, which has led to the creation of consumption advisories for fish in the majority of Park lakes (reviewed in Kallemeyn *et al.* 2003). Methylmercury concentrations in game fish in 17 lakes in the Park substantially exceeded Minnesota's criteria for human health (Wiener *et al.* 2006). Despite the Park's semi

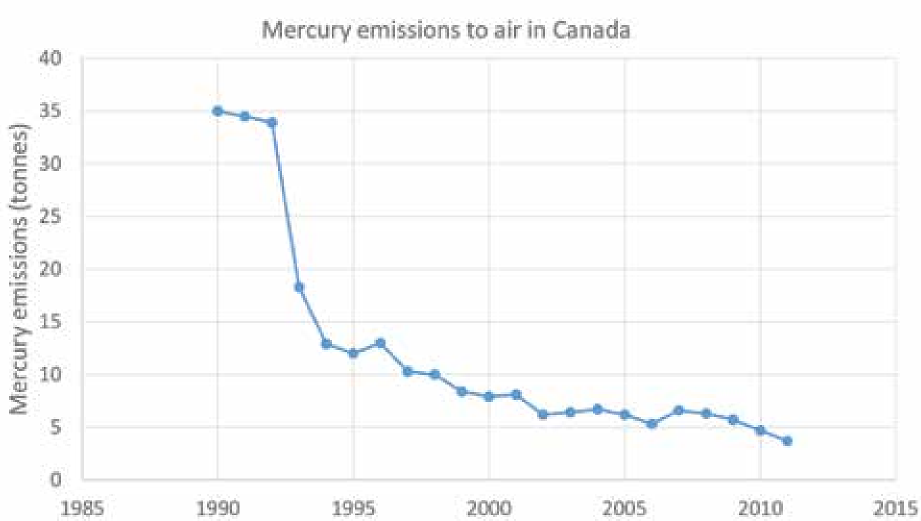

FIGURE 38 – Mercury emissions to air from Canadian sources (Environment Canada).

remote location (north-central Minnesota) and seemingly pristine condition, northern pike (*Esox lucius*) from some lakes contain the highest concentrations of mercury reported in the state (Minnesota Fish Contaminant Database, Minnesota Pollution Control Agency, St. Paul, MN). Wiener *et al.* concluded that mercury in soil and sediments is due to atmospheric deposition and that most mercury in fish is anthropogenically derived. Dissolved sulphate, total organic carbon and pH of lakewater were found to influence methylmercury concentrations in water and fish which leads to substantial variations in total mercury in yellow perch between lakes.

Many mercury in fish studies in Minnesota and elsewhere in the Great Lakes basin have shown decreasing trends in mercury in fish between the 1980s and the mid-1990s after which the trend of Hg in fish tissue begins to rise once again. One explanation for this is that although regional emissions of mercury have declined considerably over the past 30 years, these have been offset by recent increases in the global emissions of mercury (Monson 2009). Brigham presented data at the 2014 International Rainy-Lake of the Woods Watershed Forum that indicated global increases in emissions from approximately 1700 tons/yr in 1990 to approximately 2250 tons/yr in 2007. Increases were attributed to sources in Asia. Other factors that could contribute to increasing trends in recent years include increasing water temperature (methylation rates are positively correlated to epilimnetic temperature in northwestern Ontario—Bodaly *et al.* 1993) and the effects of flooding events (Balogh *et al.* 2006; Sorensen *et al.* 2005).

Brigham (2014) showed varying ecological responses to reduced mercury deposition in four lakes in Voyageurs National Park between 2000 and 2012. Wet deposition rates for mercury in northern MN declined by 32% between 1998 and 2012 with larger declines in the deposition rates of other drivers such as SO_4 (-48%) and H+ (-66%). Methylmercury in both fish and water decreased in two study lakes, increased in one other and showed no change in the fourth lake.

With respect to contaminants in fish, consumption advisories are issued in Minnesota by the MDNR/MPCA/MDH, http://www.health.state.mn.us/divs/eh/fish/index.html and in Ontario by the OMOE/OMNR http://www.ontario.ca/fishguide. The Minnesota Department of Health issues consumption advisories for mercury in most lakes and rivers where testing has occurred. Detailed information can be found at http://www.health.state.mn.us/divs/eh/fish/index.html.

In Ontario, advisories restricting fish consumption remain in effect for Rainy Lake, Rainy River, and LoW. The guidelines vary within these areas with consumption of northern pike and walleye being more restricted in Rainy Lake (Redgut Bay) compared to fish from the North and South arm of the lake. For all of these water bodies, advisories are primarily due to mercury concentrations in fish tissue. The most recent guidelines should be consulted to obtain the most recent consumption advisories for any fish caught in the R-LoW basin.

In addition to the dangers posed to humans by consumption of contaminated fish, there is recent evidence that methylmercury can cause adverse sublethal and reproductive stresses in the fish themselves. Beyer and Meador

Sport fishing—an important recreational and economic activity in the basin. (Todd Sellers)

(2011) in their review of many research projects relating to methylmercury effects on fish indicate that neurotoxic effects include modified swimming and feeding behaviour, impaired fry feeding efficiencies, impaired predator avoidance and effects on the ability to locate and capture food. Reproductive difficulties and alterations of sex hormones, oxidative stress to tissue, and altered cell metabolism and physiology are all noted, and many at concentrations that are common in fish throughout North America.

Other Contaminants
The bioaccumulation of persistent, organic substances in aquatic biota through biological sequestration has been well studied throughout the world. Although contamination of food webs by persistent pollutants, such as PCBs, do not pose immediate threats to biota, it is important to note that contaminants that include industrial chemicals (polychlorinated biphenyls (PCBs), dioxins, furans, mirex, photomirex) and pesticides (DDT, toxaphene) are released as by-products of many industrial and domestic processes. In Canada, owners or operators of facilities that use one or more of the contaminants listed in Environment Canada's National Pollutant Release Inventory (NPRI, available at http://www.ec.gc.ca/pdb/npri/npri_online_data_e.cfm) are required to report under the NPRI and are under the authority of the Canadian Environmental Protection Act (Government of Canada 1999). In Minnesota, pollutant releases are under the authority of the U.S. Environmental Protection Agency and are available on the Toxics Release Inventory (TRI) database (http://www.epa.gov/tri/tridata/index.htm).

Pesticides, particularly those which are suspected endocrine disruptors, were identified as a possible health risk factor in LoW by the IJC Health task force (Oblak 2009). Environment Canada sampled pesticides (excluding organophosphates) at eight of their LoW monitoring stations in June and September of 2009. In 2010, water samples for organophosphate analysis were collected at five sites in June and six sites in September. Samples were analysed for phenoxy acid herbicides, neutral herbicides, glyphosate, sulfonyl urea herbicides and organophosphate insecticides. The results showed that few pesticides were present in LoW surface waters and those detected were found at low concentrations. Low concentrations of a small number of neutral herbicides (atrazine, desethyl atrazine), acid herbicides (2,4-D, dicamba) and sulfonyl urea herbicides (diuron, thifensulfuron) were detected at some LoW stations. Atrazine was detected in all samples, at relatively low concentrations. Atrazine is one of the most commonly used herbicides in North America, primarily for row crops such as corn. A survey by the USGS found that it was also the most commonly detected pesticide in both surface and ground water in the United States (Gillion *et al.* 2007). Desethyl atrazine is a breakdown product of atrazine, 2,4-D and dicamba are common herbicides, commonly applied to wheat, corn and soybeans. Diuron and thifensulfuron are used in agriculture for weed control in row and fruit crops (Pascoe *et al.* 2009).

Maximum concentrations of all herbicides detected in EC's surface water samples were below Canadian Water Quality Guideline concentrations for the protection of aquatic life (CCME) by several orders of magnitude suggesting that the concentrations present in LoW do not pose a threat to biota.

Agriculture is the most common source of pesticides in surface waters. Concentrations of herbicides in LoW were low considering the potential for agricultural run-off. Concentrations of these herbicides in LoW are, in most cases, several orders of magnitude lower than concentrations found in the heavily agricultural and urbanized landscape of southern Ontario, both in Lake Erie and in southern Ontario streams (Pascoe *et al.* 2009). The primary sources of pesticides in surface waters originate from surface run off from agricultural landscapes where pesticides are applied. Agriculture accounts for only five and a half percent of land use in the R-LoW basin (DeSellas *et al.* 2009). Much of this is located south of LoW on the Ontario side of the basin and thought to enter the Rainy River from tributaries. There is also some agricultural activity on both the U.S. and Canadian sides of the

Rainy River. Primary agriculture activities in this region include the raising of livestock and the production of associated feed crops (hay, alfalfa and oats) (Statistics Canada 2006), which are not expected to be pesticide intensive (Pascoe *et al*. 2009).

In April of 2009, the province of Ontario enacted legislation which severely restricts urban pesticide use (Bill 64, and Pesticides Act R.S.O. 1990). This ban is expected to reduce pesticide inputs into surface waters in urban areas so it is not expected that urban pesticide inputs will pose a significant threat to LoW in the future from Canadian sources. This ban does not include U.S. sources of pesticides. Pesticides may also enter the watershed through aerial deposition in the form of precipitation. In remote areas this may be an important source of agricultural pesticides (Pascoe *et al.* 2009).

There are ongoing efforts to determine the effects of sulfate concentrations on wild rice in Minnesota. (http://www.pca.state.mn.us/index.php/water/water-permits-and-rules/water-rulemaking/wild-rice-study-and-process-of-revising-standard.html) and to set sulfate limits to protect wild rice. Research for the Wild Rice Sulfate Standard Study (MPCA) was completed in December 2013. The Agency presented its preliminary analysis (http://www.pca.state.mn.us/index.php/water/water-permits-and-rules/water-rulemaking/sulfate-standard-and-wild-rice/wild-rice-sulfate-analysis.html) and next steps including:

- Sulfide does not “contaminate” the rice for consumption, rather, it limits the plants’ ability to grow.
- Sulfide in sediment porewater is affected by the amount of sulfate in the water column and the amount of iron in the sediment. The presence of iron has a strong role in controlling the level of sulfide in the sediment porewater. If the iron supply is greater than the production of sulfide, then iron can precipitate sulfide as it is produced, yielding lower sulfide levels.
- Site specific standards may be needed given the complex biology and chemical interactions of different waterways.

Further scientific inquiry and analysis is required to explore adopting a sediment porewater sulfide standard to protect wild rice. A copy of the full report is available on the MPCA website: (http://www.pca.state.mn.us/index.php/view-document.html?gid=20743).

There are comparatively fewer contaminants released to LoW and the Rainy River than to other regions of North America, such as the Great Lakes Region. As we have seen with mercury, however, airborne contaminants can be deposited in areas where no point sources exist. There does not seem to be any indication that the basin is impacted by contaminants other than mercury as discussed above. For example, LoW was used as an unimpacted reference site in one study on bill deformities and organochlorine contaminant concentration in double-crested cormorant eggs, due to the fact that there were no bill deformities observed from 1988-1996 (Ryckman *et al*. 1998). In a study by Donaldson *et al.* (1999), bald eagle eggs from Lake of the Woods did not appear to be affected by organochlorine contamination, based on reproductive success, and PCB and DDE concentrations. Lake of the Woods is considered to be an uncontaminated “reference” area, and is far removed from major sources of contamination (Donaldson *et al.* 1999).

Very little is known about the prevalence of emerging contaminants of concern within the basin.

Gaps and next steps

Additional work is required to assess the nature of reduced mercury contamination from regional sources relative to sources of global atmospheric mercury.

Where sediment surveys establish that contaminated sediments are present near to historic mining locations there should be an effort to assess and delineate these areas.

Diffuse sources of contaminants should be inventoried.

The potential for contaminants to enter groundwater should be examined further.

Next steps can be identified relative to the

IMA TAC objectives listed at the beginning of this chapter. Contaminants concerns and gaps listed here should be considered within the IMA TAC overall objective #1 and 13.

PART 4: INVASIVE SPECIES

The R-LoW basin is part of the Winnipeg River drainage basin, residing within the immense Nelson River basin which outflows into Hudson Bay. LoW is vulnerable to introductions of non-native aquatic biota due to its proximity to several large water bodies and systems (i.e., Great Lakes, Mississippi drainage system, Red River) and its popularity as a tourist destination.

LoW is vulnerable to introductions of non-native aquatic biota due to its proximity to several large water bodies and systems (i.e., Great Lakes, Mississippi drainage system, Red River) and its popularity as a tourist destination.

There is awareness within public and government sectors that aquatic invasive species pose major threats to aquatic systems. This is the result of enhanced education programs, including signage at public access points. In addition, Ontario (Department of Fisheries and Oceans Canada) and Minnesota (Minnesota Department of Natural Resources) have included watercraft inspections at public access and international borders, regulation, and enforcement as part of their educational program to prevent the introductions and spread of aquatic invasive species. Their programs have recently focused efforts on the containment of the spiny waterflea (*Bythotrephes longimanus*) in the R-LoW basin.

Several non-native flora and fauna have invaded areas of the basin over the last 30 years. The hybrid cattail (*Typha xglauca*), spiny water flea (*Bythotrephes longimanus*), *Eubosmina coregoni*, rusty crayfish (*Orconectes rusticus*), papershell crayfish (*Orconectes immunis*), clearwater crayfish (*Orconectes propinquus*) and Rainbow Smelt (*Osmerus mordax*) are seven confirmed invaders in parts of LoW and the Rainy River. Zebra mussels have been reported by MN DNR in headwater lakes of the Big Fork River near Bemidji, MN (May 2013).

Gaps and next steps

There is considerable potential for invasive species distribution both downstream or by human vectors and the possibility of range expansion by the zebra mussel (*Dreissena polymorpha*) and range expansions in the benthic diatom *Didymosphenia geminata*. These threats require attention and assessment.

The recently formed AIS subcommittee of the IMA Technical Advisory Committee is currently developing a plan to address spread of AIS in the basin.

Next steps can be identified relative to the IMA TAC objectives listed at the beginning of this chapter. Invasive species concerns and gaps listed here are aligned with the IMA TAC overall objective #12 and 13.

PART 5: NUTRIENTS AND INTERNAL LOADING

The 2009 State of the Basin Report listed these remaining questions with respect to nutrients and nutrient budgets:

- What are the relative sources of phosphorus to the Rainy River and LoW?
- How sensitive is the lake to increases in shoreline development and to long-term changes in climate? And how do these sensitivities vary spatially in the lake?
- How do the frequency and intensity of algal blooms, or the production of algal toxins, vary over time and space with long-term changes in nutrient concentrations and/or other variables?

Many of these questions have been answered since the last SOBR was published. There are questions remaining regarding internal loads and their role in seasonal and between-year variation in algal production in the lake. Consideration of internal loads will be a component of ongoing nutrient modeling efforts in the U.S. portions of LoW to establish TMDLs for waters designated as impaired.

Gaps and next steps

There are elements of nutrient budgets and aspects of internal loading as indicated above that remain to be quantified. The TMDL load and mass balance modeling for U.S. impaired waters is yet to be completed and the TP load from Rainy River to LoW is yet to be quantified. Details with respect to the proportion of basin sources and loading estimates from atmospheric deposition are in the process of being described in detail. In addition the effects of climate change on these processes remains to be clarified.

Next steps can be identified relative to the IMA TAC objectives listed at the beginning of this chapter. Nutrient and internal loading concerns and gaps listed here are aligned with the IMA TAC overall objectives #1 through 6, 10, 11 and 13. They are further aligned with management goals 1 and 2.

PART 6: WATER LEVELS AND EROSION

Water levels that are maintained within Rule Curves (e.g., Rainy and Namakan Lakes) to satisfy multiple uses can rarely be optimized to provide everything for everybody especially in the face of more extreme climate events. In some cases flow and level controls may work to ameliorate the negative effects of flooding or drought and may provide further benefits from hydroelectric power generation which makes it difficult to align oneself either for or against the control of water levels. These realities tend to guarantee ongoing evaluation and monitoring of water level controls. Established Rule Curves, for example, are often evaluated to ensure that their upper and lower limits are optimised for multiple uses and this includes protections to ensure ecological function. This type of evaluation is currently under way in the Rainy and Namakan system. Presently, projects are being completed following a Plan of Study designed to fill data gaps that remain after agency monitoring and research. Upon completion of these studies in 2015-2016, the IJC will initiate the evaluation.

On Lake of the Woods, there were many potential ecological effects that followed the installation of outlet control structures at Kenora in the late 1800s. These structures raised the water level in LoW by approximately 1 meter and this has had many effects on ecological function some of which have been noted in the sediment records in LoW (Rühland *et al.* 2010). These same structures equalized the water levels in LoW and Shoal Lake making it possible for water to flow in both directions between the two lakes. Outflows from LoW (and water levels) are managed adaptively by the Canadian Lake of the Woods Control Board (LWCB), within high and low water limits prescribed by the 1925 Lake of the Woods Convention and Protocol. Within these limits (and the hydraulic capacity to regulate) the LWCB attempts to balance multiple interests in setting outflows to manage lake levels iteratively throughout the year. The LWCB lists water level and flow preferences on their webpage together with input from First Nations, resource agencies and specific interest groups (http://www.lwcb.ca/reg-guide/rgp-PT3-OVERVIEW.html). These preferences, when considered together, are combined to produce a section entitled 'Board Observations and Practice' which describes how and why water levels are regulated.

A summary of current concerns in the basin around water levels and erosion are expressed under the following headings:

1. **Fluctuation** - Fluctuating water levels are caused by many factors, such as extreme weather events, variation in spring recharge of lakes, alterations in flow regime of nearby reservoirs and dams and peaking by hydroelectric companies. Peaking occurs when hydroelectric power facilities vary their day and evening outflows to maximize efficiency during periods of high demand. This adversely affects aquatic organisms as well as personal properties (i.e., resorts, cottages, houses, land, docks) located near the shore and can destabilize river banks. Fish, such as walleye, sturgeon, lake whitefish and suckers, are sensitive to fluctuating water levels which can alter fish spawning habitat. Eggs and larvae in shallow regions can be exposed and desiccated or stranded. Water level fluctuations also leave eggs susceptible to fungal infection and predation at reduced water levels. In addition, drastic temperature changes often occur when water levels change, which may influence the timing and length of spawning period (O'Shea 2005). In recent years, control boards have been under pressure, primarily

by property owners, to maintain water levels within a range that will minimize water fluctuations. The International Joint Commission on behalf of the IRLWWB is funding ongoing efforts to evaluate the performance of water level management strategies for Rainy and Namakan Lakes and Rainy River. In 2013 Kenora Resource Consultants Inc. (KRC) was retained to undertake site visits of shoreline properties on the Rainy, Namakan, Kabetogama, Sand Point, Little Vermilion, and Crane Lakes to help gather the necessary data to assess shoreline vulnerability due to high water levels. The project is expected to be completed in March 2015.

2. **Fish Habitat** - Studies have shown that fisheries management should include maintenance of a certain range of fluctuation in water levels. There is much evidence to support this. Cohen & Radomski (1993) found a clear relationship between the difference between the yearly maximum and minimum water levels in Rainy Lake and the Namakan Reservoir and changes in commercial fish catch. Adams *et al.* (2006) found consistent but weak correlations between sturgeon year-class strength and water levels for late April to early June when spawning occurs in Rainy Lake. In Rainy Lake between 1924-1975, walleye abundance and year class strength was controlled mainly by brood stock abundance and spring water levels, although it was not possible to determine which was more influential (Chevalier 1977). It has been recommended that a minimum flow of 340 m^3/s at Manitou Rapids is required to maintain the availability of suitable fish spawning habitat in the Rainy River (O'Shea 2005). In 2007, studies on sturgeon spawning below the Rainy Lake dam and water temperatures along the Rainy River were commenced by the MN DNR, the OMNR, and the Department of Fisheries & Oceans Canada (IRLBC/IRRWPB 2006).

3. **Effects of Peaking** - A work group was established in 2002 by the Ontario/Minnesota Fisheries Committee to examine the issue of peaking on the Rainy River. This committee includes representatives from several agencies, including owners of hydroelectric dams (Boise Cascade Corporation, Abitibi-Consolidated Company of Canada/ACH Limited Partnership), government agencies (Department of Fisheries and Oceans Canada, Ontario Ministry of Natural Resources, MPCA, MN DNR, and Koochiching County Environmental Services) and First Nations (Rainy River First Nations). In 2003, Boise Cascade ended peaking but maintained their right to do so when required. In 2006, a work group established by the IRLBC and the IRRWPB formalized an agreement that, for 2007 and 2008, peaking would not be conducted during the 2.5 month spring spawning/early development period that normally occurs from April 15 to June 30. This agreement is informally continuing with no peaking conducted during the spawning season in 2013 (Matt DeWolfe pers. comm.).

4. **Barriers to Connectivity** - It has been suggested that the International Falls dam is a barrier to water connectivity in the Rainy River (O'Shea, 2005). The Ontario/Minnesota Fisheries Committee work group has made four recommendations as follows, that:
   a. the dam provide a more natural flow regime and that a restriction be placed on monthly water use to allow for natural variation in flow regime and water consumption
   b. stream flow allow biological and physical conditions to be maintained
   c. the natural hydrograph for the Rainy River be determined
   d. regular assessments of water quality and connectivity be performed (O'Shea 2005).

5. **Shoal Lake** is part of the R-LoW basin, and is connected to LoW by Ash Rapids at the eastern point of Shoal Lake. Shoal Lake currently supplies water to the city of Winnipeg. Shoal Lake's water resources may be threatened due to the effects of climate warming which

is predicted to lower water levels in this region (Magnuson *et al.*, 1997). Based on a water balance analysis by TetrES Consultants (2000), at that time Winnipeg water demands exceeded Shoal Lake's natural water renewal 50% of the time. This lack of water replacement was sustained by the net balance of LoW Inflows through Ash Rapids as authorized by the IJC Order of approval of 1914. Under increasing low water scenarios, Shoal Lake may come to rely on LoW for continued water supply and TetrES Consultants (2000) recommended that the potential impacts of Shoal Lake drawdown on LoW be monitored regularly. It may be that Winnipeg water use has been in general decline with improved conservation efforts and with the abandonment of Shoal Lake withdrawals to support Winnipeg's Centreport project http://www.centreportcanada.ca/ (Matt DeWolfe pers comm.).

6. **Erosion** - Shoreline erosion is a significant concern in the southern portion of LoW along the Minnesota lakeshore and in the Buffalo Point area in Manitoba. Phillips and Rasid (1996) provide a historical overview of erosion problems in LoW that are associated with water level controls.

Gaps and next steps

Next steps will be to assess the results of ongoing studies related to the Rainy and Namakan Rule Curve review (due to begin in 2015) when completed. Impacts of water level regulation on Shoal Lake have not been assessed.

Next steps can be identified relative to the IMA TAC objectives listed at the beginning of this chapter. Information gaps listed here are aligned with the IMA TAC overall objectives #10, 11, and 13.

(Patty Nelson)

4 INTERNATIONAL WATERSHED CONSIDERATIONS

PART 1: WATERSHED GOVERNANCE

The International Task Force Final Report to the IJC on Bi-National Management of Lake of the Woods and Rainy River Watershed (IJC 2012 Annex A) provides a Historical Context and Frameworks chapter that provides insight into the past initiatives that have influenced the present governance framework. These include:

- First Nations' treaties including Treaty #3 in Canada and treaties between the U.S. government and the Bois Forte and Red Lake Bands
- the Boundary Waters Treaty of 1909
- establishment of Superior National Forest and Quetico Provincial Park in 1909
- the 1925 Lake of the Woods Convention and Protocol
- the 1914 Shoal Lake and Lake of the Woods diversion
- the 1938 Rainy Lake Convention (and subsequent Orders, consolidated in 2001)
- the 1959 IJC Rainy River and Lake of the Woods Reference and pollution study
- the 1976 IJC alerting responsibility identification of the 2009 Namakan River power development
- the 1998 International Watershed Initiative
- the 2009 Lake of the Woods Multi-Agency Working Agreement
- the 2010 Reference to the IJC from the United States and Canada, to investigate and make recommendations on governance options and water quality issues of priority concern.

At the time of publication of the 2009 State of the Basin Report, there were steps underway to engage the IJC to create a Water Pollution Board for LoW and to create an *ad hoc* task force to coordinate complimentary research and phosphorus management plans for LoW. These goals were substantially fulfilled by the establishment, in 2013, of the International Rainy-Lake of the Woods Watershed Board (IRLWWB) and the initiation of a Lake of the Woods Basin Water Quality Plan of Study (to start in 2014).

International Rainy-Lake of the Woods Watershed Board

Established by the International Joint Commission in April 2013, the International Rainy-Lake of the Woods Watershed Board (IRLWWB) combines the former International Rainy Lake Board of Control and the International Rainy River Water Pollution Board, with an expanded geographic mandate for water quality including Lake of the Woods and upstream boundary waters. The IRLWWB is one of the IJC's first full International Watershed Initiative boards (IWI), structured along the IWI principle that local people are best positioned to prevent and solve their watershed problems. As such, the Board's complement includes designated seats for First Nations, Métis and US Tribal peoples, and for community representation from both Canada and the United States. The Board's structure is also the first to include a Community Advisory Group and an Industry Advisory Group. These groups provide advice to the Board on local issues of concern and a mechanism for two-way communication between the Board and the communities and economic interests in the basin.

The mandate of the IRLWWB is to ensure compliance with the Commission's Order pursuant to the Rainy Lake Convention, to monitor and report on the ecological health of the Lake of the Woods and Rainy Lake boundary waters aquatic ecosystem, including water quality, and to assist the Commission in resolving disputes regarding the boundary waters of the R-LoW basin.

The IRLWWB mandate, for ensuring compliance with the IJC Orders for water regulation on Rainy and Namakan lakes, is delegated to its Rainy and Namakan Lake Water Levels Committee (Water Level Committee), which acts independently of the Board, while keeping it informed.

The Board is to maintain surveillance and report to the IJC on water quality and/or ecological health objectives and may recommend revised or new objectives for the Rainy-Lake of the Woods boundary waters ecosystem. Also, it is to establish and report on water quality and/or ecosystem health Alert Levels (i.e., for parameters where formal objectives do not exist) within the basin, including areas outside of the boundary waters. The generalized governance model of this board is shown in Figure 39.

The IRLWWB does not have regulatory authority nor does it usurp the regulatory or management authorities of the local responsible jurisdictions. Rather, the IRLWWB works with and through the responsible agencies. The Water Levels Committee of the IRLWWB has the responsibility to ensure compliance with the IJC's Order pursuant to the Rainy Lake Convention and may provide direction to the dam operators for operation of their discharge facilities within the Rule Curves.

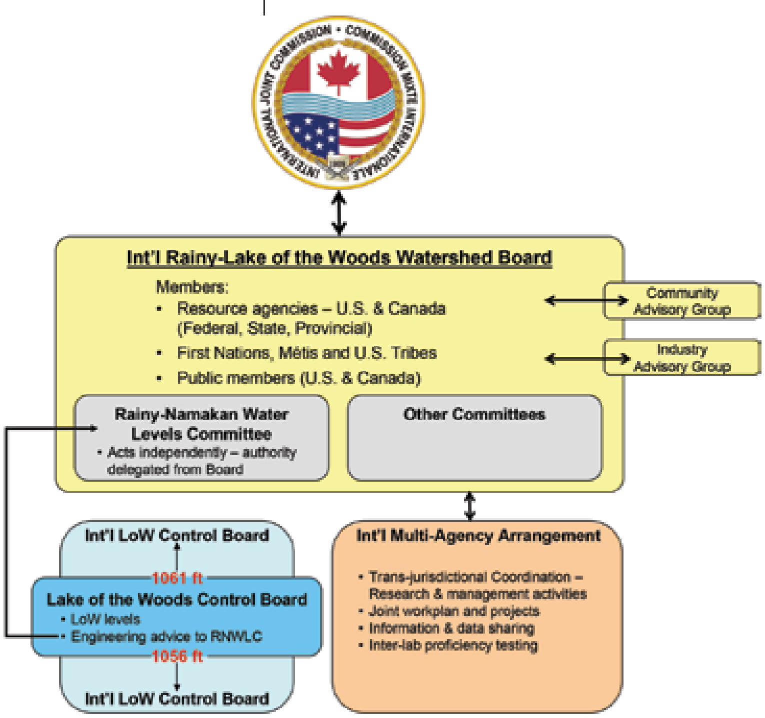

FIGURE 39 – International Rainy-Lake of the Woods Watershed Board generalized governance model.

In the case of anticipated extreme high or low inflows, after approval of the IJC, the Water Levels Committee may authorize temporary departures from the Rule Curve levels specified in the Order. The full mandate of the IRLWWB is available online at: http://ijc.org/en_/RLWWB/Mandate.

Otherwise, the responsibility for regulation and management of the R-LoW basin resources are the responsibilities of a number of federal, state/provincial, and municipal agencies involved in research and resource management for the R-LoW basin.

The jurisdictions of each of these agencies are outlined in Table 31.

The [Canadian] Lake of the Woods Control Board and the International Lake of the Woods Control Board

Concern over fluctuating water levels on Lake of the Woods led governments to refer the matter to the IJC in June 1912. Following a five year study, the IJC made a series of recommendations regarding flow regulation and recommended that the Commission be vested with authority for control of the outflows of Lake of the Woods when the lake level rises above 1061 ft or falls below 1056 ft sea level datum. Between these levels, it was recommended that *"supervision and control of water levels be exercised by the appropriate authority in Canada…"* (IJC 1917)

In 1919 a [Canadian] Lake of the Woods Control Board was established by Canadian federal Order-in-Council, which continues to this day, mandated by concurrent Canada/Ontario/Manitoba legislation (Canada: The Lake of the Woods Control Board Act, 1921; Ontario Lake of the Woods Control Board Act, 1922; Canada-Ontario-Manitoba Tripartite Agreement, 1922; Lake of the Woods Control Board Act, Manitoba 1958). The [Canadian] LWCB was further mandated binationally by the 1925 Lake of the Woods Convention and Protocol for water level regulation within "normal" high and low water levels (see below). The Lake of the Woods Control Board maintains a secretariat and complement of engineering advisors, who also provide engineering support to the Rainy-Namakan Water Levels Committee of the International Rainy-Lake of the

TABLE 31 – Agencies and organizations responsible for regulation and/or management of the Lake of the Woods and Rainy River Basin resources.

U.S. Minnesota		
Federal	Water Quality	Voyageurs National Park, National Park Service, U.S. Dept. of the Interior, Environmental Protection Agency
	Water Quantity	U.S. Army Corps of Engineers
		U.S. Geological Survey
		Federal Energy regulatory Commission
	Fisheries & Aquatic Invasives	U.S. Fish & Wildlife Service
State	Water Quality	Minnesota Pollution Control Agency
		Minnesota Dept. of Natural Resources (MDNR)
	Water Quantity	MDNR
	Fisheries & Aquatic Invasives	MDNR
Local	Water Quality	Soil and Water Conservation Districts
		All counties that have border waters in the basin
		City of International Falls
Canada		
Federal	Water Quality	Environment Canada
	Water Quantity	(Canadian) Lake of the Woods Control Board
	Fisheries & Aquatic Invasives	Department of Fisheries and Oceans
Provincial	Water Quality	Ontario Ministry of the Environment
		Manitoba Conservation and Water Stewardship
	Fisheries & Aquatic Invasives	Ontario Ministry of Natural Resources Manitoba Conservation and Water Stewardship
Local	Water Quality	City of Winnipeg
		City of Kenora
		Town of Fort Frances
		Rainy River First Nations – RR Watershed Program
	Fisheries & Aquatic Invasives	Ontario Federation of Anglers and Hunters
		Manitoba Conservation and Water Stewardship
Binational		
	Water Quality	International Rainy-Lake of the Woods Watershed Board
	Water Quantity	Water Levels Committee of IRLWWB (Rainy-Namakan) International Lake of the Woods Control Board (LoW) Canadian Lake of the Woods Control Board (LoW outflows management)

Woods Watershed Board (and previously provided engineering support to the former International Rainy Lake Board of Control). In this arrangement, there is a coordination of key hydrologic data and engineering expertise between the bodies regulating outflows and levels of the Lake of the Woods and upstream Rainy-Namakan system.

The 1925 Lake of the Woods Convention and Protocol is a treaty between Canada and the United States, that sets forth that the level of Lake of the Woods should ordinarily be held between 1056 ft. (321.87 m) and 1061.25 ft. (323.47 m) sea-level datum. Even during extreme high supply periods, the lake should not exceed elevation 1062.5 ft. The Convention and Protocol called for a Canadian Lake of the Woods Control Board to regulate the outflow from the lake. It also established a two-member International Lake of the Woods Control Board reporting to the International Joint Commission and to be appointed by the two federal governments to approve regulation decisions when the level of the lake is above 1061 ft. or below 1056 ft. sea-level datum. The International Lake of the Woods Control Board has rarely been called upon as with relatively few exceptions, such as the 1985 high water levels which slightly exceeded 1,061 ft., the lake has remained within the water level range where it is under the management authority of the [Canadian] Lake of the Woods Control Board.

Agreement on issues and coordination of research and resource management agency activities in the basin have been enabled and greatly enhanced through the International Multi Agency Arrangement (IMA) which was signed in 2009 by seven provincial/state/federal government agencies, the Lake of the Woods Water Sustainability Foundation, and the Red Lake Band of Chippewa Indians. Subsequently the Koochiching Soil and Water Conservation District has joined the IMA in 2013 and a variety of other agencies are participating on the IMA Technical Advisory Committee. An overview of coordination of research efforts between those agencies that provide governance in the basin is given below in Part 2.

LOWWSF remains a central player in the coordination of science and research in the basin together with the timely dissemination of results between international researchers.

PART 2: COORDINATING RESEARCH EFFORTS

Though there are many agencies that are involved with governance in the R-LoW basin there are, at this point in time, three primary groups that are involved with the coordination of science and research efforts in the basin. These are:

- the Lake of the Woods Water Sustainability Foundation (LOWWSF) which supports collaborative research projects and also facilitates the sharing of science information through the International Rainy-Lake of the Woods Watershed Forum where researchers collaborate on international research initiatives
- the International Rainy-Lake of the Woods Watershed Board (IRLWWB) which under its Directives may take on a role to coordinate activities with appropriate agencies and institutions as may be needed or desirable, including inter-agency working groups and other research groups conducting sound science within the watershed
- the International Multi-Agency Arrangement (IMA) group which coordinates the science initiatives of signatory agencies in the basin.

Their roles are outlined in the following sections.

Lake of the Woods Water Sustainability Foundation

The LOWWSF remains a central player in the coordination of science and research in the basin together with the timely dissemination of results between international researchers.

The LOWWSF facilitates the International Rainy-Lake of the Woods Watershed Forum each year in International Falls which allows extensive bi-national sharing of basin research and monitoring data relating to fisheries, wildlife, in-lake chemistry and biota, contaminants, external ecosystem drivers and historical reconstructions using paleoecology. Presentation of these varied topics at the forum has an additional benefit that results from the potential to coordinate research efforts through themed forum workshops.

The LOWWSF also is active in initiating and coordinating partnerships to develop and fund research in the basin. Examples of these projects include the State of the Basin Report (2009 and this current document); Development of a Preliminary Total Phosphorus Budget and Water Quality Models for the Lake of the Woods and Rainy River (i.e., the theses work of Hargan and Hadash); and funding roles in projects such as those mentioned above and the Historical Nutrient Loading Study currently underway in the basin by Edlund *et. al*.

Priority issues identified include: nutrient enrichment and harmful algal blooms, aquatic invasive species, surface and groundwater contamination, and crosscutting factors of climate change and hydrologic regulation.

In October, 2012, the LOWWSF established the International Watershed Coordination Program together with the IJC, the Minnesota Pollution Control Agency / Koochiching Soil and Water Conservation District, and the Manitoba Conservation and Water Stewardship department. This multi-agency funded program is three pronged in that it provides, through an International Watershed Coordinator: secretariat/coordinator support to the development of the IJC's *Lake of the Woods Basin Water Quality Plan of Study*, leadership and secretariat coordination to the IMA and coordination of efforts alongside local agencies on water stewardship and outreach initiatives, thereby maintaining the linkages between all of these groups in an effort to keep goals aligned and communication strong.

IJC–International Rainy-Lake of the Woods Watershed Board

Although only in its first year of operation (established April 2013), the International Rainy-Lake of the Woods Watershed Board is making rapid contributions to coordination of science and research and to dissemination of information and to engagement of stakeholders in the basin. The mandated activities of the Board are extensive http://ijc.org/en_/RLWWB/Mandate, but of note is its mandated role to coordinate its activities with appropriate institutions and groups in the basin. To this end, the IMA will provide a key resource and linkage to agencies and groups working on research and resource management in the basin.

The IRLWWB has continued the work previously undertaken by the former boards (IRLBC and IRRWPB). In particular, the IRLWWB has continued:

- to work with the Voyageurs National Park project management team to facilitate the implementation and completion of the projects underway as part of the 2009 Plan of Study for the Evaluation of the IJC 2000 Order for Rainy and Namakan Lakes
- to implement sturgeon spawning protocols for the Rainy River in collaboration with the dam operators and conducted related studies (e.g., spawning water temperature monitoring and alerting)
- to work with researchers at the Seine River First Nation to continue ongoing studies of sturgeon spawning-temperature relationship on the Seine River.

One important task of the Board in its first year was to develop a *Lake of the Woods Basin Water Quality Plan of Study* for the basin. This is requiring the cooperation of multiple agencies and the review of a great deal of information, the synthesis of which is the focus of this SOBR update. The Board participated in the development of the proposal for this current update to the SOBR in support of priorities of the IMA and the Board and recommended it for funding by the IJC International Watershed Initiative program, in collaboration with IMA member agencies.

The IRLWWB has developed a Terms of Reference for the Plan of Study which with minor modification has been approved by the IJC and which started in early 2014. The implementation of the Plan of Study will then require further coordination. Priority issues identified include:

- nutrient enrichment and harmful algal blooms
- aquatic invasive species
- surface and groundwater contamination
- and cross-cutting factors of climate change and hydrologic regulation.

The IRLWWB will also contribute greatly to the coordination of research efforts in the basin through the IJC's data harmonization protocols that are in place throughout the IJC's mandated international boundary areas (support to HSPF, nutrient modeling).

In addition, the IRLWWB has made significant strides in building collaboration and engagement with communities and industrial interests, with the formation of its Community Advisory Group and Industry Advisory Group. These groups became active with members appointed in late 2013 and in the coming years are expected to contribute local knowledge and outreach to the activities of the Board.

The purpose of the IMA is to provide trans-jurisdictional coordination on science and management activities that will enhance or restore water quality in the R-LoW basin...

International Multi-Agency Arrangement Working Group and Technical Advisory Committee

The 2009 State of the Basin Report recommended,

> *"the creation of a technical advisory committee, which will harmonize scientific goals and methodologies, the development of informal and formal agreements among government agencies and other groups working in the basin should be considered"*

The International Multi Agency Arrangement (IMA) which was developed to meet this goal was formalized in May 22, 2009. The arrangement has no termination date and implementation is overseen by the IMA Working Group which is supported by a Technical Advisory Committee and an International Watershed Coordinator (since October 2012, see LOWWSF above). The group includes as signatory members:

- Environment Canada
- U.S. Environmental Protection Agency
- Red Lake Band of Chippewa Indians
- Lake of the Woods Water Sustainability Foundation
- Minnesota Department of Natural Resources
- Minnesota Pollution Control Agency
- Ontario Ministry of the Environment
- Ontario Ministry of Natural Resources
- Manitoba Conservation and Water Stewardship
- Koochiching Soil and Water Conservation District

The purpose of the IMA is to provide trans-jurisdictional coordination on science and management activities that will enhance or restore water quality in the R-LoW basin with a focus on:

- factors influencing algal blooms
- nutrient loading to LoW, the Winnipeg River and Lake Winnipeg
- shoreline erosion issues in the southern areas of LoW
- science and support for the development of a LoW water sustainability plan.

This will aid in establishing information exchange and joint cooperative mechanisms in areas related to transboundary environmental impacts between Ontario, Manitoba, Canada, Minnesota, the Red Lake Band of Chippewa Indians and the United States by:

- promoting sharing of information and expertise on transboundary environmental impacts
- where applicable, defining joint projects and actions to mitigate or prevent transboundary pollution
- where appropriate, jointly implementing measures to prevent transboundary environmental impacts
- sharing information in the event of any incident of natural or accidental origin that may have the potential to cause adverse transboundary environmental impacts
- sharing scientific expertise about the natural environment, biodiversity and other relevant information and data of the watershed with a view toward encouraging the sustainable development of environmental resources
- sharing information on major undertakings proposed in the LoW basin
- implementing consultation and coordination mechanisms to promote cooperation and dialogue provided for in this Working Arrangement among members of the Group.

The overall (and management) objectives of the IMA 5 year workplan, which deals with specific information gaps, are listed at the beginning of Chapter 3.

Completed IMA projects include:

- the Preliminary Total Phosphorus Budgets for the Lake of the Woods and Rainy River
- the Internal Phosphorus Loading Study, Lake of the Woods
- MPCA Total Maximum Daily Load Study/Lake Modelling
- the Shoreline Erosion/Loading Study (south shore)
- data Sharing, QA/QC inter-lab proficiency trials, and development of a common database
- the Intensive Watershed Assessment (Big Fork; Little Fork)
- Load and lake mass-balance modeling for TMDL and populating FLUX and BATHTUB
- Lake of the Woods bathymetric map digitization
- enhanced communication.

Projects that are currently funded include:

- ongoing record of all fieldwork/ monitoring in basin
- the HSPF Basin Model Phase II—hydrology, nutrient load, contaminants
- Minnesota—load based watershed monitoring
- tributary monitoring in Ontario (concentrations)
- studies of historical nutrient loading (Phase 1) and lake thermal modelling (Phase 2)
- studies of sediment release rate by temperature
- remote sensing of algae blooms/citizen monitoring
- geospatial planning and implementation of data harmonization
- development of land use maps for LoW using Landsat imagery
- determining phosphorus concentrations in sediment column.

Top priorities include:

- annual maintenance of Wheeler's Point Gauge
- historical wind data set
- invasive species distribution and abundance
- development of a core monitoring/ tiered monitoring program
- development of a geospatial platform (with the IJC harmonized hydrologic data) and maintenance of load and mass-balance database.

Monitoring and Stewardship Programs

Multiple agencies, including government departments working at municipal, state/ provincial and federal levels, First Nations, Tribes and Métis, and non-governmental organizations and volunteer groups that include the general public, have an interest in the basin and have been involved with monitoring throughout the basin. These groups have varied and sometimes overlapping responsibilities, particularly when it comes to water quality monitoring activities. Jurisdictional complexity may easily translate into a duplication of monitoring efforts which makes cooperation between agencies and groups essential.

It would be difficult to list all of the monitoring programs that are in place in the basin. The list is extensive especially at it relates to citizen monitoring programs. Here we are providing a brief overview of the types and duration of monitoring efforts that have taken place together with pointers that can assist researchers or managers in gaining access to the data that is generated by these programs. Ongoing emphasis should be to centralize or increase ease of access to as many of these data as possible. Existing and discontinued monitoring programs are listed in Table 32 with brief descriptions of the programs and the coordinates of their data in those cases where they are available.

Distance and access are the main challenges to monitoring in the basin. It is approximately 400 km (250 mi) from the outflow of LoW to the edge of the watershed near to Lake Superior. Much of this area, including most of the R-LoW basin, cannot be accessed by road which requires that watercraft or aircraft be used for monitoring and sampling purposes. Lake of the Woods itself contains hundreds of bays, and more than 14,500 islands. The lakes upstream including Rainy Lake and Namakan Reservoir and a host of interconnected lakes in the Boundary Waters are no less complex. In many areas the water quality

TABLE 32 – Summary of monitoring activities in the R-LoW basin. This should be considered a partial list.

Agency	Description	Duration	Data coordinates
		Water Levels and Discharge	
Lake of the Woods Control Board and International Rainy-Lake of the Woods Watershed Board	Collection of data relating to discharge and water levels relative to Rule Curves including precipitation data from many locations throughout the basin	Ongoing	http://www.lwcb.ca and http://www.ijc.org/en_/RLWWB/Water_Levels_Data
		Lake Water Quality (WQ)	
MPCA	Short- and long-term monitoring programs in the MN portion of the basin		STORET http://ww.epa.gov/storet/dw_home.html MPCA's Environmental Data Access (EDA) website http://www.pca.state.mn.us/data/edaWater/index.cfm
MDNR/MPCA/SWCD	Fourmile Bay/Rainy River, Big Traverse Bay, Muskeg Bay, and Long Point	1991-98 end of summer, 1998 to present	
VNP	Voyageurs National Park WQ monitoring program – Rainy Lake and Namakan Reservoir	1981 - present	http://ww.epa.gov/storet/dw_home.html; Voyageurs National Park.
US NPS Great Lakes Inventory and Monitoring Network	Voyageurs National Park WQ monitoring program – small lakes upstream of Namakan Reservoir and / or Rainy Lake	2006 - present	US National Park Service Great Lakes Inventory and Monitoring Network (Ashland, WI)
CLMP	Secchi data	1972 - present	
Red Lake DNR	Red Lake band water quality sampling program	1989 - present	
OMNR/OMOE	Sector based WQ in LoW	1984 - present	
OMOE/ Queens University	20 LoW sites	2003	Dorset Environmental Science Centre - Inland Lakes Database
OMOE	Remote sensing survey sites (26) – general chemistry	1989	Dorset Environmental Science Centre - Inland Lakes Database
OMOE – Lake Partner Program	81 sites on LoW for low level TP and Secchi	2002 to present – all site records not continuous	http://www.ene.gov.on.ca/envision/water/lake_partner
Cook County Coalition of Lake Associations			
EPA	National Lakes Assessment (68 lakes in MN)	2007-present	http://water.epa.gov/type/lakes/NLA_data.cfm Results from the second (2012) survey will be available in 2014
WICOLA	Condition monitoring for the White Iron chain of lakes	Secchi since 1994 2006-present, water quality monitoring	Derrick.Passe@Co.Lake.MN.US STORET and EDA ewebsite

Tributary Water Quality			
Agency	**Description**	**Duration**	**Data coordinates**
MPCA	Short- and long-term monitoring programs in Rainy River and its tributaries, primary program is Intensive Watershed Monitoring Plan	IWMP = 81 watersheds on a 10 year cycle (8/yr) from 2008 to 2018	STORET http://www.epa.gov/storet/dw_home.html MPCA's Environmental Data Access (EDA) website www.pca.state.mn.us/data/edaWater/index.cfm
CLMP	Rainy River mostly near I. Falls/ Baudette	1953-2006/1959-2006	
USGS/MPCA	Tributaries to LoW and the Rainy River-Big and Little Fork Rivers, Baudette River, and Zippel Creek	Short periods over past few decades	
OMOE	PWQMN sample sites along the Rainy R.	Fractured or past records	
EC–EEM program	One station near the pulp & paper mill on the Winnipeg River in MB down-stream from LoW and stations located downstream on the Rainy River after pulp & paper mill outfall at Fort Frances	Present	
EC	Detailed water quality monitoring, LoW	2008	
WICOLA/MPCA	Kawishiwi Watershed Protection Project	2011-	STORET and the EDA website
Biota			
Agency	**Description**	**Duration**	**Data coordinates**
RL Conservancy and Nature Conservancy of Canada and OMNRNC	Sturgeon. Loon and cormorant research		
VNP	Amphibian populations	2013-present	US National Park Service Great Lakes Inventory and Monitoring Network (Ashland, WI); USGS Upper Midwest Environmental Science Center (La Crosse, WI)
VNP	Common loon productivity	1979–present	Voyageurs National Park
VNP	Beaver population	1927-2005 (remote sensing); 1984-1986, 1993-1996, 2004-present (cache surveys and live capture)	Voyageurs National Park
VNP	Colonial waterbirds	1975–present	Voyageurs National Park
VNP	Bald Eagles and Ospreys	1973–present	Voyageurs National Park
OMNR and MN DNR	Fisheries assessment and monitoring	Ongoing	
MN DNR	Long-term zooplankton monitoring in large and Sentinel lakes	Ongoing	

and ecological conditions are unique. This variation introduces challenges to the design of a long-term monitoring program for the basin. Specifically, there are choices to be made regarding the variables that should be monitored, and the spatial (i.e., the number and the location of sampling sites) and temporal scales (i.e., the frequency of sampling at each site within and among years) that would be required to achieve a representative view of water quality and ecological conditions in the basin. So the question is posed, 'Is the current level of monitoring sufficient?' The Technical Advisory Committee of the IMA has, as its first objective, the goal to assess the adequacy of monitoring networks in the basin.

Notwithstanding these specific recommendations, researchers and those who conduct monitoring should consider their work in light of those characteristics that define ideal monitoring programs. Some central attributes of well-designed monitoring programs are included in the following as outlined by Lovett *et al.* (2007):

1. The scale of observation in environmental monitoring will affect the interpretation of water quality conditions, and our perception of ecological relationships. Because the variables of interest in monitoring are diverse, and because they vary over space and time in their response to changing environmental conditions, there is no single, correct spatial or temporal scale at which water quality and ecological dynamics should be studied.
2. Long-term monitoring records of aquatic systems at other sites have revealed that environmental conditions may change in ways that are neither gradual nor monotonic. In an environment where there are multiple simultaneous threats or stressors to water quality and ecology (e.g., climatic change, invasive species, shoreline residential development), periods of relative chemical and biotic stability may be punctuated by rapid and dramatic shifts to new states (e.g., Rühland *et al.* 2008).

Watershed Based Programs

Agency	Description	Duration	Data coordinates
MPCA, MDNR,MBWSR	10 year cycle watershed monitoring program primary program is Intensive Watershed Monitoring Plan	2008 -2027	
EC	Lake Winnipeg Basin Initiative	2008-	
	Rainy River First Nation Watershed Program	1998-	
St. Louis and Koochiching Counties	VNP Clean Water Joint Powers Board – wastewater treatment planning	2010	
VNP	Air quality monitoring	1999-present	Data stored at US National Park Service, Air Quality Division, Fort Collins, CO.
WICOLA/MPCA/SWCD	Kawishiwi Watershed Protection Project	2011-30 month study	STORET and the EDA website http://kawishiwiwatershed.com/sites/default/files/KWPP%20Implementation%20Plan%20June%202013_0.pdf

One of the critical remaining assessments with respect to monitoring is an examination of the current monitoring network relative to the remaining information gaps.

3. In any new design, consideration should be given to the specific research questions of interest, and variables for monitoring should include multiple indicators of water quality and ecological conditions, should span multiple biotic groups and habitats, and should be positioned along known stressor gradients (Yan *et al.* 2008). Choose variables with the future in mind. A core set of variables should include basic measures of ecosystem function, sensitive indicators of change, and variables that are of interest to resource users and the general public.
4. Allow flexibility to review, provide feedback on, and to adapt the monitoring design as research questions evolve.
5. The variables to be monitored should be sampled at spatial and temporal scales that will provide a statistically representative sample of the population, recognizing that this may vary with the research question being addressed, and among variables.
6. Maintain quality and consistency of the data. A quality assurance-quality control (QA/QC) program should be initiated from the beginning of a new monitoring program, particularly given that field and analytical methodologies may vary among agencies and laboratories.
7. Plan for long-term data accessibility and sample archiving.
8. Continually examine and present the monitoring data.
9. Include monitoring within an integrated research program. Monitoring is only one of several avenues that should be pursued when addressing complex environmental issues. Long-term monitoring should be balanced with diagnosis through controlled experimentation, modelling, and cross-site experimentation, especially when choices must be made among multiple environmental stressors. Furthermore, the use of historical data, such as historical accounts, traditional knowledge, and paleoecological data can provide a longer temporal perspective that may provide additional context for modern interpretations.

The Athabasca example.
In 2011, Environment Canada produced a water quality monitoring plan (phase 1) which was seen as a first step towards a comprehensive, integrated monitoring program for the oil sands region. This plan drew on the expertise of a diverse scientific team, see: https://www.ec.gc.ca/Publications/1A877B42-60D7-4AED-9723-1A66B7A2ECE8/LowerAthabascaWaterQualityMonitoringPlanPhase1.pdf.

It concluded that programs that are designed to track change (an attribute of almost all monitoring programs) should be able to:

1. Adequately describe the current or background condition.
2. Predict the vector from this condition. that is expected due to any disturbance
3. Demonstrate whether or not the effects produced are as expected, i.e. following the predicted vector. This premise seems straightforward but the process is, in fact, difficult to put in place. There are however massive gains associated with being able to conduct this level of monitoring and research.

Baratono and Story (2013), in a proposal to the IMA TAC, outlined a draft tiered monitoring program for the Rainy-Lake of the Woods basin. This was also presented at the 2014 International Lake of the Woods Watershed Forum (Baratono and Story 2014). The four-tiered approach allows for basin scale (Tier I), sub-basin scale (Tier II), subwatershed scale (Tier III) and special studies (Tier IV) which may encompass the subwatershed, watershed and basin scale. The approach links monitoring complexity to available resources while providing, at minimum, a viable framework that allows managers to:

- expand or decrease monitoring as budgets dictate
- provide data that are useful at the subwatershed, watershed and basin scale as necessary
- determine cumulative effects
- determine how effective projects are in meeting goals.

This type of approach, if expanded to include

The harmon-ization effort is focusing on eliminating border artifacts from federal, provincial and state geospatial datasets; creating seamless and sustainable hierarchical drainages and a connected hydrographiic framework for the R-LoW basin.

in-lake monitoring, would be a valid tool to begin to assess the adequacy of current monitoring programs throughout the basin.

One of the critical remaining assessments with respect to monitoring is an examination of the current monitoring network relative to the remaining information gaps. It may be that sufficient information is currently being collected but this needs to be verified.

Data Sharing and Harmonization

Monitoring and research data are of little use to those who require it if it is scattered in a way that makes it difficult to retrieve. Central data storage and platforms or portals that facilitate data sharing are crucial in the management of extensive and multi-jurisdictional resources. The various agencies involved in the collection of data within the basin may support internal databases for water quality and biological data, and may not wish to duplicate these efforts in a unique LoW database. Problems arise however when watershed-based analyses are attempted for areas that are international in nature. Data harmonization solutions are especially critical with respect to identification of watershed boundaries and to link cross boundary digital elevation information. These aspects of watershed delineation and analysis have been very successfully harmonized so that researchers using Geographic Information System (GIS) based methods can share GIS layers successfully across international boundaries (i.e., the work of the IJC Transboundary Data Harmonization Task Force). The geospatial plan for the IMA includes a mission to provide sound and timely advice to the TAC with respect to geospatial information, geospatial data and science planning. The purpose is to:

- avoid duplication
- coordinate the development of seamless information
- facilitate information and data sharing
- improve out-reach through the use of geospatial media
- ensure project scopes are achievable, sustainable, and bi-national
- promote the idea of the shared geography –ecosystem approach
- dupport bi-national research and management activities
- enhance community appreciation and engagement via innovative GIS application.

At the 2013 and 2014 International Rainy-Lake of the Woods Water Quality/Watershed Forums, Michael Laitta, Geographic Information Systems Coordinator for the IJC, presented on the bi-national, hydrographic data harmonization effort. The harmonization effort is focusing on eliminating border artifacts from federal, provincial and state geospatial datasets; creating seamless and sustainable hierarchical drainages and a connected hydrographic framework for the R-LoW Basin (Figure 40). This effort is a key component that will support the mandate of the new IRLWWB Board and the work of the IMA. The harmonization standards were developed by Federal, Provincial and State data stewards allowing a common interpretation of the R-LoW basin. The unified view encompasses 109 subwatersheds for both U.S. and Canada. Agencies can now overlay data onto these subwatersheds (e.g., aquatic vegetation, fish populations, temperature, water chemistry, etc.). The IJC website allows users to utilize the shared geography and real time data that are linked to the mapping.

The IMA-TAC Geospatial Subcommittee is working to create unified watershed information through GIS that can be used to assemble a shared geographic understanding of ecosystems and IMA activities in the basin. These tools will support bi-national research, management and interagency needs as outlined by the IMA. The subcommittee is moving forward with ESRI licensing, Web map services, civil engagement services and social media maps.

The USGS is leading a StreamStat initiative building on the data harmonization project which created seamless GIS maps to common datum within the basin. The StreamStat project will allow web users to pinpoint locations in many locations within a stream in the international R-LoW basin (where data are sufficient) and obtain hydrological estimates based on regression analyzes. The two year project is scheduled for completion in 2014 and relies on collaboration between the USGS, Agriculture Canada and the Ontario Ministry of Natural Resources.

The USGS, OMNR and MN DNR have plans to use improvements in trans-boundary hydrologic data to include the R-LoW basin in the Mid Continent SPARROW (SPAtially Referenced Regressions On Watershed attributes) model which has been successfully implemented for the Red, Assiniboine, Qu'Appelle and Souris rivers. https://water.usgs.gov/nawqa/sparrow/sparrow-mod.html.

Digital Elevation

The physical shape of the basin including elevations at all locations must be considered to determine watershed boundaries and to assess the effects of terrain slope on runoff characteristics. There are many further uses of these types of data which are derived through the use of digital elevation models. The derivation of such models can be difficult in cases where the watershed is separated by international boundaries. Data harmonization with respect to elevation has now been completed for the basin.

Digital elevation data (both topographic and bathymetric) for the Rainy/Namakan system has also been recently harmonized and has incorporated LIDAR data for local targeted studies in the area (Jean Morin, Environment Canada, second part of Study 1, Table 3 and Figure 41).

Digital elevation models are being developed (Morin *et al.* 2014) to assess:

- submerged aquatic vegetation 2D
- large classes of wetland 2D
- wild rice 1D and 2D
- cattail 1D and 2D
- muskrat winter house sustainability 1D and 2D
- walleye reproduction 2D
- northern pike reproduction 2D
- loon nesting success 1D.

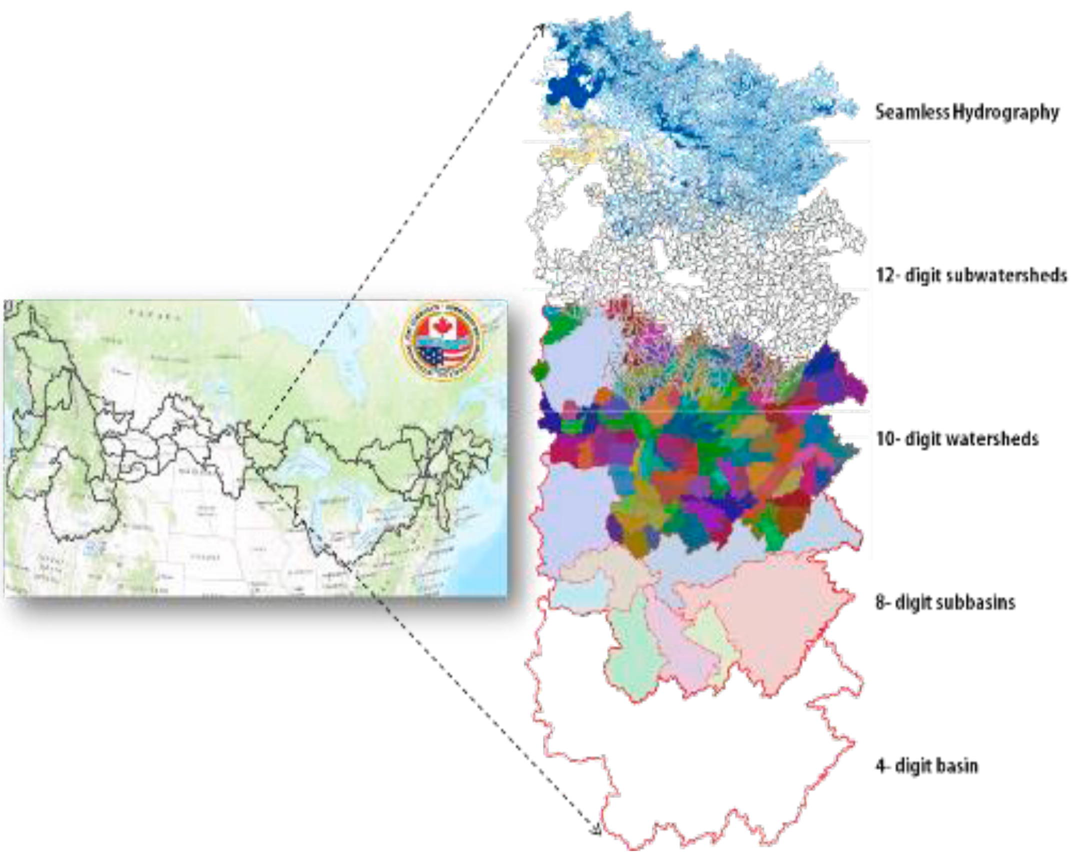

FIGURE 40 – Example of data harmonization process in the Rainy-Lake of the Woods basin (IJC).

PART 3: WATER QUALITY OBJECTIVES

Canada

Most aspects of water quality are regulated by Canadian federal laws by Environment Canada and the Canadian Environmental Protection Act (1999) http://laws-lois.justice.gc.ca/PDF/C-15.31.pdf and at the provincial level by The Ontario Ministry of the Environment and The Ontario Water Resources Act (1990) http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_90o40_e.htm.

Objectives and guidelines for a long list of substances are listed in the 1994 OMOE document *Water Management, Policies, Guidelines and Provincial Water Quality Objectives* (a.k.a "the Blue Book") which is the regulator's main tool to establish acceptable concentrations of a wide variety of elements and compounds in Ontario lakes and rivers. http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079681.pdf.

United States

The U.S. federal Clean Water Act (1972, amended 1977, 1987) establishes the basic structure for regulation of discharges of pollutants into waters of the United States and the framework for regulating quality standards for surface waters. The U.S. Environmental Protection Agency (USEPA), established in 1970, is the primary U.S. federal agency responsible for water quality in the basin. The Minnesota Pollution Control Agency, established in 1967, is the primary state agency of responsibility and which has put in place many regulations to help achieve water quality objectives in the basin.

In 2006, Minnesota passed the Clean Water Act, the purpose of which is to

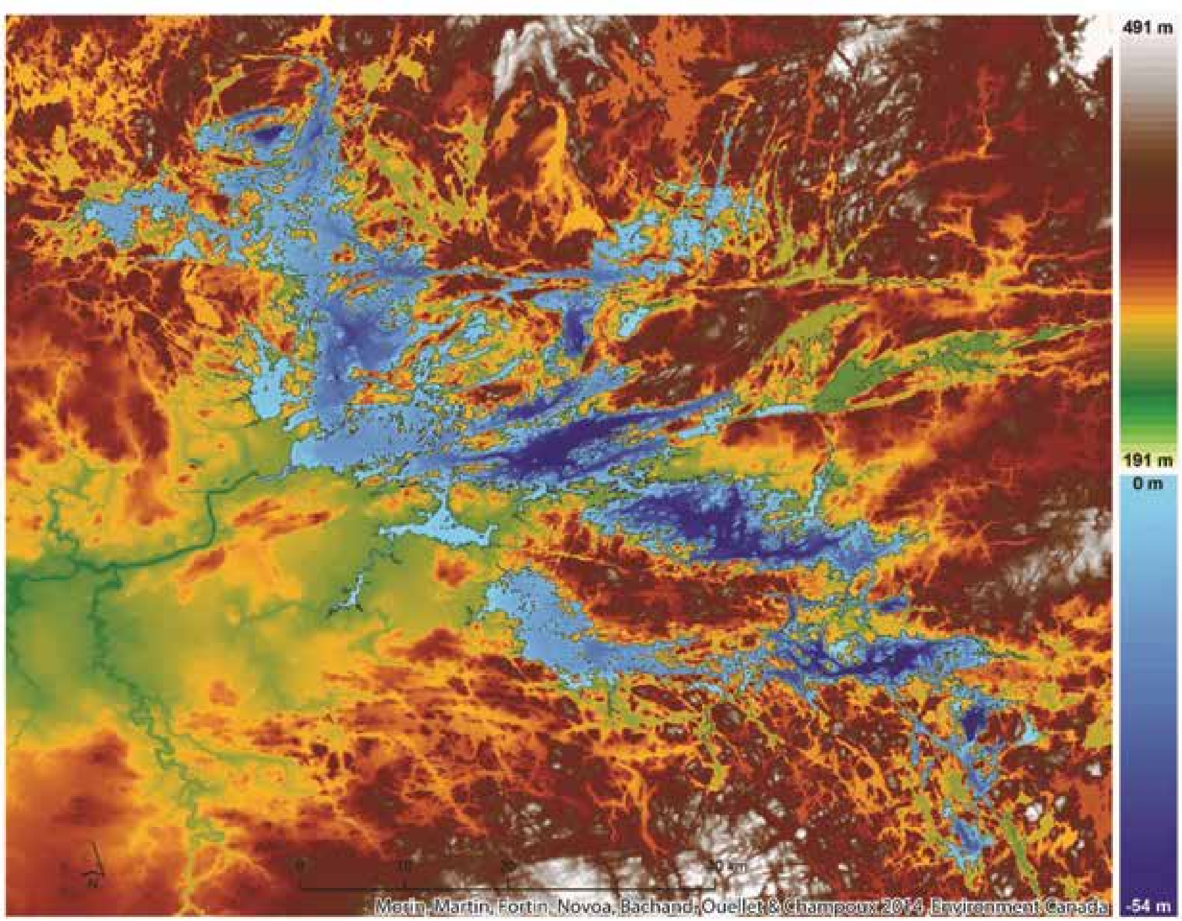

FIGURE 41 – Colour rendering of Environment Canada digital elevation data for Rainy Lake and Namakan Reservoir.

protect, enhance and restore water quality in lakes, rivers, and streams and to protect groundwater from degradation. The Act provides the authority, direction and resources to achieve and maintain water quality standards for groundwater and surface waters, including the standards required by section 303(d) of the federal Clean Water Act. Details of the Minnesota Clean Water Act are available at: https://www.revisor.mn.gov/statutes/?id=114D.

The State of MN has extensive water quality Administrative Rules, established by the State, for the most part in response to the US EPA / Clean Water Act. The primary Minnesota Administrative Rule pertinent to water quality is Chapter 7050 Waters of the State, although a variety of other rules have been enacted for specific circumstances. Minnesota Administrative Rule Chapter 7050 and other pertinent Rules administered by the Minnesota Pollution Control Agency are available at: https://www.revisor.mn.gov/rules/?agency=167.

In 2008 Minnesota passed the Clean Water, Land Legacy Amendment (CWLLA) which collects state tax dollars to protect fresh water in Minnesota. Funds have been directed to a variety of agencies , including the MPCA, the University of Minnesota's Water Resources Center (to prepare a 25 year framework for the management of water resources in the state – the 'Minnesota Water Sustainability Framework' was presented in 2011, http://wrc.umn.edu/watersustainabilityframework/index.htm), and other organizations and projects. In particular, through its Clean Water Fund, the CWLLA, is supporting:

- MPCA work in the areas of statewide water quality monitoring assessment, wild rice standards studies, TMDL study development and tool development
- soil and water conservation / protection projects at the local government / County Soil and Water Conservation District level through grants to the Board of Water and Soil Resources (BWSR)
- water research in the basin, such as the development of Hydrologic Simulation FORTRAN (HSPF) watershed models for the Rainy-Lake of the Woods basin, as part of the MPCA's Lake of the Woods TMDL work.

Excess nutrients are an important focus for USEPA and states have been charged with developing nutrient (eutrophication) standards as a part of their state water quality standards. In 2008, Minnesota promulgated lake eutrophication standards as a part of this national effort.

The Minnesota Pollution Control Agency (MPCA) has developed draft river eutrophication standards as a part of its current revision of Minnesota Rule Chapter 7050 standards rulemaking (Harris *et al.* 2013). Proposed standards (Table 33) and associated technical support documents are out for public review and comment.

International Water Quality Objectives and Alert Levels

The International Joint Commission established the International Rainy River Water Pollution Board (IRRWPB) on January 18, 1966, to assist it in complying with the Reference from the U.S. and

TABLE 33 – Draft river eutrophication criteria proposed for river nutrient regions in Minnesota.

Region	Nutrient TP µg/L	Chl-a µg/L	Stressor DO flux mg/L	BOD_5 mg/L
North	≤50	≤7	≤3.0	≤1.5
Central	≤100	≤18	≤3.5	≤2.0
South	≤150	≤35	≤4.5	≤3.0

Canadian Governments by reporting on progress to address pollution in the Rainy River, on the basis of the International Water Quality Objectives for the Rainy River as approved by the Governments in 1965. In addition, the Board was requested to report on any other water quality problems that would come to its attention. Review and recommendations with respect to International Water Quality Objectives for the Rainy River have been ongoing by the board.

The 1965 approved International Water Quality Objectives (for the IRRWPB's oversight) set forth objectives for:

- general objectives
- sanitary sewage, storm water and wastes from watercraft
- suspended solids
- Deoxygenating Wastes
- Nutrients For Slime Bacteria
- Periodic Review

In general, these objectives were targeted at restoring and maintaining desirable uses of the river at a time when the water quality was severely impaired. They were for the most part qualitative, seeking to reduce pollutants to a point whereby they were not conducive to descriptively undesirable conditions. Specific quantitative criteria were prescribed only for coliforms and dissolved oxygen concentrations. The 1965 International Water Quality Objectives for the Rainy River are included as Appendix A.

Over the ensuing decades, there were multiple initiatives by the IRRWPB to review and recommend revised and/or additional International Water Quality Objectives for the Rainy River, reported to the Commission in its 18th progress report to the IJC (1974) (Appendix B) and in the 29th progress report to the IJC (1981), at which time specific additional parameters were recommended as international objectives (Appendix C).

In its 1974 report, the IRRWPB committed to a review of additional parameters that were listed in the 1965 IJC Report (phenols, pH, odor, color, turbidity, oil, and toxic wastes) to determine whether specific objectives for these were required.

The 1981 report of the IRRWPB provided details regarding the criteria for selecting Specific Objectives and provided a more comprehensive list of parameters and recommended International Water Quality Objectives (with rationale) for the Rainy River. Parameters included: bacteria, pH, TDS, ammonia, dissolved oxygen, PCBs, cadmium, copper, iron, lead, manganese, mercury, nickel, zinc, nitrates, pesticides, color, SS, turbidity, odor, temperature, arsenic and unspecified organic compounds. It is clear that by the early 1980s the list of parameters of concern was beginning to expand.

Although recommendations were made by the IRRWPB for revised general and specific additional water quality objectives, it appears that no further International Water Quality Objectives were approved by the Governments beyond what existed in the 1965 original list.

Thus, to the best of our knowledge, the current situation with respect to International Water Quality Objectives in front of the current International Rainy-Lake of the Woods Watershed Board is the original 1965 International Water Quality Objectives inherited from the former IRRWPB. Further, these historic objectives apply only to the Rainy River and not to the expanded geographical mandate of the current IRLWWB (i.e., the entire boundary waters).

Considering this, the reality is that there are no modern International Water Quality Objectives for the Rainy River, that are of any use to current conditions and no International Water Quality Objectives at all for Lake of the Woods or the rest of the boundary waters.

Considering that there have been many recent initiatives to assess TP loading and to determine TMDLs for Lake of the Woods it may be prudent to examine the need for specific International Water Quality Objectives for certain areas within the basin. These objectives should be considered for all parameters where concerns and research to address these concerns are in place, e.g. nutrients or contaminants.

In 1992, the IJC provided the (former) International Rainy River Water Pollution Board with a revised Directive, which introduced the ability for the Board to establish and use "Alert Levels", effectively advisory thresholds or triggers for guidance in identifying and dealing with water pollutants for which International Water Quality Objectives had not been established. The establishment of Alert Levels did not imply that all listed parameters would be included in routine monitoring. Alert levels could be established by the IRRWPB for any parameter for which at least one of the "parties" (i.e., Ontario, Minnesota, Environment Canada, US EPA) have objectives, water quality standards or guidelines (or interim objectives, standards or guidelines). Alert Levels were based on the most stringent value / requirements of any of the parties. As such, values which exceed Alert Levels would be of potential concern to one of the regulatory agencies and should trigger an appropriate response. Also, Alert Levels could be (theoretically) constantly changing in response to changes in the underlying value/requirements of the most stringent regulatory authority.

Alert Levels for the Rainy River were adopted for a long list of parameters by 1994. This list of parameters and adopted Alert Levels were presented to the IJC in the 44th progress report of the IRRWPB (1994) and are shown in Appendix D. To the best of our knowledge, this list of adopted Alert Levels was not revised subsequently (e.g., additions / deletions of parameters, revisions to Alert Levels), although the Alert Levels themselves could have changed, being tied to the most stringent criteria of at least one of the agencies with jurisdiction on the Rainy River.

Thus, to the best of our knowledge, the existing situation with respect to Alert Levels in front of the current International Rainy-Lake of the Woods Watershed Boards is the 1994 list of Alert Levels for the Rainy River inherited from the former IRRWPB (albeit with potentially different threshold values given that underlying jurisdictional agency criteria may have changed over time). These historic Alert Levels were only for the Rainy River and only for traditional parameters of water quality. The newly established IRLWWB has an expanded geographical mandate for Alert Levels to waters of the entire R-LoW basin. The IRLWWB also has an expanded Alert mandate that extends beyond traditional water quality parameters to include aquatic ecosystem health indicators.

It is not clear at this time, given the recent formation of the IRLWWB, if the parameters in the 1994 Alert Levels list, are those that the IRLWWB would deem important to establish today, given the current state of conditions and issues in the basin.

Considering this, the reality is that Alert Levels do not yet substantively exist for the R-LoW basin, outside of those established historically for the Rainy River. These historical Alert Levels (and any new proposed), likely should be reviewed and updated with consideration given to:

- selection of parameters
- current and anticipated priority issues in the basin
- potential risks posed to the boundary waters
- outcomes of the Lake of the Woods Basin Water Quality Plan of Study.

Establishment of Alert Levels should be coordinated with the development of a baseline, tiered monitoring program.


(Patty Nelson)

5 RECOMMENDATIONS

SUMMARY OF RECOMMENDATIONS ESTABLISHED PRIOR TO THIS REPORT

A summary of recommendation that have been made by various agencies prior to the publication of this report are given in Table 34. The table of summaries incorporates the various IJC, Task Force Final Report (IJC 2012) recommendations either directly or through proposed board and committee functions. The Task Force noted the importance of communications and continued funding for basin research and governance initiatives. These would be addressed through the proposed (at that time) Rainy River Watershed Board Governance model although mechanisms to ensure continued funding in any given portion of the model were not specified.

The Task Force identified several priority issues which the board governance model proposes to address through Board committees or with inter-government and local Memorandums of Understanding. These include; increased First Nations, Métis, Tribal and local involvement, nutrients and algal blooms, climate change, land development, aquatic invasive species and the effects of water level regulation. The Task Force also listed many individual concerns within the basin which could be addressed through a citizen's advisory committee.

The seven IJC recommendations in Table 34, together with the function of the new board, would cover the full range of recommendations that were included in the IJC Task Force Final Report (IJC 2012).

RECOMMENDATIONS PURSUANT TO THIS REPORT

The following harmonized recommendations and suggested steps forward are formulated based on the state of the basin evaluations within the previous sections of this report and with further consideration of recommendations provided by the IJC (2012). Some of these, such as the need for continued communication or the necessity for secure funding for critical programs, go almost without saying. Others involve the collection of further information to answer those clear and compelling scientific questions or objectives that remain. The following recommendations are listed with respect to Governance and Research

Governance

1. **Continued support for the IJC Rainy–Lake of the Woods Watershed Board governance model.** Governments and IJC should continue to support development of effective governance mechanisms as reflected in the IJC recommendations listed in Chapter 5.

2. **Ensure Continued Communication.** The advances in the understanding of basin processes that have occurred over a relatively short timeframe are clearly the residue of continued communication between stakeholders in the basin over the same period of time. Continued communication between all partners who share an interest in the LoW basin is therefore recommended. Major avenues of communication would include:

   - The International Rainy-Lake of the Woods Watershed Forum—a venue that allows researchers and resource managers to exchange ideas, review existing data, and to generate future collaborative activities. It is recommended that agencies continue to support this annual initiative.
   - continued functioning of the IMA and its TAC
   - function of comprehensive Community and Industry Advisory Committees of the IRLWWB
   - increased involvement of First

TABLE 34 – A summary of recommendation that have been made by various agencies prior to the publication of this report.

Source	Recommendation
IJC Report to Governments of the United States and Canada on Bi-national Water Management of the Lake of the Woods and Rainy River Watershed 2012	To combine the functions and responsibilities of the existing International Rainy River Water Pollution Board and the International Rainy Lake Board of Control in an International Lake of the Woods and Rainy River Watershed Board (ILWRRWB)
	That the governments authorize the development of a Water Quality Plan of Study (WQPOS) for the Lake of the Woods Basin
	That the governments provide it with a reference to study the regulation of Lake of the Woods water levels and to provide governments with recommendations on any changes to the current regulatory approaches. Furthermore, the Commission recommends that a Lake of the Woods Water Levels Study include the aspects of its 2016 Rainy and Namakan Lakes Rule Curve Review
	That the governments support and participate in a Summit on the Future of the Lake of the Woods – Rainy River Watershed
	That the governments support the development of a Bi-national Comprehensive Basin Water Management Plan to help bi-nationally manage waters within the basin and to improve further reductions to point and nonpoint sources of pollution and meet basin water needs
	That the governments streamline and clarify the appointment process to the International Lake of the Woods Control Board and consider designating positions to act ex-officio unless otherwise specified
	That the governments partner with First Nations, Tribes, and Métis people in watershed governance and that the Canadian Government continue its efforts to resolve land and flooding claims by First Nations
2009 State of the Basin Report	The 2009 SOBR did not specifically make recommendations but it identified threats to the watershed and the research imperatives that were required at that time to manage outstanding issues (unanswered questions). Monitoring goals were also outlined.
	Threats included: Contaminants, Invasive Species, Water level fluctuations, Climate Change
	Unanswered questions in 2009: 1) An assessment of the relative sources of phosphorus to Rainy River and LoW; 2) An assessment of the sensitivity of different regions to shoreline development and long term changes in climate; 3) Knowledge of the variation in the frequency and intensity of algal blooms and algal toxins and how they are correlated to variation in water quality (especially nutrients) through space and time; 4) Availability of meteorological data at different locations on LoW and the Rainy River; 5) Improvement in spatial coverage of depositional water chemistry; 6) The availability of bathymetric maps and water circulation patterns; 7) Knowledge of internal loading and release rates of nutrients, especially phosphorus, from lake sediments; 8) Knowledge of the tributary load of nutrients to the Rainy River and LoW; 9) Contributions of non-point source anthropogenic loads to the nutrient budget; 10) Longer-term understanding of the spatial distribution of water quality among monitoring sites; 11) Useful and cross-jurisdictional GIS data; and 12) Information regarding long-term variation in algal abundance, composition, and algal toxins.
	Monitoring goals 1) Designing the monitoring program around compelling scientific questions; 2) Providing participants with an opportunity to review, provide feedback on, and to adapt the monitoring design as research questions evolve; 3) Accounting for the future when choosing monitoring variables; 4) Preserving data quality and consistency through the establishment of a quality assurance-quality control program at the outset of the monitoring plan; 5) Creating a data sharing and archiving policy; 6) Presenting the monitoring data at the annual International Lake of the Woods Water Quality Forum, as this will allow data to be examined by other researchers and resource managers; 7) Balancing the long-term monitoring with controlled experimentation, modeling, and cross-site experimentation which will help to discern the impacts from multiple environmental stressors; and 8) Including various forms of historical data, such as traditional knowledge and paleolimnology, to provide a temporal context for interpreting modern data.
IMA Technical Advisory Committee (TAC)	The 13 objectives of the IMA listed at the beginning of Chapter 3 should be considered as information gaps or data requirements that have been listed prior to the publication of the SOBR 2nd Edition. These have been identified relative to the basin concerns listed in Chapter 3

Nations, Métis, Tribes and local government
- data harmonization
- central data storage strategies.

3. **Secure Funding for Monitoring and Research.** Solutions for many environmental problems are expensive, require the collection and careful analysis of long-term data, and can be technically challenging. However, the costs of developing and managing sound monitoring programs are much less expensive than the value of the resources they protect, the costs of policy implementation, or the monetary benefits associated with environmental improvements. It is important to note that monitoring and research are required together such that monitoring data can be collected and used to the best effect.

   It is suffice to say that secure funding for monitoring programs and research is necessary to identify current problems, assess the viability of management initiatives designed to mitigate the problems and to identify those issues that are over the horizon before they are fully upon us.

   The complexity of the R-LoW basin, and the shared responsibilities of multiple agencies for its management, requires that core funding be generated from multiple sources. Much has been accomplished with respect to the development of working agreements between the partner agencies. These agreements help to guarantee effective monitoring and research but the recommendations must be funded. To ensure cost effectiveness, monitoring programs should be continually evaluated to ensure that they follow the guidelines established for successful monitoring programs as outlined in Chapter 4, Part 2 – Monitoring Programs. The IMA currently identifies priority unfunded programs.

Research

1. **Fill Information Gaps for Basin Concerns.** Information gaps for each basin concern (Chapter 3) should be prioritized and aligned with the objectives of the IMA. These should provide a basis for the IJC Lake of the Woods Basin Water Quality Plan of Study, soon to be completed.

2. **Assess Adequacy of Current of Monitoring Programs.** The concepts that detail the importance of proper design and use of monitoring programs are discussed in detail in the 2009 SOBR (Section 7.1). They argue that:

   "successful core monitoring programs will be designed around compelling scientific questions, will include a variety of sensitive indicators of environmental change, and sites will be chosen to be statistically representative of a population (both spatially and temporally). If designed thoughtfully, and if variables are chosen to span broad spatial and environmental gradients, then core monitoring for one set of research questions may be adaptable to other questions and emerging issues."

   Current monitoring programs across multiple agencies should be evaluated to assess whether the design of current monitoring programs is sufficient to address the current basin concerns.

   Baratono and Story (2013, 2014) outlined a tiered monitoring program for the Rainy-Lake of the Woods watershed. The four-tiered approach allows for basin scale (Tier I), sub-basin scale (Tier II), subwatershed scale (Tier III) and special studies (Tier IV, Figure 42) which may encompass the subwatershed, watershed and basin scale. The approach links monitoring complexity to available resources while providing, at minimum, a viable framework that allows managers to:
   - expand or decrease monitoring as budgets dictate
   - provide data that are useful at the subwatershed, watershed and basin scale as necessary
   - determine culminative effects
   - determine how effective projects are in meeting goals.

This type of approach, if expanded to include in-lake monitoring, would be a valid tool to begin to assess the adequacy of current programs throughout the basin.

3. **Examine the need for specific International Water Quality Objectives.** Considering that there have been many recent initiatives to assess TP loading and to determine TMDLs for Lake of the Woods, it may be prudent to examine the need for specific International Water Quality Objectives for certain areas within the basin. These objectives should be considered for all parameters where concerns and research to address these concerns are in place, e.g. nutrients or contaminants.

SUMMARY

Major improvements in governance and in the understanding of watershed processes have been realized in the five years since the first State of the Basin Report was published in 2009.

There have been many positive governance advances, including: the formation of the IMA to oversee technical aspects of basin research and management, and the reference from the IJC which led to the formation of the IRRLWB and initiation of the Lake of the Woods Basin Water Quality Plan of Study. From the beginning, the LOWWSF continues to coordinate a wide variety of basin activities with benefits to multiple stakeholders. There is at this point no apparent need for the development

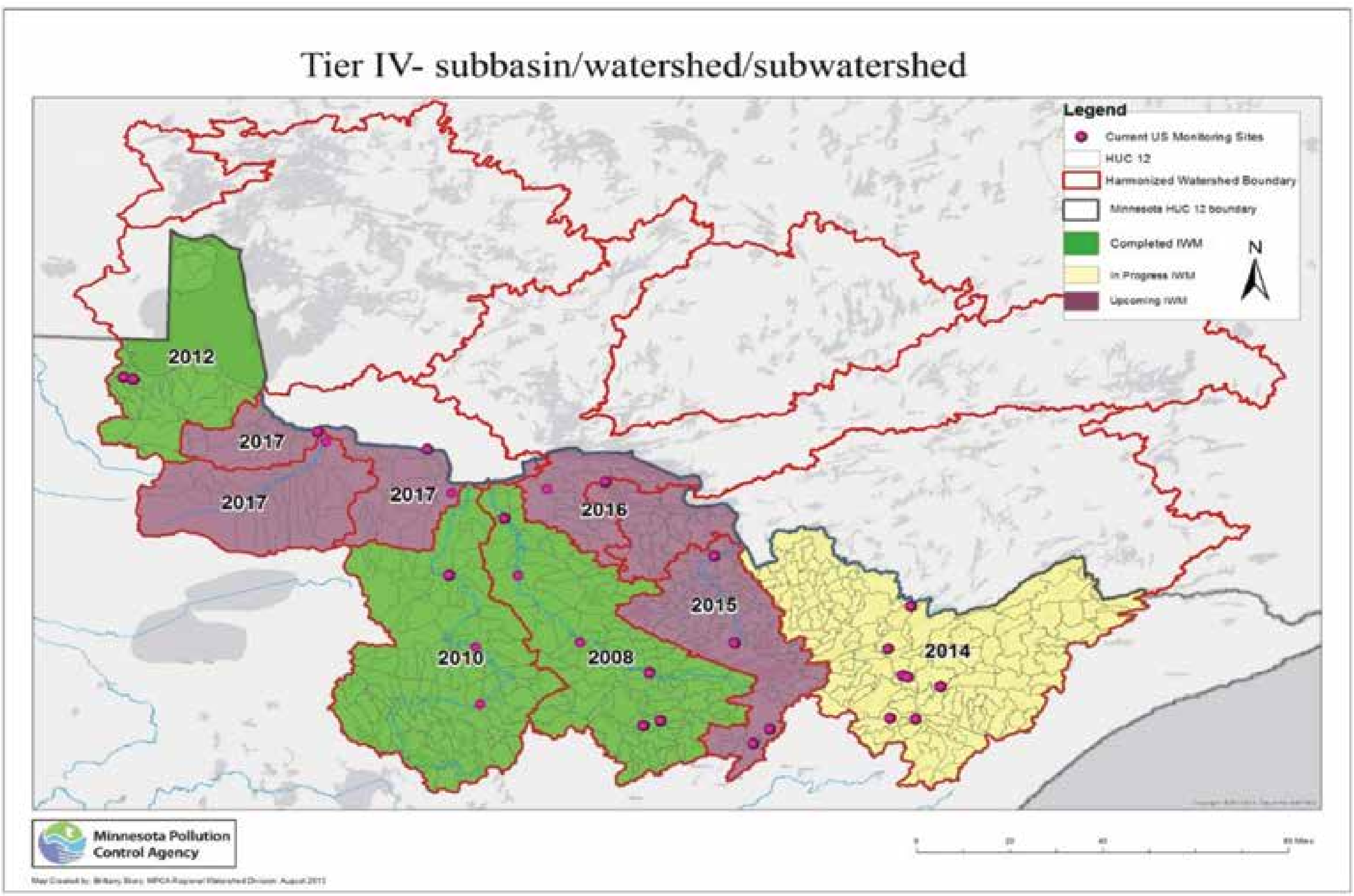

FIGURE 42 – Example of sub-basin, watershed, sub-watershed scale utilized in tiered monitoring approach proposed by the MPCA.

of any further groups to facilitate science and governance in the basin. This can be considered as a major accomplishment that has been fulfilled only in recent years.

With respect to the understanding and management of drainage basin processes, the 2009 State of the Basin Report recommended the following:

- enhance meteorological monitoring
- improve spatial coverage for the collection of deposition chemistry
- improve bathymetric maps and water circulation/internal water movement data
- collect further data on internal loading and release rates of nutrients from lake sediments
- quantify tributary nutrient loads to the Rainy River and LoW
- quantify non-point source anthropogenic contributions of nutrients
- improve the spatial distribution of water quality monitoring sites with continued discussion regarding the location and sampling frequency of core monitoring sites in LoW, the Rainy River, and its tributaries
- integrate GIS base layers from U.S. and Canadian delineated watersheds
- improve understanding of algal abundance and composition, and algal toxins in LoW.

Within the last five years many of these recommendations have been fulfilled. An examination of the recommendations in Chapter 5 reveals a similar list reduced in some aspects compared to the 2009 recommendations and expanded in several other areas.

All those who have worked on projects to better understand, safeguard or improve ecosystem integrity in the R-LoW basin should be proud of their accomplishments to date. The degree to which our understanding of this basin, and its many processes, has improved in only a few years is a rare, if not unique, accomplishment.

Loon (Bev Clark)

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ACRONYMS

CAG - Community Advisory Group
CCME - Canadian Council of Ministers of the Environment
CLMP - Citizen Lake Monitoring Program
COSEWIC - Committee on the Status of Endangered Wildlife in Canada
COSSARO - Committee on the Status of Species at Risk in Ontario
DFA - Discriminant function analysis
DOC - Dissolved Organic Carbon
EC – Environment Canada
EDA – Environmental Data Access
ELA - Experimental Lakes Area
EMAP - Environmental Monitoring and Assessment Program
HSPF - Hydrological Simulation Program
IAG - Industry Advisory Group
IBA - Important Birds Areas
IJC – International Joint Commission
ILWCB - International Lake of the Woods Control Board
IMA - International Multi-Agency Arrangement
IRLBC - International Rainy Lake Board of Control
IRLWWB - International Rainy Lake of the Woods Watershed Board
IWM - Intensive Watershed Monitoring Program
KRC - Kenora Resource Consultants
LoW - Lake of the Woods
R-LoW - Lake of the Woods and Rainy River
LWCB - Lake of the Woods Control Board
LWFAU - Lake of the Woods Fisheries Assessment Unit
MDNR - Minnesota Department of Natural resources
MPCA - Minnesota Pollution Control Agency
MFTCS - Minnesota Frog & Toad Calling Survey
NAAMP - North American Amphibian Monitoring Program
NPS - National Park Service
NWIS - National Water Information System
OMNR - Ontario Ministry of Natural Resources
OMOE - Ontario Ministry of the Environment
PCA - Principal Components Analysis
RRFN - Rainy River First Nation
SOBR - State of the Basin Report
STORET - short for STOrage and RETrieval Data Warehouse
SWCD - Soil and Water Conservation Districts
TMDL - Total Maximum Daily Loads
USEPA - United States Environmental Protection Agency
USGS - United States Geological Survey
WRAP - Watershed Restoration and Protection Program

(Patty Nelson)

APPENDIX A: Water Quality Objectives for the Rainy River (1965)

A. GENERAL OBJECTIVE

In general all wastes, including sanitary sewage, garbage, refuse, storm water and industrial effluents, should be in such a condition when discharged into the river that they do not create conditions which will adversely affect the use of these waters as a source of domestic or industrial water supply, or for navigation, fish and wildlife, bathing, recreation, agriculture and other riparian activities.

B. SANITARY SEWAGE, STORM WATER AND WASTES FROM WATERCRAFT

The coliform MPN (most probable number) median value should not exceed 2,400 per 100 ml at any point in the stream following initial dilution except in public recreational bathing areas where the median coliform values should not exceed 1,000 per 100 ml. The bacterial determinations used for this Objective include the presumptive and confirmed tests, or the MF (membrane filter) procedure for the coliform group of bacteria as given in "Standard Methods for the Examination of Water and Sewage," American Health Association, New York.

Solids and chemical constituents should be removed from all sanitary sewage, storm water and wastes from watercraft to such an extent that the effluents do not interfere with the above mentioned uses.
Undesirable

C. SUSPENDED SOLIDS

The discharge of suspended solids, including but not limited floating materials such as bark, butts, sawdust, fibres and lime sludge, should be reduced to a point that they are not conducive to slime growths, formation of sludge islands and banks, and do not injure fish or wildlife or their habitats.

This objective will be met if facilities are provided to remove substantially all suspended solids from the pulp and paper mill's effluent.

D. DEOXYGENATING WASTES

The dissolved oxygen should not fall below 5 mg/l at the average monthly flow which is exceeded 95 percent of the time in the critical month, nor below 3 mg/l at the minimum daily flow that is exceeded 95 percent of the time in the critical month.

This Objective will be met if the treatment provided substantially removes the solids, bacteria, chemical constituents and other substances capable of reducing the dissolved oxygen in these waters to an unreasonable extent.

E. NUTRIENTS FOR SLIME BACTERIA

The discharge of nutrients, including but not limited to wood sugars, should be controlled to the extent that they do not promote the nuisance growths of Sphaerotilus and other slime bacteria in the river.

This Objective will be met if there is a marked reduction or complete removal of nutrients in the effluents.

F. PERIODIC REVIEW

Specific Objectives for water quality, including but not restricted to phenols, pH, odour, color, turbidity, oils and highly toxic wastes, will be added when the Commission after a review of new and existing uses and wastes, determines that such amendments are necessary to meet the General Objectives as set forth in A above.

(Patty Nelson)

APPENDIX B: Recommended Water Quality Objectives for the Rainy River

Excerpt from the 18th Progress Report of IRRWPB to the IJC (1974)

EIGHTEENTH PROGRESS REPORT

TO THE

INTERNATIONAL JOINT COMMISSION

RAINY RIVER

INTERNATIONAL RAINY RIVER

WATER POLLUTION BOARD

September, 1974

INTERNATIONAL RAINY RIVER
WATER POLLUTION BOARD

March 1974

International Joint Commission
United States and Canada

Gentlemen:

The Rainy River Pollution Board met in Romulus, Michigan, March 29, 1974, to respond to the Commission's request for advice on further actions that may be required in the next 10 years to complete the clean-up of the Rainy River.

The Board has recognized, during the past year, the need for a review of the IJC water quality objectives for the Rainy River, in the light of water quality management policies emerging on both sides of the border. Since the actions needed in the next 10 years are going to be largely determined by the water quality requirements, both matters were considered simultaneously.

The Board reviewed the existing IJC objectives, Minnesota standards, Ontario criteria, and Federal requirements of the United States and Canada, as well as available up-to-date information on water quality conditions.

While the full effect of efficient operation of the industrial waste treatment plants at Ft. Frances and International Falls cannot be predicted, it is obvious that this will go a long way toward cleaning up the Rainy River. The Board considers that further evaluations of discharges of phenols, nutrients and bacteria will be required after operation of these treatment plants is at design efficiency.

A fish tainting problem occurred with the low flows of last year which was caused by phenols or phenol-like substances. It is believed that a nutrient balance study of Lake of the Woods should be made, to determine whether there is a need for further nutrient control measures. Algae blooms occur but the seriousness of the problem is not known. Bacterial problems associated with the paper mills may require further action than now contemplated.

Hydraulic overloading at the Ft. Frances municipal treatment plant is being addressed by Ontario. * The Board concludes that this problem must be corrected in order to meet the water quality objectives.

* Note: Deletion of the words "particularly for bacterial quality".

International Falls has combined sewers which overflow during periods of runoff and contribute to the bacterial pollution of the river. Likewise, the Board concludes that this problem must be corrected to meet water quality objectives.

Additionally, the Board has previously reported the need for control of pollution from a chicken farm on an unnamed Minnesota tributary entering a few miles below International Falls.

The Board feels that contingency planning for the prevention and control of spills of oil and other hazardous materials should be accomplished by Ontario and Minnesota.

The Board's recommendations in regard to water quality objectives are listed below.

General Objectives

It is recommended that the Commission adopt more detailed general objective statements of the "five freedoms" type. Suggested wording follows:

(a) Free from substances that enter the water as a result of human activity and that will settle to form putrescent or otherwise objectionable sludge deposits, or that will adversely affect aquatic life or waterfowl.

(b) Free from floating debris, oil, scum and other floating materials entering the waters as a result of human activity in amounts sufficient to be unsightly or deleterious.

(c) Free from materials entering the waters as a result of human activity producing color, odor, or other conditions in such a degree as to create a nuisance.

(d) Free from substances entering the waters as a result of human activity in concentrations that are or may become toxic or harmful to human, animal or aquatic life.

(e) Free from nutrients entering the waters as a result of human activity in concentrations that create nuisance growths of aquatic weeds, algae, and sphaerotilus and other slime bacteria, or that would cause undesirable bacterial re-growth.

3

Specific Objectives

It is recommended that a revised specific objective for microbiological parameters be adopted as follows:

Microbiology. The geometric mean of not less than five samples taken over not more than a 30-day period should not exceed 1,000/100 ml total coliforms nor 200/100 ml fecal coliforms. Waters used for body contact recreation activities should be substantially free from bacteria, fungi, or viruses that may produce enteric disorders or eye, ear, nose, throat and skin infections or other human diseases and infections.

Discussion. The revised objective is more stringent than the existing objective, and reflects current concern for protection of public health. As the Board has reported previously, the impact on public health of the Klebsiella bacteria is not fully understood and is the subject of further research. The Board will keep this matter under scrutiny, and will report further as information becomes available.

It is recommended that the existing objective for dissolved oxygen be retained, as follows:

Dissolved Oxygen. The dissolved oxygen should not fall below 5 mg/l at the average monthly flow which is exceeded 95 percent of the time in the critical month, nor below 3 mg/l at the minimum daily flow that is exceeded 95 percent of the time in the critical month.

Discussion. The existing objective is considered adequate for a warm water fishery (no salmonid species). However, walleye are present in the Rainy River, and there is some question as to whether additional protection for walleye is needed. The Board will seek expert advice on this question and report further.

With regard to additional parameters listed in the 1965 IJC Report, phenols, pH, odor, color, turbidity, oil, and toxic wastes, the Board will make a comprehensive review to determine whether specific objectives are required, and will report its recommendations not later than the October meeting of the Commission.

Respectfully submitted,

R. E. Tait
Chairman, Canadian Section

Carlysle Pemberton, Jr.
Chairman, United States Section

APPENDIX C: Recommended Water Quality Objectives for the Rainy River

Excerpt from the 29th Progress Report of IRRWPB to the IJC (1981)

Rainy River
Water Quality Objectives

Purpose and General Objectives

The purpose of these Water Quality Objectives is to restore and maintain the chemical, physical, and biological integrity of the waters of the Rainy River. In order to achieve this purpose, the Rainy River Water Pollution Board recommends that the Commission advises that the juristictions of Minnesota (US) and Ontario (Canada) make a maximum effort to develop programs, practices, and technology necessary for a better understanding of the Rainy River Ecosystem and to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Rainy River.

It is recommended that the following General Objectives for the Rainy River be adopted. These waters should be:

(a) Free from substances that directly or indirectly enter the waters as a result of human activity and that will settle to form putrescent or otherwise objectionable sludge deposits, or that will adversely affect aquatic life or waterfowl;

(b) Free from floating materials such as debris, oil, scum, and other immiscible substances resulting from human activities in amounts that are unsightly or deleterious;

(c) Free from materials and heat directly or indirectly entering the water as a result of human activity that alone, or in combination with other materials, will produce colour, odour, taste, or other conditions in such a degree as to interfere with beneficial uses;

(d) Free from materials and heat directly or indirectly entering the water as a result of human activity that alone, or in combination with other materials, will produce conditions that are toxic or harmful to human, animal, or aquatic life; and

(e) Free from nutrients directly or indirectly entering the waters as a result of human activity in amounts that create growths of aquatic life that interfere with beneficial uses.

Specific Objectives

1. The Specific Objectives recommended for the Rainy River are set forth subject to the following:

   (a) The philosophy used in developing Specific Objectives is one of protecting the most sensitive use of the water. It is felt that if the most sensitive use is protected, then all other uses of the water will be automatically safeguarded.

Specific Objectives (continued)

(b) The Specific Objectives represent the minimum levels of water quality desired in the Rainy River and are not intended to preclude the establishment of more stringent requirements.

(c) The determination of the achievement of Specific Objectives shall be based on statistically valid sampling data.

(d) Notwithstanding the adoption of Specific Objectives, all reasonable and practicable measures shall be taken to maintain or improve the existing water quality in those areas of the Rainy River where such water quality is better than that prescribed by the Specific Objectives, and in those areas having outstanding natural resource value.

(e) The responsible regulatory agencies shall not consider flow augmentation as a substitute for adequate treatment to meet the Specific Objectives.

(f) It is recongnized that in certain areas natural phenomena exist which, despite the best efforts of Minnesota and Ontario, will prevent the achievement of some of the Specific Objectives. As early as possible, these areas should be identified explicitly by the appropriate jurisdictions and reported to the International Joint Commission.

2. The Specific Objectives for the Rainy River or for particular portions thereof shall be kept under review by the International Rainy River Water Pollution Board and by the International Joint Commission, which shall make appropriate recommendations.

3. Minnesota and Ontario are encouraged to consult on:

(a) The establishment of Specific Objectives to protect beneficial uses from the combined effects of pollutants; and

(b) The control of pollutant loading rates to protect the integrity of the ecosystem over the long term.

4. Additional programs will be developed and implemented as necessary and desirable to meet the General and Specific Objectives.

WATER QUALITY OBJECTIVES FOR THE RAINY RIVER

Parameter	Rainy River Board Recommendations	Minnesota-Standards	Ontario Objectives	Justification	Reference
Bacteria					
Fecal Coliforms	100 organisms per 100 ml geometric mean May 1 thru Oct. 31*	200 organisms/100 ml log mean in 5 samples in 30-day period. 10 of samples not to exceed 2000/100 ml (March 1 thru October 31)	100 organisms per 100 ml geometric mean in a series of at least 10 samples per month	For the protection of whole body contact during the bathing season	Rationale for the Establishment of Ontario's Provincial Water Quality Objectives - Annex 4 - p. 171-174
Total Coliforms	1,000 organisms per 100 ml geometric mean May 1 thru Oct. 31	None	1,000 organisms per 100 ml geometric mean in a series of at least 10 samples per month		State Register - State of Minnesota, Vol. 4., Number 34 - Annex 3 p. 1338, 1348
					Annex 4 p. 171-172
Chemical Characteristics					
pH	6.5 - 8.5	6.5 - 9.0	6.5 - 8.5	For the protection of aquatic life	Annex 4 p. 4-8 Annex 3 p. 1350
TDS	must not be added to increase the ambient concentrations by more than 1/3 natural concentrations	500 mg/l (Minnesota drinking water standard)	must not be added to increase the ambient concentrations by more than 1/3 natural concentrations	For the protection of aquatic life	Annex 4 p. 137-138
Dissolved Gas					
Ammonia (un-ionized)	.02 mg/l as NH_3	.04 mg/l as N (warm water)	.02 mg/l as NH_3	For the protection of aquatic life	Annex 4 p. 9-16 Annex 5 p. 10-14
Dissolved Oxygen	5 mg/l - minimum at all times** pending further study	5 mg/l (instantaneous minimum concentration)	percent saturation determined by temperature	For the protection of aquatic life	Annex 4 p. 61-68 Annex 5 p. 19-24

* Present IJC objective - 200 organisms per 100 ml geometric mean
** Present IJC objective - 5 mg/l minimum - further study is necessary for this objective

Annex 1

WATER QUALITY OBJECTIVES
FOR THE RAINY RIVER

Parameter	Rainy River Board Recommendations	Minnesota-Standards	Ontario Objectives	Justification	Reference
Bacteria					
Fecal Coliforms	100 organisms per 100 ml geometric mean May 1 thru Oct. 31*	200 organisms/100 ml log mean in 5 samples in 30-day period. 10 of samples not to exceed 2000/100 ml (March 1 thru October 31)	100 organisms per 100 ml geometric mean in a series of at least 10 samples per month	For the protection of whole body contact during the bathing season	Rationale for the Establishment of Ontario's Provincial Water Quality Objectives - Annex 4 - p. 171-174
Total Coliforms	1,000 organisms per 100 ml geometric mean May 1 thru Oct. 31	None	1,000 organisms per 100 ml geometric mean in a series of at least 10 samples per month		State Register - State of Minnesota, Vol. 4., Number 34 - Annex 3 p. 1338, 1348 Annex 4 p. 171-172
Chemical Characteristics					
pH	6.5 - 8.5	6.5 - 9.0	6.5 - 8.5	For the protection of aquatic life	Annex 4 p. 4-8 Annex 3 p. 1350
TDS	must not be added to increase the ambient concentrations by more than 1/3 natural concentrations	500 mg/l (Minnesota drinking water standard)	must not be added to increase the ambient concentrations by more than 1/3 natural concentrations	For the protection of aquatic life	Annex 4 p. 137-138
Dissolved Gas					
Ammonia (un-ionized)	.02 mg/l as NH_3	.04 mg/l as N (warm water)	.02 mg/l as NH_3	For the protection of aquatic life	Annex 4 p. 9-16 Annex 5 p. 10-14
Dissolved Oxygen	5 mg/l - minimum at all times** pending further study	5 mg/l (instantaneous minimum concentration)	percent saturation determined by temperature	For the protection of aquatic life	Annex 4 p. 61-68 Annex 5 p. 19-24

* Present IJC objective - 200 organisms per 100 ml geometric mean
** Preser^ IJC objective - 5 mg/l minimum - further study is necessary for ^his objective

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WATER QUALITY OBJECTIVES
FOR THE RAINY RIVER

Parameter	Rainy River Board Recommendations	Minnesota-Standards	Ontario Objectives	Justification	Reference
PCBs	0.001 μg/l in water 0.1 μg/g-wet weight in fish (desirably absent)	None	0.001 μg/l	For the protection of aquatic life, animal and human consumption	Annex 4 p. 226-234
Metals (based on assumed hardness of 45 mg/l)					
Cadmium	0.2 μg/l (total)	None	0.2 μg/l (total)	For the protection of aquatic life	Annex 4 p. 27-36
Copper	5 μg/l (total)	10 μg/l (total)	5 μg/l (total)	For the protection of aquatic life	Annex 4 p. 47-54 Annex 3 p. 1350
Iron	300 μg/l (total)	300 μg/l (total)	300 μg/l (total)	To protect for human consumption	Annex 4 p. 81-85 Annex 3 p. 1348
Lead	10 μg/l (total)	None	Concentration determined by the alkalinity of the water - not to exceed 25 μg/l*	For the protection of aquatic life	Annex 4 p. 86-91
Manganese	50 μg/l (total)	50 μg/l (total)	50 μg/l (total)	To protect for human consumption	Annex 2 p. 52
Mercury	0.2 μg/l in water	None	0.2 μg/l in water 0.5 μg/g whole fish sample - wet weight basis	For the protection of aquatic life, animal life, and human consumption	Annex 4 p. 92-100
Nickel	25 μg/l (total)	None	25 μg/l (total)	For the protection of aquatic life	Annex 4 p. 101-104
Zinc	30 μg/l (total)	5000 μg/l (total) (Minnesota drinking water standard)	30 μg/l (total)	For the protection of aquatic life	Annex 4 p. 152-156

* Mean Alkalinity at Station 8 = 34 mg/l (1972-1980 data)

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WATER QUALITY OBJECTIVES
FOR THE RAINY RIVER

Parameter	Rainy River Board Recommendations	Minnesota-Standards	Ontario Objectives	Justification	Reference
Nutrients					
Nitrates	10 mg/l as N The concentration should be limited to the extent necessary to prevent nuisance growths of algae, weeds and slimes that are or may become injurious to any beneficial water use	10 mg/l as N 45 mg/l as NO_3	10 mg/l an N	To protect for human consumption	Annex 2 p. 52 Annex 3p. 1348
Pesticides	Persistent pest control products and other persistent organic contaminants that are toxic or harmful to human, animal or aquatic life should be substantially absent in the Rainy River and from whole fish samples collected from the Rainy River- Substantially absent is defined as less than the detection limits of the best available scientific analytical method	Not listed (See State Register, State of Minnesota, Vo., 4, No. 34, p. 1337-1338)	Not listed (See Water Management, Nov., 1979, Ontario Ministry of the Environment, Annex 2 p. 38-39)	For the protection of aquatic life, animal life, and human consumption	Annex 4 p. 179-221 Annex 3 p. 1337-1338 IJC Great Lakes Water Quality Agreement (1978)

WATER QUALITY OBJECTIVES
FOR THE RAINY RIVER

Parameter	Rainy River Board Recommendations	Minnesota-Standards	Ontario Objectives	Justification	Reference
Physical Parameters					
Color Suspended Solids Turbidity Odor	Water used for swimming, bathing, and other recreational activities should be aesthetically pleasing. The water should be devoid of debris, oil, scum, and any substance which would produce an objectionable deposit, color, odor, taste, or turbidity. The water in bathing areas should be sufficiently clear to estimate depth or to see submerged swimmers. In other areas, suspended matter should not be added to surface water in concentrations that will change the natural secchi disc reading by more than 10%.	15 color units (Drinking water std.) None 25 NTU None	Water used for swimming, bathing, and other recreational activities should be aesthetically pleasing. The water should be devoid of debris, oil, scum, and any substance which would produce an objectionable deposit, color, odor, taste, or turbidity. The water in bathing areas should be sufficiently clear to estimate depth or to see submerged swimmers. In other areas, suspended matter should not be added to surface water in concentrations that will change the natural secchi disc reading by more than 10%.	For aesthetic reasons swimmer safety, and the protection of aquatic life.	Annex 4 p. 143-148 p. 161-177 Annex 3 p. 1350
Temperature	The natural thermal regime of the Rainy River shall not be altered so as to impair the quality of the natural environment. The diversity, distribution and abundance of plant and animal life shall not be significantly changed.	5^{O}F above natural in streams and 3^{O}F above natural in lakes, based on monthly average of the maximum daily temperature, except in no case shall it exceed the daily average temperature of 86^{O}F.	The natural thermal regime of any body of water shall not be altered so as to impair the quality of the natural environment. The diversity, distribution and abundance of plant and animal life shall not be significantly changed.	For the protection of aquatic life	Annex 4 p. 134-136 Annex 3 p. 1350

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WATER QUALITY OBJECTIVES
FOR THE RAINY RIVER

Parameter	Rainy River Board Recommendations	Minnesota-Standards	Ontario Objectives	Justification	Reference
Toxic Substances					
Arsenic	10 μg/l (total)	10 μg/l (total)	10 μg/l (total) Ontario drinking water standards	To protect for human consumption	Annex 3 p. 1348
Phenolic Compounds	1 μg/l (total) in water. No taste problem in edible portions of fish	10 μg/l (total)	1 μg/l (total)	To protect against taste and odor in water and fish	Annex 4 p. 111-115 Annex 3 p. 1350
Unspecified Organic Compounds	For other organic contaminants, for which Specific Objectives have not been defined, but which can be demonstrated to be persistent and are likely to be toxic, the concentrations of such compounds in water or aquatic organisms should be substantially absent, i.e., less than detection levels as determined by the best scientific methodology available.			For the protection of aquatic life, animal, and human consumption	IJC Great Lakes Water Quality Agreement (1978)

LIST OF ADDITIONAL ANNEXES

1. Annex 2 - Water Management - Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment, Ontario Ministry of the Environment, November 1978.

2. Annex 3 - State Register, "Pollution Control Agency - Amendments and Renumbering of WPC 14-15, 24 and 25; and Repeal of WPC 2-3, 5-13, 16-21, 23, 26, 29, 31 and 32," State of Minnesota, Volume 4, Number 34, February 25, 1980, pp. 1330-1392.

3. Annex 4 - Rationale for the Establishment of Ontario's Provincial Water Quality Objectives, Ontario Ministry of the Environment, September 1979.

4. Annex 5 - "Statement of Need and Reasonableness, "Minnesota Pollution Control Agency, PCA-004-80-AK.

(Patty Nelson)

The mill was in compliance throughout 1994 with the Pulp and Paper Mill Effluent Chlorinated Dioxins and Furans Regulations pursuant to section 34 of the Canadian Environmental Protection Act.

OSBBC Limited Oriented Strand Board Mill (Barwick)

Boise Cascade Corporation, under the name OSBBC Limited, has made application for a Certificate of Approval for a plant to manufacture oriented strand board at a site on the Rainy River, east of Barwick, Ontario in the Township of Chapple. The plant will receive hardwood logs (birch and aspen) which will be debarked, waferized, dried, impregnated with resins, pressed into panels, cut, and shipped as a construction board product. The Barwick site was chosen following a public consultation and review process which looked at a number of potential sites in the Rainy River area.

The proposed plant is designed to produce a maximum of 400 million feet of 3/8 inch board annually. From an environmental standpoint, the process is considered to be substantially "dry" in nature with no industrial type effluent. Ministry approvals are required under the legislation for air emission sources. Notification of the project under Article V of the Canada/US Air Quality Agreement was made by the company to Environment Canada in March 1995. The company hopes to begin construction in the early summer of 1995 with a planned start-up in November 1996.

RAINY RIVER ALERT LEVELS

The International Joint Commission, in Executive Session on October 21, 1992, adopted a revised Directive to the Rainy River Board. Authorization was included for the adoption and use of Alert Levels for guidance in identifying and dealing with water pollutants for which IJC Water Quality Objectives have not been established.

Alert Levels have been adopted to provide a ready reference for evaluation of monitoring data. Values which exceed Alert Levels are of potential concern to at least one of the regulatory agencies, and should trigger an appropriate response. The establishment of Alert Levels does not imply that all of the listed parameters will be included in routine monitoring. The following concepts were followed in selecting parameters and Alert Levels:

- Alert Levels are established for any parameter for which any of the parties (the Province of Ontario, State of Minnesota, Environment Canada, or the United States, Environmental Protection Agency) have Objectives, Water Quality Standards, or Guidelines.
- Alert Levels are based on the most stringent value adopted by any of the parties.
- Alert Levels will be adopted for parameters for which Interim Guidelines or Objectives are formally adopted, but Alert Levels based on Interim values will be marked by an asterisk (*).
- The table of Alert Levels will be reviewed and updated on a regular basis. As new Water Quality Objectives, Guidelines, or Water Quality Standards are adopted by the parties, they will be incorporated into the list of Alert Levels.

Rainy River Alert Levels

Parameter	Minnesota/United States Water Quality Standards	Ontario Objectives	Environment Canada Guidelines	Alert Levels
* -Based on Interim Guidance DW - Drinking Water HH - Human Health AL - Aquatic Life ID - Industrial Use IR - Irrigation Use				
Acenapthene	12 ug/l AL			12 ug/l AL
Acetamide, N-(2-Hydroxyphenyl)		30 ug/l AL*		30 ug/l AL*
Acetanilide		100 ug/l AL*		100 ug/l AL*
Acrolein		0.03 ug/l AL*		0.03 ug/l AL*
Acrylonitrile	0.38 ug/l AL			0.38 ug/l AL
Alachlor	4.2 ug/l, AL			4.2 ug/l AL
Aldicarb			1 ug/l AL*	1 ug/l AL*
Aldrin/dieldrin		0.001 ug/l AL	0.004 ug/l AL 0.0007 ug/l HH	0.001 ug/l AL 0.0007 ug/l HH
Alkalinity		Should not be decreased > 25% of natural concentrations. AL		Should not be decreased >25% of natural concentrations. AL
Aluminum, Total	125 ug/l AL	75 ug/l AL (pH 6.5-9.0 measured in clay-free samples)	100 ug/l AL	75 ug/l AL (pH 6.5-9.0 measured in clay-free samples)
Aminoazobenzene, 4-		0.8 ug/lAL*		0.8 ug/l AL*
Aminoethyl piperazine		2400 ug/l AL*		2400 ug/l AL*
Ammonia-N	.04 mg/l as N unionized (warm water) AL	0.02 mg/l as NH_3. AL	Total NH_3 1.37 mg/l @pH 8.0;T 10°C 2.2 mg/l @ph 6.5;T 10°C	0.02 mg/l as NH_3 AL
Aniline		2 ug/l* AL	2 ug/l AL	2 ug/l AL
Anthracene	0.029 ug/l AL	0.0008 ug/l AL*		0.0008 ug/l AL*
Antimony	5.5 ug/l, AL			5.5 ug/l, AL
Arsenic, Total	2 ug/l, AL	5 ug/l AL*	50 ug/l AL	2 ug/l AL

Parameter	Minnesota/United States Water Quality Standards	Ontario Objectives	Environment Canada Guidelines	Alert Levels
Atrazine	3.4 ug/l, AL		2 ug/l AL	2 ug/l AL
Azinphos-methyl (Guthion)		0.005ug/l AL		0.005 ug/l AL
Benzaldehyde		0.09 ug/l AL*		0.09 ug/l AL*
Benzene	11 ug/l, AL	100 ug/l AL*	300 ug/l AL	11 ug/l AL
Benzidine		20 ug/l AL*		20 ug/l AL*
Benzothiazole		100 ug/l AL*		100 ug/l AL*
Benzo[g,h,i]perylene		0.00002 ug/l AL*		0.00002 ug/l AL*
Benzo[k]fluoranthene		0.0002 ug/l AL*		0.0002 ug/l AL*
Benzyl alcohol		8 ug/l AL*		8 ug/l AL*
Benz[a]anthracene		0.0004 ug/l AL*		0.0004 ug/l AL*
Beryllium		11 ug/l AL (Hardness <75 mg/l) 1100 ug/l AL (Hardness >75 mg/l)		11 ug/l AL (Hardness <75 mg/l) 1100 ug/l AL (Hardness >75 mg/l)
Biphenyl		0.2 ug/l AL*		0.2 ug/l AL*
Bis(2-chloroethyl) ether		200 ug/l AL*		200 ug/l AL*
Bisphenol A		5 ug/l AL*		5 ug/l AL*
Boron	500 ug/l IR	200 ug/l AL*		200 ug/l AL*
Bromodichloromethane		200 ug/l AL*		200 ug/l AL*
Bromoform	41 ug/l, AL	60 ug/l AL*		41 ug/l, AL
Bromomethane		0.9 ug/l AL*		0.9 ug/l AL*
Bromophenyl phenyl ether, 4-		0.05 ug/l AL*		0.05 ug/l AL*
Bromoxynil			5 ug/l AL	5 ug/l AL
Butanal		10 ug/l AL*		10 ug/l AL*
Butyl benzyl phthalate		0.2 ug/l AL*		0.2 ug/l AL*

Parameter	*Minnesota/United States Water Quality Standards*	*Ontario Objectives*	*Environment Canada Guidelines*	*Alert Levels*
Cadmium, Total	The chronic standard shall not exceed: exp.{0.7852 {1n {total hardness mg/l}] - 3.49}. 0.49 ug/l @ H=34 mg/l. AL	0.1 ug/l AL* (Hardness <100 mg/l) 0.5 ug/l AL* (Hardness >100 mg/l)	0.2 ug/l AL	0.1 ug/l AL* (Hardness <100 mg/l)
Camphene		2 ug/l AL*		2 ug/l AL*
Captan			2.8 ug/l AL*	2.8 ug/l AL*
Carbofuran			1.75 ug/l AL	1.75 ug/l AL
Carbon Tetrachloride	1.9 ug/l AL		13 ug/l AL*	1.9 ug/l AL*
Chlordane	0.00029 ug/l AL	0.06 ug/l AL	0.006 ug/l AL	0.00029 ug/l AL
Chloride	100 mg/l (total) ID			100 mg/l (total) ID
Chlorine (TRC)	6 ug/l AL	2 ug/l AL	2 ug/l AL	2 ug/l AL
Chloro-3-methyl phenol,4-		3 ug/l AL*	3 ug/l AL*	
Chlorobenzene (Mono-)	10 ug/l AL	15 ug/l AL	5 ug/l AL	10 ug/l AL
Chlorodibromomethane		40 ug/l AL*		40 ug/l AL*
Chloroform	55 ug/l AL		2 ug/l (Interim) AL	2 ug/l AL*
Chloromethane		700 ug/l AL*		700 ug/l AL*
Chloronaphthalene,1-		0.1 ug/l AL*		0.1 ug/l AL*
Chloronaphthalene,2-		0.2 ug/l AL*		0.2 ug/l AL*
Chlorophenyl phenyl ether,4-		0.05 ug/l AL*		0.05 ug/l AL*
Chlorothalinol			0.18 ug/l AL*	0.18 ug/l AL*
Chlorpyrifos	0.041 ug/l AL	0.001 ug/l AL		0.001 ug/l AL
Chromium, Trivalent	86 ug/l AL			86 ug/l, AL
Chromium, Hexavalent	11 ug/l. AL			11 mg/l Total AL
Chromium, Total	The chronic standard shall not exceed: exp. {0.819{In{total hardness mg/l}+1.561}. 100 ug/l @H=34 mg/l AL	100 ug/l AL	2 ug/l AL	2 ug/l AL

Parameter	Minnesota/United States Water Quality Standards	Ontario Objectives	Environment Canada Guidelines	Alert Levels
Chrysene		0.0001 ug/l AL*		0.0001 ug/l AL*
Cineole		100 ug/l AL*		100 ug/l AL*
Cobalt	2.8 ug/l, AL	0.6 ug/l AL*		0.6 ug/l AL*
Colour	30 color units. DW	5 color units AS		5 color units
Copper, Total	The chronic standard shall not exceed: exp. {0.62 {ln {total hardness mg/l} - 0.57}. 5.0 ug/l @ H= 34 mg/l AL	1 ug/l AL* (Hardness <20 mg/l) 5 ug/l AL* (Hardness >20 mg/l)	2 ug/l AL (Hardness=0-120 mg/l)	2 ug/l AL
Cresol		1 ug/l AL*		1 ug/l AL*
Cyanazine			2ug/l AL *	2ug/l AL *
Cyanide	5.2 ug/l (Free) AL	5 ug/l (total) AL		5 ug/l (total) AL
Cyclohexanamine		50 ug/l AL*		50 ug/l AL*
Cyclohexanol		1000 ug/l AL*		1000 ug/l AL*
Dalapon	200 ug/l, DW	110 ug/l AL		110 ug/l AL
DDT & metabolites	0.0017 ug/l AL	0.003 ug/l AL	0.001 ug/l AL	0.001 ug/l AL
Dehydroabietic acid (DHA) See Resin Acids				
Di-n-butylamine		8 ug/l AL*		8 ug/l AL*
Di-n-butyltin		0.08 ug/l AL*		0.08 ug/l AL*
Di-t-butyl-4-methylphenol, 2,6-		0.2 ug/l AL*		0.2 ug/l AL*
Diazinon		0.08 ug/l AL		0.08 ug/l AL
Dibenzofuran		0.3 ug/l AL*		0.3 ug/l AL*
Dibenz[a,h]anthracene		0.002 ug/l AL*		0.002 ug/l AL*
Dibutylamine		8 ug/l AL*		8 ug/l AL*
Dibutylphthalate		4 ug/l AL		4 ug/l AL

Parameter	Minnesota/United States Water Quality Standards	Ontario Objectives	Environment Canada Guidelines	Alert Levels
Dicamba		200 ug/l AL		10 ug/l AL*
Dichlorobenzene, 1,2- 1,3- 1,4-		 2.5 ug/l AL 2.5 ug/l AL 4 ug/l AL	 2.5 ug/l AL 2.5 ug/l AL 4 ug/l AL	 2.5 ug/l AL 2.5 ug/l AL 4 ug/l AL
Dichlorobenzidine, 3,3'-		0.6 ug/l AL*		0.6 ug/l AL*
Dichlorobut-3-ene, 1,2-		10 ug/l AL*		10 ug/l AL*
Dichloroethane, 1,1-		200 ug/l AL*		200 ug/l AL*
Dichloroethane, 1,2-	3.8 ug/l AL	100 ug/l AL*		3.8 ug/l AL
Dichloroethylene, 1,1-		40 ug/l AL*		40 ug/l AL*
Dichloroethylene, 1,2-		200 ug/l AL*	100 ug/l AL	100 ug/l AL*
Dichloroguaiacol, 4,5-		6 ug/l AL*		6 ug/l AL*
Dichlorophenols		0.2 ug/l AL	0.2 ug/l AL	0.2 ug/l AL
Dichlorophenoxyacetic Acid, 2,4- (2,4-D)		4 ug/l AL	4 ug/l AL	4 ug/l AL
Dichloropropane, 1,2-		0.7 ug/l AL*		0.7 ug/l AL*
Dichloropropylene, trans-1,3		7 ug/l AL*		7 ug/l AL*
Diclofop-methyl			6.1 ug/l AL	6.1 ug/l AL
Dieldrin	0.000026 ug/l AL	+aldrin-0.001 ug/l	0.004 ug/l AL	0.000026 ug/l AL
Diethyl-m-toluamide, N,N-		200 ug/l AL*	200 ug/l AL*	
Diethylene glycol		11000 ug/l AL*	31 mg/l AL*	11000 ug/l AL*
Diethylhexylphthalate		0.6 ug/l AL		0.6 ug/l AL
Dimethoate			6.2 ug/l AL*	6.2 ug/l AL*
Dimethyl disulphide		0.2 ug/l AL*		0.2 ug/l AL*
Dimethylamine		3 ug/l AL*		3 ug/l AL*

Parameter	Minnesota/United States Water Quality Standards	Ontario Objectives	Environment Canada Guidelines	Alert Levels
Dimethylbenzylamine		40 ug/l AL*		40 ug/l AL*
Dimethylformamide, N,N-		5000 ug/l AL*		5000 ug/l AL*
Dimethylnaphthalene, 1,3-		0.09 ug/l AL*		0.09 ug/l AL*
Dimethylnaphthalene, 2,6-		0.02 ug/l AL*		0.02 ug/l AL*
Dimethylphenol, 2,6-		8 ug/l AL*		8 ug/l AL*
Dimethylphenol, 2,4-		10 ug/l AL*		10 ug/l AL*
Dimethylphenol, 3,4-		20 ug/l AL*		20 ug/l AL*
Dinitro-o-cresol, 4,6-		0.2 ug/l AL*		0.2 ug/l AL*
Dinitrobenzene, p-		2 ug/l AL*		2 ug/l AL*
Dinitrobenzene, o-		1 ug/l AL*		1 ug/l AL*
Dinitrobenzene, m-		1 ug/l AL*		1 ug/l AL*
Dinitrotoluene, 2,4-		4 ug/l AL*		4 ug/l AL*
Dinitrotoluene, 2,6-		3 ug/l AL*		3 ug/l AL*
Dinoseb			1.75 ug/l AL	1.75 ug/l AL
Dioxane, 1,4-		20 ug/l AL*		20 ug/l AL*
Dioxin and Furan 2,3,7,8-TCDF	0.632 pg/l HH based on fish consumption site specific for the Rainy River.			0.632 pg/l HH
Dioxin and Furan 2,3,7,8-TCDD	0.0091 pg/l HH based on fish consumption site specific for the Rainy River.	15 pg/g Total 2,3,7,8 = TCDD equivalents in Edible portion - fish tissue.		0.0091 pg/l HH
Diphenyl ether		0.03 ug/l AL*		0.03 ug/l AL*
Diphenylamine		3 ug/l AL*		3 ug/l AL*
Diphenylhydrazine, 1,2-		0.3 ug/l AL*		0.3 ug/l AL*
Diquat		0.5 ug/l AL		0.5 ug/l AL

Parameter	Minnesota/United States Water Quality Standards	Ontario Objectives	Environment Canada Guidelines	Alert Levels
Dissolved Gases		Should not exceed 110% of saturation AL		Should not exceed 110% of saturation. AL
Dissolved Oxygen	5 mg/l (minimum) AL	4 to 7 mg/l minimum AL	5.0 - 9.5 ug/l AL	5.0 - 9.5 mg/l (minimum) AL
Diuron		1.6 ug/l AL		1.6 ug/l AL
Divinyl benzene		8 ug/l AL*		8 ug/l AL*
Effluent Toxicity		96 HR LC_{50} > 100% Effl. Rainbow Trout Daphnia magna AL		96 HR LC_{50} > 100% Effl. Rainbow Trout Daphnia magna AL
Endosulfan	0.029 ug/l, AL	0.003 ug/l AL	0.02 ug/l AL	0.003 ug/l AL
Endrin	0.016 ug/l AL	0.002 ug/l AL	0.0023 ug/l AL	0.002 ug/l AL
Escherichia coli		100 *E. Coli* per 100 ml		100 *E. Coli* per 100 ml
Ethanolamine		200 ug/l AL*		200 ug/l AL*
Ethylbenzene	68 ug/l AL	8 ug/l AL*	700 ug/l AL*	8 ug/l AL*
Ethylene dibromide		5 ug/l AL*		5 ug/l AL*
Ethylene diamine		0.1 ug/l AL*		0.1 ug/l AL*
Ethylene thiourea		60 ug/l AL*		60 ug/l AL*
Ethylene Glycol			2000 ug/l AL*	2000 ug/l AL*
Eugenol		30 ug/l AL*		30 ug/l AL*
Fecal Coliform	200/100 ml geometric mean 10% of samples not to exceed 2,000 based on a minimum of 5 samples in a 30 day period from March 1 - October 31. HH	100 organisms/100 ml geometric mean in a series of samples for swimming. Total Coliforms - 1,000 organisms/100 ml geometric mean in a series of samples. HH	100/100 ml geometric mean. - Total coliforms 1000/100 ml geometric means. IR	100 organisms/100 ml geometric mean in a series of samples for swimming. Total Coliforms - 1,000 organisms/100 ml geometric mean in a series of samples. HH
Fenthion		0.006 ug/l AL		0.006 ug/l AL
Fluoranthene	20 ug/l, AL	0.0008 ug/l AL*		0.0008 ug/l AL*
Fluorene		0.2 ug/l AL*		0.2 ug/l AL*

Parameter	Minnesota/United States Water Quality Standards	Ontario Objectives	Environment Canada Guidelines	Alert Levels
Formaldehyde		0.8 ug/l AL*		0.8 ug/l AL*
Furfuryl alcohol		1 ug/l AL*		1 ug/l AL*
Glyphosate			65 ug/l AL	65 ug/l AL
Guaiacol		1 ug/l AL*		1 ug/l AL*
Heptachlor epoxide	0.00048 ug/l AL	+Heptachlor - 0.001 ug/l AL	+Heptachlor 0.01 ug/l AL	0.00048 ug/l AL
Heptachlor	0.00039 ug/l AL	+H. Epoxide - 0.001ug/l AL	+H. Epoxide - 0.01 ug/l AL	0.00039 ug/l AL
Hexachlorobenzene	0.00024 ug/l, AL	0.0065 ug/l AL	0.0065 ug/l AL	0.00024 ug/l AL
Hexachlorobutadiene		0.009 ug/l AL*	0.1 ug/l AL	0.009 ug/l AL*
Hexachlorocyclohexane isomers			0.01 ug/l AL	0.01 ug/l AL
Hexachlorocyclopentadiene		0.07 ug/l AL*		0.07 ug/l AL*
Hexachloroethane		3 ug/l AL*		3 ug/l AL*
Hydrogen Sulfide	0.02 ug/l, AS	2 ug/l AL		0.02 ug/l AS
Hydroxybiphenyl, 2-		6 ug/l AL*		6 ug/l AL*
Iodine		100 ug/l AL*		100 ug/l AL*
Iron	300 ug/l DW	300 ug/l AL	300 ug/l AL	300 ug/l AL
Isopropyl alcohol		300 ug/l AL*		300 ug/l AL*
Lead	Total - The chronic standard shall not exceed: exp. {1.273{ln(total hardness mg/l)}-4.705}). 0.8 ug/l @ H=34 ug/l. AL	1 ug/l AL* (Hardness <30 mg/l) 3 ug/l AL* (Hardness 30-80 mg/l) 5 ug/l AL* (Hardness >80 mg/l)	1 ug/l AL (Hardness 0 - 60 mg/l)	0.8 ug/l AL (@Hardness = 34 mg/l)
Limonene		4 ug/l AL*		4 ug/l AL*
Lindane	0.032 ug/l AL	0.01 ug/l AL		0.01 ug/l AL
Malathion		0.1 ug/l		

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MCPA (2-Methyl-4-Chlorophenoxyacetic acid)			2.6 ug/l AL*	2.6 ug/l AL*
Mercury	0.0069 ug/l Total AL	0.2 ug/l in filtered water AL 0.5 ug/l in fish flesh (edible portion-wet weight) HH	0.1 ug/l AL	0.0069 ug/l Total AL
Methanol		200 ug/l AL*		200 ug/l AL*
Methoxychlor		0.04 ug/l AL		0.04 ug/l AL
Methyl ethyl ketone		400 ug/l AL*		400 ug/l AL*
Methyl-2-pentanol, 4-		600 ug/l AL*		600 ug/l AL*
Methyl-t-butyl ether		200 ug/l AL*		200 ug/l AL*
Methylene chloride	46 ug/l AL	100 ug/l AL*	98 ug/l AL*	46 ug/l AL
Methylnaphthalene, 2-		2 ug/l AL*		2 ug/l AL*
Methylnaphthalene, 1-		2 ug/l AL*		2 ug/l AL*
Metolachlor		3 ug/l AL*	8 ug/l AL*	3 ug/l AL*
Mirex		0.001 ug/l AL		0.001 ug/l AL
Molybdenum		10 ug/l AL*		10 ug/l AL*
Monochlorophenol			7 ug/l AL	7 ug/l AL
Monomethylamine		50 ug/l AL		50 ug/l AL
Morpholine		4 ug/l AL*		4 ug/l AL*
Naphthalene	81 ug/l, AL	7 ug/l AL*		7 ug/l AL*
Nickel	The chronic standard (CS) shall not exceed exp. (0.846 {ln(total hardness mg/l}}+1.1645}.(63 ug/l @H = 34 mg/l) AL	25 ug/l AL	25 ug/l AL (Hardness 0 - 60 mg/l)	25 ug/l AL
Nitrite			60 ug/l AL	60 ug/l AL
Nitrobenzene		0.02 ug/l AL*		0.02 ug/l AL*
Nitronaphthalene, 1-		4 ug/l AL*		4 ug/l AL*

Parameter	Minnesota/United States Water Quality Standards	Ontario Objectives	Environment Canada Guidelines	Alert Levels
Nitrophenol, 3-		20 ug/l AL*		20 ug/l AL*
Nitrophenol, 4-		50 ug/l AL*		50 ug/l AL*
Nitrophenol, 2-		0.5 ug/l AL*		0.5 ug/l AL*
Nitrosodiphenylamine, N-		7 ug/l AL*		7 ug/l AL*
Nitrosomorpholine, N-		0.9 ug/l AL*		0.9 ug/l AL*
Nonyl phenol		0.04 ug/l AL*		0.04 ug/l AL*
Oil and Grease	500 ug/l. HH			500 ug/l. HH
Oleic acid		1 ug/l AL*		1 ug/l AL*
Parathion	0.013 ug/l AL	0.008 ug/l AL		0.008 ug/l AL
Pentachlorobenzene		0.03 ug/l AL	0.030 ug/l AL	0.030 ug/l AL
Pentachlorophenol	1.9 ug/l, AL	0.5 ug/l AL	0.5 ug/l AL	0.5 ug/l AL
Perylene		0.00007 ug/l AL*		0.00007 ug/l AL*
pH	6.5 - 8.5 AL	6.5 - 8.5 AL	6.5 - 9.5 AL	6.5 - 8.5 AL
Phenanthrene	2.1 ug/l AL	0.03 ug/l AL*		0.03 ug/l AL*
Phenol	123 ug/l AL	5 ug/l AL*		5 ug/l AL*
Phenols (4AAP Method)		1 ug/l AL	1 ug/l AL	1 ug/l AL
Phenylxylylethane		0.02 ug/l AL*		0.02 ug/l AL*
Phosphorus	30 ug/l AL	<30 ug/l - rivers <20 ug/l - lakes		30 ug/l AL
Phthalate Esters				
DBP		4 ug/l AL	19 ug/l AL	4 ug/l AL
DEHP	1.9 ug/l AL	0.6 ug/l AL	16 ug/l AL	0.6 ug/l AL
DOP	30 ug/l AL			
Other phthalate esters		0.2 ug/l AL	0.2 ug/l AL	0.2 ug/l AL
Polychlorinated biphenyls (Total PCBs)	0.029 ng/l HH - based on Fish Consumption.	0.001 ug/l AL	0.001 ug/l AL	0.029 ng/l HH

Parameter	Minnesota/United States Water Quality Standards	Ontario Objectives	Environment Canada Guidelines	Alert Levels
Polychlorinated naphthalenes		0.0002 ug/l AL*		0.0002 ug/l AL*
Propyl diphenyl		0.1 ug/l AL*		0.1 ug/l AL*
Propylene glycol, 1,3-		10000 ug/l AH*		10000 ug/l AL*
Propylene glycol			74 mg/l AL*	74 mg/l AL*
Propylene glycol, 1,2-		44000 ug/l AL*		44000 ug/l AL*
Pyrethrum		0.01 ug/l AL		0.01 ug/l AL
Quinoline		10 ug/l AL*		10 ug/l AL*
Radionuclides ^{137}Cesium ^{131}Iodine ^{226}Radium ^{90}Strontium Tritium		 50 beqs/l DW 10 beqs/l DW 1 beq/l DW 10 beqs/l DW 40000 beqs/l DW		 50 beqs/l DW 10 beqs/l DW 1 beq/l DW 10 beqs/l DW 40000 beqs/l DW
Resin Acids Total Resin Acids		 1 ug/l AL* at pH 5 3 ug/ l AL* at pH 5.5 4 ug/l AL* at pH 6 9 ug/l AL* at pH 6.5 25 ug/l AL* at pH 7.0 45 ug/l AL* at pH 7.5 52 ug/l AL* at pH 8.0 60 ug/l AL* at pH 8.5 62 ug/l AL* at pH 9		 25 ug/l @pH=7.0 45 ug/l @pH=7.5 52 ug/l @pH=8.0 AL 8 ug/l @pH=7.0 11.8 ug/l @pH=7.5 12.9 ug/l @pH=8.0 AL
Dehydroabietic		1 ug/l AL* at pH 5 2 ug/l AL* at pH 5.5 2 ug/l AL* at pH 6 4 ug/l AL* at pH 6.5 8 ug/l AL* at pH 7 12 ug/l AL* at pH 7.5 13 ug/l AL* at pH 8 14 ug/l AL* at pH 8.5 14 ug/l AL* at pH 9		
Salinity, total	1000 mg/l WL			1000 mg/l, WL
Selenium	Total 5 ug/l. AL	100 ug/l (total) AL	1 ug/l AL	1 ug/l AL

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Silver	Total - The chronic standard shall not exceed 1.0 ug/l. AL	0.1 ug/l AL	0.1 ug/l AL	0.1 ug/l AL
Simazine		10 ug/l AL	10 ug/l AL	10 ug/l AL
Styrene		4 ug/l AL*		4 ug/l AL*
Temperature	5°F above natural in streams and 3°F above natural in lakes, based on monthly average of the maximum daily temperature, except in no case shall it exceed the daily average temperature of 86°F. AL	▲T<10°C		5°F above natural in streams and 3°F above natural in lakes, based on monthly average of the maximum daily temperature, except in no case shall it exceed the daily average temperature of 86°F.
Tetrachlorobenzene, 1,2,3,4- 1,2,3,5- 1,2,4,5-		 0.1 ug/l AL 0.1 ug/l AL 0.15 ug/l AL	 0.1 ug/l AL 0.1 ug/l AL 0.15 ug/l AL	 0.1 ug/l AL 0.1 ug/l AL 0.15 ug/l AL
Tetrachloroethane, 1,1,1,2-		20 ug/l AL*		20 ug/l AL*
Tetrachloroethane, 1,1,2,2-	1.54 ug/l AL	70 ug/l AL*		1.54 ug/l AL
Tetrachloroethylene	3.8 ug/l AL	50 ug/l AL*	110 ug/l AL	3.8 ug/l AL
Tetrachloroguaiacol		0.009 ug/l AL*		0.009 ug/l AL*
Tetrachlorophenols, 2,3,4,5- 2,3,4,6- 2,3,5,6-		 1.0 ug/l AL 1.0 ug/l AL 1.0 ug/l AL	1 ug/l AL	1 ug/l AL
Tetraethyl lead		0.0007 ug/l AL*		0.0007 ug/l AL*
Tetramethyl lead		0.006 ug/l AL*		0.006 ug/l AL*
Thallium	0.28 ug/l, AL	0.3 ug/l AL*		0.28 ug/l AL
Toluene	253 ug/l AL	0.8 ug/l AL*	300 ug/l AL	0.8 ug/l AL*
Tolytriazole		3 ug/l AL*		3 ug/l AL*
Toxaphene	0.0013 ug/l AL	0.008 ug/l	0.008 ug/l AL	0.0013 ug/l AL
Triallate			0.24 ug/l AL*	0.24 ug/l AL*

Parameter	Minnesota/United States Water Quality Standards	Ontario Objectives	Environment Canada Guidelines	Alert Levels
Tributyl phosphate		0.6 ug/l AL*		0.6 ug/l AL*
Tributyltin		0.000005 ug/l AL*	0.008 ug/l AL*	0.000005 ug/l AL*
Trichlorobenzene,				
1,2,3-		0.9 ug/l AL	0.9 ug/l AL	0.9 ug/l AL
1,2,4-		0.5 ug/l AL	0.65 ug/l AL	0.65 ug/l AL
1,3,5-		0.65 ug/l AL	0.5 ug/l AL	0.5 ug/l AL
Trichloroethane, 1,1,2-		800 ug/l AL*		800 ug/l AL*
Trichloroethane, 1,1,1-	263 ug/l AL	10 ug/l AL*		10 ug/l AL*
Trichloroethylene, 1,1,2-	25 ug/l AL	20 ug/l AL*	20 ug/l AL*	20 ug/l AL*
Trichloroguaiacol, 4,5,6-		0.8 ug/l AL*		0.8 ug/l AL*
Trichloroguaiacol, 3,4,5-		0.1 ug/l AL*		0.1 ug/l AL*
Trichlorophenols			18 ug/l AL	
2,3,4-		18 ug/l AL		18 ug/l AL
2,3,5-		18 ug/l AL		18 ug/l AL
2,4,5-		18 ug/l AL		18 ug/l AL
2,4,6-	2.0 ug/l AL	18 ug/l AL		2.0 ug/l AL
Triethyl lead		0.4 ug/l AL*		0.4 ug/l AL*
Triethyltin		0.4 ug/l AL*		0.4 ug/l AL*
Trifluralin			0.1 ug/l AL	0.1 ug/l AL
Trimethylbenzenes		3 ug/l AL*		3 ug/l AL*
Triphenyltin		0.002 ug/l AL*	0.02 ug/l AL*	0.002 ug/l AL*
Tungsten		30 ug/l AL*		30 ug/l AL*
Turbidity	25 NTU AL	Discharges should not increase the Secchi disc reading by more than 10 percent from natural.	secchi disc visible at ≥ 1.2 metres	25 NTU
Uranium		5 ug/l AL*		5 ug/l AL*
Vanadium		7 ug/l AL*		7 ug/l AL*
Vinyl Chloride	0.18 ug/l, AL	400 ug/l AL*		0.18 ug/l AL

Parameter	Minnesota/United States Water Quality Standards	Ontario Objectives	Environment Canada Guidelines	Alert Levels
Xylene, *p*-		30 ug/l AL*		30 ug/l AL*
Xylene (total *m*, *o*, and *p*)	166 ug/l AL			166 ug/l AL*
Xylene, *m*-		2 ug/l AL*		2 ug/l AL*
Xylene, *o*-		40 ug/l AL*		40 ug/l AL*
Zinc	Total - The chronic standard shall not exceed: exp. {0.8473 {In {total hardness mg/l} + 0.7615. 42 ug/l @H=34 mg/l. AL	20 ug/l AL*	30 ug/l AL*	20 ug/l AL*
Zirconium		4 ug/l AL*		4 ug/l AL*