State of the Basin Report

FOR THE LAKE OF THE WOODS AND RAINY RIVER BASIN

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Prepared in cooperation with:
The Lake of the Woods Water Sustainability Foundation
The Ontario Ministry of the Environment
Environment Canada
The Minnesota Pollution Control Agency

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1 EXECUTIVE SUMMARY

Lake of the Woods

Lake of the Woods (LOW) is shared between Ontario, Manitoba and Minnesota. Two-thirds of LOW is in Canada and the remaining one-third is in the U.S. state of Minnesota. The lake and its associated tributaries provide benefits shared by thousands of people. Electricity and water for domestic and industrial uses, recreation, agriculture, and fisheries are all sustained by these water bodies. For example, First Nations' domestic and commercial fisheries of LOW are valued at $1 million with an additional $34 million associated with the sports fishery, the largest non-resident sport fishery in Ontario. Minnesota has a $44 million per year sport fishery. LOW supports a $125 million tourism industry in Ontario (Minnesota Department of Natural Resources and Ontario Ministry of Natural Resources, 2004). In addition, LOW is hydrologically connected to Lake Winnipeg via the Winnipeg River and to Shoal Lake, which supplies water to the City of Winnipeg through a series of aqueducts.

GREG MCCULLOUGH, AFTER MODIS RAPID RESPONSE TEAM, U. MARYLAND

Satellite image showing algal blooms in south basin of Lake of the Woods, October 5, 2006.

Many federal, provincial, and state agencies have been monitoring and reporting on water quality in LOW and the Rainy River for several years. These agencies work together through partnerships and collaborations to monitor environmental conditions on the lake and river.

LOW experiences cyanobacterial algal blooms that develop in the southern part of the lake in the spring and make their way northward throughout the summer and fall. Historical evidence suggests that algal blooms have consistently occurred on this lake and that the background levels of phosphorus are naturally elevated compared to other lakes on the Canadian Shield, which may contribute to the persistence of these algal blooms. However, there have been rising concerns that these algal blooms are occurring more frequently and are becoming more widespread in recent years.

What is the State of the Basin Report and why is it important?

Despite the existence of several monitoring programs in Ontario, Manitoba and Minnesota described above, there remains a need to compile all of the data from all the various agencies into a single summary document that provides useful environmental information about LOW, and some information on the Rainy River that pertains to the nature of algal blooms, spatial and temporal variations in nutrient concentrations, and sources of nutrients to the lake.

With a perceived increase in the frequency and intensity of cyanobacterial algal blooms on the lake, there was a call to evaluate the nature of the blooms, examine spatial and temporal variations in nutrient concentrations, and identify nutrient sources to the lake by the governmental, non-governmental, and public organizations.

The State of the Basin Report is a synthesis of what is currently known about the water quality of LOW, based on the data gathered by multiple agencies. The report provides a snapshot of the water quality of LOW and will serve as a working tool to set provisional targets against which water quality and the effectiveness of water management strategies can be compared. The goal of the report is to describe the current environmental conditions within the LOW and Rainy River Basin, and to provide the Lake of the Woods Water Sustainability Foundation (LOWWSF) and the Lake of the Woods District Property Owners Association (LOWDPOA) with the tools needed to evaluate long-term environmental changes and sustainability of the lake. In addition, protection of this source water is essential, as it supplies drinking water

A goal of this report is to facilitate liaison between federal, provincial, and state agencies and to create a forum for data sharing and increase public involvement in resource management decisions and actions.

to three-quarters of a million people in northwestern Ontario and Minnesota, including First Nations' communities, the cities of Kenora and Winnipeg, numerous cottages and resorts, rural areas, and other communities along the Winnipeg River in Ontario and Manitoba.

A goal of the State of the Basin Report is to prioritize management needs and identify "data gaps" (i.e., key responding variables, monitoring criteria and targets and areas of research where data are unavailable), which may vary among basins and watersheds. Another goal of this report is to facilitate liaison between federal, provincial, and state agencies and to create a forum for data sharing and increase public involvement in resource management decisions and actions. This approach would facilitate the integration of many jurisdictions, agencies, and interests to create a useful resource management tool.

The State of the Basin report assesses many aspects of LOW's aquatic environment, including climate, geography, hydrology, morphometry, water chemistry, trophic status, and biological communities. In addition, it examines potential future threats to water quality, including contaminants, invasive species, water level shifts, and climate change. In most cases, the State of the Basin Report does not attempt to address the exact causes of the underlying environmental conditions.

Characteristics of the Drainage Basin (Section 3)

LOW was formed by the retreat of melting glaciers. Isostatic rebound – the rise of the earth's surface that was depressed by the weight of a large land mass – is responsible for the difference in elevation between the south and north ends of the basin and the northwestern drainage of the lake. The isostatic rebound in the south is currently slowing relative to the north causing the lake to slowly tip to the south. For this reason, increased erosion and higher water levels may be more apparent in the southern part of the lake.

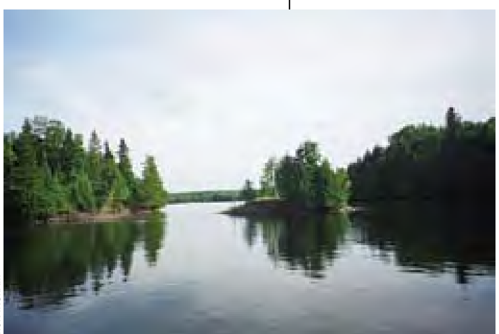
The LOW region is divided into several geologically distinct regions. The northern portion of the lake rests upon bedrock of the Canadian Shield that contains areas of glacial till with large outcroppings of bedrock in many areas. The north is characterized by forest cover, thin soils, and many lakes, ponds, and connecting channels. The southern portion of the lake is underlain by glacial till and is typically flat in nature. Peat deposits and wetland areas are common. The main land use activities in the region are forestry, aquatic recreation, tourism, agriculture, and hunting.

The region of LOW and the Rainy River experiences a continental climate with four distinct seasons. Temperature records among the six meteorological stations in the region were strongly correlated, while precipitation records showed weaker correlations. Annual temperature anomalies indicate warmer temperatures in recent years along with an average increase in the length of the frost-free season by 13 days in the last 88 years. Similar to observed conditions in other northern hemisphere lakes, long-term ice out records indicate ice-out on Whitefish Bay, an unimpacted region of LOW that is isolated from the main south-north flow of water from the Rainy River, is occurring approximately 15 days earlier than compared to ~40 years ago.

The water levels, inflows, and outflows of LOW and the Rainy River are managed by three agencies: the Lake of the Woods Control Board (LWCB), the International Rainy Lake Board of Control (IRLBC) and the International Lake of the Woods Control Board (ILWCB). The water levels of LOW are currently regulated between 321.87 and 323.47 m (above sea level), although sometimes it is not feasible to maintain this range. In general, the mean daily water levels of LOW have stabilized in recent years.

State of the Basin – Part 1: Physical, Chemical, and Trophic State Observations (Section 4)

Water quality at different locations on LOW and the Rainy River has been monitored by various agencies since the mid-1950s. Based on water quality measurements in recent years, the Minnesota Pollution Control Agency (MPCA) has designated the southern portion of LOW (located on the U.S. side of the national border) as impaired for water quality based on mean total phosphorus (TP), chlorophyll-a (chl-a), and Secchi transparency measurements as defined by section 303(d) of the U.S. Federal Clean Water Act. The Ontario Ministry of Natural Resources Fisheries Assessment Unit (OMNR-FAU) has also been monitoring water quality in the Ontario waters of LOW since 1984 as part of the FAU Core Data Program. Their purpose was to establish baseline water quality to begin a long-term water quality monitoring program for purposes of fish habitat and community assessment.



RON INGRAM

Nutrients play an important role in the productivity (or trophic status) of LOW. The trophic status of this lake has traditionally been quantified using TP concentrations, algal biomass (measured as chl-a), and (visible) light penetration (Secchi depth). LOW is a 'multi-trophic' lake where TP concentrations can vary from eutrophic to mesotrophic or oligotrophic levels over space and time. TP concentrations at any site in the lake can differ from year to year or month to month, but depending on the region, phosphorus concentrations have been recorded by the OMNR-FAU that range from 9.9 µg/L in Whitefish Bay in the northeast to 46.0 µg/L in Big Traverse Bay in the south. An examination of spatial trends in water quality in LOW demonstrates that the lake is separated spatially along two chemical gradients. The strongest gradient is defined by nutrient (i.e., N, P) concentrations, pH, and depth while a weaker secondary gradient is defined by alkalinity and ionic concentrations. In general, sampling sites in the eastern region that are isolated from the south-north nutrient-rich water flow from the Rainy River and Big Traverse (i.e., Whitefish Bay) are lower in nutrients and ions. Sites in the extreme southern region of the lake had the highest nutrient concentrations and lower ion levels compared to sites in the north that had lower levels of nutrients and higher levels of ions.

The Rainy River provides a major source of water and nutrients to LOW. Long-term historical TP data from the Rainy River monitoring station at International Falls demonstrate a general trend of decreased variation in phosphorus concentrations through time, with average TP concentrations declining slightly after 1985. TP concentrations are generally higher downstream at the Baudette monitoring station than they are at the upstream International Falls location. This difference appears to result from point and non-point sources of nutrients entering the river downstream of International Falls, such as runoff from agricultural areas and peatlands, sewage and pulp and paper mill effluent, and septic system runoff, and erosion.

Sources of nutrients to LOW are difficult to identify and predict as they vary from year to year. Since the Rainy River provides an estimated ~70% of the hydrological inflow to LOW, it may be a major source of nutrients to the lake. In fact, TP concentrations at two sites close to the Rainy River outflow to LOW coincide with TP concentrations in the Rainy River. Several other point and non-point sources of nutrients have been identified on the U.S. portion of LOW. Based on general nutrient modeling, 11% of the total annual phosphorus load to the Rainy River Basin is estimated to originate from point sources (such as industrial and domestic waste effluent and commercial and industrial processes), and the remainder from non-point sources (such as atmospheric deposition, non-agricultural rural runoff, and stream bank erosion).

State of the Basin – Part 2: Biological Communities (Section 5)

The State of the Basin Report also provides an update on the current knowledge of the biological communities on LOW, including algae, zooplankton and other invertebrates, aquatic macrophytes, fish, reptiles and amphibians, and waterbirds. However, with the exception of fish and for the most part, birds, LOW's biological communities are somewhat understudied.

In temperate regions of North America, algae are primarily regulated by phosphorus concentrations. Since the algal and cyanobacterial[1] community is fundamental in the production of algal blooms, they formed an integral part of this ecological assessment. Previous studies of five sites in LOW determined that diatoms and small flagellates represent the majority of the algal community in June, whereas cyanobacteria, green algae, and golden-brown algae dominate in July and August. Cyanobacteria (certain species of which are responsible for blue-green algal blooms on the lake) have been recorded in 65-80% of the algal community in the southern basin of the lake. Despite the existence of these reports on the algal communities, further broad-scale long-term studies (i.e., longer than 2 years) are required to provide a complete picture of the seasonal transition, abundance, and spatial occurrence of algae, including cyanobacteria, in LOW.


KATHY DEGAGNE

Zooplankton occupy a higher trophic level in the aquatic food chain compared to algae, and are microscopic invertebrates which feed on bacteria, algae, and other smaller zooplankton. Zooplankton are in turn consumed by larger organisms including fish and thus play an essential role in the function of aquatic ecosystems. They are also sensitive to changes in the environment, such as shifts in fish predation regimes and nutrient enrichment. However, with the exception of a few data collected for the purpose of fish assessments between 1992 and 1999, extensive studies of the zooplankton communities have not been conducted. The available data to date have demonstrated a general long-term increase in certain zooplankton groups (cladocerans and copepods), a decline in others (rotifers), and an overall decline in zooplankton species richness between 1992-99. Since these zooplankton data provide a limited record of zooplankton condition prior to the establishment of the invasive spiny water flea, further studies are necessary. Both the OMNR-FAU in Kenora, Ontario and the Minnesota Department of Natural Resources (MDNR) in Baudette, Minnesota, reinstated zooplankton sampling on the lake in 2007 to document any changes that may result from possible establishment of the spiny water flea and other invasive species.

Similar to zooplankton, the zoobenthic organisms (the community of animals that live on or in the substrate[2]-water interface) are significantly understudied in LOW. These organisms are also important food sources for fish, especially perch and whitefish, which are preyed upon by piscivourous fish species. Some sporadic zoobenthos data have been collected by the MPCA in stream and river communities in the Rainy River Basin. Analyses of these data indicate that benthic organisms demonstrate spatial variation in community composition that is dependant on the differences in stream and river substrates.

Unlike the previously mentioned biological communities, an abundance of information has been collected on fisheries and fish communities on LOW and the Rainy River. The fish in this region are regularly monitored by the OMNR-FAU and the MNDNR. The details of these sampling programs and the fish communities are located in the Ontario Minnesota Boundary Waters Fisheries Atlas (OMNR/MNDNR, 2004) which is published every five years. Therefore, the State of the Basin Report provides general details on the LOW fishery

[1] While the term 'algae' refers to eukaryotes and therefore does not technically include cyanobacteria, for simplicity in this report 'algae' will be used in reference to both groups unless otherwise specified.
[2] Sediment, submerged rock, etc.

... there has been an overall long-term trend of increased late-summer lake trout habitat at most sites in the Clearwater Bay area, although these sites are still vulnerable to changes in water quality over time.

with information on three recreational and economically important fish populations: lake sturgeon, walleye, sauger, and lake trout. Historically, these fisheries in LOW and Rainy River experienced intense pressure due to commercial harvesting and sportfishing. However, their populations are currently increasing or stable. This recovery in recent years has followed management efforts and reductions and restrictions on harvest levels for fish that whose populations were once critically low, such as sturgeon and lake trout. Regulations on both sides of the international border are currently in place to manage the fish populations and to avert future declines. In addition, habitat quality and quantity specific to lake trout has been assessed in Clearwater/Echo Bays by examining dissolved hypolimnetic oxygen levels in LOW. These data show that there has been an overall long-term trend of increased late-summer lake trout habitat at most sites in the Clearwater Bay area, although these sites are still vulnerable to changes in water quality over time.

There are no broad-scale studies of reptiles and amphibians in LOW. Currently, there are two volunteer-based programs that exist to monitor frog and toad populations in Ontario and Minnesota: The FrogWatch Program in Ontario and the North American Amphibian Monitoring program (NAAMP) in Minnesota. Although there are relatively few monitoring stations located around LOW, the results demonstrate that the frog and toad communities currently contain relatively high species numbers in LOW.

Many waterfowl, wading birds, and other birds nest, stop-over, or permanently reside in LOW. Their species richness, composition, abundance, and biomass are influenced by littoral macrophytes, lake trophic status, and lake morphometry. Many regions of preferred bird habitat in LOW are sensitive to environmental changes, such as the Sandspit Archipelago that includes the Sable Islands, Windy Point, and Burton Island. A large amount of research has been conducted on different bird populations that occur around LOW throughout the year, including the American white pelican, double-crested cormorant, common tern, bald eagle, and piping plover. Many of these birds utilize the shoreline for feeding and breeding grounds and are sensitive to shoreline alterations, development, and rising water levels.

Emerging Threats to Water Quality and Biological Communities (Section 6)

In order to better understand the potential for future changes in LOW water quality, a solid understanding of current, possible, and impending stressors is essential. LOW is a large, economically important, international water body. Managers will likely be faced with managing the lake in the face of a number of important stressors which are affecting lakes worldwide, including contaminants, invasive species, water level fluctuations, climatic change, and shoreline development and urbanization.

Contaminants (Section 6.1)

Contaminants, including persistant, organic pollutants (POPs) and pesticides are generally in low concentrations in the waters of LOW and thus the biota in the lake and the river are not at any immediate risk of high exposure. However, the detection of mercury in the biota of this lake has resulted in fish consumption advisories due to the health risks posed by eating contaminated fish. Despite its importance as a contaminant to the lake, the current state of knowledge about the fate, transport, and occurrence of mercury in LOW is minimal.

Invasive species (Section 6.2)

Due to its proximity and connection to other water bodies, increasing tourism, and a diverse array of habitat suitable to many biota, LOW is vulnerable to the introduction of non-native species. In the LOW and Rainy River Basin, there have been several confirmed invasions by aquatic species, including the hybrid cattail, spiny water flea, rusty crayfish, papershell crayfish, clearwater crayfish, and rainbow smelt. An increased understanding and involvement from the government and public sectors in recent years has led to increased awareness of invasive species and prevention and management strategies are currently being tested and employed.

Climate Change (Section 6.3)

RON INGRAM

Investigation of the effects of climate change on the physical, chemical, and biological properties of LOW has begun in recent years. Mean annual air temperature shows a rise of approximately 2.5 °C since 1899, with the greatest increases occurring during the winter over the past three decades. The frost-free season has lengthened by 15 days since the 1920s. LOW is ice-free for more than two weeks longer than in the 1960s, with earlier ice-off dates in the spring accounting for most of this change.

Precipitation patterns have changed with more variability reported within and among the various meteorological stations around the lake basin. In recent decades, storm events have become fewer but more intense, resulting in shorter periods with very high stream flows, interspersed with long periods of low input flows.

The timing and cause of flood events appears to be changing. Historically driven by spring runoff, flood events now more commonly reflect heavy rainfall interspersed throughout the year, including rain-on-snow conditions associated with warmer winter temperatures.

Increases in mean summer and autumn precipitation and associated increased late season runoff may be contributing to recent increases in discharge from the lake outflow during the winter months. Nevertheless, there is substantial variability, with this record punctuated in recent years by periods of unusually (near record) low inflows and discharge. Extremes of low and high discharge are consistent with expectations under most climate change scenarios.

The effects of climate change on LOW have not been investigated in depth. However, detailed studies conducted at the nearby Experimental Lakes Area provide a glimpse of the changes that may be observed in the Lake of the Woods and Rainy River Basin over the next few decades, including: more intermittent and variable stream inflows, increased water temperatures and water transparency, and exacerbation of blue green algal blooms.

Evidence is emerging that algal assemblages may already be changing in response to climate change in the region. Recent paleolimnological studies show shifts in diatom species composition since pre-industrial times (pre-1850), with marked changes occurring over the past three decades. These changes are coupled to the increases in air temperature and increased length of the ice free season for LOW.

Water Level Fluctuations (Section 6.4)

LOW is regulated hydrologically by three agencies (LWCB, ILWCB, and IRLBC). In recent years, concerns about the water level fluctuations on LOW have been raised, including the effects of hydroelectric peaking (i.e., whereby facilities vary their day and evening outflows to maximize efficiency during high demand periods) on fish habitat and spawning areas. Therefore, peak habitat conditions were determined and general agreement was reached between the Ontario/Minnesota Fisheries Committee in 2002 and the owners of hydroelectric dams, other government agencies, and First Nations, to avoid peaking at the dam at Rainy River during the 2.5 month spring spawning period for sturgeon. The agencies responsible for the maintenance in water levels on the lake will continue to work together with both private and public sectors to balance the diverse interests of water users, such as cottagers, boaters, anglers, residents, water suppliers, sewage disposal, farmers, hydroelectric power industries, etc.

However, the possibility of extreme weather conditions in this region in future years with the advent of climatic warming will likely lead to challenges in the future.

Data Gaps and Monitoring Needs (Section 7)

The next three to five years represents a critical period for the development of a coordinated, multi-agency monitoring program for the Lake of the Woods and Rainy River Basin. This program should be based on clear and compelling scientific questions. Managing the technical and jurisdictional challenges that are unique to this international waterbody will be difficult. Thus, it is recommended that water quality monitoring in the Lake of the Woods and Rainy River Basin be mediated through a Basin-wide Technical Advisory Committee, and that an inter-agency partnerships be formalized through the development of cooperative agreements. Initiatives developed by the Technical Advisory Committee would help resource managers to focus their scientific objectives and to monitor in an effective and coordinated fashion.

In the design of a useful and cost-effective monitoring program for the Lake of the Woods and Rainy River Basin, several goals should be considered, including: 1) designing the monitoring program around compelling scientific questions; 2) providing participants 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.

Several important research questions have been identified, many of which are in the process of being addressed, including: 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 meterological 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. This report and the ideas and gaps it outlines are intended to provide resource managers with baseline scientific data that may generate new hypotheses, focus scientific objectives for the Basin, and encourage collaboration in monitoring initiatives.

2 DEFINING THE SYSTEM

Lake of the Woods (LOW) is an important recreational, natural, and economic aquatic resource. It is also a vital source of drinking water for several communities in the region, including the city of Kenora, the surrounding area, and the city of Winnipeg which draws its drinking water from Shoal Lake.

At a broader regional scale, LOW is the largest lake in the Winnipeg River drainage basin, and together with its largest tributary, the Rainy River, drains the southeast portion of the Lake Winnipeg drainage basin. LOW is an international lake with approximately two-thirds of its surface area located in Canada (Ontario and Manitoba), and the remaining one-third in the United States (Minnesota). Therefore, water level management is a responsibility that is shared between two countries and several agencies, including the (Canadian) Lake of the Woods Control Board (LWCB) and the International Lake of the Woods Control Board (IRLBC). In addition, the International Rainy Lake Board of Control (IRLBC) regulates and monitors the water levels of both Rainy and Namakan lakes, which contribute about two-thirds of the overall inflow to LOW.

BEV CLARK

The hydrology and geology of LOW varies drastically between the southern and northern regions of the lake. The main bay in the south, Big Traverse Bay, is shallow, wide, and expansive, and receives the majority of its inflow from the Rainy River. This southern region is hydrologically connected to the north end of the lake through a series of channels and waterways and contains many inlets and bays. The main direction of flow in LOW is in a northwesterly direction from the Rainy River outflow at Four Mile Bay in the south to the Norman power dam and Kenora generating station in Kenora, Ontario in the north. The north and south are separated into two geologically distinct portions based on a geological boundary of glacial till to the south and Precambrian Shield to the north. The south consists mainly of a shallow but expansive bay (Big Traverse Bay) with a large fetch. The northern portion is more irregular in nature and consists of a series of 14,500 islands and many bays and inlets.

The water quality of LOW has been under increased scrutiny in recent years in part due to the algal blooms that develop in the southern portion of the lake (such as Big Traverse Bay) in the summer and fall. Blooms also appear in the northern bays in the summer and early fall. Historical accounts from the 19th century and anecdotal evidence from the early- to mid-1900s suggests that algal blooms have occurred historically in the lake. Also, paleolimnological evidence has demonstrated that the background levels of phosphorus in this lake are naturally elevated compared to other lakes on the Precambrian Shield, which may contribute to the generally high algal biomass observed in this lake. However, there are rising concerns that the magnitude and frequency of these blooms may have increased in recent years. Furthermore, evidence of the presence of microcystin, a liver toxin produced by some cyanobacteria, in some open-water and shoreline regions of the lake is also a cause for concern (Kotak et al., 2007; Chen et al., 2007).

As in other temperate North American lakes, phosphorus and nitrogen are considered to be the most important nutrients influencing algal biomass. Based on ice-free annual averages from the OMNR-FAU (2002-06), nutrient concentrations in

LOW are highly variable both spatially and temporally, with higher TP concentrations in the south (37 – 46 ug/L; i.e., Big Traverse and Four Mile Bays) compared to moderate TP concentrations in the north central sectors (18.3 – 30.3 μg TP/L), and lower concentrations in the northwest and northeast basins (9-16 μg TP/L; i.e., Clearwater Bay and Whitefish Bay) that are relatively isolated from the main flow of water in the lake. In fact, the trophic status at many sites varies between mesotrophic (10 – 20 μg TP/L) and eutrophic (>20 μg TP/L) between sampling dates within and among years (Vollenweider, 1979). It is difficult to generalize on the nutrient concentrations of LOW because it contains several regions that are distinct in both hydrology and limnology. LOW may be more accurately defined in hydrological terms as a large, shallow, round lake in the south (Big Traverse) and a large, deeper, but convoluted lake in the north with two bays to the north and east (Clearwater Bay and Whitefish Bay, respectively) that are isolated from the main direction of south-north flow.

Satellite image showing algal blooms throughout central and north basins of Lake of the Woods and in Shoal Lake, October 10, 2006.

A number of agencies are responsible for monitoring and reporting on fisheries and water quality in Lake of the Woods and the Rainy River, including the Ontario Ministry of Natural Resources (OMNR), Minnesota Department of Natural Resources (MNDNR), 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 the lake and river.

The State of the Basin Report for Lake of the Woods and the Rainy River was produced in response to a growing need for a collective document that summarizes all of the water quality and biological data available up to and including the fall of 2007. The purpose of the report is to provide a reference for future monitoring and research and some working benchmarks against which future environmental change can be assessed. This report is one of the first steps in developing a Lake of the Woods and Rainy River Long-Term Monitoring Plan.

3.1 Climate

General

There are six meteorological stations with long-term climate data in the Lake of the Woods (LOW) and Rainy River Basin (Table 3.1). Of these, the station 'Kenora A' has the longest continuous temperature and precipitation records (years 1899 and 1916, respectively). In general, temperature records among stations are strongly correlated, while weaker, but significant correlations exist for precipitation (Table 3.2). Below, we present the climate record from the station 'Kenora A' to illustrate long-term temperature and precipitation data for the LOW region (Environment Canada, 2007a). The Kenora A dataset is composed of two short-term records that have been joined here to create a single, long-term historical 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 (see Vincent & Gullett, 1999 and Mekis & Hogg, 1999 for details).

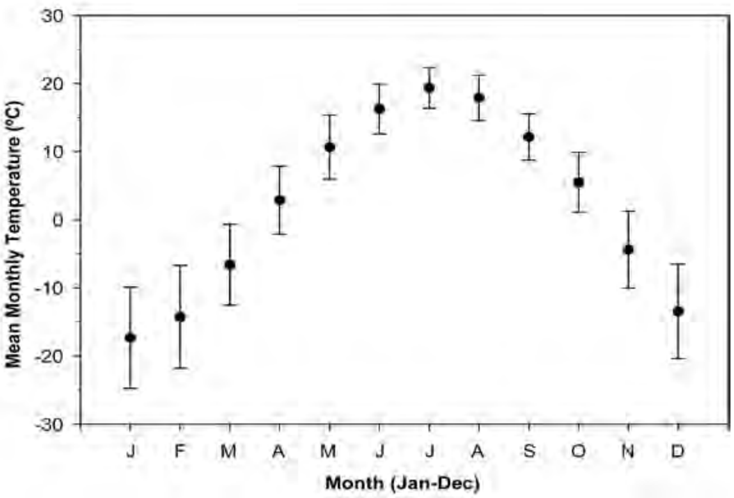


FIGURE 3.1. Means and standard deviations (+/- 2 SD units) in mean monthly temperatures for Kenora, Ontario (1899-2004).

Taking up ice on the Lake of the Woods.

Temperature

The LOW region experiences a continental climate with variation in temperature among four, distinct seasons. These seasons are based on the conventional meteorological definitions (winter = December-February, spring = March-May, summer = June-August, autumn = September-November), and on the annual cycle of hemispheric air temperature with maxima occurring in January and July (Chapman & Walsh, 1993). Mean summer and winter temperatures are 17.8ºC (64.0ºF) and -15.0ºC (5ºF), respectively. Snow is typically on the ground from November through April, with the warmest month being July (Figure 3.1).
A comparison of the differences in annual temperatures (anomalies[3]) indicate that warmer than average temperatures have occurred in recent years (Figure 3.2). This trend is especially apparent in the winter season, with warmer temperatures occurring consistently since 1998 (Figure 3.2b). The length of the frost-free season has increased by 13 days, on average, over the last 88 years (Figure 3.3).

Within each year, the ice-on date for LOW may vary across the lake. Long-term ice records were 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-FAU, Kenora, ON, 2007, unpublished data; R. Beatty, Pers. Comm.). Long-term ice-out records from the north end of Whitefish Bay (OMNR-FAU, Kenora, ON, 2007, unpublished data) indicate that the length of the ice-free season is increasing in the LOW, with ice-out occurring approximately 15 days earlier than the beginning of the monitoring record (0.3 days/year from 1964-2007; Figure 3.4, OMNR-FAU, Kenora, ON, 2007, unpublished data). A similar pattern has been reported in other lakes in the region, including Voyageurs National Park (Kallemeyn et

[3] An anomaly, as it is used here, is defined as the deviation of temperature and precipitation in a region for a specified period of time from what is considered to be the normal value for that region. In this case, the mean temperature and precipitation data from 1950-1990 was used to calculate the deviation from normal for the station 'Kenora A'.

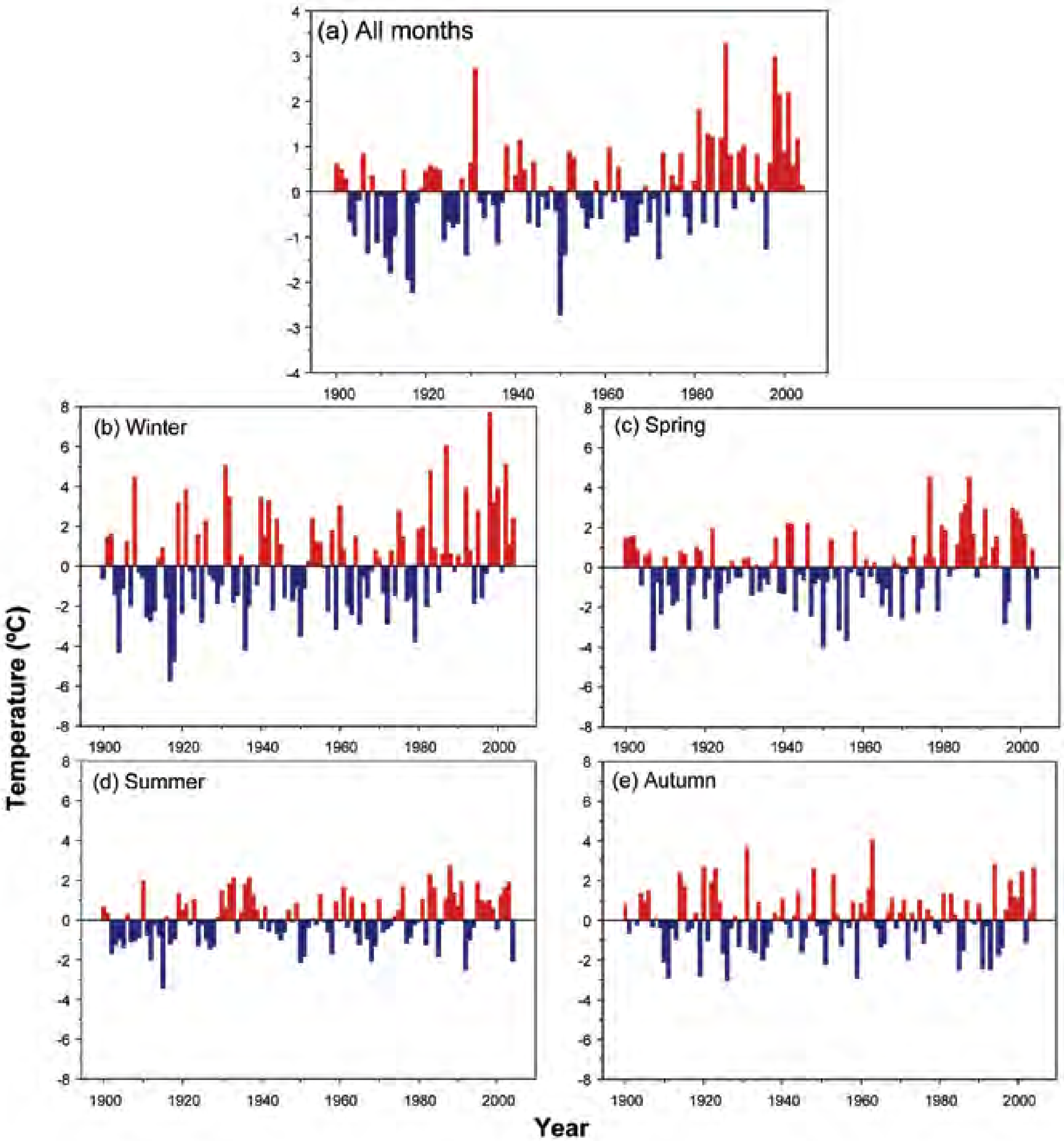


FIGURE 3.2. Average annual temperature anomalies for Kenora, Ontario, from 1899-2004 for (a) all months, (b) winter (December-February), (c) spring (March-May), (d) summer (June-August), and (e) autumn (September-November). The mean temperature data from 1950-1990 was used to calculate the deviation from normal for the station 'Kenora A'.

TABLE 3.1. Climate monitoring stations in the region of the Lake of the Woods and Rainy River Basin, their geographical location, and length of temperature and precipitation records.

Station No.	Name	Province/ State	Latitude (N)	Longitude (W)	Elevation (m)	Temperature Record (continuous)	Precipitation Record (continuous)
6022476[a]	Fort Frances A	ON	48º65′	93º43′	342	1912-2004	1912-1995
72747[b]	International Falls	MN	48º57′	94º37′	110	1948-2006	1948-2006
6034075[a]	Kenora A	ON	49º78′	94º37′	406	1899-2004	1916-2004
	Lake 239 ELA[c]	ON	49º66′	93º72′	393	1969-2006	1969-2006
6048261[a]	Thunder Bay A	ON	48º37′	89º33′	199	1895-2004	1895-1993
5023222[a]	Winnipeg International A	MB	49º92′	97º23′	239	1895-2004	1895-2004

[a] = Adjusted Historical Canadian Climate Database

[b] = National Oceanographic and Atmospheric Administration Climate Anomaly Monitoring System

[c] = Environment Canada, Department of Fisheries and Oceans

TABLE 3.2. Pearson correlation matrices for (A) temperature and (B) precipitation from several climate monitoring stations within the region of Lake of the Woods and the Rainy River Basin. * indicate significant correlations at $P \leq 0.05$ based on Bonferroni adjusted probabilities. For both temperature and precipitation, Lake 239 in ELA is only compared from 1970-2004 due to the shortened dataset. Thunder Bay and Fort Frances were excluded from the precipitation correlations due to large gaps in the precipitation datasets from 1992-2005.

(A)	Fort Frances A	International Falls	Kenora A	Lake 239 ELA	Thunder Bay A	Winnipeg Int'l A
Fort Frances A	1.000*					
International Falls	0.955*	1.000*				
Kenora A	0.957*	0.945*	1.000*			
Lake 239 ELA	0.956*	0.938*	0.992*	1.000*		
Thunder Bay A	0.931*	0.912*	0.933*	0.949*	1.000*	
Winnipeg Int'l A	0.944*	0.934*	0.965*	0.977*	0.897*	1.000*

(B)	International Falls	Kenora A	Lake 239 ELA	Winnipeg Int'l A
International Falls	1.000*			
Kenora	0.321*	1.000*		
Lake 239 ELA	0.607*	0.832*	1.000*	
Winnipeg	0.454*	0.544*	0.749*	1.000*

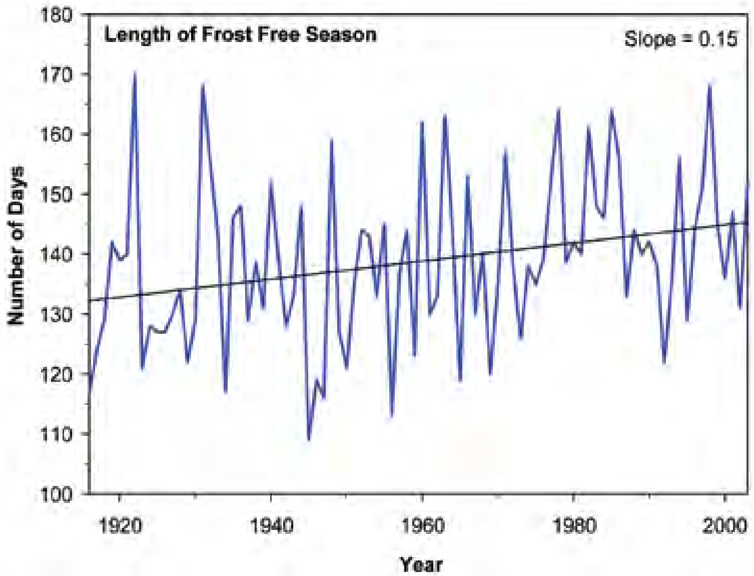


FIGURE 3.3. Length of the frost-free season for Kenora, Ontario (1916-2003).

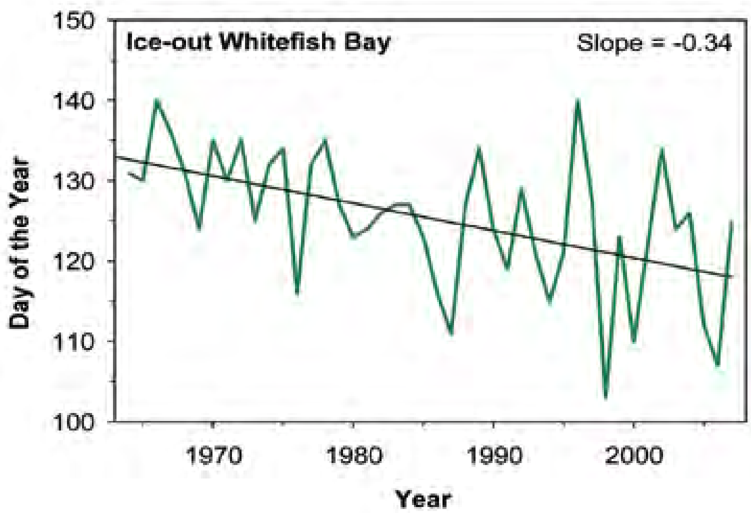


FIGURE 3.4. Ice-out dates (1964-2007) for the north end of Whitefish Bay in Lake of the Woods, Ontario (Ontario Ministry of Natural Resources, 2007, unpublished data).

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).

Precipitation

The region receives an average of 742 mm (1916-2004) of precipitation per year, most of which falls between the months of May and September, although there is large inter-annual variability within each month (Figure 3.5). Approximately 70% of the precipitation falls in the form of rain, with July being the wettest month (Figure 3.5). The average total precipitation in summer and winter is 287 mm and 115 mm, respectively.

Historical trends in annual precipitation in Kenora show an increased frequency of wet years since the mid-1990s, similar to the wet period seen in the late 1960s etc. with annual total precipitation having increased 2.6 mm between 1916 and 2004 (Figure 3.6). However, there is a strong seasonality to this trend, with below average precipitation recorded since the 1970s during the winter months. This is in contrast to spring, summer and fall months where general trends of increasing wet periods have been observed (Figure 3.6). 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 may cause elevated runoff and flow conditions in streams, rivers, and lakes within the Rainy River Basin. For example, a series of elevated thunderstorms caused record one-day rainfalls of 200-400 mm 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). The highest amounts were recorded in the LOW and the Rainy River regions, with secondary maxima in the region of Fort Frances along the Manitoba-U.S. border (Murphy et al., 2003). As a result of this severe rainfall event, Rainy Lake experienced a net 7-day inflow of approximately 1900 m^3/s on June 13, 2002, the highest on record since monitoring began in 1911 (Murphy et al., 2003).

3.2 Geography

Based on the Hydrological Unit (HU) classification system used by the USGS, MPCA, and MNDNR, a drainage basin

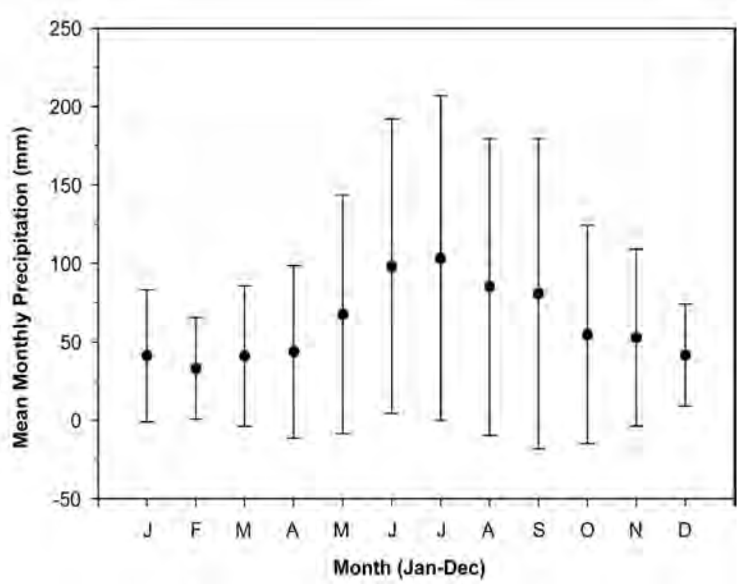


FIGURE 3.5. Means and standard deviations (+/- 2 SD units) in mean total monthly precipitation for Kenora, Ontario (1916-2004).

(or basin) is a land area that is drained by a river or a lake and its tributaries. Each drainage basin is comprised of smaller units called watersheds which correspond to the tributary drainage of a lake system (MPCA, 2007a). Based on the HU system, the Lake of the Woods and Rainy River Basin is a component of the larger Winnipeg River drainage basin. The Lake of the Woods and Rainy River Basin is an international watershed that covers an approximate area of 69,750 km^2. This basin is comprised of four watersheds (the Lake of the Woods and the Upper, Central, and Lower Rainy River watersheds) (Section 3.3. Hydrology, Figures 3.7-3.8). Specifically, the Upper Rainy River watershed includes the Canadian portion of the watershed; the Central Rainy River watershed covers the region draining into the Namakan River; and the Lower Rainy River watershed is located between the lower Rainy River and LOW. The Upper, Central, and Lower Rainy River watersheds comprise the Rainy River Basin and have drainage areas of 18,813 km^2, 19,314 km^2, and 16,760 km^2, respectively (Gartner Lee Limited, 2007). All three drain into the Rainy River, with the Upper and Central Rainy River watersheds draining into the Rainy River through Rainy Lake at Fort Frances/International Falls.

The LOW watershed drains an approximate area of 14,864 km^2 (Gartner Lee Limited, 2007). These four watersheds are referenced throughout this report. However, for the purposes of this report we will focus primarily on the regions associated closely with LOW and the Rainy River.

Generally, the region is sparsely populated, and is divided among many territorial divisions or jurisdictions (Table 3.3). Minnesota has three counties whose boundaries lie within the LOW watershed. From east to west they are Koochiching County, including the city of International Falls; Lake of the Woods County, including the city of Baudette; and Roseau County, which includes the city of Warroad. On the Canadian side of the watershed, there are two large districts – the Rainy River and Kenora Districts (Table 3.3). 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 is the Kenora District, which includes the city of Kenora, as well as the Municipal Township of Sioux Narrows-Nestor Falls (Table 3.3). Many First Nations communities are also located in this region. Finally, in the Ontario sector, outside of the boundaries of the Kenora District, Sioux Narrows-Nestor Falls and Lake of the Woods Township, there are vast areas of unincorporated territory, mostly provincial crown land but some is patent (i.e., private) land.

Glacial Lake Agassiz

LOW and many of its tributaries are remnants of what used to be glacial Lake Agassiz. Formed by melting glaciers, Lake Agassiz covered much of what is now western Minnesota, eastern North Dakota, southern Manitoba, and southwestern Ontario, from approximately 12,500 to 7,500 years ago. When Lake Agassiz retreated, several large lakes and rivers remained in the low-lying areas, including LOW. Isostatic rebound (defined as the "bouncing back" or rise of the earth's surface that was depressed by the weight of a large land mass, such as a glacier) that

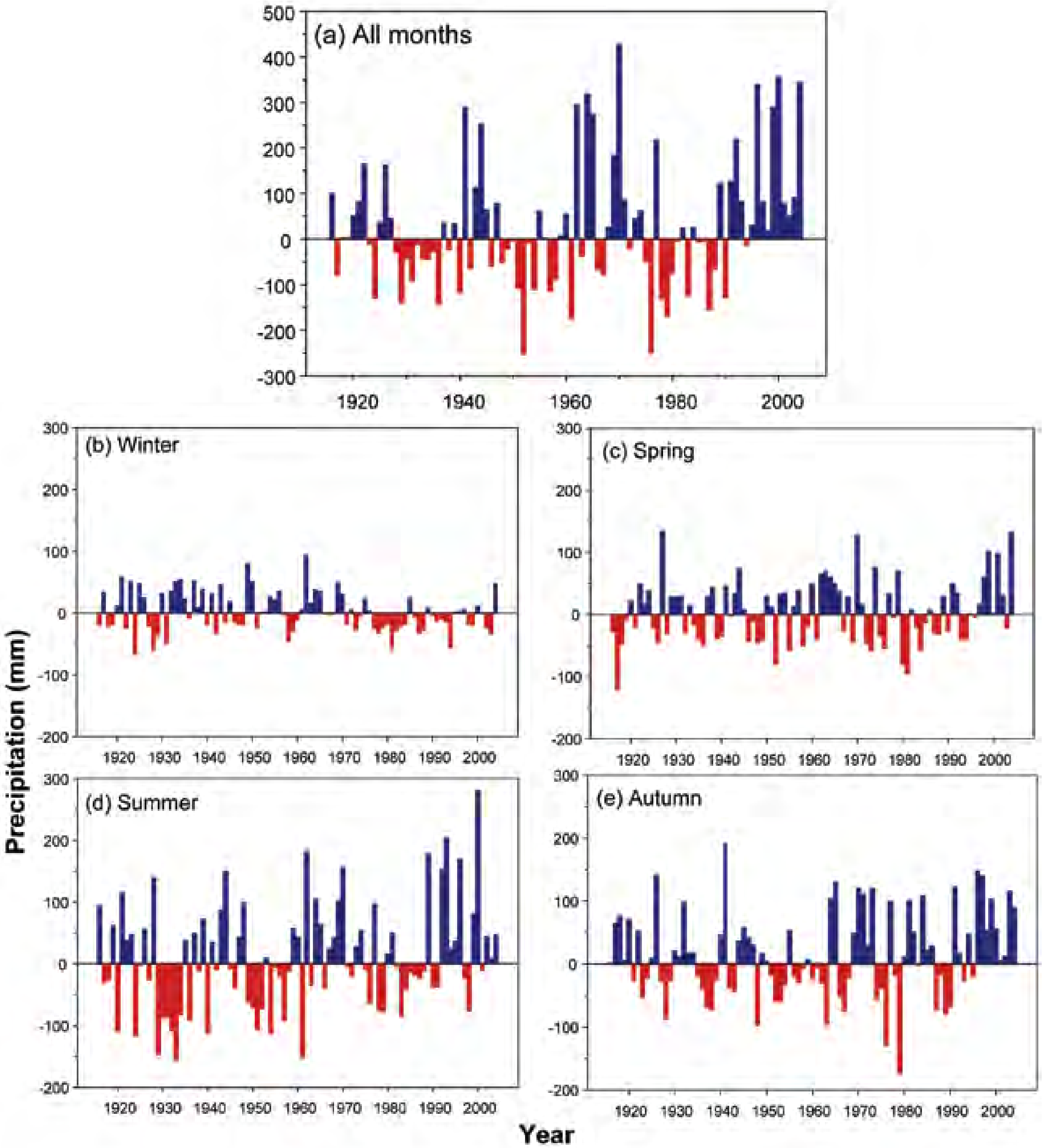


FIGURE 3.6. Total annual precipitation anomalies for Kenora, Ontario, from 1916-2004 for (a) all months, (b) winter (December-February), (c) spring (March-May), (d) summer (June-August), and (e) autumn (September-November). The mean precipitation data from 1950-1990 was used to calculate the deviation from normal for the station 'Kenora A'.

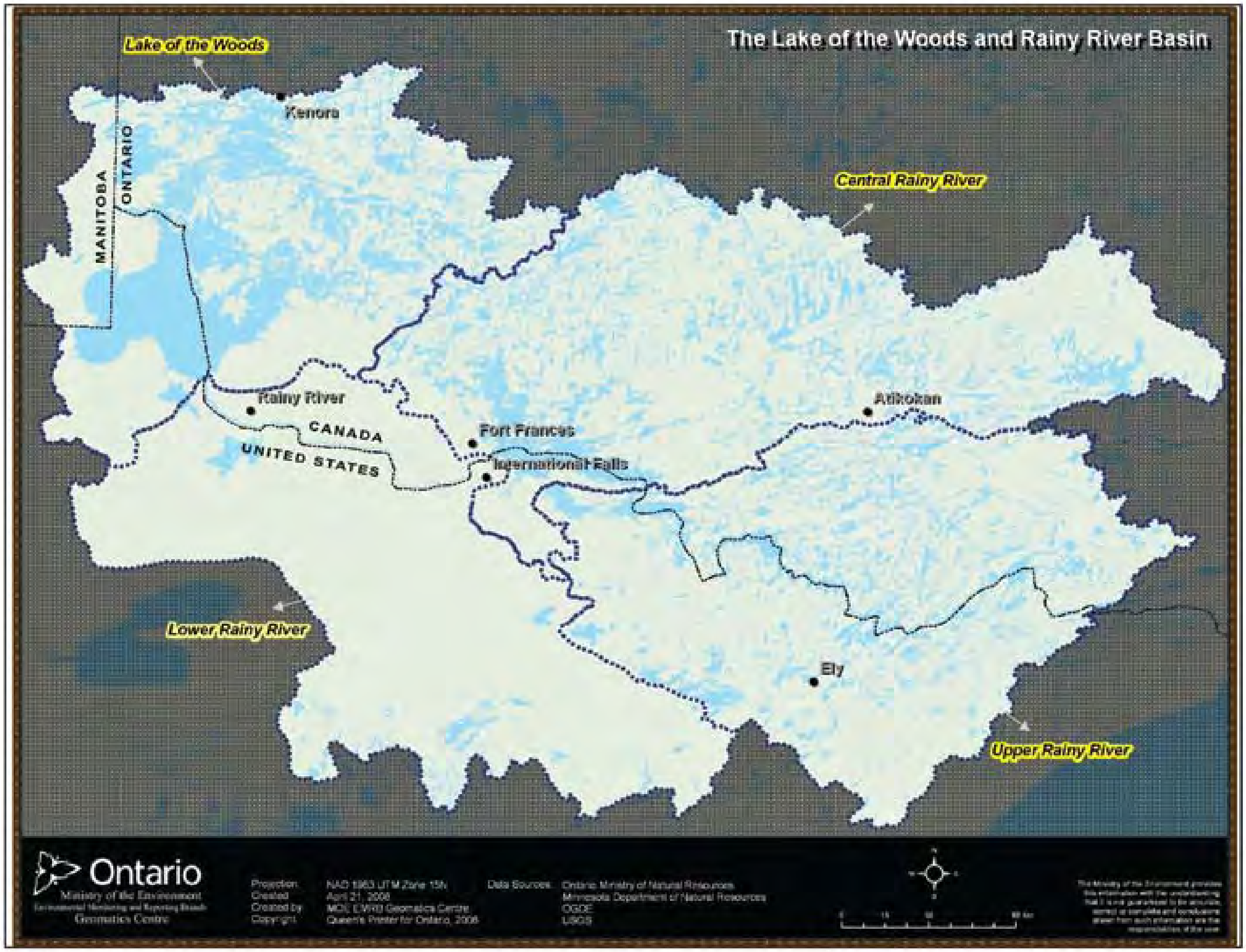
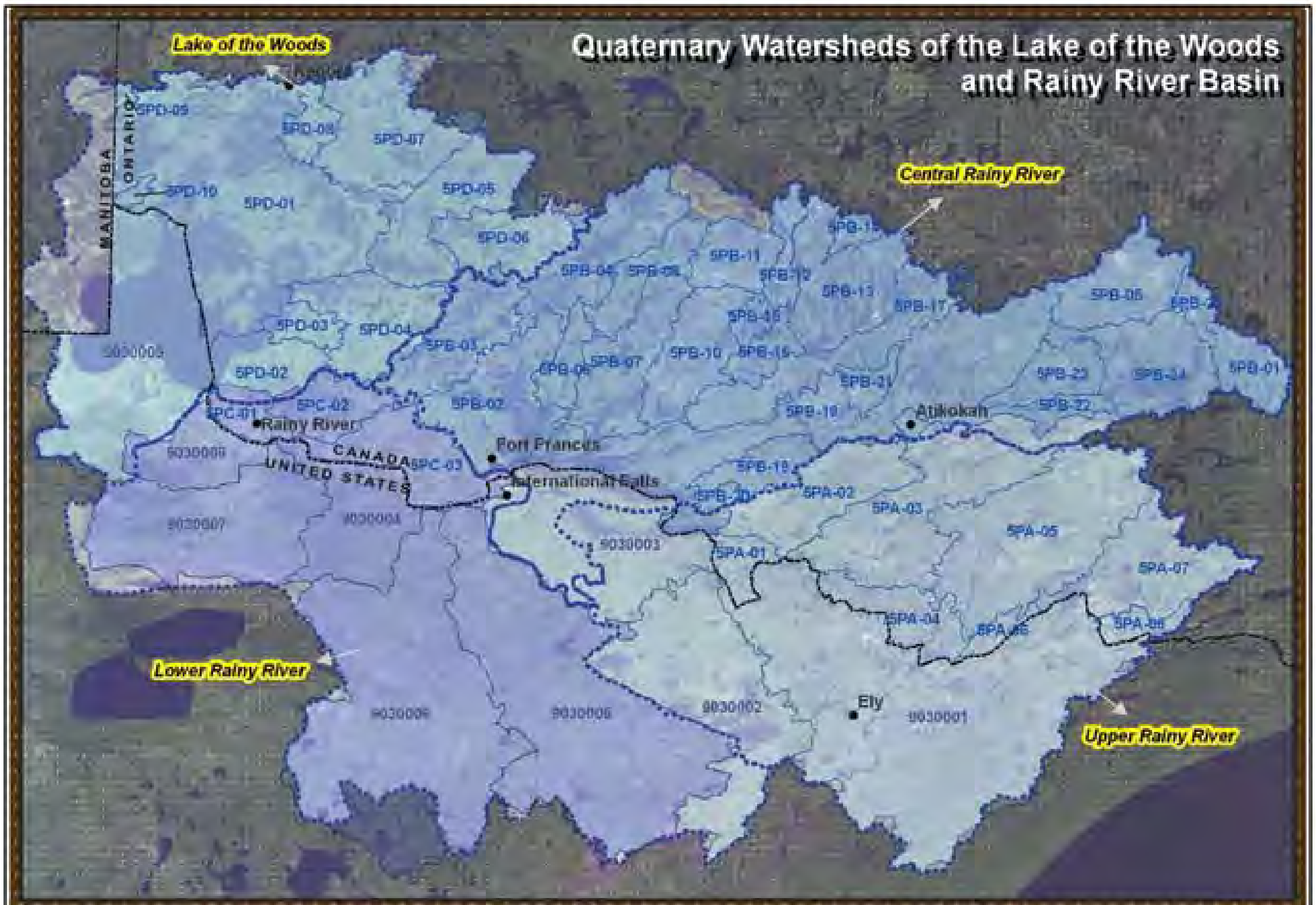


FIGURE 3.7. Location of the Upper, Central, Lower, and Lake of the Woods watersheds that comprise that comprise the Lake of the Woods and the Rainy River Basin.

followed the retreat of the glacier greatly shaped the early history of the LOW and Rainy River Basin (Yang and Teller, 2005). A difference in elevation exists between the south and north ends of the basin because of the differential rebound that occurred after Lake Agassiz retreated, which tilted the land's surface to the northeast (Tackman et al., 1998). Consequently, the lake drains in a northwesterly direction, forming part of the Winnipeg River drainage basin. It should be noted that 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. While it will likely be several thousand years before waters from LOW begin flowing to the south, the differing rebound rates may affect lake shore properties in the near future. As the lake basin gradually tips to the south, increased erosion and higher water levels may be prevalent in the south (Lake of the Woods Erosion Working Group, N. Baratono, MPCA, International Falls, MN, Pers. Comm.).

Geological Features

There are vast differences in geological features across the LOW and Rainy River



Lake of the Woods

Country	Quarternary Watershed	Watershed Name
Canada	5PD-01	Lake of the Woods
	5PD-02	Little Grassy River
	5PD-03	Grassy River
	5PD-04	Splitrock - Sabaskong Rivers
	5PD-05	Dogpaw River
	5PD-06	Rowan R.
	5PD-07	Adams - Black Rivers
	5PD-08	Rushing River
	5PD-09	Falcon River
	5PD-10	-
Country	**HUC Code**	**Watershed Name**
US	9030009	Lake of the Woods

Lower Rainy River

Country	Quarternary Watershed	Watershed Name
Canada	5PC-01	-
	5PC-02	Pinewood River
	5PC-03	Lower Rainy River
Country	**HUC Code**	**Watershed Name**
US	9030004	Upper Rainy
	9030005	Little Fork
	9030006	Big Fork
	9030007	Rapid
	9030008	Lower Rainy

Central Rainy River

Country	Quarternary Watershed	Watershed Name
Canada	5PB-01	Savanne River
	5PB-02	Northwest Rainy Lake
	5PB-03	Manomin River
	5PB-04	Manitou River
	5PB-05	Firesteel River
	5PB-06	Canoe Creek
	5PB-07	Redgut Bay
	5PB-08	Meggisi Creek
	5PB-10	Turtle River
	5PB-11	Rawlinson Creek
	5PB-12	Wabageisi Creek
	5PB-13	Kinmoapiku Creek
	5PB-14	Balmoral River
	5PB-15	Kenorain Creek
	5PB-16	Manion Creek
	5PB-17	Little Turtle River
	5PB-18	Lower Seine River - South East Rainy Lake
	5PB-19	Pipestone River
	5PB-20	Falls River - Namakan Lake
	5PB-21	Eye River
	5PB-22	Atikokan River
	5PB-23	Mercutio River
	5PB-24	Upper Seine River
	5PB-25	Little Savanne River

Upper Rainy River

Country	Quarternary Watershed	Watershed Name
Canada	5PA-01	-
	5PA-02	Lower Namakan R.
	5PA-03	Lower Maligne - middle Wildgoose Cr.
	5PA-04	Upper Namakan - Lower Basswood Rivers - Darky Cr.
	5PA-05	Middle Maligne - Middle Basswood Rivers
	5PA-06	Upper Basswood R.
	5PA-07	Upper Maligne - Lower Granite Rivers
	5PA-08	Upper Granite R.
Country	**HUC Code**	**Watershed Name**
US	9030001	Rainy Headwaters
	9030002	Vermilion
	9030003	Rainy Lake

LEGEND

International Boundary

River Basin

Quaternary Watersheds

Lake of the Woods

Upper Rainy River

Central Rainy River

Lower Rainy River

Ontario
Ministry of the Environment
Environmental Monitoring and Reporting Branch
Geomatics Centre

0 12.5 25 50 Km

Data Sources: Ontario Ministry of Natural Resources
USGS
Projection: NAD 1983 UTM Zone 15N
Created: April 14, 2008
Created by: MOE EMRB Geomatics Centre
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FIGURE 3.8. Map of U.S. and Canadian basins and watersheds of the Lake of the Woods and Rainy River Basin.

There are vast differences in geological features across the LOW and Rainy River drainage basin.

drainage basin. The basin rests upon bedrock of the North American Precambrian Shield (Figure 3.9). This hard, impermeable bedrock consists mainly of granitic and metavolcanic rocks, including igneous, metamorphic, and sedimentary rocks. A band of Archean metasedimentary rock transects the Upper and Lower Rainy River watersheds (Figure 3.9). The Lake of the Woods and Central Rainy River watersheds as well as the northern portion of the Upper Rainy River watershed, consist of a veneer of discontinuous glacial till with large outcroppings of bedrock (Fulton, 1995). This area is predominantly forested with a thin soil cover and numerous lakes, ponds, and connecting channels (International Joint Commission (IJC), 1984).

The Upper and Lower Rainy River watersheds, including the southern portion of LOW (i.e., Big Traverse Bay), are also underlain by sediment deposited by glacial Lake Agassiz, such as glacial drift and silt, clay, loam, and sand (Figure 3.10). These regions are fairly flat with a vertical fall of merely 15 m (50 feet) between Rainy Lake and LOW (IJC, 1984). Peat deposits are widespread, and wetlands, peat bogs, and marshes dominate the landscape.

Geographical Features

The terms used to describe the terrestrial zones of vegetation in the LOW and Rainy River Basin are different in Canada and the United States. In Canada, the Boreal Shield ecozone stretches 3,800 km from Newfoundland to Alberta (Environment Canada, 2007b). Contained within this ecozone are the LOW and Rainy River ecoregions (Environment Canada, 2007b). In the Rainy River ecoregion, forestry, aquatic 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, recreation, and hunting are the main land use activities (Environment Canada, 2007b).

In the U.S., Minnesota is divided into seven terrestrial ecoregions, two of which comprise the Lake of the Woods and Rainy River Basin. These are the Northern Minnesota Wetlands ecoregion and the Northern Lakes and Forests ecoregion (MPCA, 2001). 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 some localized farming along the western edge of the ecoregion where some grains for livestock, such as hay, are cultivated (MPCA, 2001). In the Northern Lakes and Forests ecoregion, agriculture is limited to some beef and dairy farms due to thin soil cover over bedrock and reduced levels of soil nutrients (MPCA, 2001). In addition, a majority of lakes in this ecoregion are used for recreational purposes.

Terrestrial Vegetation

In most regions of the Lake of the Woods and Rainy River Basin the soil is sandy and poor in nutrients, forest fires are frequent, and the forest composition is largely influenced by drainage and topography. An estimated 59% of the drainage basin is forested (Gartner Lee Ltd., 2007), 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,

TABLE 3.3. General land cover and population statistics for the main jurisdictional sections of the Lake of the Woods drainage basin. Statistics for the Minnesota counties and Ontario districts are taken from the 2000 U.S. and the 2006 Canadian censuses, respectively. These statistics do not include First Nations' Communities in the area.

County/Township	Minnesota	Ontario	Land Cover (km^2)	Population	Density (#/km^2)	Main city/town centres (population)
Roseau County	X		41,440	16,338	0.39	Roseau (2,756); Warroad (1,722)
Lake of the Woods County	X		3358	4,522	1.35	Baudette (1,104)
Koochiching County	X		8035	14,355	1.79	International Falls (6,703)
Rainy River District		X	15,472	21,564	1.39	Fort Frances (8,103)
Kenora District		X	407,193	64,419	0.15	Kenora (15,177)

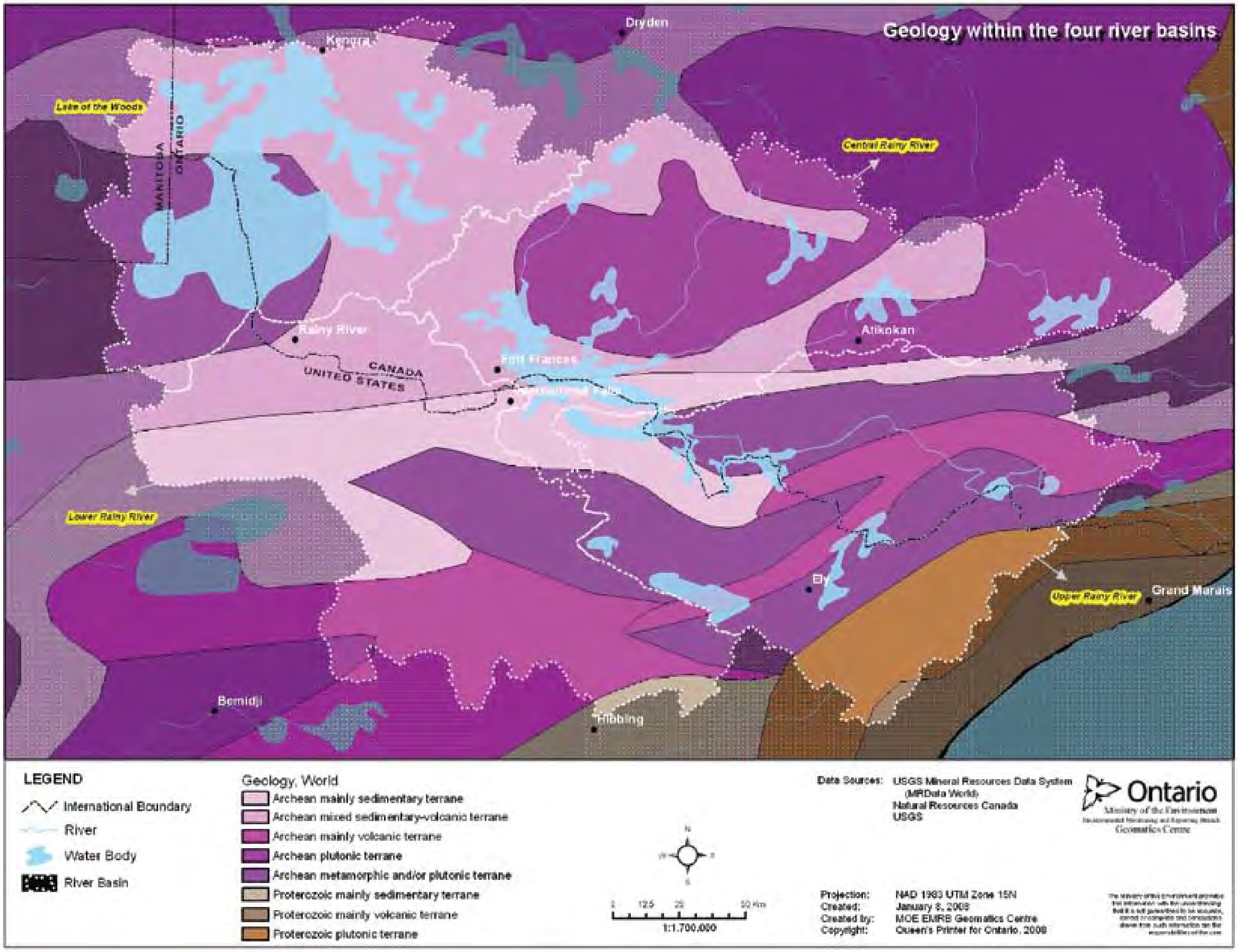

FIGURE 3.9. Geology of the four watersheds (Lake of the Woods watershed and the Upper, Central, and Lower Rainy River watersheds) within the Lake of the Woods and the Rainy River Basin. Data sources are from the United States Geological Survey and Natural Resources Canada.

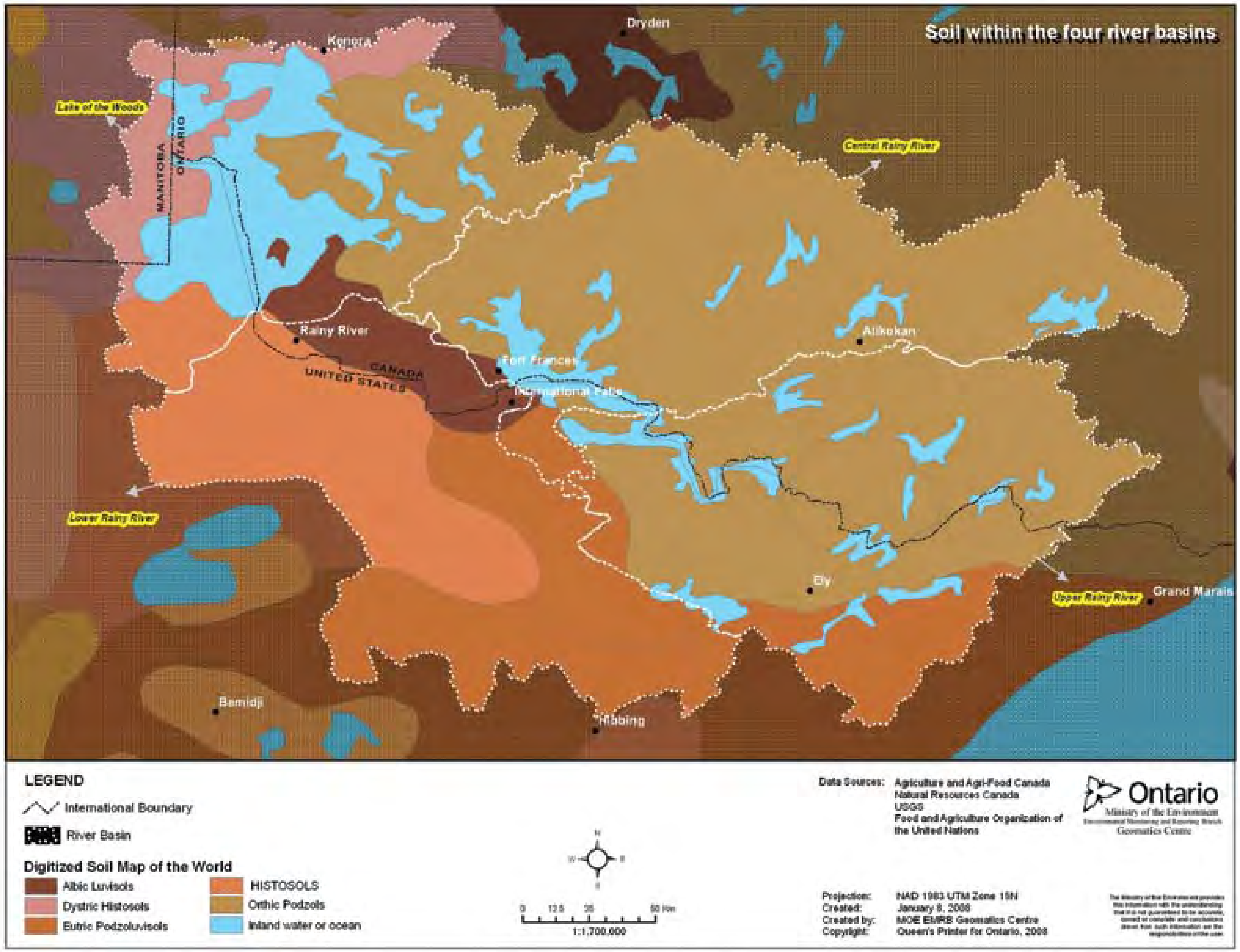

FIGURE 3.10. Soil composition of the four watersheds (Lake of the Woods watershed and the Upper, Central, and Lower Rainy River watersheds) within the Lake of the Woods and the Rainy River Basin. Description of soil terms is as follows: Albic Luvisols = sandy/silty particles; Dystric Histosols = peat soils; Eutric Podzoluvisols = leached, poor quality, sandy soils; Histols = wetland conditions; thick, organic layer at the surface; Orthic Podzols = typical of coniferous regions, poor and heavily leached, sandy soils. Data sources are from Agriculture and Agri-Food Canada, Natural Resources Canada, the United States Geological Survey, and the Food and Agriculture Organization of the United Nations.

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 (*Populus tremuloides*), paper birch (*Betula papyrifera*), and jack pine (*Pinus banksiana*), with white spruce (*Picea glauca*), black spruce (*Picea mariana*), and balsam fir (*Abies balsamea*) developing secondarily. Red pine (*Pinus resinosa*) and eastern white pine (*Pinus strobus*) occur in warmer regions, while black spruce and tamarack (*Larix laricina*) occur in cooler and wetter regions. The shrub-level species that occupy the region beneath the forest canopy include beaked hazel (*Corylus cornuta*), mountain maple (*Acer spicatum*), honeysuckle (*Lonicera spp.*), and dogwood (*Cornus spp.*), as well as various mosses and herbs.

LAKE OF THE WOODS MUSEUM

Construction of the first Kenora powerhouse/dam, 1892.

To the south, between LOW and Rainy Lake, lies the Rainy River ecoregion, which is the Canadian equivalent to the Northern Minnesota Wetlands Ecoregion in the U.S. This region contains mixed forests that include trembling aspen, paper birch, and jack pine with secondary succession to white spruce, black spruce and balsam fir. Some regions support red and sugar maples (*Acer rubrum* and *A. saccharum*) and eastern white pine. In the Northern Lakes and Forests ecoregion, coniferous forests dominate, with the exception of areas that have been logged or burned where primary forest species occur.

3.3 Hydrology, Lake Level, and Flow Regulation

Drainage

LOW is the largest lake in the Winnipeg River drainage basin. LOW and its drainage basin comprise 47% of the Winnipeg River drainage basin (LWCB, 2002). Although the primary focus of this report is the aquatic environments of Lake of the Woods and the Rainy River, this section will include Rainy and Namakan Lakes due to their size, proximity, and influence on the hydrology of LOW.

Long-term hydrological data have been collected at ten gauging stations in the LOW watershed, with the earliest record beginning in the mid-1890s (Winnipeg River below LOW; Table 3.4, Figure 3.11). Beginning at the inflow at Rainy and Namakan Lakes and moving west- and northward to the outflows at Kenora, Ontario, the following sections provide an overview of the lake and river flows, levels, and regulations by incorporating outflow and water level data from five long-term monitoring stations in the LOW Basin, including (1) the Rainy River at Fort Frances (Water Survey of Canada (WSC) station # 05PC019); (2) the Rainy River at Manitou Rapids (WSC station

TABLE 3.4. Riverflow, streamflow, and Lake of the Woods outflow monitoring stations in the Lake of the Woods watershed.

Station No.	Name	Latitude (N)	Longitude (W)	Drainage Area (km^2)	Mean annual flow (m^3/s)	Period of record (continuous)	Regulated/ Unregulated
05PC018[a]	Rainy River at Manitou Rapids, ON	48°38′04″	93°54′48″	50,200	277.0	1928-2007	R
05PC019[a]	Rainy River at Fort Frances, ON	48°36′30″	93°24′12″	38,600	366.1	1905-2007	R
5131500[b]	Little Fork R. at Little Fork, MN	48°23′45″	93°32′57″	4,351	30.1	1929-2007	U
5132000[b]	Big Fork River at Big Falls, MN	48°11′45″	93°48′25″	3,833	20.7	1929-2007	U
5134200[b]	Rapid River near Baudette, MN	48°32′10″	94°33′45″	4,406	--	1956-1985	U
Outflows from LOW:							
05PE020[a]	Winnipeg River below Lake of the Woods, ON	49°47′04″	94°30′47″	70,400	433.6	1893-2007	R
05PE011[a]	Lake of the Woods western outlet at Norman Dam and Powerhouse, ON	49°46′19″	94°31′28″	--	298.0	1913-2007	R
05PE006[a]	Lake of the Woods eastern outlet at Kenora Powerhouse, ON	49°46′21″	94°30′11″	--	100.0	1908-2007	R
05PE004[a]	Lake of the Woods outlet at Mill 'C' Keewatin, ON	49°45′50″	94°33′20″	--	16.3	1913-1972	R
05PE003[a]	Lake of the Woods outlet at Boat Lift Channel, ON	49°45′50″	94°33′30″	--	15.3	1913-1979	R
05PE005[a]	Lake of the Woods outlet at Mink Creek, ON	49°45′53″	94°33′13″	--	3.2	1813-2007	R

a = Water Survey of Canada (WSC) gauging station
b = United States Geological Survey (USGS) gauging station

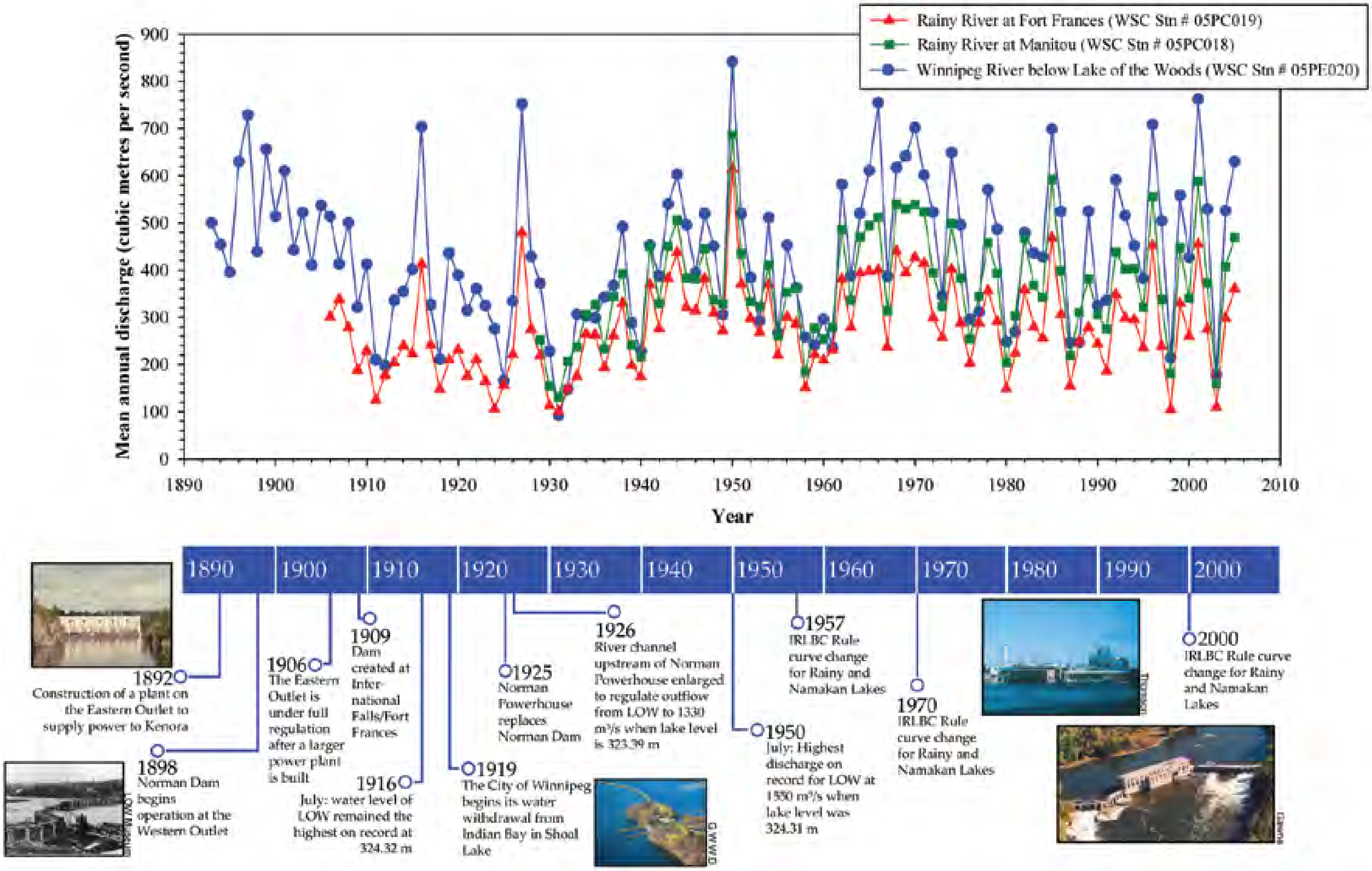

FIGURE 3.11. Upper: mean annual discharge for the gauging stations at Rainy River at Fort Frances (1906-2005), Rainy River at Manitou Rapids (1929-2005), and Lake of the Woods (1893-2005). Lower: timeline for important hydrological changes to Lake of the Woods and the Rainy River Basin, (1892-2000).

Water levels and flows have been regulated for over 100 years – providing extensive long-term hydrologic data.

05PC018; USGS station #05133500); and (3) the Winnipeg River below LOW (WSC station # 05PE020) gauging stations (Table 3.4). Collectively, these stations drain water from 159,200 km^2 of land with little variability in mean annual discharge at each station (Figure 3.11). The Winnipeg River below LOW station is not a physical site, but includes total outflow from all discharges from LOW, including the Norman Dam and powerhouse, the Kenora powerhouse, and Mink Creek. In addition, we include data from: (4) the Little Fork River at Littlefork, MN (USGS station # 05131500); and (5) the Bigfork River at Big Falls, MN (USGS station # 05132000) gauging stations. These stations represent two of the largest tributaries to the Rainy River, and drain the area south-east of LOW in Minnesota.

Rainy and Namakan Lakes

Rainy and Namakan Lakes are located along the international boundary upstream of the Rainy River. Thus, the timing of water release from these lakes has a significant impact on LOW water level regulation. Since the early 1900s, these large lakes have been controlled by regulatory dams on Namakan Lake's two outlets and a hydroelectric dam at Rainy Lake's outlet.

The International Rainy Lake Board of Control (IRLBC) was created by the IJC in 1941 to deal with the issue of emergency conditions within the Rainy Lake watershed. This board has been involved in regulating water levels within Rainy and Namakan Lakes, and hence, inflows to Rainy River and LOW, since 1949. The IRLBC manages water levels according to the Consolidated Order of January 2001, which defines a water level band with upper and lower rule curves for Rainy and Namakan lakes, minimum outflow requirements under normal flow conditions, 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; IRLBC, 2007). The International Falls-Fort Frances dam is normally operated within the defined rule curve bands, and the middle portion of these bands are targeted. However, in periods of high or low inflows, the IRLBC (with approval from the IJC) may sanction the raising or lowering of lake levels outside the maximum or minimum levels defined by the rule curves.

The IRLBC's regulations for Namakan Lake allow a seasonal variation in water level of 2.0 m, with a target of 1.5 m (LWBC, 2007). Average inflows to Namakan Lake fluctuate from 73 m^3/s in early March to 342 m^3/s in late May, but inflows can get 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, 2007). The IRLBC's regulations for the water level of Rainy Lake indicate a maximum seasonal variation in level of 1.05 m with a target of 0.80 m. Average inflows range from 151 m^3/s in early March to 519 m^3/s in June, although inflows have ranged from 0 to 1,733 m^3/s in the past (LWCB, 2007). Throughout the year, average outflows vary from 167 to 465 m^3/s, with an annual average outflow of 290 m^3/s (LWCB, 2007).

Rainy River and its main tributaries

The Rainy River is 130 km long and is the primary tributary to LOW. The area above Fort Frances-International Falls represents 55% of the total area of the Rainy River Basin that drains into LOW (LWCB, 2007). The outlet from Rainy Lake to Rainy River is controlled by a dam at International Falls and Fort Frances (Rainy River at Fort Frances gauge station, Table 3.4). Approximately 70% of the LOW watershed lies above the gauging station at Manitou Rapids (LWCB, 2007). Although this location provides an essential indication of inflow to LOW, it is highly influenced by backwater ice on the Rainy River in the wintertime (LWCB, 2007). The Rainy River itself is predominantly flat and slow moving, with the exception of Manitou and Long Sault Rapids. However, this slope can change considerably, resulting in stage increases of 5 to 9 m and significantly increased water velocities (LWCB, 2007).

The two largest inflows to the Rainy

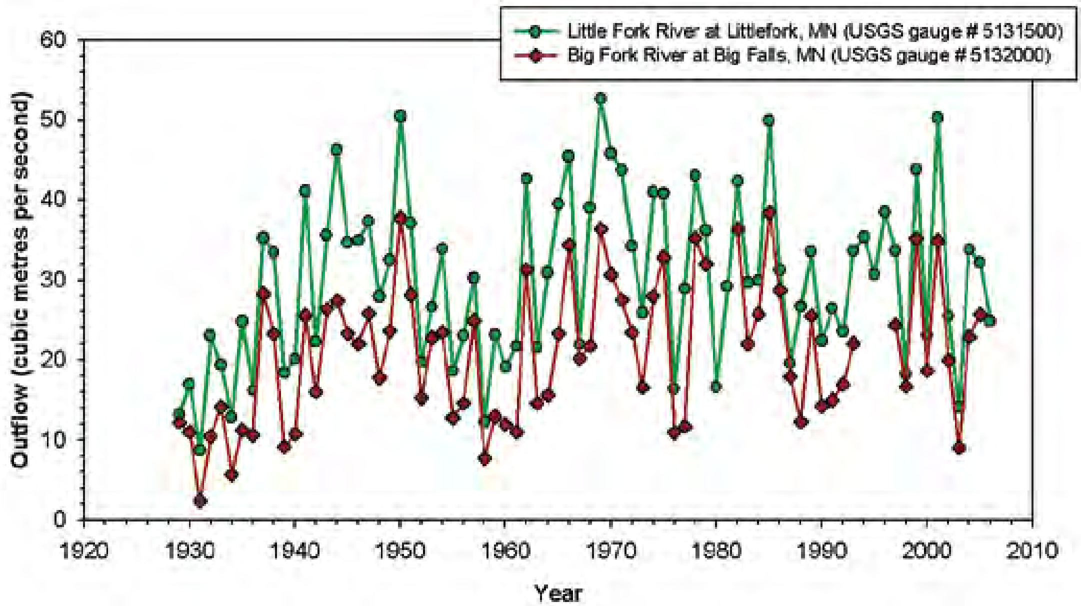

FIGURE 3.12. Annual fluctuations in streamflow for the Little and Big Fork Rivers in Minnesota for the 1929-2005 interval.

River are the Little and Big Fork Rivers, which drain 12% of the LOW and Lower Rainy River watersheds (combined) and contribute 10% of the total inflow to LOW (LWCB, 2007). These tributaries empty into the Rainy River upstream of Manitou Rapids. These rivers have experienced erosion, undercutting, and straightening of their streambanks in recent years which may be contributing high sediment loads and hence, phosphorus, to the Rainy River (Anderson et al., 2006a). The Little Fork River drains a watershed area of 4,773 km^2 and flows a distance of 258 km from its headwaters in northeastern Minnesota to the confluence with the Rainy River. The Big Fork River, to the west, drains a watershed of 5,343 km^2. It is 105 km long and originates at Dora Lake in Northern Itasca County, Minnesota, and ends at the Rainy River approximately 9 km west of the Little Fork confluence with the Rainy River. The USGS has been monitoring streamflow at the towns of Littlefork on the Little Fork River and Big Falls on the Big Fork River continuously since 1929.

Lake of the Woods covers an area of 3,850 km^2, spanning maximum distances of 105 km from north to south and 90 km from east to west. It contains approximately 14,500 islands, which make it extremely hydrologically-complex ...

Despite their similar geographical location, there are differences between the outflows and water levels of the Little and Big Fork Rivers. For example, despite its smaller watershed area, the Little Fork River has a higher discharge than the Big Fork River (Figure 3.12). In addition, the Little Fork River and its tributaries have approximately twice the water yield compared to other area streams, and changes in runoff and precipitation can cause water levels to rise and fall rapidly (Anderson et al., 2006a). These differences between the two rivers have been attributed to: (1) a larger area of peatland in the Big Fork watershed, which moderates runoff and flow; (2) a higher proportion of pasture land in the Little Fork watershed, which generates more runoff than mature forests; (3) a greater number of lakes in the Big Fork watershed (420 versus 165 in the Little Fork), which 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). Recovery of the Little Fork River watershed from the impacts of historical logging is currently being examined. Further studies are currently underway to assess current logging practices in the Little Fork watershed and to determine what other differences between these two watersheds may contribute to increased runoff and flow in the Little Fork River (Anderson et al., 2006a). There are very little data on flows from tributaries on the Canadian side of the border.

Lake of the Woods

LAKE OF THE WOODS MUSEUM

High water mark No. 15 at Yellow Girl Bay, June 26, 1913.

Lake of the Woods covers an area of 3,850 km^2, spanning maximum distances of 105 km from north to south and 90 km from east to west. It contains approximately 14,500 islands, which make it extremely hydrologically-complex (Figure 3.13; Heiman & Smith, 1991). Approximately 65% of the lake is within Canada (including Ontario and Manitoba), and the remainder is in Minnesota in the United States (Rusak & Mosindy, 1997). As mentioned previously, the Rainy River is the primary source of inflow to the lake, and the Warroad River is of secondary importance. Based on calculated net inflows (from measured outflows and net change in lake storage and elevation), average inflows to LOW from the Rainy River range from 210 m^3/s in mid-August to 1,010 m^3/s in late April, with an average annual inflow of 460 m^3/s (LWCB, 2007). 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, but in the past they have discharged as much as 1,550 m^3/s (i.e., in 1950, when the lake level reached 324.31 m; LWCB, 2002). Peak outflows generally occur from June to July, with mean flows of approximately 550 m^3/s during this time (Figure 3.14-3.16). Mean outflow generally declines between August and October, and remains stable during the winter months of December to March. Between April and May there is commonly an increase in discharge associated with ice and snow melt, and spring precipitation.

Two boards are responsible for managing water and waterways within the LOW and Rainy River Basin. Based on recommendations by the IJC, a treaty between the United States and Canada was formed (i.e., the 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 when the lake is 323.39 m. The (Canadian) LOW Control Board (LWCB) was established in 1919 by the governments of Ontario and Canada. It was established to implement the recommendations of the IJCs 1912-17 reference to study lake levels in LOW. The mandate of the LWCB is, among other tasks, to control the outflow from LOW under normal lake levels. This treaty 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, fishing, and navigation.

Currently, water level data are obtained from several different gauges to inform hydrological decisions in LOW (R. Cousins, LWCB, Pers. Comm., 2007), including Warroad (U.S.; WSC gauge # 05PD001), Hanson Bay (WSC gauge # 05PD008), Clearwater Bay (WSC gauge # 05PD011), Cyclone Island (WSC gauge # 05P029). There is a second U.S. gauge at Springsteel Island (USGS gauge # 05140521). There is also a gauge at Keewatin (WSC gauge # 05PD014) that reads lower than the main lake (depending on outflow), because it is downstream of several constrictions between the main lake and the lake outlets.

Although some annual fluctuations in water levels are common in LOW, mean daily levels have tended to stabilize in recent years due, for the most part, to regulation (Figure 3.15). The water levels in LOW

FIGURE 3.13. Lake of the Woods and its major bays and islands. Grey lines represent either the international border between Ontario or Manitoba and Minnesota or the national border separating Ontario and Manitoba.

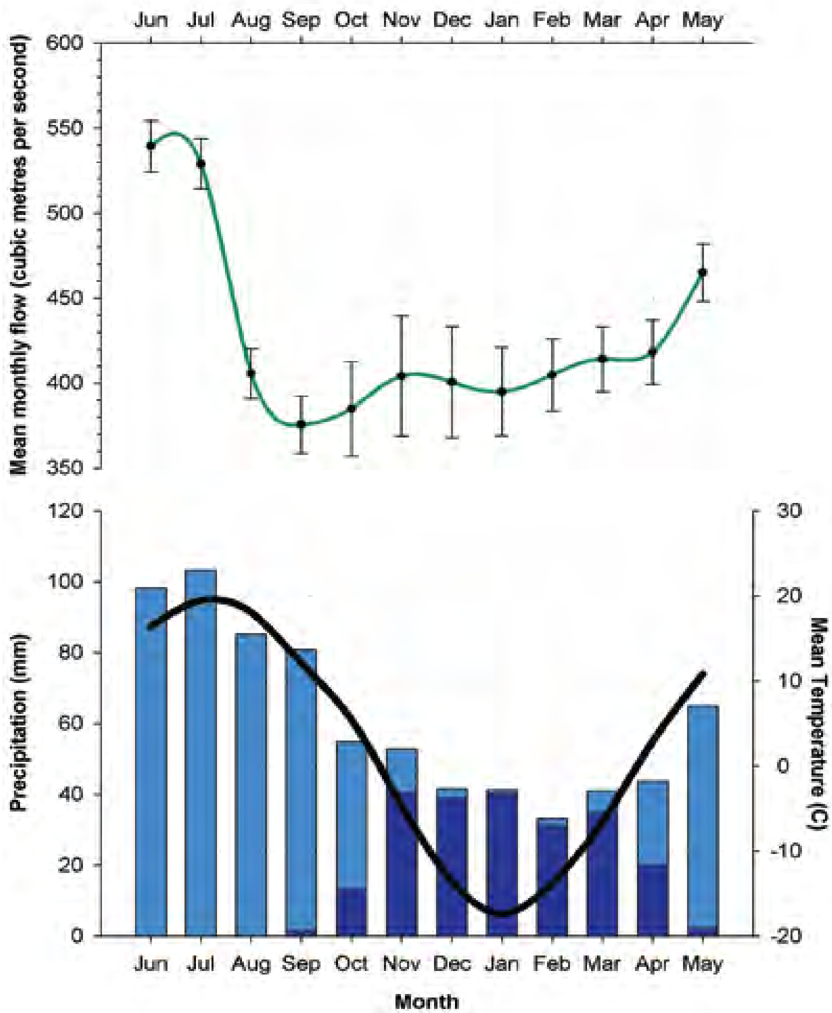

FIGURE 3.14. Average hydroclimatic conditions in Lake of the Woods. The upper chart shows standard error bars of mean monthly outflow for the Winnipeg River below Lake of the Woods gauge (WSC # 05PE020) calculated for the 1893-2005 interval. The lower chart shows the climograph for Kenora, Ontario calculated for the 1916-2005 interval. Vertical bars shaded dark blue and light blue represent the amount of precipitation in the form of snow and rain, respectively. The black line represents temperature.

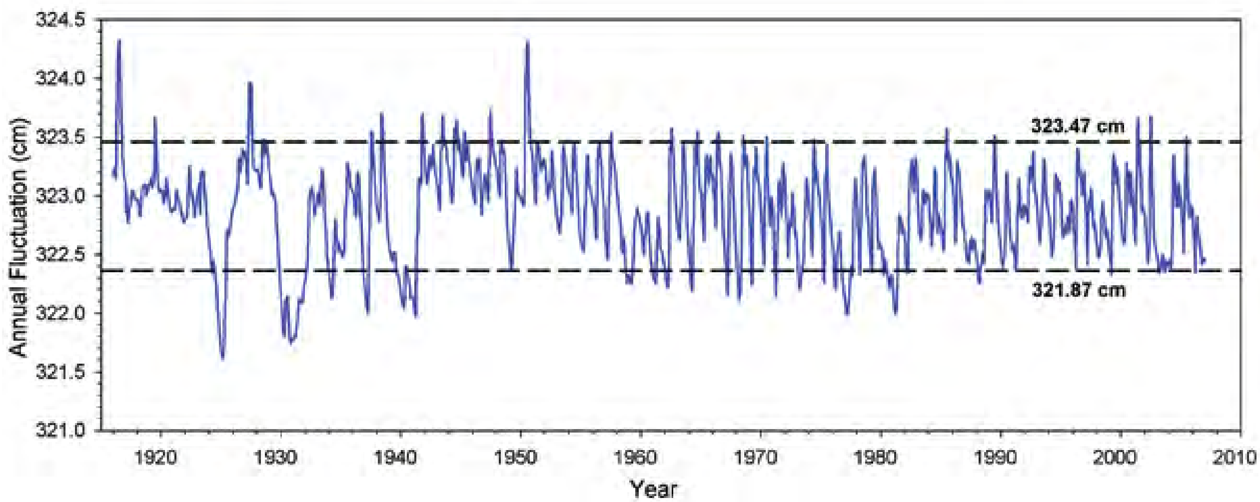

FIGURE 3.15. Fluctuations in water levels on Lake of the Woods, 1893-2005. The mean daily water levels are derived from the Lake of the Woods Control Board (LWCB) provisional data by averaging data from several different Water Survey of Canada water level stations (Springsteel, Cyclone, Hanson, and Clearwater). The dotted lines indicate the upper (321.87 cm) and lower (323.47 cm) desirable ranges in water levels, as regulated by the LWCB.

are currently regulated 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 not exceeding a height of 323.85 m (LWCB, 2002). Similarly, during drought periods when inflow to LOW remains low, outflow is adjusted to maintain a balance between upstream and downstream interests. However, average annual variation is only 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). This lake level stabilization in recent years is a result of better climatic predictive capability and better engineering actions to anticipate and control lake levels.

Historically, the natural outflow of Shoal Lake, located to the northwest of Clearwater Bay, was into Lake of the Woods via Ash Rapids. When the north end dams were constructed and LOW levels increased in the late 1890s, 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 lake (LOW) levels, and local inflows to Shoal Lake. Since 1919, Shoal Lake has supplied water to the city of Winnipeg via the 135 km aqueduct running from Indian Bay at the westernmost end of the lake to Deacon's Reservoir on the eastern outskirts of Winnipeg. The resulting shift in flow direction results in 1% of the average annual outflow from LOW exiting through Shoal Lake (LWCB, 2007). In practice, the City of Winnipeg withdrawals have been approximately 50% of the allowable limit over the past 30 years (i.e, in 2000 averaged 227 million litres per day (Shoal Lake Watershed Working Group, 2002). The last outlet is the water that is removed from LOW by the water treatment plant in Kenora for municipal usage, the bulk of which discharges into the Winnipeg River (at Rideout Bay).

3.4 Lake Morphometry

Lake morphometry can influence almost all chemical, physical, and biological parameters of a lake. LOW and its tributaries were formed through ice movements from glacial Lake Agassiz (Section 3.2. Geography). As mentioned previously, LOW spans 105 km from north to south and 90 km from east to west. The lake contains approximately 14,500 islands (Heiman & Smith, 1991). The earliest maps with detailed bathymetric profiles for LOW and the Rainy River can be found in Meyer & White (1915).

The Rainy River is gently sloping and is almost flat in most areas, with the exception of areas with rapids (e.g., Long Sault Rapids, Manitou Rapids). The characteristics of LOW differ between the southern U.S. side and the northern Canadian side. Almost all of the southern shoreline of LOW is flat and shallow with few bays, inlets, or islands. These southern regions of the lake, including Big Traverse, Muskeg, Buffalo, and Four Mile Bays, the Northwest Angle Inlet, and the western portion of Little Traverse Bay, are shallow and gently sloping. The flat-bottomed and marshy nature of this region of the lake is due to its geology of thin, glacial veneer over top of Precambrian bedrock, with many peat bogs and swamps in the region. The northern Canadian portion of the lake is located on Precambrian Shield and thus has a typically rocky shoreline. The basins and bays of the central and northern portion of LOW are seep sided and deep, a characteristic attributed to their Precambrian Shield geology.

Maximum depths range from 10 m in the southern region near Big Traverse Bay to 66 m in Whitefish Bay. Morphometric characteristics for LOW including Shoal Lake and its six Ontario sectors, as defined by the LOW Fisheries Assessment Unit (OMNR-FAU, Kenora, ON, 2007, unpublished data), are presented in Table 3.5. The OMNR-FAU routinely samples six regions of the Ontario portion of LOW that have been defined as being limnology and geologically distinct (Sectors 1-6, Figure 3.17, Table 3.5). The primary constituent of the southern portion of LOW is Big Traverse Bay on the U.S. side (Figure 3.17, Table 3.6).

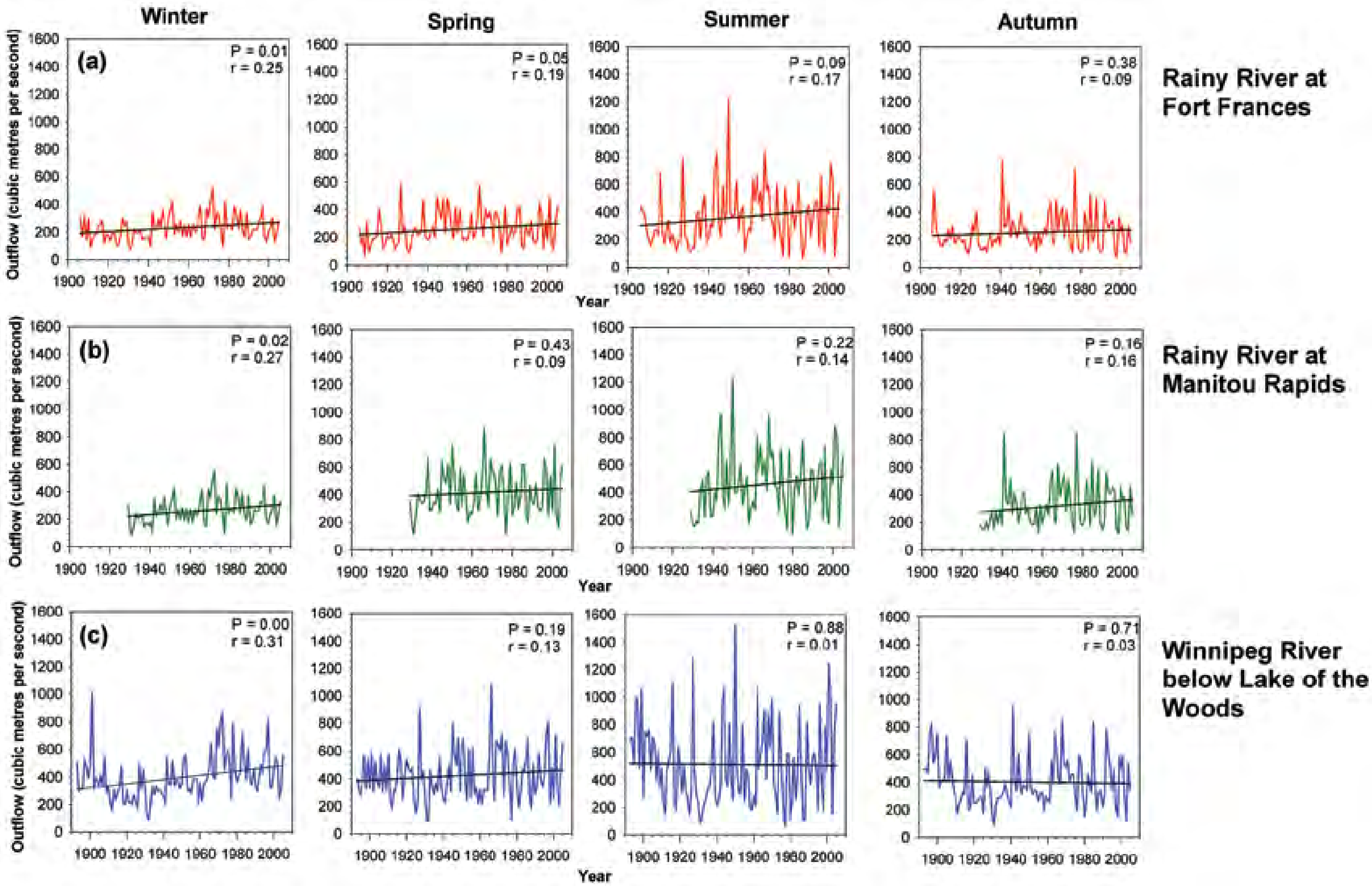

FIGURE 3.16. Trends and regression statistics for mean winter (December-February), spring (March-May), summer (June-August), and autumn (September-November) outflow from three gauges in the Lake of the Woods watershed: a) Rainy River at Fort Frances (WSC # 05PC019); (b) Rainy River at Manitou Rapids (WSC gauge # 05PC018); and (c) Winnipeg River below Lake of the Woods (WSC # 05PE020).

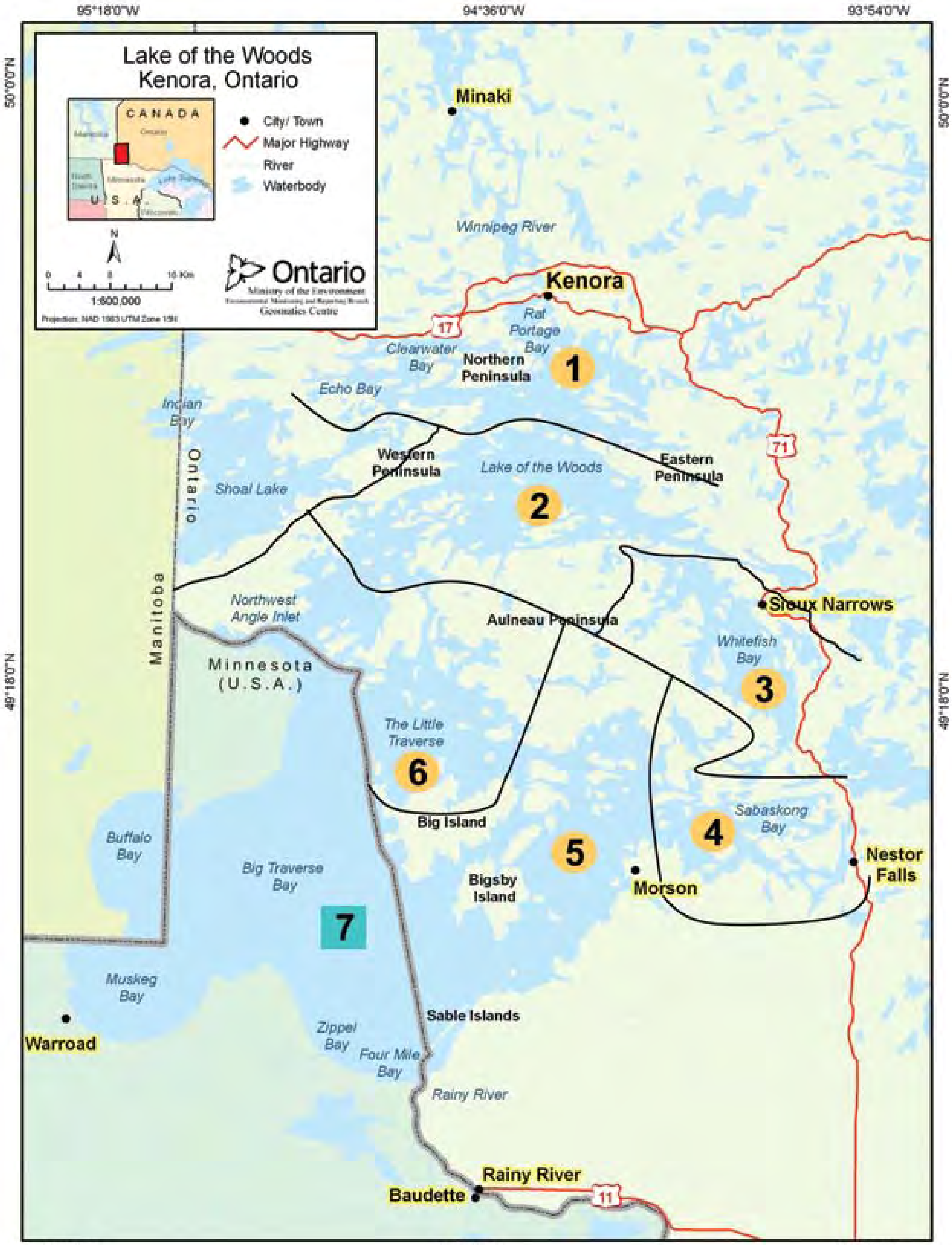

FIGURE 3.17. Map showing the location of the six sectors in LOW that have been routinely sampled since the mid-1980's by the Ontario Ministry of Natural Resources Fisheries Assessment Unit in Kenora, ON and the region routinely sampled by the Minnesota Pollution Control Agency and the Minnesota Department of Natural Resources. Numbers are defined as follows:1 = northern/Clearwater Bay; 2 = central; 3 = Whitefish Bay; 4 = Sabaskong Bay; 5,6 = southern; 7 = Big Traverse Bay, including Four Mile Bay and Muskeg Bay. Details of these sectors are reported in Tables 3.5-3.6. These sectors are referred to throughout this report. Modified from OMNR, 1985.

Lake surface area is an important factor in 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 unimpeded surface area with a high fetch. This, combined with its shallow depth (maximum 11.0 m, Table 3.6), causes the water to be mixed completely throughout the summer months (i.e., summer stratification does not occur).

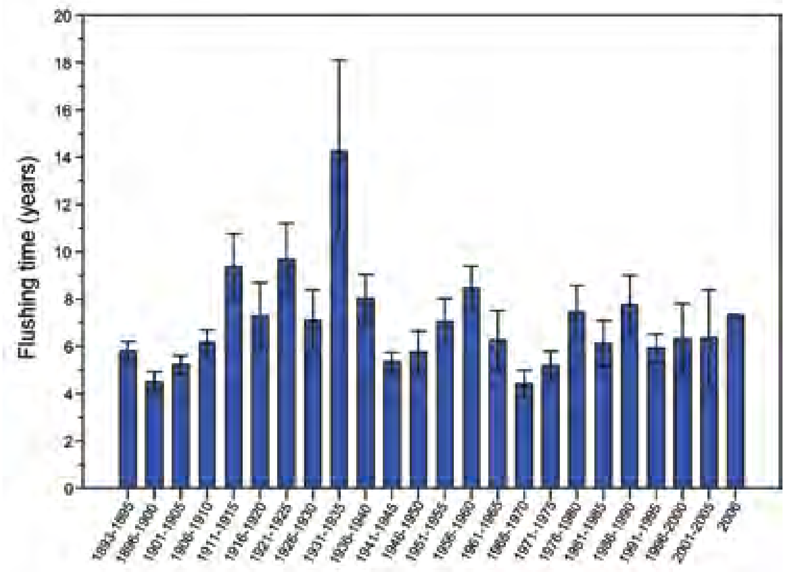

FIGURE 3.18. Estimated historical mean flushing times (in years) for Lake of the Woods from 1893-2006. Each bar represents the mean flushing time calculated at an annual scale for a five year period with standard error bars. Mean flushing times were estimated using area data provided by the Ministry of Natural Resources' Fisheries Assessment Unit. Outflow data for the Winnipeg River below Lake of the Woods monitoring station (Stn # 05PE020) was obtained from the Water Survey of Canada (http://www.wsc.ec,gc.ca.staflo/).

Flushing Time and Drainage Ratio

Flushing time is the amount of time it takes for a lake to completely replace its volume of water. This relatively simple parameter is very important limnologically as it moderates the flow and loss of nutrients in the lake, and regulates the response of the lake to environmental stressors. Estimated mean flushing times for LOW in its entirety have varied between 4 and 14 years, with an average of 7 years between 1893-2006 (Figure 3.18). These estimated flushing times are strongly influenced by hydrology, climate, and anthropogenic regulation and have shown some variation from 1893-2006 (Figures 3.18-3.19).

The drainage ratio (watershed area to lake area, WA:LA) of a lake can provide a rough indication of the influence of the export of chemical compounds (e.g., nutrients) to a lake relative to catchment area (Schindler, 1971; Hall & Smol, 1993; Forrest et al., 2002). The drainage ratio that combines the Central, Upper and Lower Rainy River watersheds and LOW

TABLE 3.5. Physical and morphometric characteristics of Lake of the Woods, including various Ontario sectors and Shoal Lake. Data are from Ontario Ministry of Natural Resources Fisheries Assessment Unit; Schupp and Macins (1977). Numbers are defined as follows:1 = northern/ Clearwater Bay; 2 = central; 3 = Whitefish Bay; 4 = Sabaskong Bay; 5,6 = southern region.

	Lake of the Woods		Sector						
Parameter	**Entire lake**	**Ontario portion**	**1**	**2**	**3**	**4**	**5**	**6**	**Shoal L.**
Lake area (ha)	385,000.0	222,280.0	29,450.0	40,300.0	20,600.0	18,240.0	71,690.0	42,000.0	25,900.0
Mean depth (m)	7.9	7.1	8.5	8.3	13.1	4.9	5.5	5.5	8.9
Maximum depth (m)	65.9	65.9	53.0	31.6	65.9	17.6	12.8	33.5	35.6
Depth ratio	-	-	0.2	0.3	0.2	0.3	0.4	0.2	0.3
Volume development ratio	-	-	0.5	0.8	0.6	0.8	1.3	0.5	0.8
Relative depth ratio (%)	-	-	2.74	1.40	4.07	1.15	0.42	1.45	1.96
Perimeter (km)	-	6,165	-	-	-	-	-	-	663.0
Island Shoreline (km)	-	3,938	-	-	-	-	-	-	-
Shoreline Development Factor	-	4.02	-	-	-	-	-	-	-
Watershed/lake area ratio	18.2	-	-	-	-	-	-	-	-
Catchment (ha)	7,003,000.0	-	-	-	-	-	-	-	-
Secchi depth (m) - July/August	-	2.03	2.8	2.3	5.0	1.1	1.3	1.4	3.6

[a] does not include Shoal Lake

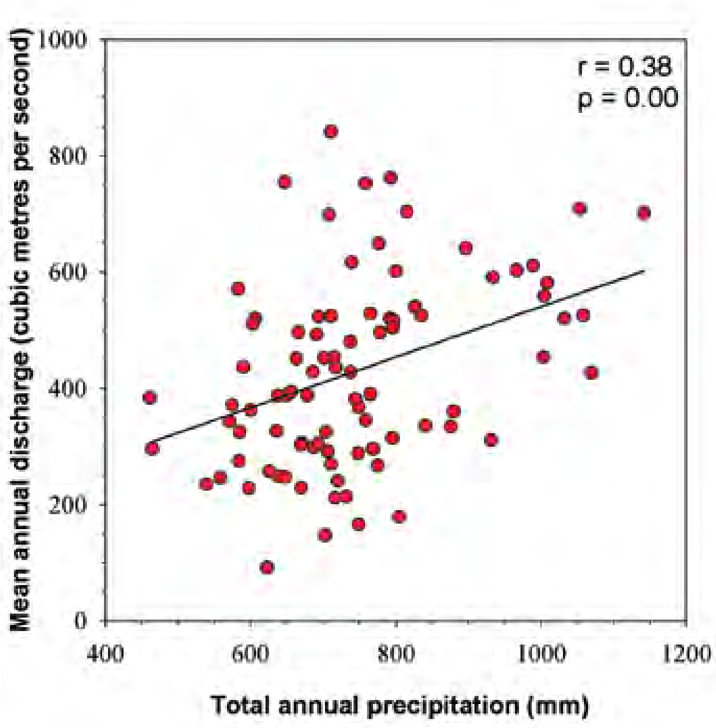

FIGURE 3.19. The relationship between total annual precipitation for Kenora, ON and mean annual discharge from Lake of the Woods (WSC # 05PE020) for the 1916-2004 interval.

TABLE 3.6. Physical and morphometric characteristics of the U.S. portion of Big Traverse Bay, Lake of the Woods. Data from the Minnesota Pollution Control Agency, 2008.

Parameter	Lake of the Woods Big Traverse Bay
Lake area (ha)	139,533.6
Maximum depth (m)	11.0 m
Littoral Area	32,072.6
Secchi depth (m) - June-Sept. 2006	1.2

watersheds is 18.1:1 (WA:LA of 69,750 km^2:3,850 km^2), but this is likely an overestimate, since both the central and upper Rainy River watersheds drain into Rainy and Namakan lakes before entering the Rainy River. A more relevant ratio may include only the Lower Rainy River and LOW watersheds, since these watersheds drain directly into the Rainy River and LOW. Including these two watersheds yields a ratio of 8.2:1 (WA:LA 31,624 km^2:3,850 km^2).

3.5 Stream geomorphology (including flood plain characteristics)

As mentioned previously (3.2 Geography), the LOW and Rainy River Basin is divided into two very distinct parts. The northern and eastern portion primarily consists of shallow soils – generally less than one foot in depth – overlaying Canadian Shield rock. The western portion, downstream of Fort Frances and International Falls lies 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. Generally northern/eastern streams are connected to well established, one to two year event floodplains and channels are 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 and/or land use activities including forest management practices, residential and recreational development and mining activities (MPCA, unpublished assessment data).

Many western portion streams show evidence of relatively recent (within the last 100 years) downcutting events. Streams have eroded (downcut) from their original floodplain. While there are limited data, field measurements indicate that many of these streams would require at a minimum a 50-year flood event for water to reach the original 1.5 year event floodplain. Many of the western streams have at least one and sometimes two terraces below the original floodplain. Most of the streams in the western portion of the basin appear to have reached Schumm's Stage V, Dynamic Equilibrium (Watson, 2002), but much more data is needed to confirm this observation (MPCA, unpublished assessment data). One study on the Little Fork River and one currently in progress comparing the Little Fork and Big Fork Watersheds, both by the MPCA, point

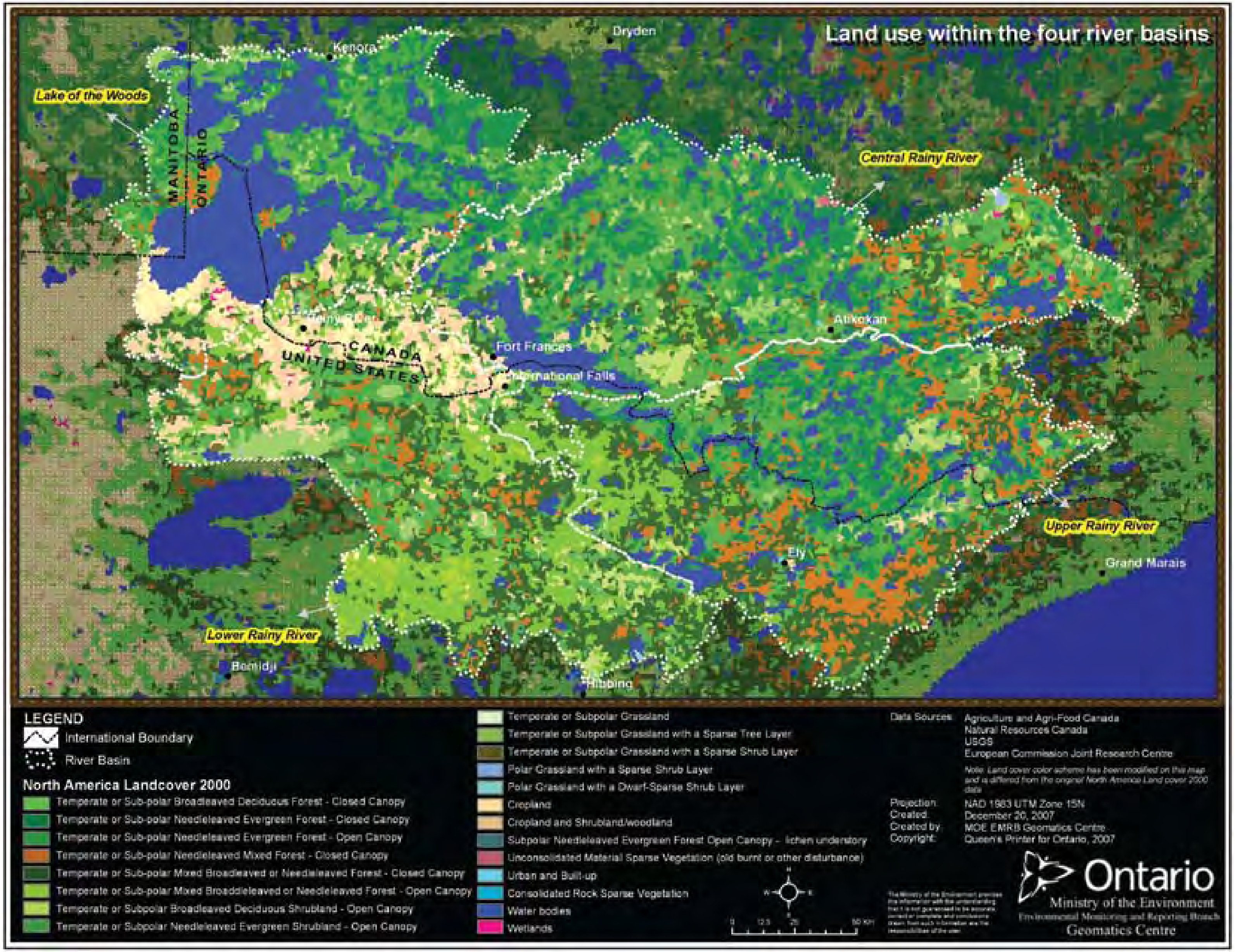

FIGURE 3.20. Land use characteristics for the four watersheds (Lake of the Woods watershed and the Upper, Central, and Lower Rainy River watersheds) within the Lake of the Woods and the Rainy River Basin. Data sources are from Agriculture and Agri-Food Canada, Natural Resources Canada, and USGS and are representative of the year 2000. Due to the low resolution of this map (1 km²), land use characteristics and estimates of their various proportions within the basin should be interpreted with caution.

to human activities causing the initial destabilization; these include clear cutting of the old growth forest, log drives, drainage projects and conversion of forest lands to agriculture (Anderson et al., 2006a; MPCA, unpublished assessment data).

Studies indicate that the Little Fork River, unlike most of the Rainy River Basin's western streams, remains very unstable with bank erosion contributing to high turbidity in the Little Fork and sediment loading to the Rainy River. In 2006 the Little Fork River was added to Minnesota's Impaired Waters List for turbidity. A Total Maximum Daily Load (TMDL) process to address the impairment is scheduled to begin in 2012.

There are several studies underway in the LOW and Rainy River Basin that will provide much needed geomorphic information in the next few years; most notably the development of a hydrologic model for the Rainy River and the Little Fork/ Big Fork Paired Watershed Study.

Potential stressors to the stability of western portion streams include climate change, development and forest management practices (Anderson et al., 2006a; St. George, 2006).

3.6 Jurisdictional and agency responsibilities

The responsibility for regulation and management of the LOW and Rainy River Basin resources are the responsibilities of a number of federal, state/provincial, and municipal agencies involved in research and resource management for the LOW and Rainy River Basin. The jurisdictions of each of these agencies are outlined in Table 3.7.

3.7 Land Use

Based on data from 2000, the LOW and Rainy River Basin is predominantly tree-covered (~59%; Table 3.8). Historic and present land uses in this region include agriculture and cropland, urbanization and development, and timber harvesting. Figure 3.20 and Table 3.8 list the relative proportions of the major land use classes for the four watersheds. Due to the low resolution of this map (1 km^2), land use characteristics and estimates of their various proportions within the basin should be interpreted with caution. As noted above, all are predominantly forested, although the LOW watershed contains a large area of open water (~ 34% or 5,093 km^2). Although human populations are concentrated in a few city centres (such as Kenora, Fort Frances, International Falls, Atikokan, Ely, Baudette, Warroad, Roseau), these developments do not occupy large areas of land.

A total of 3,827 km^2 (5.5% of total) of land in the LOW and Rainy River Basin is used for agriculture (noted in Figure 3.20 as Cropland or Cropland and Shrubland/ woodland). The Lower Rainy River and the LOW watersheds contain the highest proportion of cropland (2,316 and 1,085 km^2, respectively). 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). However, specific statistics for each are not available. Agricultural activities can influence water quality and quantity, through runoff 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.

Compared to the other watersheds, the LOW watershed contains the highest concentration of wetland area (15.9 km^2). Development has resulted in the drainage and alteration of some wetlands in this region. Wetlands perform significant functions which are important to both water quality and quantity, including temporal and spatial patterns in uptake, sequesterment and discharge of sediment and nutrients from runoff and groundwater, and serve as recharge areas for groundwater sources.

Forestry activities occur within each of the four watersheds and the majority of disturbed forest (noted in Figure 3.20 as "unconsolidated material sparse vegetation")

TABLE 3.7. Jurisdictional and agency responsibilities/involvement in water quality and quantity, fisheries, and aquatic invasive species in the Minnesota, Ontario, and Manitoba portions of Lake of the Woods and the Rainy River Basin.

Water Quality	Water Quantity	Fisheries & Aquatic Invasive Species
U.S. - Minnesota		
Federal Voyageurs National Park (VNP; National Park Service, U.S. Department of the Interior) Environmental Protection Agency (EPA)	Federal United States Army Corps of Engineers (USACE) United States Geological Survey (USGS) Federal Energy Regulatory Commission (FERC)	Federal United States Fish & Wildlife Service (U.S. Department of the Interior
State Minnesota Pollution Control Agency (MPCA) MDNR	State MDNR	State Minnesota Department of Natural Resources (MDNR)
Local Soil & Water Conservation Districts (SWCD) in Koochiching, Lake of the Woods and Roseau Countys Lake of the Woods County Koochiching County Rainy River First Nations - Rainy River Watershed Program Roseau County Lake of the Woods Land and County Courthouse City of International Falls	Local	Local
Canada - Ontario & Manitoba		
Federal Environment Canada	Federal (Canadian) Lake of the Woods Control Board (LWCB)	Federal Department of Fisheries & Oceans Canada (DFO)
Provincial Ontario Ministry of the Environment (MOE) Manitoba Water Stewardship	Provincial	Provincial Ontario Ministry of Natural Resources (MNR)
Local City of Winnipeg City of Kenora Town of Fort Frances	Local	Local
International (Minnesota, Ontario, & Manitoba)		
Federal International Rainy River Water Pollution Board (IRRWPB)	Federal International Rainy Lake Board of Control (IRLBC)	Federal

TABLE 3.8. Land use characteristics for the four watersheds within the Lake of the Woods and the Rainy River Basin at a resolution of 1 km^2 (Lake of the Woods, Upper Rainy River, Lower Rainy River, and Central Rainy River watersheds). Data sources are from Agriculture and Agri-Food Canada, Natural Resources Canada, and USGS and are representative of the year 2000. Due to the low resolution of this map (1 km^2), land use characteristics and estimates of their various proportions within the basin should be interpreted with caution.

Land Use Characteristic	Lake of the Woods watershed		Lower Rainy River watershed		Central Rainy River watershed		Upper Rainy River watershed		Entire Basin	
	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2
Vegetation (including Deciduous, Coniferous, Grassland, etc.)	58.6%	8770	84.5%	14044	84.9%	16623	88.8%	16221	80.1%	55656
Water bodies	34.0%	5093	1.5%	250	12.9%	2527	10.8%	1969	14.2%	9841
Cropland and Shrubland/Woodland	7.2%	1085	13.9%	2316	1.8%	360	0.4%	66	5.5%	3827
Burnt or sparse vegetation	0.0%	2	0.0%	0	0.2%	48	0.1%	14	0.1%	63
Wetlands	0.1%	16	0.1%	11	0.1%	14	0.0%	0	0.1%	41
Urban and Built-up Areas	0.0%	0	0.0%	1	0.0%	10	0.0%	4	0.0%	15
Consolidated Rock Sparse Vegetation	0.0%	3	0.0%	2	0.0%	0	0.0%	0	0.0%	6

is located in the Central Rainy River watershed (47.6 km^2). Forest fires, timber harvesting, and other 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. In fact, sediment yields from some drainage basins in other regions of the continent have increased three- to tenfold following deforestation (Dearing & Foster, 1993). Reforestation, however, results in a slow return to the vegetated state in most instances.

In 2008, the U.S. portion of Lake of the Woods was listed as an Impaired Water for excess phosphorus and chlorophyll-a.

Various water quality monitoring programs by federal, provincial and state agencies have focused on LOW, the Rainy River, and its tributaries since the mid-1950s (Tables 4.1 - 4.3). The most extensive and currently active stations (noted by asterisks in Tables 4.1 - 4.2, Figure 4.1, Table 4.4-4.5) have been monitored by the MPCA since the early 1950s and the Lake of the Woods Fisheries Assessment Unit (FAU) of the OMNR in Kenora, ON, since 1984.

The MPCA has been involved in several short and long-term monitoring programs in Rainy River, its tributaries, and the southern portion of LOW (i.e., Big Traverse Bay; Table 4.1). These water quality data are available on the Environmental Protection Agency's STORET database (http://www.epa.gov/storet/dw_home.html) and the MPCA's Environmental Data Access (EDA) website (http://www.pca.state.mn.us/data/edaWater/index.cfm). Although the Minnesota Department of Natural Resources (MDNR) has monitored end-of-summer water quality at these sites in LOW since 1991, the data collected were not extensive, and in 1998 they partnered with the MPCA and the Lake of the Woods Soil and Water Conservation District (SWCD) to expand the sampling effort (Anderson et al., 2006b). Four sites were monitored during this collaboration: Four Mile Bay/Rainy River, Big Traverse Bay, Muskeg Bay, and Long Point (Figure 4.1, Table 4.5). Water quality data from these sites are considered in this report for the U.S. portion of LOW. Three reports have been produced as a result of this monitoring effort: Anderson et al., (2000 and 2006b) and Heiskary (2007). Data from these reports focused specifically on phosphorus, chlorophyll-a, and Secchi transparency measurements and were used by the MPCA as evidence for a formal assessment of the southern (U.S.) portion of LOW. This assessment determined that LOW exceeded the ecoregion expectations for all three parameters. The MPCA recommended in its Impaired Waters Report (303[d]) to the U.S. Congress that the U.S. portion of LOW be listed for nutrient over-enrichment. In June of 2008, the U.S. Environmental Protection Agency approved the MPCA's Report and LOW was officially placed on the Impaired Waters List. A Total Maximum Daily Load (TMDL) study, which will define the maximum amount of all point and non-point sources of phosphorus that LOW can receive without exceeding water quality standards, will commence in 2010[4]. In addition, Minnesota runs a volunteer-based monitoring program called the Citizen Lake Monitoring Program (CLMP), which has been in place since 1972. This program combines water quality data collected on lakes by volunteer citizens (mainly Secchi disk readings once per week throughout the summer) with the scientific resources of the MPCA. This program increases the MPCA's water-quality sampling data while educating volunteers about water quality and pollution in their lakes.

The Fisheries Assessment Unit (FAU) of the Ontario Ministry of Natural Resources (OMNR) in Kenora, Ontario, in conjunction with the Ontario Ministry of the Environment (OMOE), began monitoring water quality in the Ontario waters of LOW in 1984 as part of the FAU Core Data Program (Mosindy, 1987). Since 1984, water quality data have been collected at sites within three discrete sectors (north/central, east, and Clearwater/Echo bays) monthly from May to November on a rotating schedule of two consecutive years for five years (i.e., each sector is returned to every six years; Table 4.2). Located within the North Sector, Clearwater Bay contains four sampling stations (Clearwater Bay East, Deception Bay, Clearwater Bay West in Clearwater Bay proper, and Echo Bay)

[4] Subsection 303(d) of the EPA's United States Federal Clean Water Act states that each U.S. State is required to estimate for certain waters "the total maximum daily thermal load required to assure protection and propagation of a balanced, indigenous population of shellfish, fish and wildlife. Such estimates shall take into account the normal water temperatures, flow rates, seasonal variations, existing sources of heat input, and the dissipative capacity of the identified waters or parts thereof. Such estimates shall include a calculation of the maximum heat input that can be made into each such part and shall include a margin of safety which takes into account any lack of knowledge concerning the development of thermal water quality criteria for such protection and propogation in the identified waters or parts thereof." Excerpt from Section 303(d) of the U.S. Federal Clean Water Act at http://www.epa.gov/region5/water/pdf/ecwa_t3.pdf, August 27, 2007.

TABLE 4.1. List of water quality monitoring stations in Lake of the Woods and the Rainy River Basin that are under the jurisdiction of Minnesota agencies [Minnesota Department of Natural Resources (MNDNR), Minnesota Pollution Control Agency (MPCA), United States Environmental Protection Agency (USEPA), and United States Geological Survey (USGS)]. Asterisks denote long-term monitoring sites.

Agency	Station ID	Station Name	Station Type	First Sampling Year	Latest Sampling Year	Latitude (°)	Longitude (°)	Summary of monitoring data
MNDNR	34	RAINY RIVER NEAR BAUDETTE	stream	1964	1969	48°43′20″	94°35′21″	no data
MNDNR	50	RAINY RIVER KOOCHICHING COUNTY	stream	1964	1964	48°34′60″	93°27′00″	no data
MNDNR	53	LOW	lake	1972	1972	48°58′00″	95°01′60″	no data
MPCA	* 39-0002-01	LAKE: LAKE OF THE WOODS (WHOLE LK) AT WARROAD	lake	1993	2006	49°04′60″	95°00′02″	water quality, nutrients, algae, turbidity, sediments
MPCA	* 39-0002-02	LAKE: LAKE OF THE WOODS (4 MI BAY) AT WHEELERS PT	lake	1993	2006	48°51′27″	94°42′53″	water quality, nutrients, algae, turbidity, sediments
MPCA	* S000-007	RAINY R INTERNATIONAL BR AT INTERNATIONAL FALLS	stream	1953	2006	48°36′26″	93°24′07″	water quality, turbidity, DO
MPCA	S000-029	RAINY R 200 FT S OF I'FALLS GOLF CLUB HOUSE	stream	1953	1963	48°34′34″	93°27′43″	water quality
MPCA	* S000-063	RAINY RIVER AT INTERNATIONAL BRIDGE AT BAUDETTE	stream	1958	2006	48°43′08″	94°35′24″	water quality
MPCA	* S000-069	WINTER ROAD RIVER MN-11 BRIDG 4 MI W OF BAUDETTE	stream	1958	2006	48°42′39″	94°41′53″	water quality, ambient trace metals
MPCA	S000-103	RAINY RIVER 4 MI E OF PELLAND	stream	1964	1971	48°34′34″	93°27′43″	water quality
MPCA	S000-109	LAKE OF THE WOODS - BOAT SAMPLE	lake	1967	1968	48°57′42″	95°04′34″	water quality
MPCA	* S000-173	BIG FORK RIVER BRIDGE ON MN-11, 4 MI E OF LOMAN	stream	1971	2006	48°30′46″	93°42′38″	water quality, Hg, ambient trace metals
MPCA	* S000-179	LITTLE FORK R MN-11 BRIDGE, 0.5 MI W OF PELLAND LF-0.5	stream	1971	2006	48°31′17″	93°35′12″	water quality, Hg, ambient trace metals, turbidity
MPCA	S000-182	RAINY R AT ACCESS OFF SHOREWOOD DR W OF I'FALLS	stream	1971	2003	48°35′33″	93°26′45″	water quality, Hg, ambient trace metals
MPCA	* S000-184	RAPID RIVER AT BRIDGE ON MN-11 AT CLEMENTSON	stream	1971	2006	48°41′28″	94°25′60″	water quality, Hg, ambient trace metals
MPCA	S000-280	RAINY R AT RR BR AT RAINY LAKE OUTLET IN RANIER	stream	1974	1998	48°36′54″	93°21′12″	water quality
MPCA	S000-335	MOONLIGHT ROCK CK ABOVE S I'FALLS WWTP DSCH DIT	stream	1974	1980	48°35′47″	93°21′51″	water quality
MPCA	S000-336	RAINY R S31 BTN NWQ/NEQ 11 MI NW OF LITTLE FORK	stream	1974	1974	48°31′02″	93°43′59″	water quality
MPCA	S000-337	RAINY R NW OF INTERNATIONAL FALLS HOSPITAL	stream	1974	1974	48°35′42″	93°26′01″	water quality
MPCA	S000-338	RAINY R BTN ISLANDS AND DAM N OF I'FALLS	stream	1974	1974	48°36′24″	93°24′41″	water quality
MPCA	S000-714	MOONLIGHT ROCK CK AT CSAH-11 1 MI SW OF RANIER	stream	1980	1980	48°36′06″	93°22′24″	water quality
MPCA	S000-715	MOONLIGHT ROCK CK BELOW S I'FALLS WWTP DSCH DIT	stream	1980	1980	48°35′47″	93°21′60″	water quality
MPCA	S000-716	RAINY R IN T71N/R24W/S35/NWQ/NEQ W OF I'FALLS	stream	1980	1980	48°36′15″	93°23′18″	water quality
MPCA	S000-717	RAINY R N OF N/S RR TRACKS IN S35 W OF I'FALLS	stream	1980	1980	48°36′18″	93°22′47″	water quality
MPCA	S000-718	RAINY R IN S25SWQSWQ BTN FORT FRANCIS & JAMESON	stream	1980	2003	48°36′22″	93°22′05″	water quality, Hg, ambient trace metals
MPCA	S000-794	WILLIAMS CK/CD1 AT CSAH-8 6 MI NE OF WILLIAMS	stream	1981	1984	48°50′40″	94°52′46″	water quality
MPCA	S000795	WILLIAMS CK AT CR-61 1 MI NE OF WILLIAMS	stream	1981	2006	48°46′57″	94°56′53″	water quality, sediments, turbidity, DO, nutrients, watershed monitoring
MPCA	S000-796	WILLIAMS C ABV WILLIAMS WWTP IN SEQ OF SWQ OF S7	stream	1981	1981	48°50′12″	94°41′57″	water quality
MPCA	S000-797	WILLIAMS CK AT CSAH-13 AT WILLIAMS	stream	1981	1984	48°45′51″	94°57′31″	water quality
MPCA	S000-906	WILLIAMS CK/CD1 CSAH - 125.5 MI NE OF WILLIAMS	stream	1982	2005	48°49′48″	94°52′19″	water quality, turbidity, DO
MPCA	* S000-907	WILLIAMS CK/CD1 - NW CORNER OF S4 NE OF WILLIAMS	stream	1982	2006	48°48′02″	94°54′52″	water quality, turbidity, DO
MPCA	S000-908	WILLIAMS CK-N HLF OF S7 BY PRIV DR N OF WILLIAMS	stream	1982	1982	48°46′18″	94°57′24″	water quality
MPCA	S000-946	BAUDETTE RIVER DOWNSTREAM OF MN-11 AT BAUDETTE	stream	1983	2003	48°42′46″	94°35′48″	Hg, ambient trace metals, water quality
MPCA	S000-992	WILLIAMS CK/CD 1-NW CORNER OF S2 NE OF WILLIAMS	stream	1984	1984	48°47′17″	94°56′14″	water quality
MPCA	* S001-150	BEAR R. AT CSAH-1, 4 MI E OF LINDFORD BRR-8.7	stream	1987	2006	48°24′14″	93°41′22″	water quality, turbidity
MPCA	S001-218	RAINY R 1000 FT UPST OF CONF WITH L FORK R	stream	1995	1998	48°31′35″	93°34′60″	water quality
MPCA	S001-369	RAINY RIVER IN INTERNATIONAL FALLS, MN	stream	1999	1999	48°36′12″	93°25′12″	transparency
MPCA	S001-960	RAINY R, DOCK AT END OF ANCHOR BAY ROAD, 3 MI NW OF BAUDETTE	stream	2000	2003	48°44′31″	94°38′46″	water quality, Hg, ambient trance metals, turbidity, DO
MPCA	S001-961	RAINY R DOCK AT PUBLIC ACCESS OF MN-172 IN WHEELER'S PT	stream	2000	2003	48°32′34″	93°28′60″	water quality
MPCA	S001-962	BLACK R, 0.1 MI N OF MN-11 BR AT CAMPGROUND, JUST E OF LOMAN	stream	2000	2003	48°30′52″	93°47′60″	water quality, Hg, ambient trace metals
MPCA	S001-964	RAINY R BY CR-85 BELOW RAPIDS 2 MI NE OF BIRCHDALE	stream	1984	2003	48°38′33″	94°03′34″	Hg, ambient trace metals, water quality
MPCA	* S002-551	LITTLE FORK R AT MN-65, 1.75 MI SW OF SILVERDALE, MN	stream	2004	2006	47°58′34″	93°08′38″	water quality, turbidity, sediments
MPCA	S002-552	LITTLE FORK R AT MN-65 BR, 13.25 MI. SE OF LITTLEFORK, MN	stream	2004	2004	48°12′33″	93°29′48″	water quality, sediments, nutrients
MPCA	* S002-556	LITTLE FORK R. AT MN-217 AT LITTLE FORK, MN	stream	2004	2006	48°23′37″	93°33′43″	nutrients, turbidity, water quality, watershed loads
MPCA	* S002-855	BIG FORK R AT CR1 AT LINDFORD	stream	1994	2006	48°24′39″	93°47′04″	water quality
MPCA	* S002-856	BIG FORK AT STURGEON LNDG, 5 MI W OF BIG FALLS	stream	1994	2006	48°12′45″	93°52′58″	water quality, nutrients, algae, turbidity, sediments
MPCA	* S002-857	BIG FORK R AT GRUNWALD LNDG, 5.5 MI SE BIG FALLS	stream	1994	2006	48°08′08″	93°43′39″	water quality
MPCA	* S002-858	BIG FORK R. AT CR5, 5 MI NE OF EFFIE	stream	1994	2006	47°54′19″	93°36′43″	water quality
MPCA	S003-695	W BR ZIPPEL CK/CP1 INTERSEC. CSAH-2/CSAH-8 5.25 MI N WILLIAMS	stream	1974	1975	48°50′39″	94°57′35″	water quality, DO, turbidity
MPCA	S003-697	WILLIAMS CK AT CSAH - 2, 0.5 MI S OF WILLIAMS	stream	1973	2005	48°46′29″	94°57′09″	water quality, DO, turbidity
MPCA	S003-998	NETT LK R, .05 MI E OF CSAH 8, 13.5 MI S OF LITTLEFORK, MN	stream	2006	2006	48°12′60″	93°26′45″	turbidity, sediment, water quality
MPCA	S004-000	BIG FK R AT BIG FK AVE, .3 MI N OF BIG FALLS, MN	stream	2006	2006	48°11′45″	93°48′26″	water quality, sediments, turbidity, DO, nutrients, watershed monitoring
USEPA	2385	RAINY RIVER @ INTERNATIONAL FALLS	stream	1984	1984	48°36′30″	93°24′13″	organic compounds
USEPA	274501	LAKE OF THE WOODS	lake	1972	1972	49°11′15″	94°50′31″	water quality
USEPA	274502	LAKE OF THE WOODS	lake	1972	1972	48°53′45″	94°43′60″	water quality
USEPA	274503	LAKE OF THE WOODS	lake	1972	1972	48°55′15″	95°16′60″	water quality
USEPA	MINN25	RAINY RIVER AT INTERNATIONAL FALLS	stream	1975	1975	48°34′60″	93°25′60″	water quality
USGS	5129400	RAINY RIVER NR FORT FRANCES, ONTARIO	USGS	1970	1970	48°38′31″	93°19′60″	water quality
USGS	5131500	LITTLE FORK RIVER AT LITTLEFORK, MN	USGS	1962	1986	48°23′45″	93°32′58″	stream water quality, sediments
USGS	5131500	LITTLE FORK RIVER AT LITTLEFORK, MN	USGS	1962	1986	48°23′45″	93°32′58″	water quality
USGS	5132000	BIG FOR RIVER AT BIG FALLS, MN	USGS	1963	1977	48°11′45″	93°48′25″	water quality
USGS	5133500	RAINY RIVER AT MANITOU RAPIDS, MN	USGS	1968	1994	48°38′04″	93°54′48″	water quality
USGS	5134100	NORTH BRANCH RAPID RIVER NEAR BAUDETTE, MN	USGS	1972	1972	48°31′56″	94°38′50″	water quality
USGS	5134200	RAPID RIVER NEAR BAUDETTE, MN	USGS	1962	1980	48°32′10″	94°33′46″	water quality
USGS	5139500	WARROAD R. NEAR WARROAD, MN	USGS	1963	1980	48°52′01″	95°21′21″	water quality
USGS	5140000	BULLDOG RUN NEAR WARROAD, MN	USGS	1980	1980	48°51′30″	95°20′21″	water quality
USGS	5140500	EAST BRANCH WARROAD RIVER NEAR WARROAD, MN	USGS	1980	1980	48°51′30″	95°18′40″	water quality

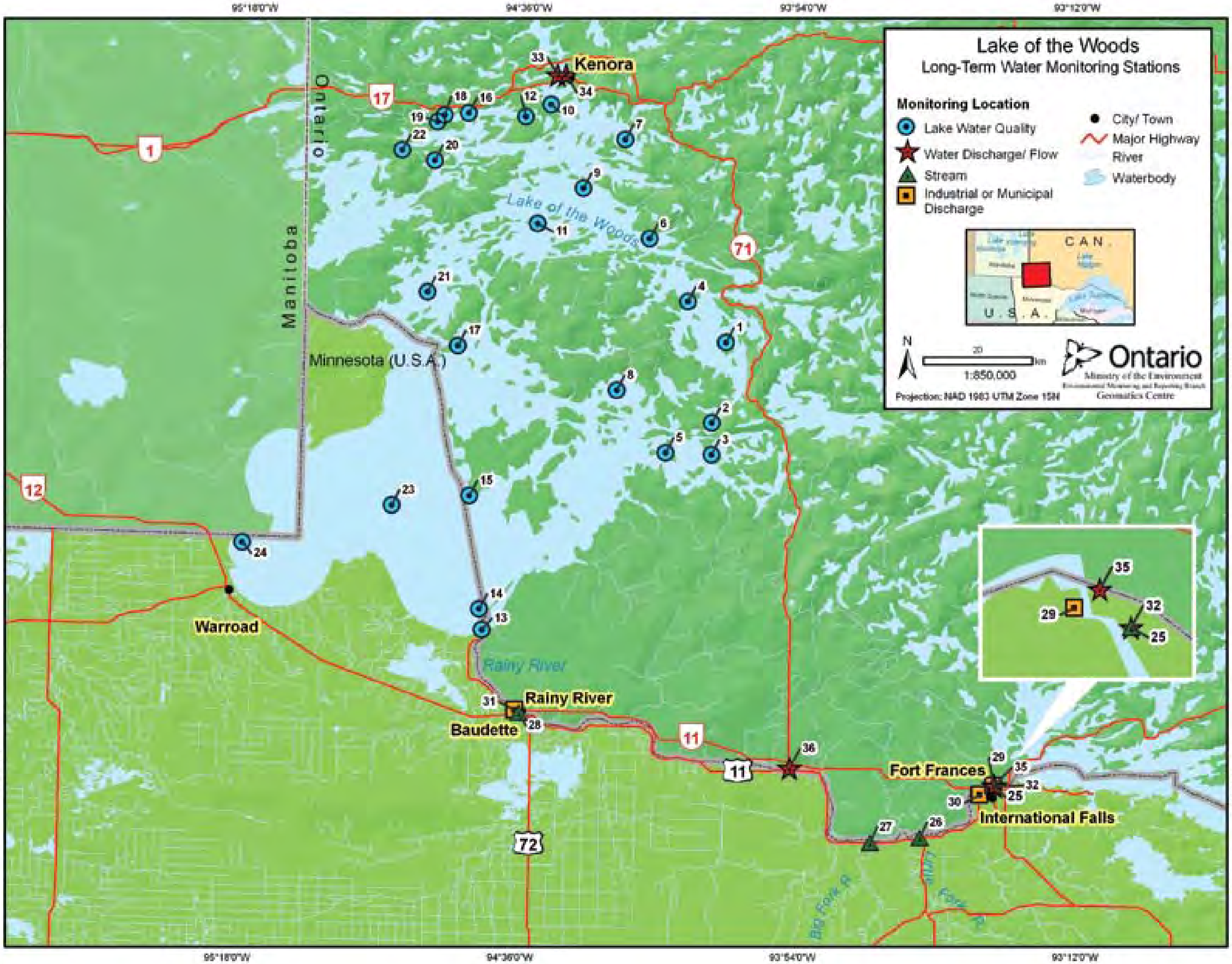

FIGURE 4.1. Map of Lake of the Woods and the Rainy River showing the locations of the various lake, stream, and point source discharge water quality monitoring locations used in this report. Corresponding site codes, symbols, names, and geographical locations are listed in Table 4.4.

TABLE 4.2. List of water quality monitoring stations in the Lake of the Woods and Rainy River Basin that are under the jurisdiction of Ontario agencies [Environment Canada (EC), Ministry of Natural Resources (OMNR), Ministry of the Environment (OMOE). Asterisks denote long-term monitoring stations.

Agency	Station ID	Sector (MNR)	Station Name	Station Type	First Sampling Year	Latest Sampling Year	Latitude (°)	Longitude (°)	Project	Summary of monitoring data
EC	* MA05PF0022		WINNIPEG RIVER AT POINT DuBOIS (ABOVE THE POWER STATION)	river	1972	2007	50°18'03"	95°33'21"		nutrients, major ions, total and dissolved metals, bacteria and various herbicides
EC	19000100102 A		WINNIPEG RIVER 1ST CPR BRIDGE WEST OF MAIN STREET	river	1968	1995				nutrients, major ions, total and dissolved metals
EC	19000100202 A		WINNIPEG RIVER NORTHWEST OF OLD FORT ISLAND	river	1968	1995				nutrients, major ions, total and dissolved metals
OMOE	19000103401		RAINY RIVER - HWY 11, NODEN CAUSEWAY, COUCHICHING	river	1975	1977	48°39'10"	93°18'13"	PWQM	nutrients, ions, metals, TSS, pH, alkalinity, conductivity, turbidity, bacteria
OMOE	19000103902		RAINY RIVER - UPSTREAM TOLL BRIDGE AT FORT FRANCIS	river	1990	1992	48°36'48"	93°21'49"	PWQM	nutrients, ions, metals, TSS, pH, alkalinity, conductivity, turbidity, bacteria
OMOE	19000100302		RAINY RIVER - DOWNSTRM EMO, S OF HWY 11	river	1968	1990	48°38'05"	93°54'53"	PWQM	nutrients, ions, metals, TSS, pH, alkalinity, conductivity, turbidity, bacteria
OMOE	19000100402		RAINY RIVER - TOLL BRIDGE, FORT FRANCES	river	1968	1990	48°36'20"	93°23'17"	PWQM	nutrients, ions, metals, TSS, pH, alkalinity, conductivity, turbidity, bacteria
OMOE	19000100902		RAINY RIVER - DOWNSTREAM CONFLUENCE WITH BAUDETTE RIVER	river	1969	1992	48°43'16"	94°35'33"	PWQM	nutrients, ions, metals, TSS, pH, alkalinity, conductivity, turbidity, bacteria
OMOE	19000101002		RAINY RIVER - UPSTREAM CONFLUENCE WITH BAUDETTE RIVER	river	1969	1990	48°42'58"	94°33'08"	PWQM	nutrients, ions, metals, TSS, pH, alkalinity, conductivity, turbidity, bacteria
OMOE	19000101102		RAINY RIVER - ABOVE EMO, W OF HWY 602, S OF HWY 11	river	1969	1992	48°37'30"	93°49'54"	PWQM	nutrients, ions, metals, TSS, pH, alkalinity, conductivity, turbidity, bacteria
OMOE	19000101202		RAINY RIVER - DOWNSTREAM FORT FRANCES, NORTH	river	1969	1992	48°32'38"	93°29'07"	PWQM	nutrients, ions, metals, TSS, pH, alkalinity, conductivity, turbidity, bacteria
OMOE	19000101302		RAINY RIVER - DOWNSTREAM FORT FRANCES, CENTRE	river	1969	1981	48°32'37"	93°29'07"	PWQM	nutrients, ions, metals, TSS, pH, alkalinity, conductivity, turbidity, bacteria
OMOE	19000101402		RAINY RIVER - DOWNSTREAM FORT FRANCES, SOUTH	river	1969	1981	48°32'36"	93°29'07"	PWQM	nutrients, ions, metals, TSS, pH, alkalinity, conductivity, turbidity, bacteria
OMNR	* 99WOODS0027	North/Central	RAT PORTAGE	lake	1985	2006	49°43'23"	94°32'21"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR	* 99WOODS0028	North/Central	BIGSTONE	lake	1985	2006	49°40'03"	94°20'54"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR	* 99WOODS0029	North/Central	EAST ALLIE	lake	1985	2006	49°35'10"	94°27'09"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR	* 99WOODS0030	North/Central	YELLOW GIRL	lake	1985	2006	49°30'17"	94°16'56"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR	* 99WOODS0031	North/Central	DONALD DUCK	lake	1985	2006	49°31'35"	94°34'02"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR	* 99WOODS0032	East	INDEX ISLAND	lake	1986	2006	49°24'08"	94°11'00"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR	* 99WOODS0033	East	HIGHROCK ISLAND	lake	1986	2006	49°20'07"	94°05'07"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR	* 99WOODS0034	East	TURTLE BAY	lake	1986	2006	49°12'08"	94°07'04"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR	* 99WOODS0035	East	HAY ISLAND	lake	1986	2006	49°09'00"	94°07'04"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR	* 99WOODS0036	East	BUFF ISLAND	lake	1986	2006	49°09'07"	94°14'00"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR			MONKEY ROCKS REEF 1	lake	1988	1990	49°24'35"	94°50'33"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR			MICA PT 2	lake	1988	1990	49°19'19"	94°45'45"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR			BASIL PT 3	lake	1988	1990	49°04'31"	94°43'29"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR			HORSESHOE ISLAND 4	lake	1988	1990	49°14'14"	94°21'33"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR/OMOE	99WOODS0001		THOMPSON ISLAND N	lake	2003	2003	49°41'22"	94°29'13"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR/OMOE	99WOODS0002		PORTAGE BAY	lake	2003	2003	49°43'13"	94°32'12"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR/OMOE	* 99WOODS0003	Clearwater/Echo Bays	WHITE PARTRIDGE BAY	lake	2003	2006	49°14'25"	94°36'07"	FAU Monitoring Study/DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR/OMOE	* 99WOODS0004	Clearwater/Echo Bays	CLEARWATER BAY WEST	lake	1984	2006	49°41'17"	94°49'25"	FAU Monitoring Study/DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR	*	Clearwater/Echo Bays	CLEARWATER BAY EAST	lake	1984	2006	49°42'23"	94°44'52"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR/OMOE	* 99WOODS0005	Clearwater/Echo Bays	ECHO BAY	lake	1984	2006	49°38'16"	94°54'30"	FAU Monitoring Study/DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR/OMOE	* 99WOODS0006	Clearwater/Echo Bays	CUL DE SAC	lake	2003	2006	49°37'22"	94°49'29"	FAU Monitoring Study/DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMNR	*	Clearwater/Echo Bays	DECEPTION BAY	lake	1984	2006	49°42'08"	94°48'36"	FAU Monitoring Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0007		PTARMIGAN BAY	lake	2003	2003	49°38'31"	94°42'15"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0008		CHISHOLM ISLAND	lake	2003	2003	49°31'44"	94°23'16"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0009		KENNEDY ISLAND	lake	2003	2003	49°30'06"	94°35'58"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0010		BISHOP BAY	lake	2003	2003	49°28'00"	94°47'10"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0011		MONKEY ROCKS REEF 1	lake	2003	2003	49°23'40"	94°46'59"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0012		LONG BAY	lake	2003	2003	49°26'19"	94°02'45"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0013		REGINA BAY	lake	2003	2003	49°24'34"	94°02'00"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0014		WHITEFISH BAY TURTLE POINT	lake	2003	2003	49°21'20"	94°04'28"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0015		WHITEFISH BAY SOUTH	lake	2003	2003	49°12'31"	94°07'26"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0016		TURTLE LAKE	lake	2003	2003	49°11'19"	94°07'08"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0017		SABASKONG BAY	lake	2003	2003	49°09'13"	94°10'30"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0018		LITTLE TRAVERSE	lake	2003	2003	49°15'00"	94°40'18"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0019		BIGSBY ISLAND	lake	2003	2003	49°05'16"	94°25'00"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	99WOODS0020		BIG TRAVERSE BAY	lake	2003	2003	48°59'31"	94°41'07"	DESC Paleolimnology Study	nutrients, ions, metals, pH, alkalinity, conductivity
OMOE	LOW 1		TOWN ISLAND		1989	1989	49°41'47"	94°29'00"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 10		SABASKONG BAY		1989	1989	49°09'11"	94°23'15"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 11		BURNT ISLAND		1989	1989	49°04'33"	94°25'00"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 12		BIGSBY ISLAND		1989	1989	49°06'01"	94°29'36"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 13		ELM ISLAND		1989	1989	49°00'20"	94°28'00"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 14		DEEP BAY		1989	1989	49°02'21"	94°36'52"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 15		BASIL POINT		1989	1989	49°05'22"	94°36'45"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 16		BASIL CHANNEL		1989	1989	49°06'25"	94°36'38"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 17		SUGAR POINT		1989	1989	49°07'24"	94°45'00"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 18		BUFFALO BAY NORTH		1989	1989	49°10'20"	95°09'30"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 19		BUFFALO BAY SOUTH		1989	1989	49°01'10"	95°13'07"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 2		ALLENS REEF		1989	1989	49°38'13"	94°29'08"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 20		LITTLE TRAVERSE BAY		1989	1989	49°17'15"	94°40'30"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 20		LITTLE TRAVERSE BAY		1989	1989	49°17'15"	94°40'30"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 21		BISHOP BAY		1989	1989	49°24'33"	94°52'00"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 22		SHOAL LAKE PINE ISLAND		1989	1989	49°31'07"	94°57'38"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 23		SHOAL LAKE MACKEY ISLAND		1989	1989	49°29'21"	95°04'53"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 24		SHOAL LAKE TWIN ISLAND		1989	1989	49°29'21"	95°04'53"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 25		LAKE INDIAN BAY		1989	1989	49°36'45"	95°11'38"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 3		ANDREW BAY		1989	1989	49°36'45"	94°21'00"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 4		CLINTISS ISLAND		1989	1989	49°31'14"	94°32'53"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 5		CLIFF ISLAND		1989	1989	49°30'49"	94°25'15"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 6		YELLOW GIRL BAY		1989	1989	49°30'24"	94°15'30"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 7		WHITEFISH BAY NORTH		1989	1989	49°25'15"	94°09'37"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 8		WHITEFISH BAY SOUTH		1989	1989	49°12'16"	94°07'45"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
OMOE	LOW 9		SABISKONG BAY EAST		1989	1989	49°09'55"	94°11'15"	Hutchinson Clark Satellite	nutrients, ions, pH, alkalinity, conductivity
EC			Pulp and Paper Mill - Abitibi-Consolidated (Kenora)						EEM	
EC			Pulp and Paper Mill - Abitibi-Consolidated (Fort Frances)						EEM	

TABLE 4.3. List of sampling locations and years for various sites on Lake of the Woods that are monitored as part of the Ontario Ministry of the Environment's Lake Partner Program.

Site ID	Station Name	First Sampling Year	Latest Sampling Year	Latitude (º)	Longitude (º)
1	Whitefish Bay-Camp Bay	2004	2006	49º15′11″	94º02′24″
2	Andrew Bay-Riches Bay	2002	2006	49º35′30″	94º21′50″
3	Ash Bay	2004	2004	49º37′25″	94º45′26″
4	Bay nr Longbow L outlet	2002	2006	49º41′20″	94º21′10″
5	Bigstone Bay-Eagle Pass	2002	2006	49º38′23″	94º19′15″
8	Clearwater Bay-Kendall Inlet	2002	2006	49º42′50″	94º39′30″
9	Clearwater Bay-Is Bay	2002	2006	49º41′00″	94º45′00″
10	Clearwater B-Kendal Inlet	2003	2006	49º43′10″	94º39′25″
12	Clearwater B-Mud Portage B	2002	2006	49º40′45″	94º50′10″
15	Clearwater B-Deception B	2004	2006	49º42′19″	94º48′19″
17	Echo Bay-W Webcoa Rd	2004	2006	49º38′36″	94º55′05″
20	Echo Bay	2002	2003	49º39′05″	94º53′38″
21	Echo Bay - SE End	2002	2006	49º39′00″	94º51′30″
23	French Narrows	2002	2006	49º35′55″	94º26′00″
24	French Narrows-off E Allie	2002	2006	49º35′20″	94º26′30″
28	Lobstick Bay	2002	2005	49º25′00″	93º57′43″
29	Long Bay, Sioux Narrows	2002	2006	49º27′00″	94º05′10″
31	Middle Island-SW Bay	2002	2006	49º39′36″	94º27′05″
32	Ptarmigan Bay	2003	2006	49º38′38″	94º43′33″
33	Poplar Bay	2002	2006	49º41′28″	94º33′19″
34	E off Dawson Is.	2004	2006	49º07′21″	94º29′55″
36	Ptarmigan B-W Corkscrew Is	2002	2006	49º39′11″	94º43′15″
38	S/W of Corkscrew Chan	2002	2002	49º39′00″	94º43′00″
39	S/W of Coney Is	2002	2006	49º44′40″	94º31′40″
40	Matheson Bay #2	2002	2002	49º43′33″	94º27′29″
41	S of Coney Island.	2002	2002	49º44′55″	94º30′49″
43	Rush Bay	2002	2004	49º39′56″	94º54′00″
44	Rush Bay - Brown's Is	2002	2005	49º39′40″	94º54′55″
47	Heritage Pk- Little Grassy	2003	2006	49º00′20″	94º27′30″
48	Scotty Is.-Nanton Is.	2002	2006	49º41′00″	94º27′00″
49	Second Chan-Lily Pad B	2002	2006	49º42′34″	94º31′49″
50	Long Bay, Sioux Narrows	2002	2006	49º26′40″	94º03′20″
51	Bishop B,Toadstool/Royal I	2002	2006	49º28′40″	94º44′07″
53	Whitefish Bay-Sioux Nar	2002	2006	49º24′11″	94º07′11″
54	Whitefish Bay -W Bell Is	2004	2006	49º20′00″	94º12′15″
57	Pine Portage Bay, N end	2004	2004	49º43′31″	94º21′56″
60	S Morson, Frenchmans Rk.	2002	2006	49º01′00″	94º25′00″
65	N of Mineral Is.	2004	2006	49º02′40″	94º29′25″
66	Obabikon Bay	2004	2006	49º13′29″	94º16′38″
68	Woodchuck Bay	2002	2002	49º41′18″	94º51′32″
71	Poplar Bay	2003	2006	49º41′26″	94º32′23″
73	Oliver Is- SW Allie Is.	2002	2005	49º35′00″	94º30′00″
74	Sabaskong B-Nestor Fall	2003	2003	49º07′07″	93º56′14″
75	Andrew Bay-Queer Is	2002	2006	49º37′11″	94º25′52″
76	Bulman Is W.	2006	2006	49º43′47″	94º33′25″
78	Bulman Bay	2002	2006	49º43′17″	94º33′14″
82	Monkey Rocks Reef	2002	2002	49º24′05″	94º47′46″
83	Clearwater Bay E.	2002	2002	49º42′25″	94º40′40″
84	Mica Point, Kenora	2002	2002	49º19′39″	95º45′46″
85	Clearwater Bay W	2002	2002	49º41′27″	94º49′15″
86	Echo Bay W	2002	2002	49º38′45″	94º54′39″
87	Deception Bay centre	2002	2002	49º42′26″	94º48′01″
88	Horseshoe Island	2002	2002	49º50′15″	94º21′15″
90	Abbott Is.W	2006	2006	49º43′58″	94º33′27″
93	White Partridge Bay	2005	2006	49º42′00″	94º36′50″
95	Snake Bay-Sioux Narrows	2003	2005	49º22′27″	94º02′24″
96	Whitefish Bay-Snake Bay	2003	2005	49º22′07″	94º04′34″
98	Gourlay Is.N	2006	2006	49º44′15″	94º32′46″
99	Welcome Channel	2003	2003	49º40′22″	94º32′42″
100	N/W Angle In, W Clipper Is.	2003	2004	49º24′00″	94º54′19″
101	Route Bay	2002	2006	49º40′14″	94º18′10″
103	Storm Bay	2006	2006	49º40′51″	94º18′57″
104	EB4	2003	2003	49º42′29″	94º25′33″
105	#35	2003	2003	49º42′37″	94º25′33″
106	CS5	2003	2003	49º42′46″	94º25′22″
107	CB3	2003	2003	49º42′43″	94º25′31″
108	#23	2003	2003	49º42′38″	94º25′24″
109	#39	2003	2003	49º42′41″	94º25′26″
110	Bigsby Is. Black Pt.	2004	2006	49º00′34″	94º33′43″
111	Big Traverse-W Basil Chan.	2004	2004	49º07′26″	94º34′50″
112	Bigsby Is. Deep Bay	2004	2006	49º02′15″	94º36′15″
113	Little Traverse-Sandy Bay	2004	2004	49º17′26″	94º33′52″
114	L.Traverse-W Fadden's Is	2004	2004	49º13′14″	94º32′32″
115	Sabaskong Bay-Brule Pt	2006	2006	49º07′40″	94º20′25″
116	Crow Rock Is & Shamis Is	2004	2006	49º36′25″	94º33′57″
117	Sabaskong Bay-Nr Morson	2004	2006	49º08′21″	94º17′20″
118	N/E off Pentney Is.	2004	2004	49º05′03″	94º28′52″
120	S/E Dawson Is.	2004	2004	49º06′15″	94º31′25″
126	Nestor Falls	2006	2006	49º07′10″	93º55′53″
127	Bald Indian Bay-N end	2004	2004	49º43′05″	94º24′27″
129	Matheson Bay-E Town Is	2004	2005	49º42′15″	94º27′07″

that have been monitored since 1984; in 2003, Cul de Sac and White Partridge Bay sampling stations were added to the series (Table 4.2). The purpose of this program was to establish baseline water quality data for this region and to begin a long-term monitoring program for LOW. These water quality data are used for many purposes, including monitoring of fish habitat and communities, and are examined here for water quality trends.

The OMOE, in partnership with Queen's University (Kingston, Ontario), conducted water quality sampling at 20 LOW sites in 2003 in support of a paleolimnological project (e.g., Pla et al., 2005). In addition, the OMOE has sampled 26 stations as part of a remote sensing study by N.J. Hutchison & B.J. Clark (MOE, unpublished data) in 1989 (Table 4.2). The OMOE's Lake Partner Program (LPP; http://www.ene.gov.on.ca/envision/water/lake_partner/) engages LOW-area citizens in a volunteer-based water quality monitoring program that is similar to Minnesota's CLMP (Table 4.3). In this program, Secchi depth and TP data at approximately 81 sites on the Ontario side of LOW have been collected by volunteers since 2002. In addition, the OMOE's Provincial Water Quality Monitoring Program (PWQMP) has sampled ten stations along the Rainy River in the past (Table 4.2). Finally, as part of their Environmental Effects Monitoring Program (EEM), Environment Canada currently monitors one station near the pulp and paper mill on the Winnipeg River in Manitoba downstream from LOW and stations located downstream on the Rainy River after pulp and paper mill outfall at Fort Frances, Ontario (Table 4.2). Environment Canada also engaged in detailed water quality monitoring of LOW in 2008.

Water quality along the Rainy River has been monitored for several decades, with the majority of the data collected at sites near International Falls (MPCA site S000-063) from 1953-2006, and Baudette (MPCA site S000-069) from 1958-2006. Some tributaries to LOW and the Rainy River have also been monitored for short

... the LOW sampling sites [are separated] into geographically distinct groups based upon a ... primary gradient of nutrients, pH, and depth and a ... secondary gradient of alkalinity and ions.

periods over the past several decades by the USGS and MPCA, including sites on the Big and Little Fork Rivers, Baudette River, and Zippel Creek (Table 4.1). There are currently no tributaries on the Canadian side of the International border being monitored for water quality.

The following two subsections (4.1 Water Chemistry and 4.2 Nutrients and Trophic Status) provide assessments of Rainy River and LOW water quality using the data obtained from various U.S. and Canadian monitoring programs. Since these long-term water quality data do not extend beyond the 1980s, a third subsection (4.3 Paleoecology) describes current paleolimnological research on LOW that has led to the construction of historical water quality, including total phosphorus.

4.1. Water Chemistry

General water quality

This section provides an assessment of spatial and temporal trends in water quality across Lake of the Woods using ice-free data sampled by the OMNR-FAU and the MPCA. It is important to note that there are differences in the ways in which these two agencies obtain their water samples. Data from the MPCA were obtained through integrated two-metre surface and hypolimnion water samples along with field measurement of the water column profile, while water samples from the OMNR-FAU were obtained as an integrated sample collected through a depth of 1 times the Secchi depth.

The water chemistry of LOW is highly variable across the different regions of the lake. Data from the most recent ice-free year of sampling from all U.S. (MPCA) and Canadian (OMNR) sources were tested for normality (SigmaStat Ver. 3.1, Systat Software, 2006). Ice-free mean Secchi transparency, chlorophyll-a, alkalinity, and conductivity data were log (x) transformed prior to analysis. A principal components analysis (PCA) was performed using Canoco version 4.5 (ter Braak & Šmilauer, 2002). PCA can be used to distinguish patterns in complex datasets by identifying the most important environmental gradients, and then projecting the data in the primary direction of variation in the dataset. The PCA separated the LOW sampling sites into geographically distinct groups based upon a strong primary gradient of nutrients, pH, and depth and a weaker secondary gradient of alkalinity and ions (Figure 4.2). The amount of variation explained by the first and second axes of the PCA biplot were 60.9% and 19.0%, respectively. This spatial separation of sites was comparable to that of Pla et al. (2005), who determined that mid-summer water chemistry varied across multiple sites in LOW in 2003. The eastern sites in the Whitefish Bay area are generally low in total phosphorus (TP) (9.9 – 15.9 μg TP/L), nitrogen (302 – 384 μg TKN/L), and alkalinity (48.2 – 54.0 mg alkalinity/L), and appear in the top left quadrant of the PCA biplot (Figure 4.2: Highrock Island, Index Island, Turtle Bay, and Yellow Girl). The remaining sites and regions were separated along a strong gradient of nutrients and lake depth, in a south-north transect from Rainy River in the south to Kenora in the north. Sites in the extreme southern part of the lake in Minnesota are shallow (5.0 – 10.1 m), high in phosphorus (37.0 – 46.0 μg TP/L), nitrogen (508 – 800 TKN/L), pH (8.20 – 8.54), and are located in the top right quadrant of the biplot (Figure 4.2: Four Mile Bay, Big Traverse Bay, Long Point, Muskeg Bay). Moving northward, sites in the south and north-central sectors that were characterized by moderate levels of TP (18.3 – 30.3 μg TP/L), nitrogen (358 – 553 μg TKN/L), and alkalinity (47.6 – 53.2 mg alkalinity/L) occur in the bottom right quadrant of the biplot (Figure 4.2: Basil Point, Horseshoe Island, Monkey Rocks Reef, Donald Duck, East Allie, Rat Portage, with the exception of Bigstone which was located in the bottom left quadrant). Sites in the northwest (i.e., Clearwater/Echo Bays) are generally deeper (14.4 – 52 m), higher in pH (7.65 – 7.83) and alkalinity (48.2 – 54.0 mg alkalinity/L), and lower in phosphorus (9.3 – 16.3 μg TP/L) and nitrogen (420 – 451

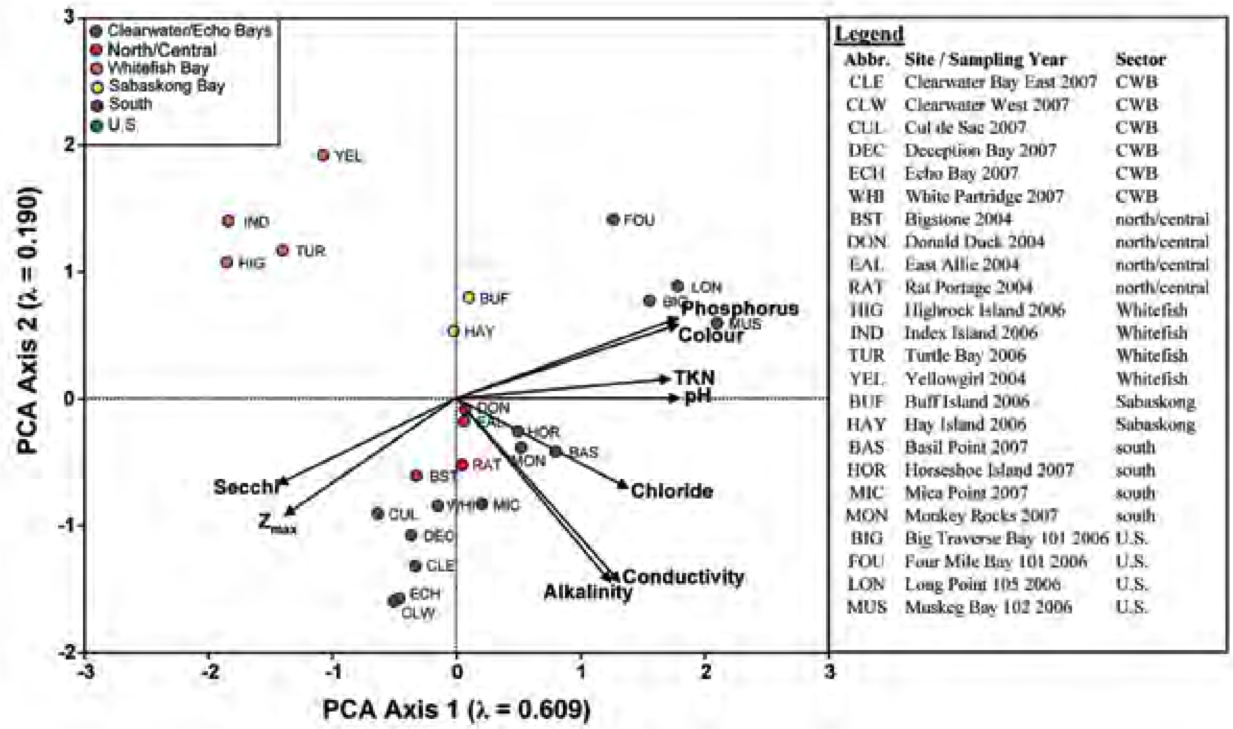

FIGURE 4.2. Principal components analysis (PCA) biplot of nine physical and chemical environmental variables from 24 sites in Lake of the Woods. Data is from the ice-free season of the most recent sampling year for each site, as indicated in the legend to the right of the biplot. The PCA has determined that there are two main directions of variation in the data, a primary nutrient gradient along axis 1 and a secondary, weaker gradient of ions and alkalinity along axis 2. Data from the Minnesota (U.S.) sites (Big Traverse Bay 101, Four Mile Bay 101, Long Point 105, and Muskeg Bay 102) were collected by the Minnesota Pollution Control Agency and analysed by the Minnesota Department of Health. The remaining sites within the Ontario portion of Lake of the Woods were collected by the Ontario Ministry of Natural Resources' Fisheries Assessment Unit and analysed at the Ontario Ministry of the Environment's Dorset Environmental Science Centre.

µg TKN/L) concentrations, and appear in the bottom left quadrant of the biplot (Figure 4.2: White Partridge, Cul de Sac, Deception Bay, Clearwater Bay East, Clearwater Bay West, Echo Bay). The two sites in Sabaskong Bay (Figure 4.2: Buff Island and Hay Island) occurred in the top-centre of the biplot. These sites have phosphorus (26.2 – 32.3 µg TP/L) and nitrogen (566 – 594 µg TKN/L) concentrations similar to those in the south and north/central sectors (Canadian side), but are generally lower in alkalinity (42.4 – 42.5 mg alkalinity/L).

Inter-sector comparisons

Similar to the PCA, patterns were seen for each sector throughout the ice-free seasons of the most recent sampling year for each Canadian site (Figures 4.3 - 4.5). Nutrients including ammonium, total Kjeldahl nitrogen (TKN), total phosphorus, nitrate and nitrite, colour, and dissolved organic carbon (DOC) differed between sectors, with the highest mean concentrations typically occurring in the southern sectors and the lowest in Whitefish Bay (Figures 4.3 a-d). Both the extreme south and extreme north sectors (i.e., Clearwater Bay, north/central, southern, Big Traverse Bay sectors) had higher alkalinity, conductivity, silicates and other ions compared to the sectors that are more isolated from the main south-north flow of water (Whitefish Bay and Sabaskong Bay sectors; Figure 4.4 - 4.5). Mean pH was lowest in Whitefish Bay (pH 7.25 – 7.54), but also showed more inter-site variability during the ice-free season than other sectors (Figure 4.4 a). Sulfate, aluminum, and iron concentrations were much higher in the

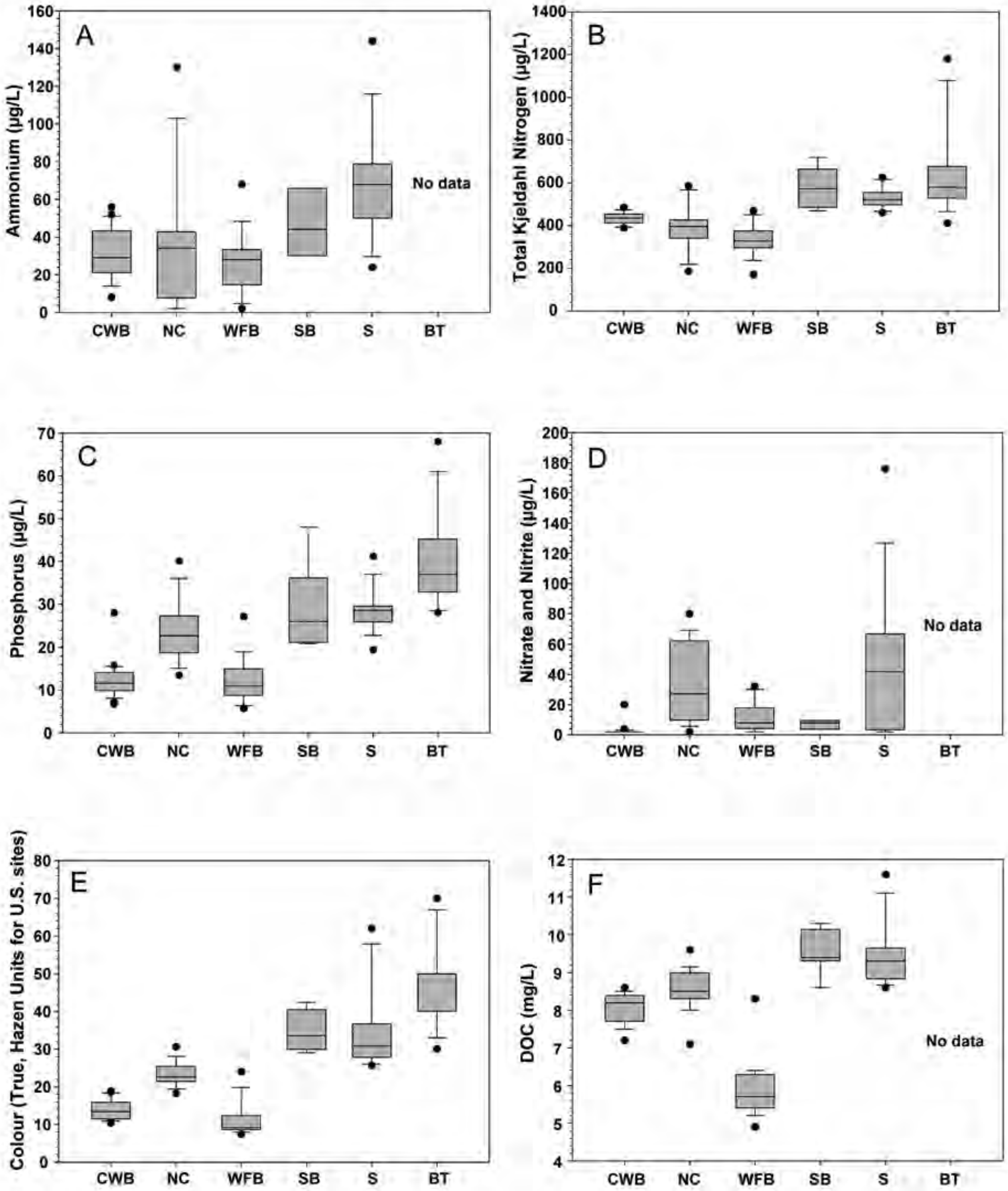

FIGURE 4.3. Comparison of monthly a) ammonium, b) total Kjeldahl nitrogen, c) phosphorus, d) nitrate and nitrite, e) colour, and f) dissolved organic carbon (DOC) data from the ice-free season for the most recent sampling year for 24 sites within six sectors in Lake of the Woods.

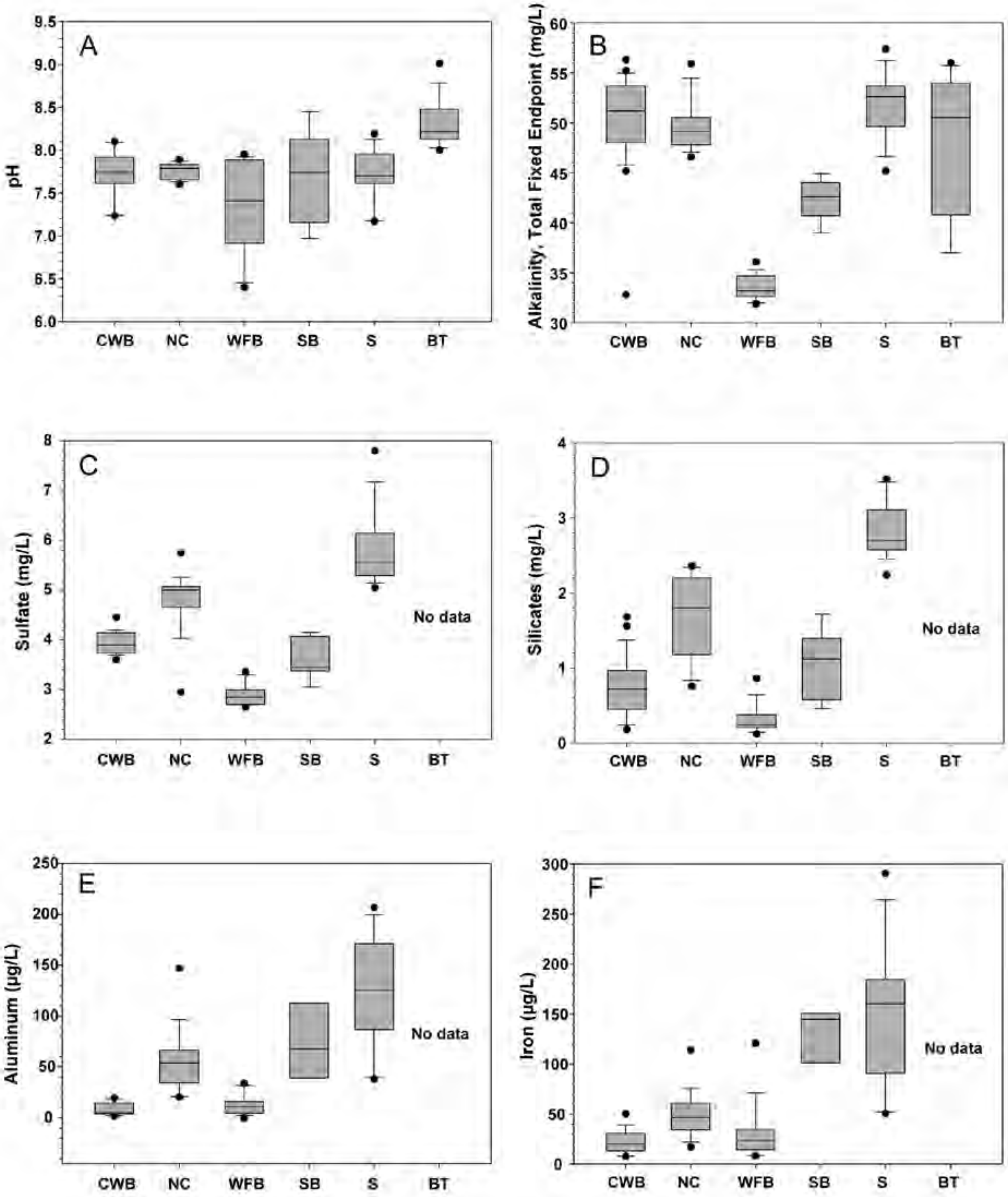

FIGURE 4.4. Comparison of monthly a) pH, b) alkalinity, c) sulfate, d) silicate, e) aluminum, and f) iron data from the ice-free season for the most recent sampling year for 24 sites within six sectors in Lake of the Woods.

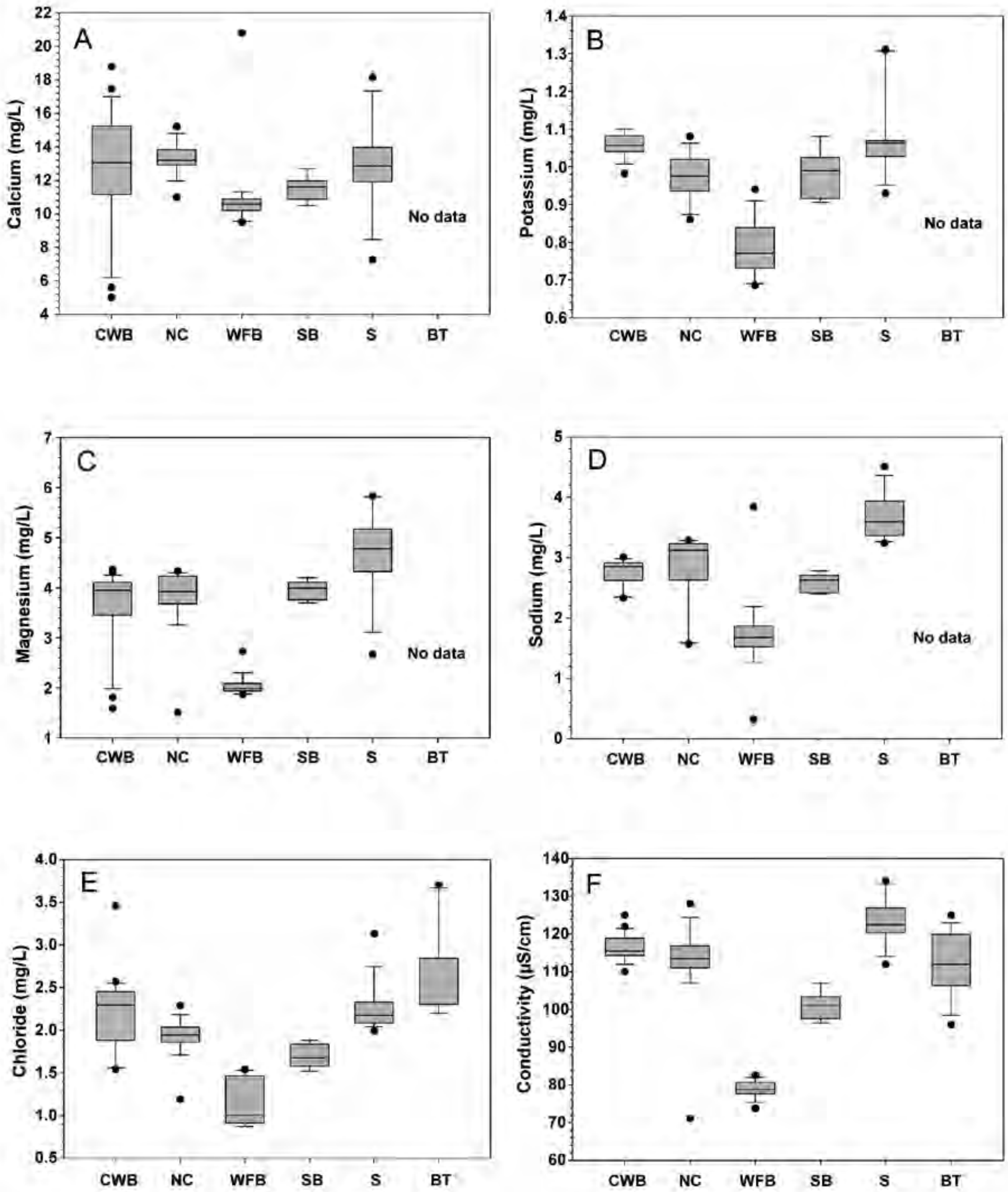

FIGURE 4.5. Comparison of monthly a) calcium, b) potassium, c) magnesium, d) sodium, e) chloride, and f) conductivity data from the ice-free season for the most recent sampling year for 24 sites within six sectors in Lake of the Woods.

south sector compared to the other sectors (Figure 4.4 c, e, f).

Long-term changes in water quality

There were visible differences in nutrient concentrations and colour between modern-day data (2000s) and recent historical data (1980s) at the same 25 sites in LOW. However, based on a comparison of the mean concentration in recent compared to the 1980s, ammonium concentration was the only nutrient variable that demonstrated a statistically significant change (Figure 4.6 a). The other measurements of nutrient concentration and colour, including TKN, phosphorus, and nitrate-nitrite, colour, and DOC, did not show statistically significant differences between the two time periods (Figures 4.6 b-f). These comparisons are useful because they provide a visual representation of the changes in water quality parameters from a historical time period to present. However, they are only based on snapshots in time, and so should be interpreted with caution.

Similar to nutrients, comparisons between recent history (~1980's) and present-day (~2000's) data from approximately 25 sites in LOW show that there have been statistically significant changes in other chemical variables over time (significance based on Wilcoxon signed-rank test, $P \leq 0.05$; Figures 4.6 – 4.8). For example, ionic concentration (i.e., sulfate, calcium, magnesium and chloride) and acidity (pH) have declined significantly, on average, since the 1980s (Figures 4.7 a, c, 4.8 a, c, e). Other measures of ionic concentration have either increased significantly (sodium, Figure 4.8 d), or shown no significant change over these time periods (Gran alkalinity, silicate, potassium, conductivity; Figures 4.7 b, d, 4.8 b, f).

> ... the majority of the U.S. shoreline of LOW has been partially exposed by historical logging or contains undeveloped wetland areas, and erosion is increased in these regions through wave action. The eroded material that washes into the lake brings with it phosphorus, which is naturally high in the soils of this region.

Discussion of trends in water quality across sectors

Although the complexity of LOW makes it difficult to determine specific causes for differences in water chemistry among sectors, variations in morphological, geological, geographical, and hydrological patterns among sectors provide some insight.

LOW is comprised of two geologically distinct regions: the glacial silt from Lake Agassiz and slow-eroding Precambrian Shield to the north (Section 3.2). Wetlands comprise 15% of the entire basin (Gartner Lee, 2007), but predominate in the southern region where the landscape is covered with softer, more erodible materials. In the southern part of the basin (i.e., the Upper and Lower Rainy River watersheds, including the southern portion of LOW), the land is mainly flat and consists primarily of glacial silt, clay, loam and sand (Section 3.2). Since the land drains in a northwesterly direction, LOW, the Rainy River, and other tributaries receive water from watersheds in southern Minnesota where agriculture, farming, and timber harvesting are common practices. The Rainy River contributes approximately 70% of the tributary inflow to the lake (Gartner Lee, 2007; Section 3.3). In the southern portion of LOW, such as Big Traverse Bay, the bottom is relatively flat and depths are shallow, predominately ranging from 5 – 10 m, with shallower regions nearshore. There are very few islands, inlets and bays, as open water predominates.

Moving northward (i.e., the Lake of the Woods, Central Rainy River, and the northern portion of the Upper Rainy River watersheds), the area is underlain by hard, impermeable bedrock that is more resistant to erosion (Section 3.2). This region is dominated by large outcroppings of bedrock and a thin layer of discontinuous glacial till (Fulton, 1995). In addition, the area is heavily forested and is dotted with numerous lakes, ponds, and their tributaries (International Joint Commission, 1984). This part of LOW is very different from the south. It is predominated by thousands of islands, bays and inlets, and depths vary from approximately 10 – 52 m, with some shallower regions nearshore. The deepest regions occur in the extreme northern sectors (i.e., Clearwater/Echo Bays and North/Central sectors).

Surficial geology and morphometry are

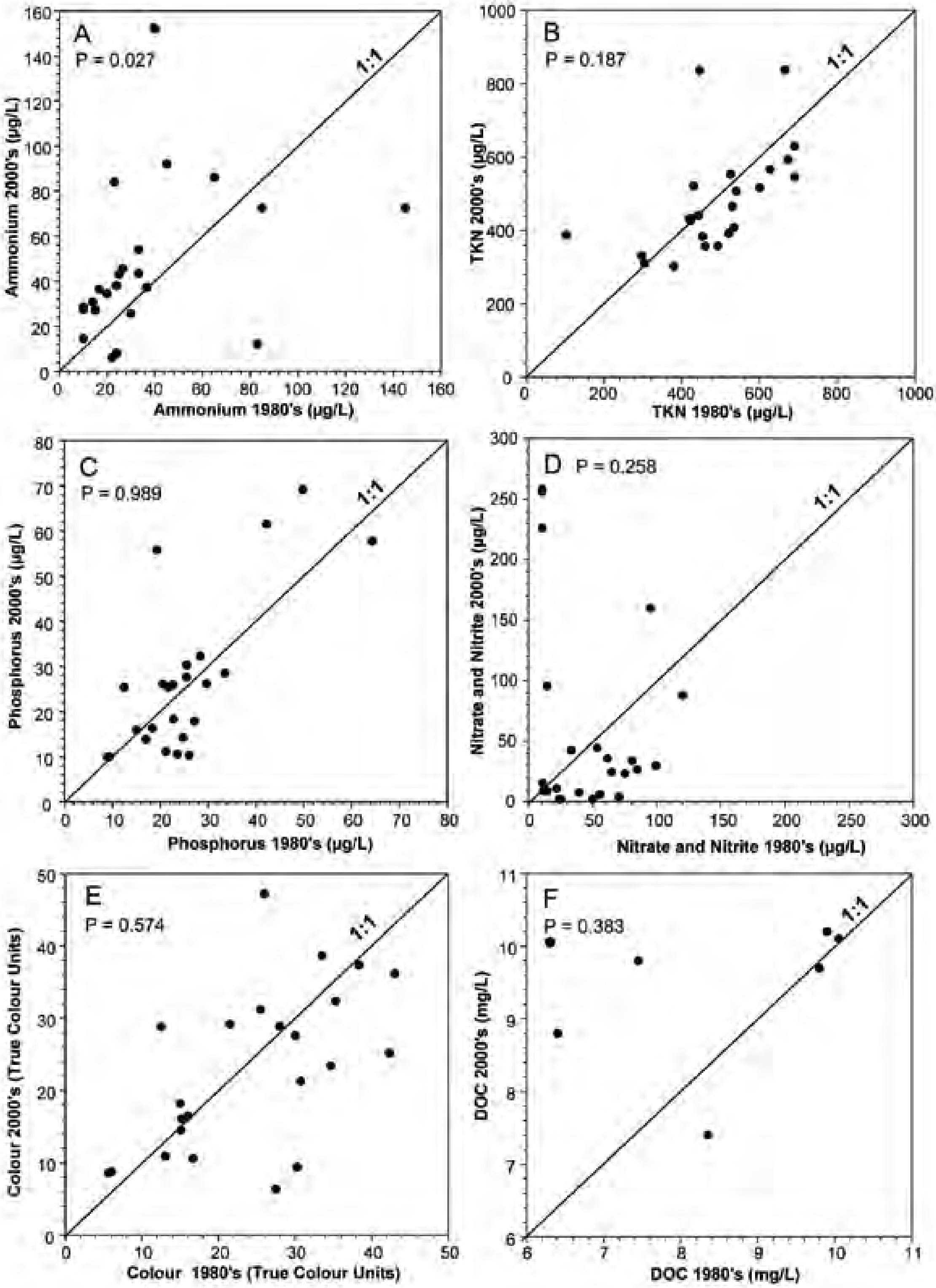

FIGURE 4.6. Comparison of a) ammonium, b) total Kjeldahl nitrogen (TKN), c) phosphorus, d) nitrate and nitrite, e) colour, and f) dissolved organic carbon (DOC) data from the 1980s and 2000s from approximately 25 sites within Lake of the Woods. P values were generated by a Wilcoxon signed-rank test comparing the historical and recent water chemistry data (alpha = 0.05).

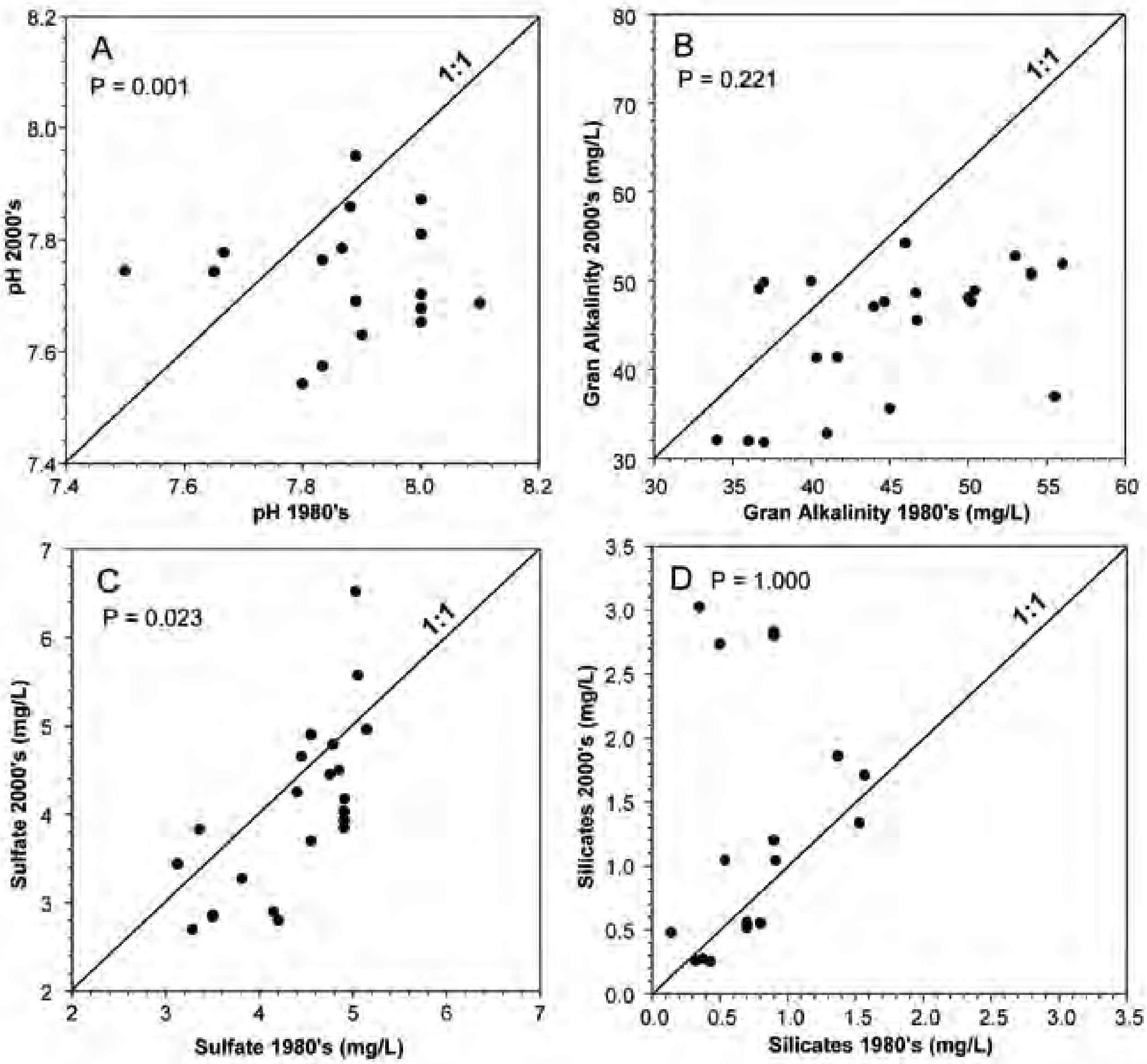

FIGURE 4.7. Comparison of a) pH, b) Gran alkalinity, c) sulfate, and d) silicate data from the 1980s and 2000s from approximately 25 sites within Lake of the Woods. P values were generated by a Wilcoxon signed-rank test comparing the historical and recent water chemistry data (alpha = 0.05).

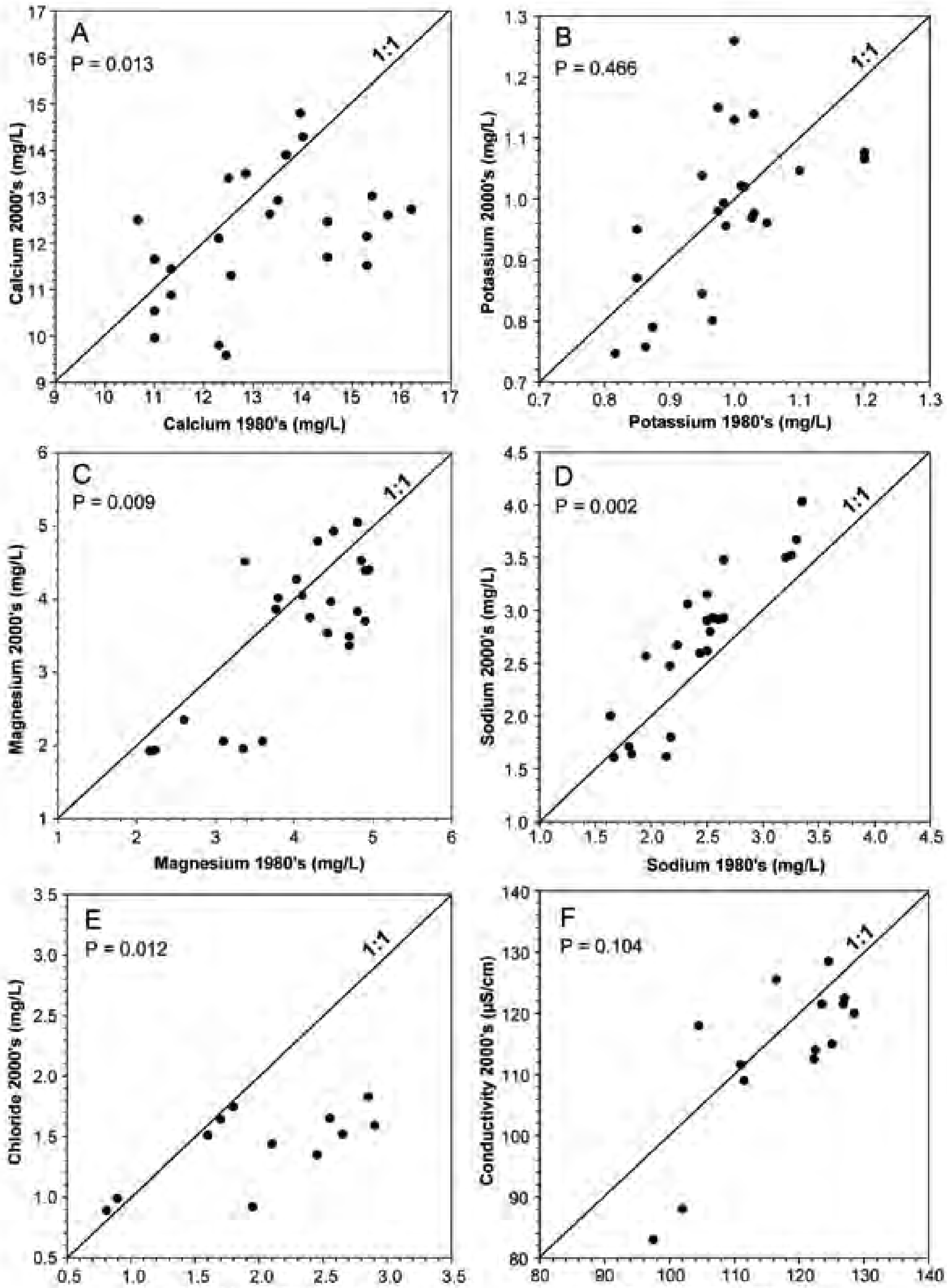

FIGURE 4.8. Comparison of a) calcium, b) potassium, c) magnesium, d) sodium, e) chloride, and f) conductivity from the 1980s and 2000s from approximately 25 sites within Lake of the Woods. P values were generated by a Wilcoxon signed-rank test comparing the historical and recent water chemistry data (alpha = 0.05).

also involved in controlling surficial water chemistry. For example, the U.S. sites located in or near Big Traverse Bay are generally higher in nitrogen, phosphorus, colour and pH than other sectors (Figures 4.2, 4.3 b, c, e, 4.4 a). Under windy conditions in shallow regions, nutrient-rich lake sediments may be resuspended in the water column. Also, the majority of the U.S. shoreline of LOW has been partially exposed by historical logging or contains undeveloped wetland areas, and erosion is increased in these regions through wave action (Herb et al., 2005). The eroded material that washes into the lake brings with it phosphorus, which is naturally high in the soils in this region. It has also been suggested that the Rainy River is a large contributor to lake colour in LOW, as sites closer to the mouth of the river have, in the past, had higher DOC and colour compared to more upstream sites (Anderson et al., 2006b). Another important contributor to lake colour in the south are the peat-rich wetlands that export large amounts of DOC to the lake. Previous studies in Canadian Shield landscapes have shown that DOC is highly correlated to percent area covered by peat bogs (e.g., Dillon & Molot, 1997).

In contrast to the southern portion of LOW, the limnology of the bays and inlets of the northern region is more typical of Precambrian Shield lakes in that they are deeper, have smaller surface areas, and are more likely to thermally stratify. The

TABLE 4.4. List of locations and corresponding codes of lake, stream, and point source discharge water quality monitoring stations on Lake of the Woods and the Rainy River that are shown in Figure 4.1. Agencies' abbreviations are as follows: OMNR (Ontario Ministry of Natural Resources); MPCA (Minnesota Pollution Control Agency); USEPA (United States Environmental Protection Agency); IRLBC (International Rainy Lake Board of Control); EC (Environment Canada); USGS (United States Geological Survey).

Site Name	Code	Latitude	Longitude	Agency
Highrock Island	1	49°20'07"	94°05'07"	OMNR
Turtle Bay	2	49°12'08"	94°07'04"	OMNR
Hay Island	3	49°09'00"	94°07'04"	OMNR
Index Island	4	49°24'08"	94°11'00"	OMNR
Buff Island	5	49°09'07"	94°14'00"	OMNR
Yellow Girl	6	49°30'17"	94°16'56"	OMNR
Bigstone	7	49°40'03"	94°20'54"	OMNR
Horseshoe	8	49°15'14"	94°21'33"	OMNR
East Allie	9	49°35'10"	94°27'09"	OMNR
Rat Portage	10	49°43'23"	94°32'21"	OMNR
Donald Duck	11	49°31'35"	94°34'02"	OMNR
White Partridge Bay	12	49°42'08"	94°36'08"	OMNR
Four Mile Bay	13	48°51'16"	94°41'10"	MPCA
Big Traverse Bay	14	48°53'19"	94°41'38"	MPCA
Basil Point	15	49°04'31"	94°43'29"	OMNR
Clearwater Bay East	16	49°42'23"	94°44'52"	OMNR
Mica Point	17	49°19'19"	94°45'45"	OMNR
Deception Bay	18	49°42'08"	94°48'36"	OMNR
Clearwater Bay West	19	49°41'26"	94°49'38"	OMNR
Cul de Sac	20	49°37'37"	94°49'53"	OMNR
Monkey Rocks Reef	21	49°24'35"	94°50'33"	OMNR
Echo Bay	22	49°38'33"	94°54'53"	OMNR
Long Point	23	49°03'24"	94°55'11"	MPCA
Muskeg Bay	24	48°59'20"	95°17'31"	MPCA
Rainy River at International Falls	25	48°36'26"	93°24'07"	MPCA
Little Fork River	26	48°31'17"	93°35'12"	MPCA
Big Fork River Bridge	27	48°30'46"	93°42'38"	MPCA
Rainy River at International Bridge at Baudette	28	48°43'08"	94°35'24"	USEPA
Boise Paper Solutions (International Falls, MN)	29	48°36'28"	93°24'16"	USEPA
North Koochicing Waste Water Treatment Plant (International Falls, MN)	30	48°35'33"	93°26'20"	USEPA
Baudette Lagoon (Baudette, MN)	31	48°43'22"	94°36'01"	USEPA
Rainy Lake outflow at International Falls/Fort Frances	32	48°36'26"	93°24'07"	Boise Cascades/IRLBC
Lake of the Woods wester outlet at Norman Dam and Powerhouse	33	49°46'19"	94°31'28"	EC
Lake of the Woods eastern outlet at Kenora Powerhouse	34	49°46'21"	94°30'11"	EC
Rainy River at Fort Frances	35	48°36'30"	93°24'12"	EC
Rainy River at Manitou Rapids	36	48°38'04"	93°54'47"	EC/USGS

surrounding basin is mainly forested with little agriculture, many cottages, and a large amount of exposed bedrock. Hydrological patterns and water flow play an important role in distribution of nutrients and other substrates from the southern shallow basin (i.e., Big Traverse Bay) to the more northern sectors. The north/central Sectors receive inflows from the southern portion of the lake and this may contribute to the moderate nutrient concentrations of this sector. The Clearwater Bay region also gains nutrients and ions from the local watershed. In contrast, sites within the Whitefish Bay sector are isolated from the main direction of water flow. Therefore, this sector is less likely to be influenced by water inflow from the southern part of LOW. Due to their hydrological isolation and distinct water quality, sites within Whitefish Bay are often used as reference points for undisturbed conditions within LOW (e.g., Pla et al., 2005).

The anions and cations measured in LOW are highly influenced by the geology of this region of the basin. The hard, crystalline rock of the Precambrian Shield weathers slowly and thus produces a very dilute (softwater) runoff as compared to more southerly areas of the lake whose soils contain more carbonates. Runoff from road salt and sand may contribute to ion concentrations at sites close to major and local roads, which may explain the significant increase in sodium concentrations in LOW since the 1980s (Figure 4.8 d). For example, the oligotrophic sites within the Clearwater/Echo Bay sector are located south of the city of Kenora and the Trans-Canada highway, which may partially explain why they are higher in ions and alkalinity despite the low-weathering capacity of the surrounding bedrock (Figures 4.2, 4.4 b). Similarly, sites within the Whitefish Bay sector are typically oligotrophic, but generally have much lower ion concentrations than those within Clearwater/Echo Bays (Figures 4.2, 4.4, 4.5), which may be due to their isolation

TABLE 4.5. Details of the lake, stream, and point source discharge water quality monitoring locations that are provided in Figure 4.1.

Site Name	Site Type Code	Site Code	Site Type	Latitude	Longitude	Agency
Rat Portage	L	1	lake	49º43′23″	94º32′21″	MNR
Bigstone	L	2	lake	49º40′03″	94º20′54″	MNR
East Allie	L	3	lake	49º35′10″	94º27′09″	MNR
Yellow Girl	L	4	lake	49º30′17″	94º16′56″	MNR
Donald Duck	L	5	lake	49º31′35″	94º34′02″	MNR
Index Island	L	6	lake	49º24′08″	94º11′00″	MNR
Highrock Island	L	7	lake	49º20′07″	94º05′07″	MNR
Turtle Bay	L	8	lake	49º12′08″	94º07′04″	MNR
Hay Island	L	9	lake	49º09′00″	94º07′04″	MNR
Buff Island	L	10	lake	49º09′07″	94º14′00″	MNR
White Partridge Bay	L	11	lake	49º14′25″	94º36′07″	MNR
Clearwater Bay East	L	12	lake	49º41′17″	94º49′25″	MNR
Clearwater Bay West	L	13	lake	49º42′23″	94º44′52″	MNR
Echo Bay	L	14	lake	49º38′16″	94º54′30″	MNR
Cul de Sac	L	15	lake	49º37′22″	94º49′29″	MNR
Deception Bay	L	16	lake	49º42′08″	94º48′36″	MNR
Four Mile Bay	L	17	lake	48º51′16″	94º41′40″	MPCA
Big Traverse Bay	L	18	lake	48º53′19″	94º41′38″	MPCA
Muskeg Bay	L	19	lake	48º59′20″	95º17′31″	MPCA
Long Point	L	20	lake	49º03′24″	94º55′11″	MPCA
Boise Paper Solutions (International Falls, MN)	P	1	point source (industrial)	48º60′77″	93º40′45″	MPCA
North Koochiching Waste Water Treatment Plant (International Falls, MN)	P	2	point source (municipal)	48º59′26″	93º43′89″	MPCA
Baudette Lagoon (Baudette, MN)	P	3	point source (municipal)	48º72′28″	94º60′04″	-
Rainy River at International Falls	S	1	stream	48º36′26″	93º24′07″	MPCA
Rainy River at International Bridge at Baudette	S	2	stream	48º43′08″	94º35′24″	MPCA
Big Fork River Bridge on MN-11, 4 mi E. of Loman	S	3	stream	48º30′46″	93º42′38″	MPCA
Little Fork River MN-11 Bridge, 0.5 mi W. of Pelland LF-0.5	S	4	stream	48º31′17″	93º35′12″	MPCA

Specific nutrient sources to the entire lake have not yet been determined, and it is currently difficult to identify the exact origins of the nutrients in both the south and north ends of the lake. This is an area of on-going research.

from many local and major roadways and other urban centres. It is important to note, however, that the main basin of LOW is composed of a Shield basin fed hydrologically by a non-Shield basin. The southern portion of the Lake is comprised of faster-weathering materials and receives the majority of its water from the Rainy River and other tributaries. Specific nutrient sources to the entire lake have not yet been determined, and it is currently difficult to identify the exact origins of the nutrients in both the south and north ends of the lake. This is an area of on-going research.

Statistically significant declines were observed for some base cations, including calcium, magnesium, and chloride (Figures 4.8 a,c,e). In smaller lakes whose watersheds lie completely within the hard Precambrian crystalline igneous or metamorphic bedrock, base cation declines have been associated with changes in acid precipitation between the 1980s and the 2000s (e.g., Driscoll et al., 1998; Keller et al., 2001). In many regions around the world, lakes that have been impacted by acid precipitation are increasing in pH due to reduced sulfate inputs in recent years (Stoddard et al., 1999). However, chemical recovery of some of these lakes has been delayed because base cations (such as calcium) that were titrated from the watershed soils by acidic deposition and deforestation are now depleted in watershed soils (Stoddard et al., 1999; Watmough et al., 2003). However, the drainage basin of LOW differs in that it has not received substantial levels of acidic deposition. For example, concentrations of calcium, important in forming the carapaces of many freshwater invertebrates, range from 9.6 – 14.8 mg/L in LOW. In the nearby Experimental Lakes Area (ELA) in northwestern Ontario, calcium concentrations range from 1.8 – 3.0 mg/L (Turner et al., 2007). This can be attributed to the sedimentary calcium carbonate rock deposit in the southwestern portion the Winnipeg River Drainage Basin that extends into Minnesota south of LOW.

4.2. Nutrients and trophic status

A lake's trophic status, or productivity, can be classified as either oligotrophic (nutrient poor), mesotrophic (moderately productive), or eutrophic (very productive). 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 section characterizes previous and ongoing monitoring efforts in LOW and the Rainy River, with regards to algal nutrients and lake trophic status.

Lake trophic status in LOW and the Rainy River is estimated using measurements of total phosphorus (TP), chlorophyll-a, and Secchi depth. Chlorophyll-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). Since algal biomass tends to increase in response to enhanced phosphorus inputs, chlorophyll-a concentrations provide an indirect measurement of algal biomass. Water transparency is influenced by algal density; thus Secchi depth provides an inexpensive estimate of lake productivity based on water clarity. In general, Secchi depth may decrease in the summer months in temperate lakes due to an increase in algal biomass in the water column. However, Secchi depth is not a useful measure of lake trophic status in dystrophic (tea-stained) systems since water clarity is also controlled by concentrations dissolved organic carbon in these lakes. Dystrophic systems may also be less responsive to increased phosphorus inputs through increased phytoplankton biomass since much of the nutrients are tied-up with the organics and therefore unavailable for algal production.

Of the major nutrients required for the metabolism, nutrition, and structure of aquatic biota (e.g., phosphorus, carbon, nitrogen, carbon, silica), phosphorus is often present in the lowest quantity in oligotrophic, mid-latitude lakes and therefore, may limit biological productivity (e.g., Dillon & Rigler, 1974). Consequently, a positive relationship may be found between total phosphorus concentration and algal biomass (e.g., chlorophyll-a) among and within lakes over time. The relative importance of phosphorus in structuring algal biomass may vary temporally (annually, monthly, and seasonally) and spatially across LOW (Pla et al., 2005).

Long-term monitoring of the lake has shown that LOW experiences significant inter-annual and spatial variability in trophic status and nutrient concentrations.

Although phosphorus (P) is the primary limiting nutrient in Precambrian Shield lakes (Schindler, 1975; Hecky & Kilham, 1988), nitrogen (N) can also be an important nutrient in some circumstances in LOW as N concentrations may be important in determining what 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, and the N:P ratio remains quite high (Downing & McCauley, 1992), which suggests a state of P limitation. 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 in LOW that resulted in N limitation or co-limitation of P and N in the phytoplankton over time (Pla et al., 2005). 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). Further work will be required to determine the relative importance of P and N in limiting phytoplankton biomass and species composition spatially and seasonally within LOW.

Other possible contributors to the spatial variation of nutrients and chlorophyll-a in LOW may include variations in light, temperature, mixing regimes, and lake depth among sites (Pla et al., 2005). 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

TABLE 4.6. List of point source discharges to the Rainy River and Lake of the Woods where nutrient data has been collected. Modified from Gartner Lee Ltd (2007).

Name	Type	Station ID	Agency	Period of Record	Latitude	Longitude
Warroad Sewage Treatment Facility (Warroad, MN)	Municipal	MN0025194	MPCA EDA; MPCA DELTA	1998-2007		
Abitibi-Consolidated Pulp & Paper Mill (Fort Frances, ON)	Industrial		Environment Canada: Environmental Effects Monitoring	2001-2006		
Boise Paper Solutions (International Falls, MN)	Industrial	MN0001643-SD-1	MPCA EDA; MPCA DELTA	1999-2007	48.6077	-93.4045
Emo Lagoon (Emo, ON)	Municipal		MOE Kenora	2001, 2003-2006		
Barwick Lagoon (Barwick, ON)	Municipal					
Rainy River Lagoon (Rainy River, ON)	Municipal					
Manitou Rapids Lagoon (Manitou, ON)	Municipal					
Fort Frances Waste Water Treatment Plant (Fort Frances, ON)	Municipal		MOE Kenora	2002-2005		
North Koochiching Waste Water Treatment Plant (International Falls, MN)	Municipal	MN0020257-SD-2	MPCA EDA; MPCA DELTA	1999-2007	48.5926	-93.4389
Baudette Lagoon (Baudette, MN)	Municipal	MN0029599-SD-1	MPCA EDA; MPCA DELTA; IRRWPB Report to IJC (2006)	1998-2004, 2004, 2005	48.7228	-94.6004
Abitibi-Consolidated Pulp & Paper Mill (Kenora, ON)	Industrial		Environment Canada: Environmental Effects Monitoring	2001-2006		

utilize the nutrient-rich, well-lit epilimnion. This, in turn, influences phytoplankton assemblage composition and biomass (Watson et al., 1997).

Nutrient sources to the Rainy River Basin

In the past, the Minnesota and Ontario pulp and paper companies at International Falls and Fort Frances and domestic sewage inputs were considered to be major point sources of nutrients to the Rainy River. However, the implementation of regulations for treatment of industrial and domestic waste effluent, remedial measures, and ongoing monitoring (International Joint Commission, 1965), have led to significant improvements in water quality in recent decades (Beak Consultants Limited, 1990, 1996).

Currently, several point and non-point sources of nutrients to the U.S. portion of the Rainy River Basin have been identified (Tables 4.6-4.7). Estimated P loads and sources have been determined for the area of the Rainy River Basin south of the U.S. – Canada border (MPCA, 2004; Table 4.7). Of the approximately 400,000 kg/year in total P load received by the Rainy River Basin, an estimated 44,300 kg/year (11%) of this is from point source effluent, and the remainder is considered to be from non-point sources (MPCA, 2004). Based on data from 2001-03, it was determined that atmospheric deposition and non-agricultural rural runoff account for the majority of the TP and bioavailable P (BP)[5] loads to the Rainy River Basin under high, low, and average flow conditions. In addition, stream bank erosion contributed moderate portions of TP and BP loads under high and average flow conditions (Table 4.7). Commercial and industrial processes contributed significantly to both TP and BP loads under low flow conditions and to BP under average flow conditions (Table 4.7). These results may indicate that natural, non-point sources of P are more bioavailable than point sources in the Rainy River Basin (MPCA, 2004). Trends similar to the data shown in Table 4.7 have been observed in the Little Fork River (2004-06 data) and Zippel Creek (2004 data) (N. Baratono, MPCA, International Falls, MN, 2007, Pers. Comm.). Other potential sources of nutrients to the Rainy River and LOW not mentioned above include internal loading, recreational facilities (such as campgrounds), residential and cottage septic systems, hospitality facilities (such as resorts), and cosmetic and industrial fertilizers, although their relative contributions have not been quantified.

TABLE 4.7. Summary of point (Commercial/Industrial Process Water, Human Waste, Other) and non-point sources (Atmospheric Deposition, Non-Agricultural Rural Runoff, Streambank Erosion, Other) of total phosphorus (TP) and bioavailable phosphorus (BP) loadings to the Minnesota side of the Rainy River Basin for low, average, and high water years. The TP load received by the Rainy River Basin each year is estimated to be approximately 400,000 kg/year (Data obtained from Minnesota Pollution Control Agency (2004). Detailed assessment of phosphorus sources to Minnesota watersheds. Prepared by Barr Engineering Company.

Flow Condition	Low		Average		High	
Source Category	**TP (%)**	**BP (%)**	**TP (%)**	**BP (%)**	**TP (%)**	**BP (%)**
Commercial/Industrial Process Water	13.7	24.8	9.1	17.4	5.5	10.1
Human Waste	0.9	1.6	0.6	1.1	0.4	0.7
Other	0.4	0.6	0.3	0.4	0.2	0.3
Point Sources (Total)	**15.0**	**27.0**	**10.0**	**19.0**	**6.0**	**11.0**
Atmospheric Deposition	52.6	35.9	40.9	29.2	25.0	19.8
Non-Agricultural Rural Runoff	24.1	25.7	27.4	29.6	19.8	23.9
Streambank Erosion	minimal	minimal	12.6	10.3	40.9	35.6
Other	8.2	11.4	9.2	12.0	8.3	9.7
Non-Point Sources (Total)	**85.0**	**73.0**	**90.0**	**81.0**	**94.0**	**89.0**

Nutrient and Trophic Status Data

This section will discuss and compare trends in nutrient (mainly TP) data for the LOW region, starting at the Rainy River outflow and moving northward through LOW.

Rainy River

The MPCA has been collecting water quality data at two long-term monitoring stations on the Rainy River since the mid 1950s (Table 4.1, Figure 4.1). These are Rainy River at International Falls (S000-007; 1953-present) and Rainy River at Baudette (S000-063; 1958-present).

The long-term historical records of total phosphorus concentrations in the Rainy River at International Falls show a trend of

[5] Bioavailable phosphorus (BP) is defined as the proportion of the total dissolved phosphorus fraction that is available for plant growth. It is comprised primarily of orthophosphate (PO43-) and soluble reactive phosphorus (SRP).

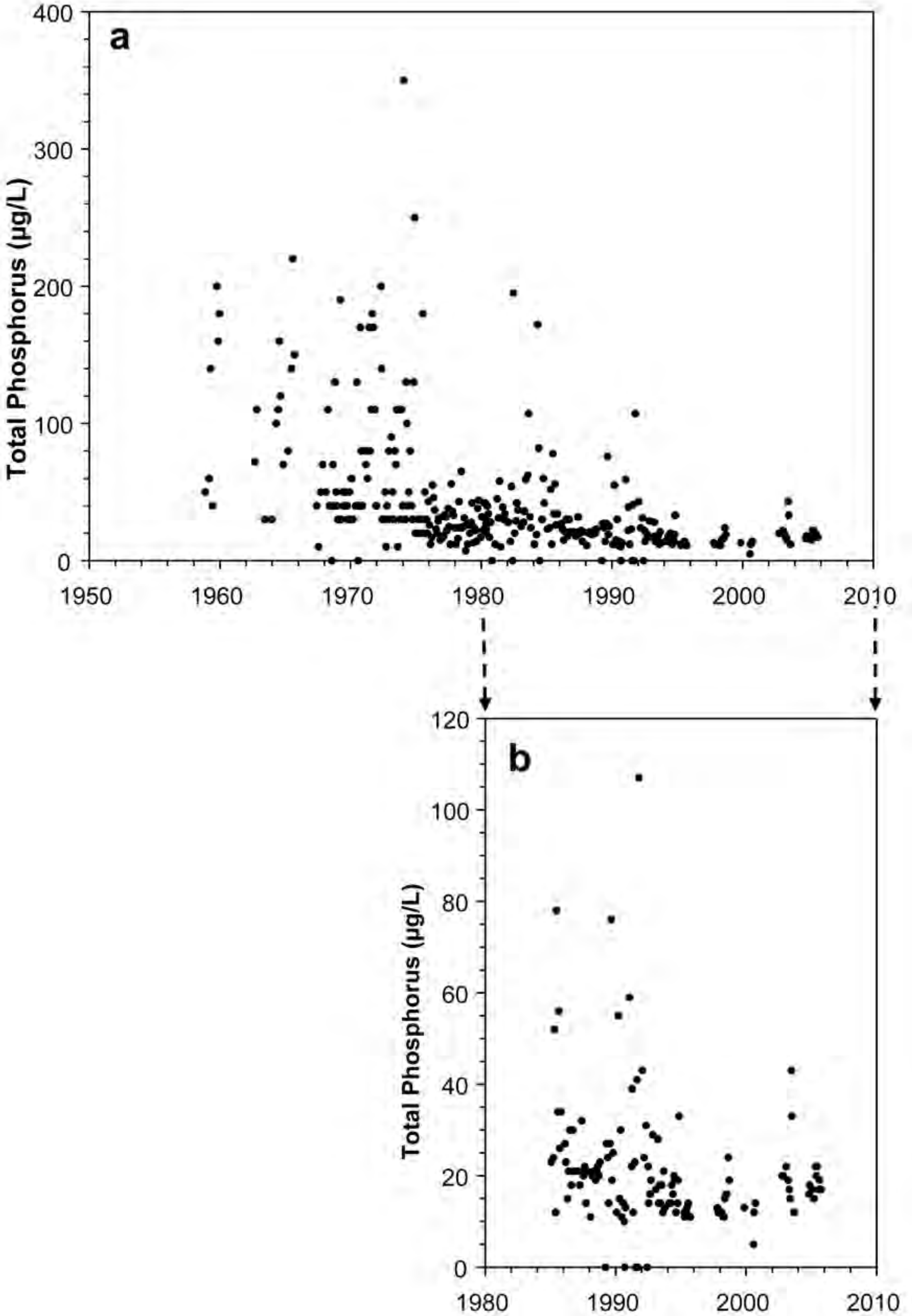

FIGURE 4.9. Total phosphorus (TP) concentrations for the Rainy River at International Falls monitoring station from 1958-2005. TP values of zero represent a "non-detect" value.

decreased variation in TP concentrations through time, with a slight decline in P after 1985 (Figure 4.9). This trend could be attributed to improved analytic precision or reduced impact of large point source loads. Monthly comparisons of data from two different sites along the Rainy River demonstrate that TP and chlorophyll-a concentrations in 2005 were significantly higher at the Rainy River at Baudette monitoring site compared to Rainy River at International Falls (P = 0.002) based on a 2-Way ANOVA with a Tukey post hoc multiple comparison test, although this pattern was less clear for chlorophyll-a (Figure 4.10). This trend of higher nutrient concentration and algal biomass at the site further downstream is likely due to the point and non-point sources of nutrients within the watershed and downstream of International Falls, including municipal waste water treatment plant effluent, industrial effluent, atmospheric deposition, non-agricultural runoff, and streambank erosion (Tables 4.6 - 4.7). For example, Merriman et al. (1992) found that, based on monitoring data from 1979-85, nutrient concentrations were significantly higher at a downstream site at the outlet of Rainy River at LOW compared to an upstream site at the outlet of Rainy Lake. This was attributed to runoff from agricultural areas and peatlands, effluent from sewage treatment plants and pulp and paper mills, and cottage septic system runoff.

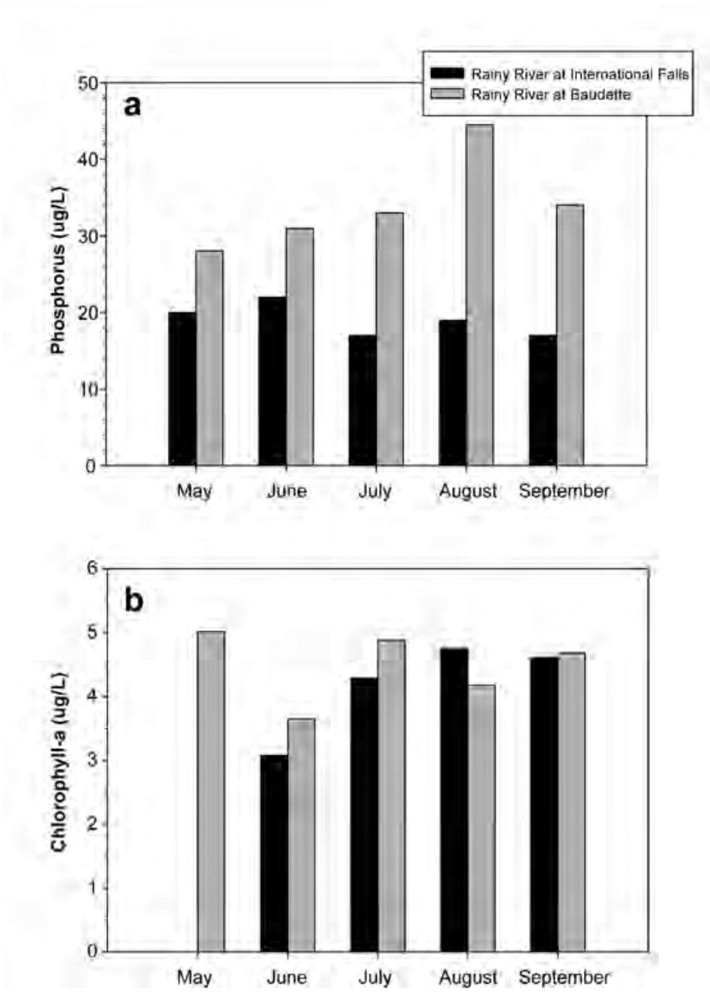

FIGURE 4.10. 2005 monthly a) total phosphorus (TP) and b) chlorophyll-a concentrations for two monitoring sites along the Rainy River: Rainy River at International Falls (Site # S000-007) and Rainy River at Baudette (Site # S000-063). TP and chlorophyll-a concentrations in 2005 were significantly higher at the Rainy River at Baudette monitoring site compared to Rainy River at International Falls (P = 0.002) based on a 2-Way ANOVA with a Tukey post hoc multiple comparison test.

The Rainy River is a significant tributary to LOW, with a mean daily discharge of 365 m^3/s (LWCB, 2002) and mean TP concentrations at the Baudette monitoring site of 30 – 35 µg/L in both 1999 and 2005 (Anderson et al., 2006b). TP concentrations in the Rainy River at Baudette were comparable to those of the U.S. portion of LOW 1999 and 2005 (Figure 4.11). This was analogous to findings by Anderson et al. (2006b), where both TP and chlorophyll-a concentrations increased on a seasonal basis from May to September in 2005 at all four monitoring sites in the Minnesota portion of LOW.

Minnesota Portion of LOW

The MNDNR has monitored August water quality at four sites on LOW since 1991 (Figure 4.1, Table 4.1), with sampling coinciding with late summer algal blooms. These four sites in the southern portion of LOW are: Four Mile Bay/Rainy River, Big Traverse Bay, Muskeg Bay, and Long Point (Table 4.4). The sampling data, which includes Secchi transparency and an evaluation of water physical appearance (very good to poor), and lake recreational suitability (high to low algal visibility), as well as all water quality parameters are available on the Environmental Protection Agency's STORET database (http://www.epa.gov/storet/dw_home.html). The MPCA joined with the MNDNR in 1998 to expand this sampling effort by including an extra site on the Rainy River at Baudette. The intention was to define the among-year variability in trophic status among monitoring sites in the Minnesota portion of LOW (Anderson et al., 2006b).

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, MNDNR, and the SWCD. The four southern sites (Four Mile Bay/Rainy River, Big Traverse Bay, Muskeg Bay, Long Point) were sampled. These studies concluded that the means of TP, chlorophyll-a concentrations, and Secchi depths for these sites were near or exceeded 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 (refer to Section 4.1 for more details; Anderson et al., 2000; Anderson et al., 2006b; Heiskary, 2007).

There were some noticeable patterns of temporal variation and spatial variation in TP and chlorophlyll-a concentrations at these MPCA monitoring sites on LOW during the most recent years of data collection (Figure 4.11; 1999, 2005, 2006). Mean TP increased on an annual basis across all sites (Figure 4.11 a). Mean chlorophyll-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) (Figure 4.11 b). The elevated chlorophyll-a concentrations observed at the Muskeg Bay and Long Point monitoring sites in 1999 and 2006 (Figure 4.11 b) could be attributed to late summer severe nuisance algal blooms (Anderson et al., 2006). In addition, there was some temporal variability in Secchi transparency among the four monitoring sites (Figure 4.11 c). For example, Secchi transparency was low at Four Mile and Big Traverse Bay sites in 1999 and 2005, and also in 2006 at Big Traverse Bay, as compared to the other two sites (Figure 4.11 c). This 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 (June-September) Secchi transparency were seen from 1993-2006 (MPCA, Environmental Data Access, 2007b). It is of note that elevated chlorophyll-a concentrations at the two sites furthest from Rainy River inflow, Long Point and Muskeg Bay, in 2006 did not lead to corresponding declines in Secchi depth readings at these sites. This suggests that the low Secchi transparency of Four Mile and Big Traverse Bays was strongly influenced by turbidity due to suspended solids and DOC from the Rainy River (Anderson et al., 2006b).

Nutrient parameters were extremely variable on a monthly basis for each sampling year at each site (Figures 4.12 - 4.14). For example, in 2005 (the year with the most complete data record), slight increases in TP were evident throughout the summer from May to August before declining again in September at all sites (Figure 4.12). The variability of nutrients on a monthly and inter-annual basis demonstrates the need for long-term monthly and annual sampling programs during the ice-free season in LOW. In order to reliably predict the response of algal biomass (measured as chlorophyll-a) to TP in lakes in this region, a multi-year consecutive sampling programs with consistent sampling methodologies is imperative (Molot & Dillon, 1991; see Section on Future Monitoring Initiatives).

Canadian Portion of LOW

The most recent years of nutrient data (2003, 2004, or 2005) from monitoring sites within the three sectors have been sampled by the OMNR-FAU in Kenora, ON, and analyzed by the chemistry laboratory at the OMOE's Dorset Environmental Science Centre in Dorset, Ontario. Based on these data, there was variation in TP and chlorophyll-a concentrations between the north/central,

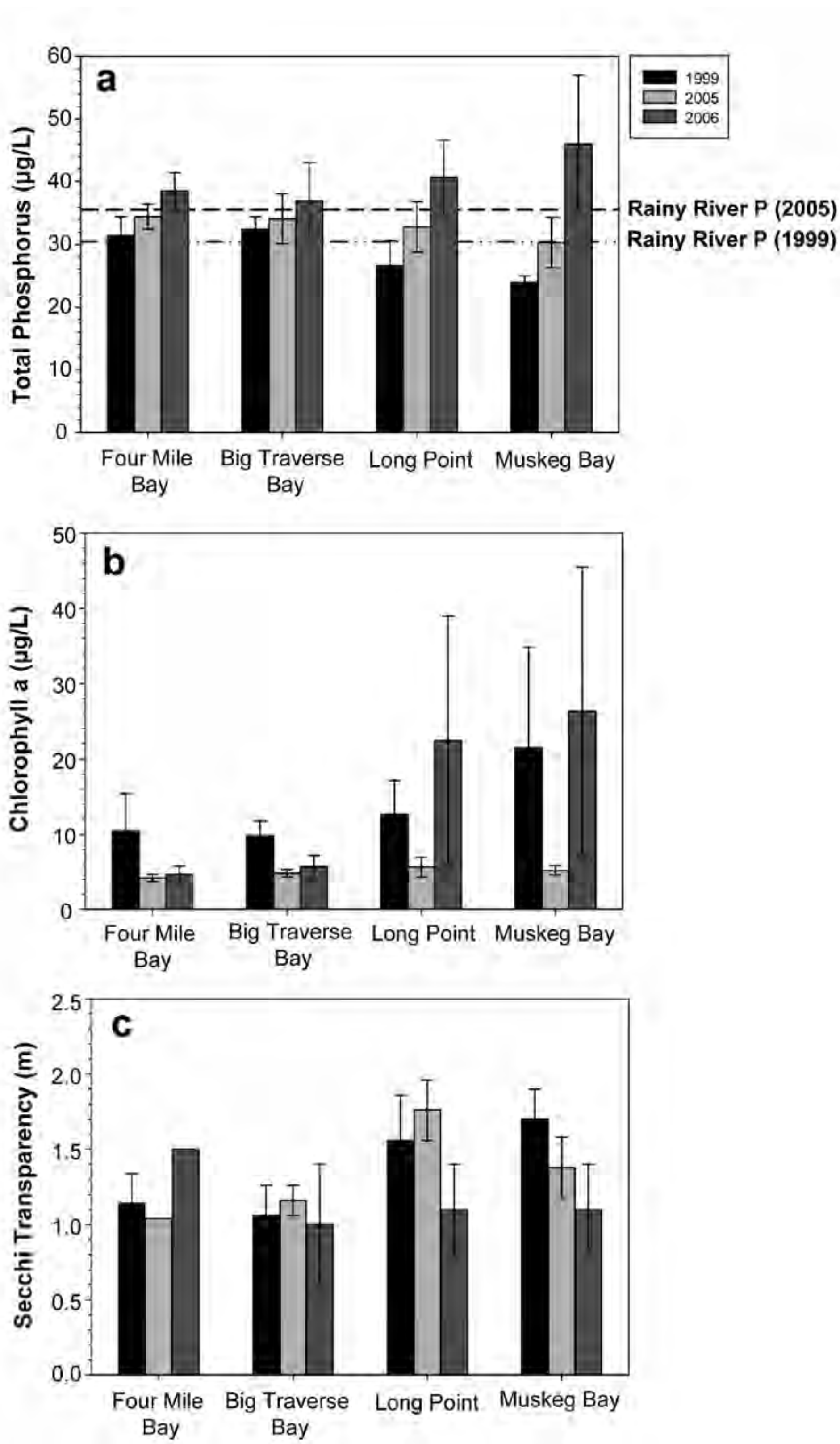

FIGURE 4.11. Mean (with standard error bars) a) total phosphorus (TP), b) chlorophyll-a, and c) Secchi transparency for the four MPCA monitoring stations in the Minnesota portion of Lake of the Woods for 1999, 2005, and 2006.The dotted lines in a) represent mean TP concentrations from the Rainy River at Baudette for May-September, 1999 and 2005.

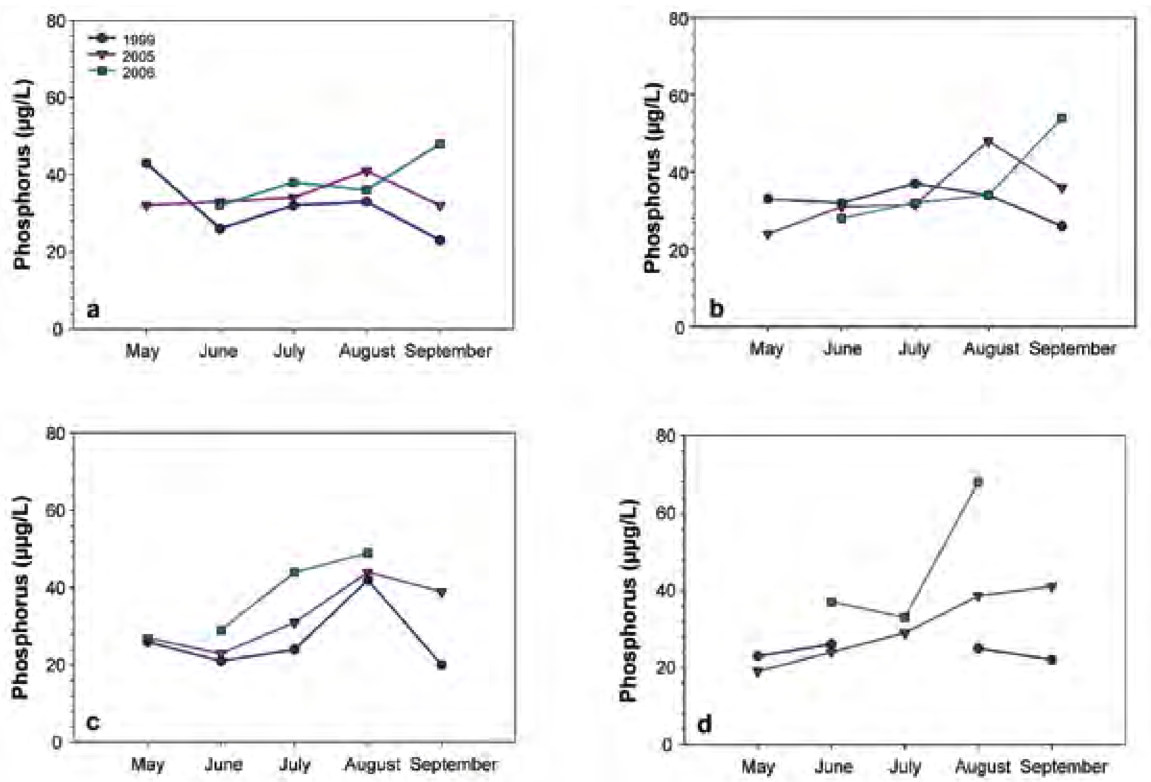

FIGURE 4.12. Total phosphorus concentrations for a) Four Mile Bay, b) Big Traverse Bay, c) Long Point, and d) Muskeg Bay for May-September 1999, 2005, and 2006.

east, and Clearwater/Echo Bays sectors (Figures 4.15 a-c, Figure 4.16). TP was highest in the north/central sector (Figure 4.16 a, Figure 4.17) and was lowest in Clearwater/ Echo Bays (Figure 4.15 c, Figure 4.16, 4.17).

There was also considerable spatial variation within each sector (Figures 4.15 a-c). In the north/central sector, Rat Portage and Donald Duck exhibited higher TP concentrations than Bigstone and Yellow Girl (Figure 4.15 a). In the east sector, Buff Island had the highest TP concentration, while Highrock Island had the lowest (Figure 4.15 b). Although there was minimal variation among sites within the Clearwater/ Echo Bays sector, the site at Clearwater Bay West had the highest TP concentration, while Echo Bay had the lowest (4.15 c). The mean TP for the north/central sector in 2004 and east sector in 2005 were higher than the mean TP of Clearwater Bay in 2004.

Sampling in Clearwater Bay has been ongoing by the OMNR-FAU since 1984, but the most complete recent record of nutrient data is available for the years 2003-2005. Based on data from these years, there was minimal variation between sites at the Clearwater/Echo Bays sector, with an increase in TP between 2003 and 2005 (with the exception of White Partridge and Echo Bays, which showed slight declines in TP between these years; Figure 4.16 a). In addition, there was an increase in chlorophyll-a concentrations for the Clearwater/Echo Bays sector between 2003 and 2004.

Based on the most recent data for all sites in both the northern (Canada OMNR-FAU data) and southern (U.S. MPCA data) sides of LOW, TP and chlorophyll-a concentrations were noticeably higher in the south (Figure 4.17). Furthermore, comparisons of spring and late-summer TP data from LOW demonstrate a general trend of increasing TP throughout the summer at the southern sites (Four Mile Bay, Big Traverse Bay, Long Point, and

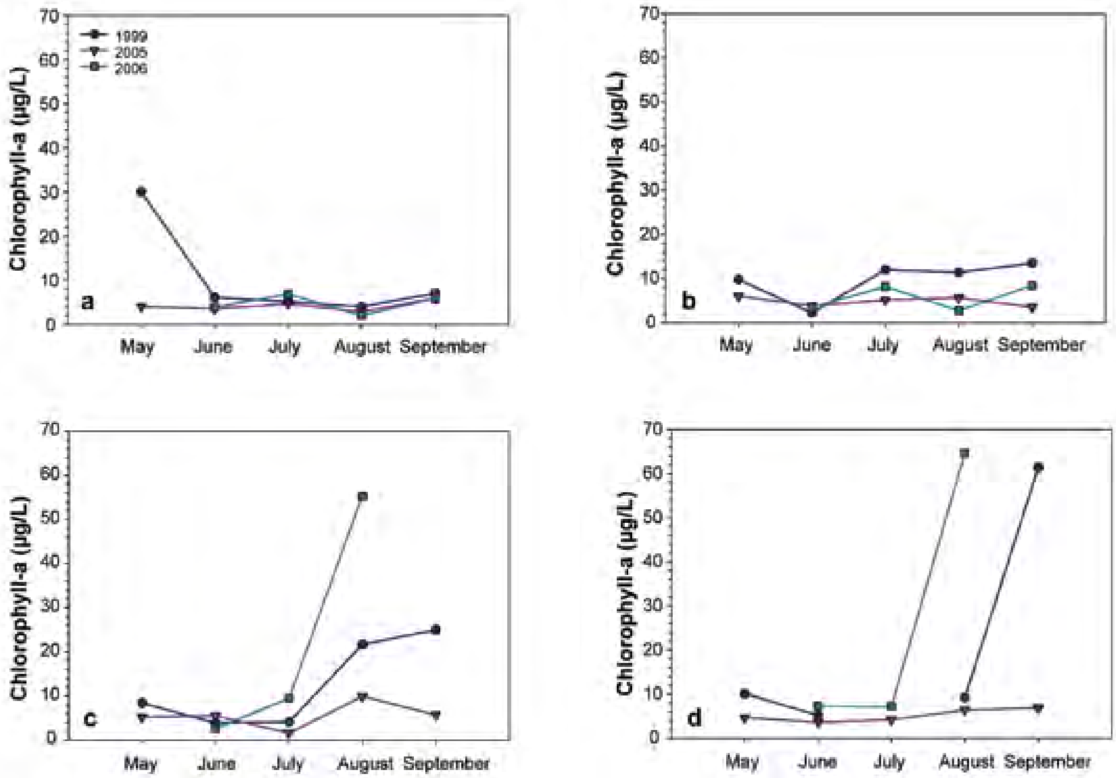

FIGURE 4.13. Chlorophyll-a concentrations for a) Four Mile Bay, b) Big Traverse Bay, c) Long Point, and d) Muskeg Bay for May-September 1999, 2005, and 2006.

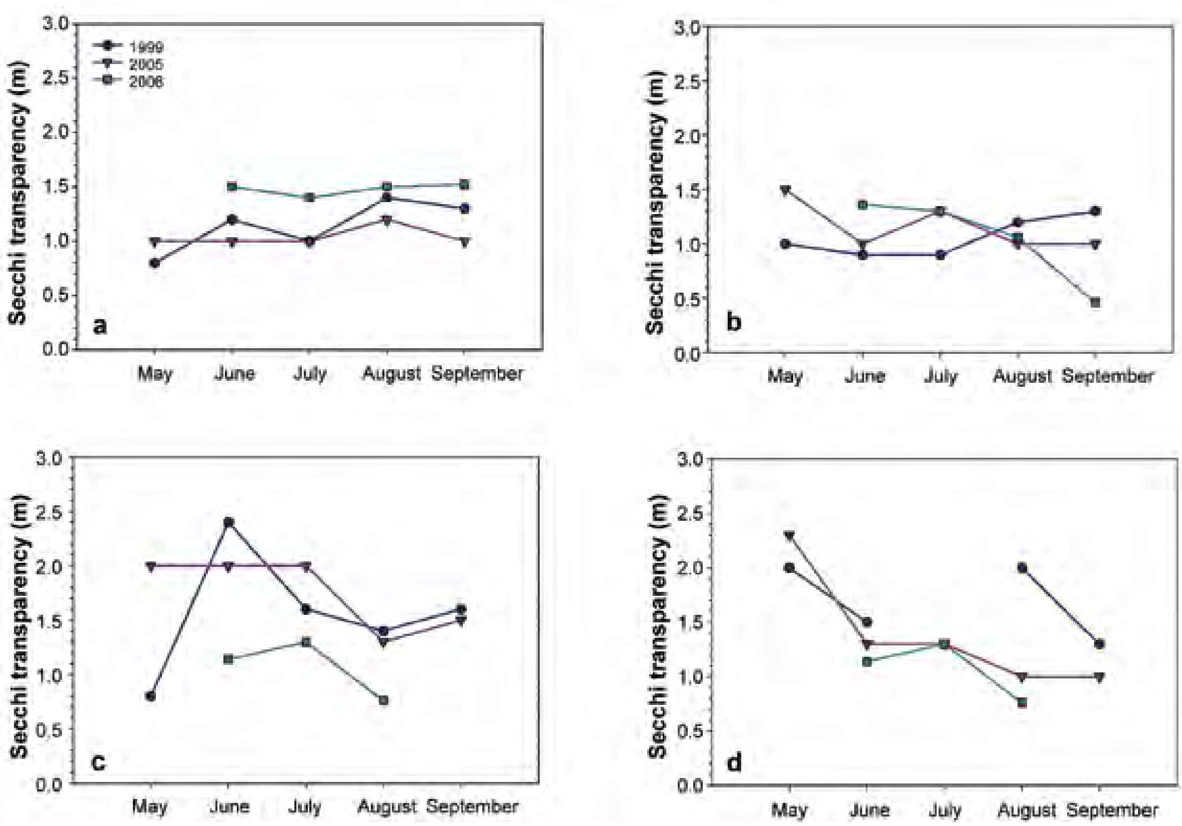

FIGURE 4.14. Secchi transparency for a) Four Mile Bay, b) Big Traverse Bay, c) Long Point, and d) Muskeg Bay for May-September 1999, 2005, and 2006.

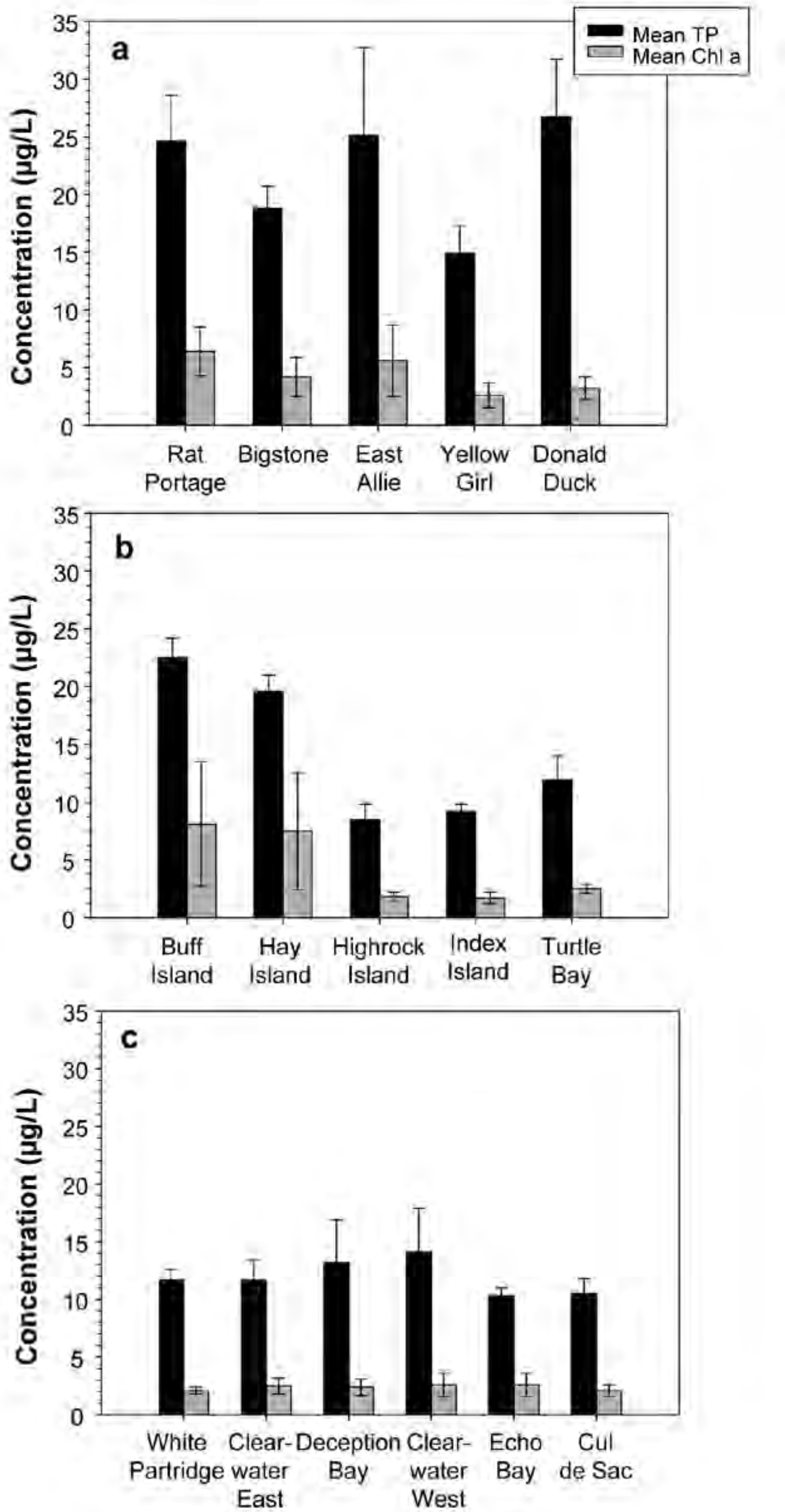

FIGURE 4.15. Mean TP and chlorophyll-a concentrations for three sectors on the Canadian side of Lake of the Woods, including a) the north/central sector in 2004, b) the east sector in 2005, and c) the Clearwater/Echo Bays sector in 2005. Data was obtained from the Ontario Ministry of Natural Resources Fisheries Assessment Unit.

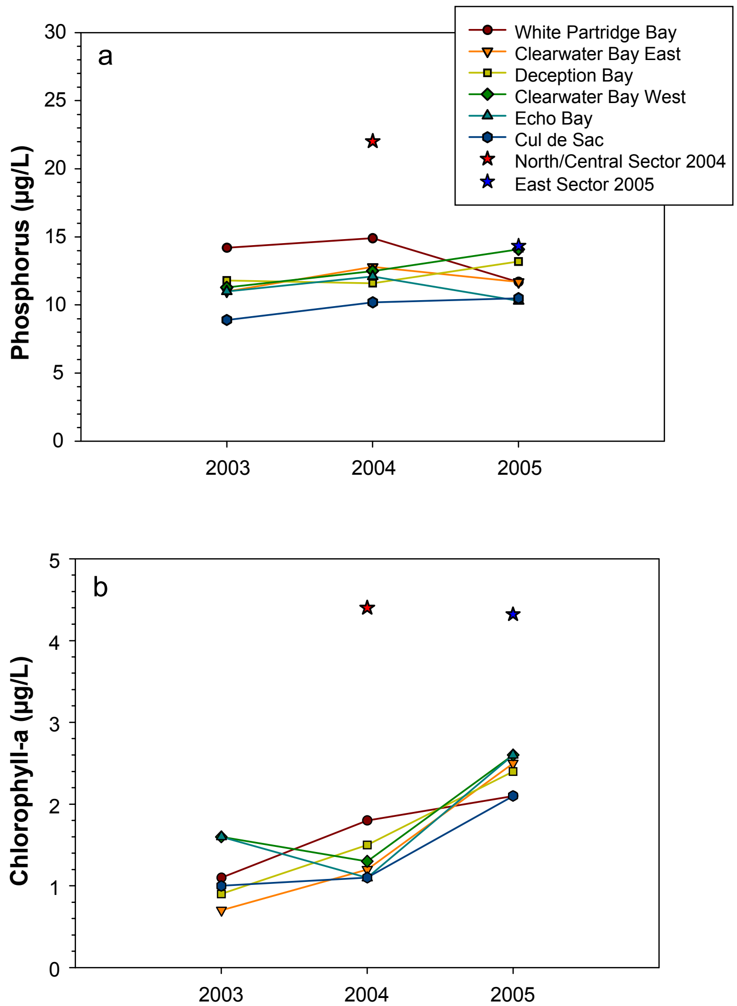

FIGURE 4.16. Variation in a) total phosphorus and b) chlorophyll-a concentrations for the six sites within the Clearwater/Echo Bays monitoring sector located within the northern portion of LOW for 2003-05. The stars represent mean concentrations for the north/central and east monitoring sectors in 2004 and 2005, respectively.

Muskeg Bay) and declining TP levels in at the northern sectors that are isolated from the main south-north direction of flow (Whitefish Bay, Clearwater/Echo Bays) (Figure 4.18). Increased nutrient loading in the southern portion of the lake or internal loading in the relatively shallow Big Traverse Bay throughout the summer months may explain this trend. The trend of decreasing TP throughout the summer months in the northern portion of the lake 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 epilimion to deeper, colder waters (Kalff, 2002).

Fluctuations in trophic status at individual sampling locations – the relationship between phosphorus and water clarity

The OMOE's 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 in 2002, there has been ongoing monitoring of several sites in LOW on a monthly basis, allowing examination of long-term trends in phosphorus and water clarity. LOW is one of the few places in Ontario where there is a strong relationship between water clarity and total phosphorus at individual sample locations. Phosphorus 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 phosphorus and water clarity. This relationship between phosphorus and water clarity is possible due to large seasonal changes in the phosphorus concentrations in this part of the lake which, in turn, influences the algal biomass. For example, there is a strong relationship between phosphorus and water clarity for a location near Coney Island in the northern portion of the lake (Figure 4.19). These seasonal changes are similar at many other locations in the northern part of the lake, although a wide range in phosphorus concentrations are noticeable (Figure 4.20). It is important to note that these patterns are similar between years and have not changed appreciably in recent years (Figure 4.21). These fluctuations in phosphorus concentrations are likely too large to be the result of local diffuse inputs (camp septic systems, etc.) and may be due to a pulse of nutrient rich waters from the southern, enriched portion of the Lake that receives the majority of its water directly from the Rainy River.

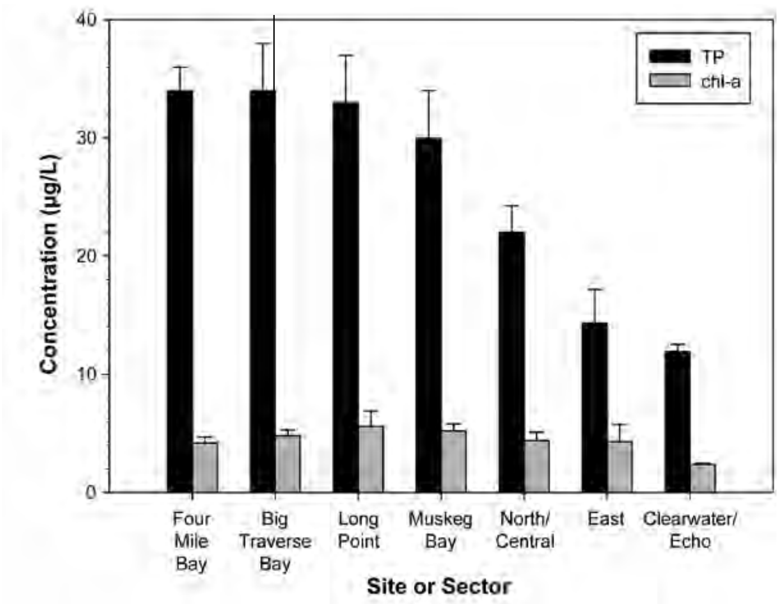

FIGURE 4.17 Mean TP and chlorophyll-a concentrations for the southern portion of LOW, including Four Mile Bay, Big Traverse Bay, Long Point, and Muskeg Bay (May-September, 2005), and northern portion of LOW, including the north/central (mean May, June, August, 2004), east (mean May, June, September, 2005), and Clearwater/ Echo Bays (May-August, 2005) sectors.

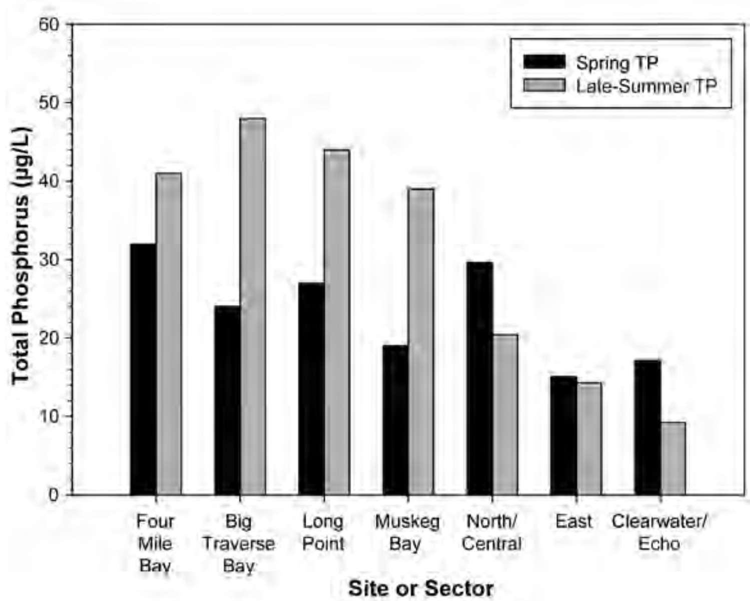

FIGURE 4.18. Comparison of spring versus late-summer TP concentrations for the southern portion of LOW, including Four Mile Bay, Big Traverse Bay, Long Point, and Muskeg Bay (May and September, 2005), and northern portion of LOW, including the north/central (May and August, 2004), east (May and September, 2005), and Clearwater/Echo Bays (May and August, 2005) sectors.

Lake watersheds, nutrient loading, and phytoplankton abundance

As mentioned previously (Section 3.4), the drainage ratio that combines the Lower Rainy River and LOW watersheds yields a ratio of 8.2:1 (WA:LA 31,624 km^2:3,850 km^2). It has been suggested that there is an increase in the importance of watershed sources of phosphorus when the drainage ratio is >5 (Carignan et al., 2000; Paterson et al., 2002). However, this pattern is dependent on the magnitude of the disturbance, such as the proportion of the local watershed that has been deforested (Carignan et al., 2000; Forrest et al., 2002; Nicholls et al., 2003) as well as the lake volume and water residence time or flushing rate (approximately 5.2 years for LOW), as incoming nutrients are likely to be diluted in larger volume lakes (Schindler, 1971). In LOW, the flushing times for the smaller, more isolated basins (Clearwater/Echo Bays, Whitefish Bay) are less impacted by water flow and are much more likely to be impacted by local watershed sources (Pla et al., 2005).

4.3. Paleoecology and the Reconstruction of Historical Water Quality

Knowledge of background or pre-impact conditions is important for environmental work, as it can assist in the establishment of realistic reference conditions or mitigation goals (Smol, 2008). Paleolimnology is the 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 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

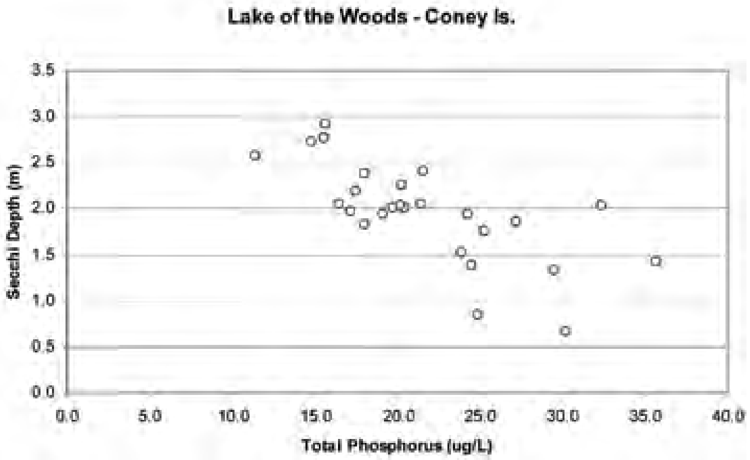

FIGURE 4.19. The relationship between water clarity and total phosphorus at Coney Island, Lake of the Woods. Data is from the Ontario Ministry of the Environment's Lake Partner Program and includes data from 2002 to 2007.

integrative, thus reducing inter-annual variability (Glew, 1988).

Paleolimnological studies commonly use detailed assessments of sediment core profiles. This method is advantageous because it provides a large amount of detailed information on ecological and environmental trends over long time scales. However, this approach is very time-consuming, and is often not practical from a management perspective (Smol, 2008). Alternatively, paleolimnologists may use the "top-bottom" paleolimnological approach, which is convenient because it provides a snapshot of present-day and pre-disturbance conditions in several lakes across a region in a time-efficient manner. With this approach, comparisons are made between indicators preserved in the surface sediment (i.e., sediment sample from the top of a core representing present-day

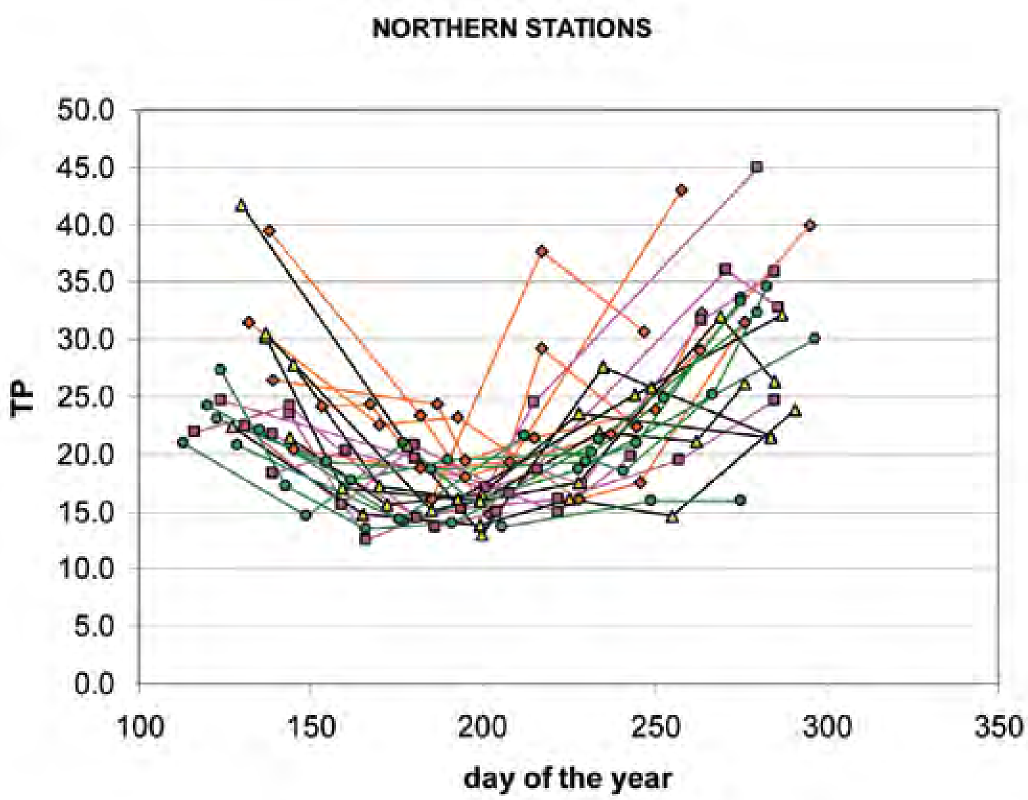

FIGURE 4.20. Seasonal total phosphorus concentrations at locations throughout the northern portion of Lake of the Woods (LOW). Each line is a different site within the northern portion of LOW. This monthly data is from the Ontario Ministry of the Environment's Lake Partner Program for the years 2002-2007 at several locations in the northern end of Lake of the Woods.

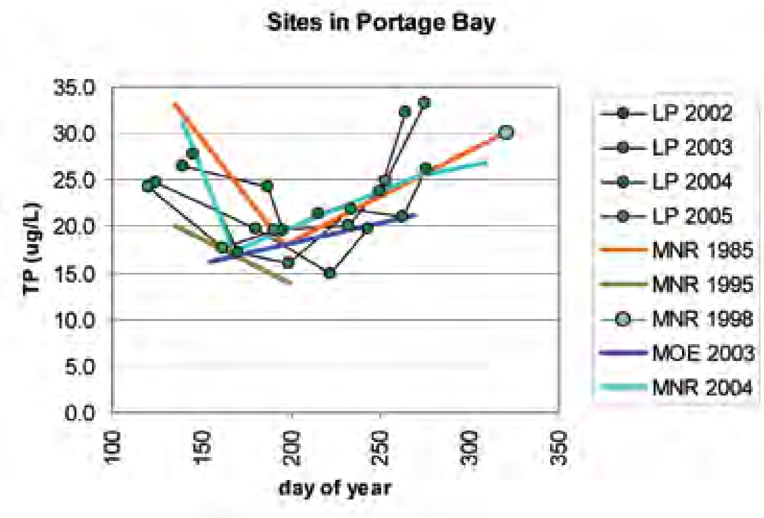

FIGURE 4.21. Seasonal phosphorus patterns between years in Portage Bay, Lake of the Woods. Data is from the Ontario Ministry of the Environment's (MOE) Lake Partner (LP) Program, the Ontario Ministry of the Environment's (MOE) sampling programs, and the Ministry of Natural Resources (MNR) Fisheries Assessment Unit in Kenora, ON.

conditions) and pre-industrial sediment (i.e., sediment sample from the bottom of a core, representing the pre-1850 time period). From this assessment, general questions can be answered about environmental change in many lakes across larger spatial scales. This section will outline previous and current paleoecological research on LOW (Figure 4.22 and Table 4.8).

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 (see landuse section). 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.

As a first step in assessing the spatial patterns in water quality across LOW, Pla et al., (2005) examined the surface sediment (i.e., "present-day") diatom assemblages in multiple cores from the LOW basin. Similar to the results presented in this report (Section 4.4 Nutrients and Trophic Status), Pla et al. used paleolimnological techniques from a number of sedimentary cores from LOW and determined that there are significant spatial trends in water chemistry across LOW and this is reflected in the sedimentary diatom assemblages. Notably, total phosphorus 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 deposition at sites with lower sedimentation rates, and thus more diverse assemblages are possible (after Smol, 1981).

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.

Stainton et al. (2007) collected six short sediment cores in 2002 (representing the last 150 years of sediment accumulation) from various regions in LOW in 2002, including

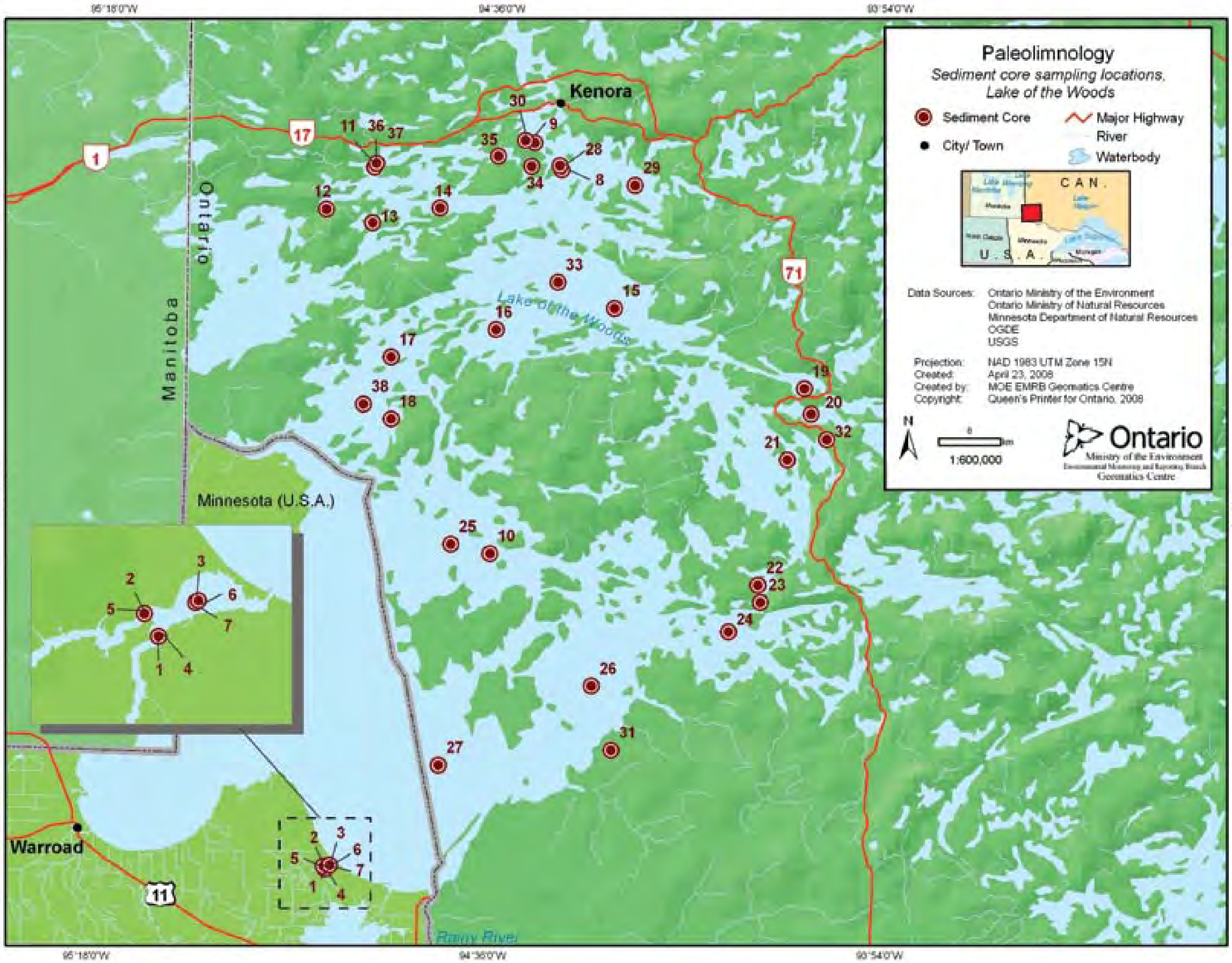

FIGURE 4.22. Locations of paleolimnological sediment cores that have been obtained in Lake of the Woods from 2004-05. Corresponding site codes are located in Table 4.7.

Grassy Reserve, Whitefish Bay, White Poplar Bay, Clearwater Bay, and Monkey Rocks. Sediment sections from these cores were analysed for their carbon, nitrogen, phosphorous and chlorophyll content and deposition rate. Two of the cores were analysed for biogenic silica and two for carbon and nitrogen stable isotopes. Profiles of the specific sedimentation rates of each constituent were determined. In addition to the chemical analyses performed by Stainton et al. (2007; see Water Quality subsection), quantification of siliceous and non-siliceous biological remains were performed on various sediment intervals from cores from Grassy Reserve, Whitefish Bay, White Poplar 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 et al. concluded that phosphorus concentrations increased significantly in lake sediments starting in the mid 1950s or so, with this trend being seen more in the areas of the lake subject to main basin flow than in the "isolated" bays of Clearwater/Echo Bay and Whitefish Bay.

RON INGRAM

An archive of information is preserved in this vertical sediment core.

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) and some eastern regions of the lake (Sabaskong Bay, Regina Bay) compared to shallow, more isolated (Long Bay, Whitefish Bay south) or macrophyte-rich (Turtle Lake) regions (Suchy & Hann, 2007).

Morphology, Geology, and Hydrological Control

Differences in morphology and geology among the different regions and basins of LOW are reflected in the sedimentary diatom assemblages (Pla et al., 2005). For example, sediment cores from regions on the Precambrian Shield (east and northwest) had diatom assemblages that are more typical of other lakes on the Precambrian Shield. Differences in morphometry were prevalent throughout LOW (Pla et al., 2005). For example, in sites 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 *Aulacoseira* taxa and an increase in the relative abundance of *Stephanodiscus* species, perhaps indicative of increased water column stability. 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 (Pla et al., 2005). Alternatively, planktonic species more common in mesotrophic conditions (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 also had marked effects on the lake's phytoplankton communities. 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 watershed of Namakan Lake have had impacts that have increased sedimentation rates, decreased species richness, and increased total phosphorus concentrations and conductivity.

Nutrient loading/erosion

Reavie & Baratono (2007) examined the sources and rates of sedimentation in Zippel Bay, a region of LOW that is experiencing shoreline erosion and elevated nutrients. They determined that the majority of fluvial sediments to Zippel Bay are originating at the South Arm and have drastically increased since the 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.


KATHLEEN RUHLAND

A sediment core is retrieved from a deep location in Lake of the Woods.

Climate change

The effects of climate change on LOW have been examined at two different time scales. Yang & Teller (2005) examined large-scale changes in LOW since 11,000 years B.P. and the change depth and size of LOW since the retreat of the Laurentide Ice Sheet in northwestern Ontario. After the separation of the lake from Lake Agassiz, LOW has expanded and deepened as a result of 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 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 2 x CO_2 (MacDonald et al., 1993).

Rühland et al. (2008) examined the sedimentary diatom assemblages from Whitefish Bay, LOW (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 extensive increases in the length of the ice-free season on LOW have caused a reorganization of diatom community composition that is typical of environmentally-sensitive Arctic lakes. Serieyssol et al. (2009) also found evidence of climate warming impacts in the sedimentary diatom communities in both Namakan Lake (a dammed lake) and Lac La Croix (a reference lake).

PART 2: BIOLOGICAL COMMUNITIES

5.1 Algal communities

Algal blooms on Lake of the Woods (LOW) have mystified residents and scientists for several decades. The earliest reports of algal blooms in LOW are over 200 years old 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 has been increasing concerns about deteriorating water quality and an increased frequency of severe algal blooms on LOW. This section provides a review of the current available knowledge on phytoplankton in LOW.

GERRY WILSON

Blue-green algae, Coney Island, September 2007.

Phytoplankton

Phytoplankton composition varies temporally (i.e., 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).

The phytoplankton of LOW are a relatively understudied group of organisms. As of 2007, there were no monitoring programs that routinely (weekly, monthly, or annually) sampled and characterized the phytoplankton communities in LOW and the Rainy River. In recent years, some 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 (Diatomeae; *Asterionella* spp., *Fragilaria* spp., and *Stephanodiscus* spp.) and small flagellates in Cryptophyceae (mostly *Cryptomonas* spp. and *Rhodomonas* spp.) constituted the highest portion of the total phytoplankton biomass in June. In July and August, diatoms were replaced by Cyanobacteria (Cyanophyta), green algae (Chlorophyta), and golden-brown algae (Chrysophyceae). Dinoflagellates (Peridineae) and photosynthetic flagellates (Haptophyta) were rare throughout the season. The cyanobacteria species that were present included *Aphanothece* spp., *Aphanizomenon flos-aquae*, *Anabaena flos-aquae*, *A. lemmermannii*, *A. mendotae*, *Homeothrix janthina*, *Pseudoanabaena* spp., *Aphanocapsa* spp., and *Woronichinia* spp. (refer to *Cyanobacterial and Algal Blooms*, below). These findings were similar 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. At sites located in the southern basin during the summer of 2005, Anderson et al. (2006b), reported similar findings, demonstrating that diatom abundances were moderately high throughout May and June, but cyanobacteria were the most important taxa, representing 65-80% of the phytoplankton community.

Benthic algae

Benthic algae are attached or closely

associated with aquatic substrate. Very little data exists on the benthic algal communities in LOW. In a preliminary study of the benthic algal community in Clearwater Bay, Kling et al. (Algal Taxonomy and Ecology Inc., Winnipeg, MB, 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 the control, unimpacted sites at 82%. 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.

TODD SELLERS

Nutrients and phytoplankton abundance

As noted previously (above and Section 4.2. Nutrients and Trophic Status), phytoplankton are primarily limited by phosphorus in Precambrian Shield lakes, as many are naturally oligotrophic and low in nutrients (Schindler, 1975; Hecky & Kilham, 1988). In these oligotrophic (nutrient-poor) systems, most lakes receive less phosphorus than nitrogen from their relatively undisturbed watersheds, and the ratio of nitrogen to phosphorus (N:P) is high (Downing & McCauley, 1992). This creates a state of phosphorus limitation of phytoplankton.

Lakes can receive nutrients from various external (e.g., fertilizers, wastewater, septic runoff, terrestrial sediments, atmospheric deposition) and internal sources (e.g., nutrient cycling and resuspension of nutrient-rich lake sediments). Some lakes have elevated background levels of nutrients, and thus are "naturally" meso- or eutrophic, such as a subset 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 (eutrophication; e.g., Nicholls & Dillon, 1978). This positive relationship between nutrient loading and lake productivity is well established (e.g., Dillon & Rigler, 1974; Schindler, 1978; Smith, 1982).

Cyanobacteria algal blooms

Algal blooms are often caused by phytoplankton in the group Cyanobacteria. 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. 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. In addition, they can accumulate in the viscera (liver, kidneys) of fish and in molluscs such as clams, although the levels that accumulate depend on the location and severity of the bloom (Health Canada, 2007). In the presence of a bloom, it is commonly recommended by Health Canada that no recreational activities 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).

One group of toxins produced by certain cyanobacteria are the neurotoxins. The three types of neurotoxins are anatoxin-a, anatoxin-a(s), and saxitoxin and neosaxitoxin. In freshwater environments, anatoxin-a can be produced by *Anabaena flos-aquae*, *Ana. spiroides*, *Ana. planctonica*, *Aphanizomenon flos-aquae*, *Microcystis* *aeruginosa*, *Cylindrospermum* sp., *Planktothrix agardhii*, and *P. rubescens* and anatoxin-a(s) can be produced by *Ana. flos-aquae*, *Ana. lemmermannii*, and *P. agardhii* (*sensu* Kotak & Zurawell, 2007). Saxitoxin and neosaxitoxin are known as the paralytic shellfish poisons (PSPs), but are produced by the freshwater cyanobacteria species *Aphanizomenon flos-aquae*, *Aph. issatschenkoi*, *Ana. circinalis*, *Cylindrospermopsis raciborskii*, *Lyngbya wollei*, *Planktothrix* sp., and possibly *Ana. lemmermannii* (*sensu* Kotak & Zurawell, 2007). Certain cyanobacteria species also produce hepatotoxins, which affect the liver. Hepatotoxins are produced by *Microcystis*, *Anabaena*, *Planktothrix*, *Anabaenopsis*, and *Nostoc* sp. (Kotak & Zurawell, 2007).

[There was a] positive correlation between surface water total phosphorus concentrations and total cyanobacterial biomass at 4 of 5 study sites [in LOW in 2005 and 2006].

Microcystin-LR

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.). Health Canada has recently established a drinking water guideline of 1.5 ug/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.

Elevated Microcystin-LR concentrations in LOW have been reported during the summer months in LOW (Chen et al., 2007; Kotak et al., 2007, unpublished data, *sensu* Kotak et al., 2007). For example, Microcystin-LR was detected in LOW water samples in 2004 and 2005 (Chen et al., 2007). The World Health Organization (WHO) has established risk categories for exposure to microcystin concentrations: <10 µg/L would cause minimal health effects, 10-20 µg/L would pose a moderate risk and >20 µg/L a high risk. In August and 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 (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). Off shore 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). In addition, Microcystin-LR has also been detected in clams and leeches in Lake of the Woods (H. Kling, Algal Toxonomy and Ecology Inc., Winnipeg, MB, unpublished data).

The limnological variables important in influencing the abundance of Microcystin-LR-producing cyanobacteria vary across Canada. In twelve naturally eutrophic Boreal Plain lakes in Alberta that are underlain by phosphorus-rich sediments, it was determined that the fluctuation of Microcystin-LR is negatively correlated to the nitrogen to phosphorus ratio in lakes (Kotak et al., 2000). However, it is likely that this relationship does 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). In four eutrophic lakes in Quebec's eastern townships, it was determined that cellular microcystin concentration was positively correlated to water column total nitrogen concentration (Rolland et al., 2005).
In these Quebec lakes, increased toxic cyanobacterial biomass occurred during periods of increased water column stability, higher light extinction coefficient, and low dissolved nutrients (Rolland et al., 2005).
In 22 lakes spanning a wide gradient of trophic status (4.9 – 130 µg TP/L), it was determined that biomass and toxicity of cyanobacterial algae was correlated to total concentrations of phosphorus and nitrogen, as opposed to their ratios (Giani et al., 2005). In LOW, Chen et al. (2007) found a

positive correlation between surface water total phosphorus concentrations and total cyanobacterial biomass at 4 of 5 of their study sites. This relationship was driven by the cyanobacteria species *Aph. flos-aquae*, which was dominant in the months of July and August. This species was also the dominant cyanobacterium in the southern basin during the summer months of 2005 (Anderson et al., 2006b). In addition, microcystin-LR toxin concentrations were positively correlated to surface water ammonium concentrations, but not to total cyanobacterial biomass (Chen et al., 2007). Microcystin-LR production in blooms in LOW during the summer of 2004 was attributed to *Anabaena* spp. and *Aphanocapsa* spp. (Chen et al., 2007), which has been shown in other studies on lakes in Quebec (Rolland et al., 2005), Lake Erie (Rinta-Kanto & Wilhelm, 2006), and other lakes worldwide (Conti et al, 2005; Lindholm et al., 2003).

5.2 Zooplankton

Zooplankton records provide another useful tool in the assessment of environmental change. They inhabit many aquatic environments and have 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 (i.e., phytoplankton) and bacteria. 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).

Since zooplankton size structure is influenced by size selective predation of planktivorous fish (Brooks and Dodson 1965; Sweetman & Finney 2003), most zooplankton sampling programs have provided some insight into planktivorous fish predation. For a short period of time during the late 1990s, the OMNR-FAU sampled zooplankton at various stations on LOW (Tables 5.1, 5.2; analysed by Dr. Richard Bland Associates, London, Ontario).

From 1992-1999, zooplankton sampling was included in the MNDNR (Baudette) sampling protocol to look at the relationship between zooplankton prey and their fish predators (Heinrich, 1990-2006). Their analyses 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 indicates 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 (Table 5.3). This is particularly useful because it provides a record of composition prior to the invasion of the spiny water flea (*Bythotrephes longimanus*), which was discovered in 2007 in the Rainy River and in Wheeler's Point at the outflow of Rainy River to LOW. Sampling by the MNDNR (Baudette) Fisheries Office was conducted from the first week of June at four week (near-monthly) intervals through August between the years 1992 to 1999 (Table 5.3; Heinrich, 1992). The sampling locations were 4 km northeast of the mouth of Zippel Bay and 2.5 km east of Long Point using an 80 μm mesh, a 30 cm diameter net, and 90% ethanol for preservation (for details see Heinrich, 1992–99). These data show an increase in crustacean (including cladoceran and copepod) and decline in rotifer total mean density (Table 5.3; Figure 5.1 a), and an overall decline in zooplankton species richness between 1992-1999 (Table 5.3; Figure 5.1 b). In 1999, it was reported that the smallest mean size of crustacean zooplankton consistently occurred in June, suggesting that zooplanktivorous fish are

TABLE 5.1. Crustacean zooplankton sampling information for different sites in the Ontario portion of Lake of the Woods, 1993-1995. Zooplankton were sampled from 1 m off the lake bottom to the surface by the Ontario Ministry of Natural Resources Fisheries Assessment Unit using a 80 μm Wisconsin net. Zooplankton were quantified by Dr. Richard Bland ssociates (London, Ontario).

		Zooplankton Species Abundance (#/L)				
	Species	Highrock (1993)	Index (1993)	Poplar Bay (1994)	Clearwater Bay West (1994)	Echo Bay (1994)
Copepods	*Cyclops bicuspidatus*	0.09	0.01	0.41	0.25	0.59
	Diaptomus sicilis	0.13	0.30	0.04	0.11	
	Diaptomus sp.				0.35	0.06
	Limnocalanus macrurus	0.14	0.01		0.25	0.56
	Senecella calanoides					0.09
	Nauplii	0.34	0.98	0.71	0.46	1.09
	Copepodids	3.25	4.14	7.64	4.47	7.60
	Total	3.94	5.44	8.80	5.89	9.99
Cladocerans	*Bosmina longirostris*	0.26	5.34	0.97	0.53	2.13
	Ceriodaphnia reticulata	0.01	0.03	0.34	0.04	0.18
	Chydorus sphaericus	0.02	0.08			
	Daphnia dubia	0.14	0.06	0.07		
	Daphnia longiremis		0.01			
	Daphnia recurvata	0.16	0.18	0.41	0.39	0.30
	Daphnia sp.				0.11	
	Diaphanosoma sp.	0.05	0.16	0.11	0.04	0.12
	Holopedium gibberum	0.02	0.01	0.04		0.06
	?*Ilyocryptus* sp.					0.09
	Total	0.66	5.86	1.94	1.11	2.88
Rotifers	*Asplanchna* sp.	0.40	0.07	3.07	0.50	1.66
	Brachionus sp.		0.04	0.07		
	Kellicottia longispina	0.31	0.22	2.17	2.70	3.02
	Keratella cochlearis		0.09	0.07	0.99	1.24
	Keratella quadrata		0.02	1.57	0.14	0.18
	Polyarthra sp.	0.04	0.02			
	Trichocerca cylindrica		0.06	0.45		
	Unidentified rotifers		0.09	0.45	0.07	
	Total	0.74	0.62	7.85	4.40	6.10
Grand Total		5.34	11.91	18.59	11.40	18.97

TABLE 5.2. Crustacean zooplankton species concentration for different regions of the Ontario portion of Lake of the Woods in 1993 and 1994. Data was obtained from composite zooplankton samples for each sampling date for the ice-free season (see Table 5.2.1.). Zooplankton were sampled from 1 m off the lake bottom to the surface by the Ontario Ministry of Natural Resources Fisheries Assessment Unit using a 80 μm Wisconsin net. Zooplankton were quantified by Dr. Richard Bland Associates (London, Ontario).

MNR Sampling Sites	Years	Months
Highrock	1993	May, August, November, Composite
Index Island	1993	May, August, November, Composite
Poplar Bay	1994	May, August, November, Composite
Clearwater Bay West	1994	May, August, November, Composite
Echo Bay	1994	May, August, November, Composite
Bigstone	1995	May, July
Donald Duck	1995	May, July

more prevalent in June with a decline in late summer (Heinrich, 1999). In addition, it was observed that rotifer abundance was lower during periods of high blue-green algal density (Heinrich, 1999).

Following the discovery of the spiny water flea (*Bythotrephes longimanus*) in Rainy Lake in 2006 and the Rainy River in 2007,

TABLE 5.3. Crustacean zooplankton mean length and density (by month or date) from two sampling locations in the Minnesota portion of Lake of the Woods by the Minnesota Department of Natural Resources (Baudette Fisheries Office). Sampling locations were 4 km northeast of the mouth of Zippel Bay and 2.5 km east of Long Point. All samples were collected with a 30 cm, 80 µm mesh plankton net and preserved with 90% ethanol. Modified from Heinrich (2007).

Year	Month	Mean Length (mm)	Density (number l^{-1})
1992	June		
	July		
	August		
1993	June		
	July		
	August		
1994	June	0.86	31.61
	July	0.76	23.33
	August	0.85	31.12
1995	June	---	---
	July	---	---
	August	0.95	28.3
1996	June	0.83	14.35
	July	1.17	14.43
	August	1.03	24.14
1997	June	1.4	8.67
	July	0.8	17.24
	August	0.9	21.69
1998	June	1.03	20.12
	July	0.97	10.29
	August	0.86	21.06
1999	June July August	---	---
2007	May-30	1.21	24.26
	Jun-14	1.27	25.7
	Jun-26	1.42	21.85
	Jul-13	1.03	16.19
	Jul-26	1.35	36.78
	Aug-06	1.19	20.91
	Aug-29	0.96	22.48
	Oct-01	1.05	11.7

the MNDNR (Baudette) office reinstated their zooplankton sampling program at weekly intervals for the 2007 ice-free season (T. Heinrich, MNDNR Baudette, Pers. Comm.). Of the zooplankton taxa identified between 1992-1999 and 2007, 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. (1992-1999 only) (Table 5.4). The MNDNR did not quantify rotifers in 2007.

In addition to the zooplankton sampling program being completed by the MNDNR, the OMNR (Fort Frances) is also planning to increase their sampling effort in the Rainy River to track potential shifts in the zooplankton community. However, there are currently no plans to conduct zooplankton sampling on the northern (Canadian) portions of LOW (T. Mosindy, OMNR Fisheries Assessment Unit, Kenora, Ontario, Personal Communication). 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 Cladocera in lake sediment cores (Paleoecology, see Section 4.3) 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.

5.3 Zoobenthos

The 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. The zoobenthos

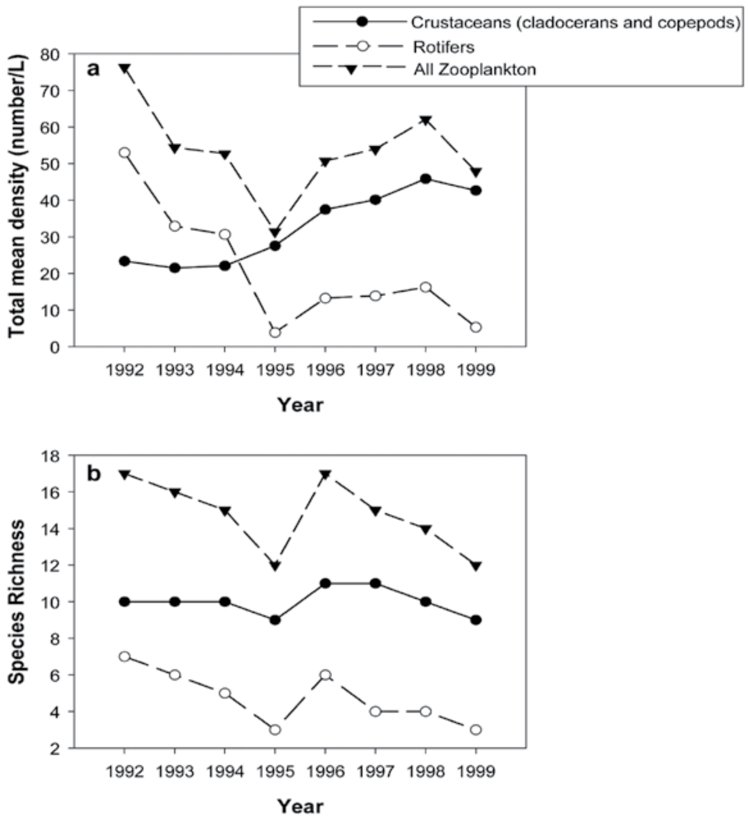

FIGURE 5.1. Total mean density (a) and species richness (b) of zooplankton Minnesota portion of Lake of the Woods from 1992-1999. Zooplankton were sampled using a net with a 30 cm diameter mouth and 80 μm mesh and were preserved with 90% ethanol. Data were pooled from samples taken at monthly intervals at two sampling sites (4 km northeast of the mouth of Zippel Bay and 2.5 km east of Long Point) using an 80 μm mesh, a 30 cm diameter net, and 90% ethanol for preservation (for details see Heinrich, 1992–99). Data were provided by the Minnesota Department of Natural Resources Baudette Office (for details, see Heinrich, 1992-1999)..

is normally species rich compared to the open-water zooplankton assemblages, with the highest numbers occurring in the littoral zone where the necessary resources are plentiful (including organic matter, oxygen and nutrients), temperatures are higher, and there is reasonable protection from fish and bird predators. This section will address the macrozoobenthos, which are zoobenthic organisms that are large enough to see with the naked eye (<1000-400 μm in length). Macrozoobenthos taxa, sometimes referred to as the macroinvertebrates, may include (but are not limited to) amphipods, crayfish, molluscs, snails, bivalves, larval insects (including dragonflies, damselflies, stoneflies, mayflies, blackflies, caddisflies, and midges), beetles, and water striders. Macrozoobenthic organisms are an important part of the diet of many fish species, such as perch and whitefish. Although the stomach content of lake trout and northern pike is >75% fish, their prey are largely dependent on the zoobenthos (Kalff, 2002). In addition, the zoobenthos provide food to other invertebrates and birds, such as grebes and ducks (Kalff, 2002). Since macroinvertebrate sampling in LOW and the Rainy River Basin has been sparse, baseline or long-term data are inconsistent and project-specific (T. Mosindy, OMNR, Fisheries Assessment Unit, Kenora, Ontario, Pers. Comm.; J. Vandenbroeck, Ministry of Natural Resources, Fort Frances, Ontario, Pers. Comm.) especially in LOW and the Canadian portion of the Rainy River Basin.

TABLE 5.4. Crustacean zooplankton species present at two sites in the Minnesota portion of Lake of the Woods 1992-1999, 2007. Zooplankton were sampled using a net with a 30 cm diameter mouth and 80 μm mesh and were preserved with 90% ethanol. Data were pooled from samples taken at monthly intervals at two sampling sites (4 km northeast of the mouth of Zippel Bay and 2.5 km east of Long Point). Data were provided by the Minnesota Department of Natural Resources Baudette Office (for details, see Heinrich, 1992-1999).

1992–1999			2007	
Copepods	**Cladocerans**	**Rotifers**	**Copepods**	**Cladocerans**
Diacyclops bicuspidatus thomasi	*Bosmina longirostris*	*Asplanchna* sp.	*Diacyclops bicuspidatus thomasi*	*Bosmina longirostris*
Epischura lacustris	*Chydorus sphaericus*	*Chonochilus* sp.	*Diaptomidae (mainly Leptodiaptomus minutus and Skistodiaptomus oregonensis)*	*Chydorus sphaericus*
Leptodiaptomus minutus and Skistodiaptomus oregonensis	*Daphnia mendotae*	*Chromogaster ovalis*	*Epischura lacustris*	*Daphnia galeata mendotae*
Limnocalanus macrurus	*Daphnia retrocurva*	*Filinia* sp.	*Limnocalanus macrurus*	*Daphnia retrocurva*
Mesocyclops edax	*Diaphanosoma birgei*	*Kellicottia* sp.	*Mesocyclops edax*	*Diaphanosoma birgei*
Tropocyclops prasinus mexicanus	*Eubosmina coregoni*	*Keratella quadrata*	*Tropocyclops prasinus*	*Eubosmina coregoni*
	Holopedium gibberum	*Keratella* sp.		*Leptodora kindti*
	Leptodora kindti	*Lecane* sp.		
	Sida crystallina	*Polyartha* sp.		
		Synchaeta sp.		

From 1977-1979, the MPCA conducted invertebrate sampling at an 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 another invertebrate survey of the Rainy River and the southern portion of LOW in 1987 by the MNDNR (MNDNR, 1987, unpublished data). The results demonstrated that the highest densities of invertebrates were in the upper reaches of the Rainy River as compared to that of 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 corresponding physico-chemical variables (including conductivity, turbidity, dissolved oxygen, pH, total phosphorus, total suspended solids, nitrogen, and waterflow) on one day at streams and wetlands in the Rainy River Basin, including two sites along the Rainy River and many of its tributaries (Table 5.5). This program is 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 (caddisflies); 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), and composition measures (e.g., percent Chironomidae, percent Diptera) (Table 5.5). The HBI estimates overall pollution by weighting abundance using tolerance values (Barbour et al., 1992). Redundancy analysis (RDA), a constrained ordination method, was run using the benthic metrics (Table 5.5) and the associated environmental data (including substrate type and HBI) for 26 stream and river locations, obtained from the MPCA's 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

TABLE 5.5. Representatives of the zoobenthos communities of 34 sampling locations in streams, tributaries, and rivers of the Rainy River Basin, Minnesota. Sampling was performed by the Minnesota Pollution Control Agency (MPCA) in 2005 as part of the MPCA's Biological Criteria Development Program (MPCA, 2007) and the Environmental Monitoring Assessment Program (EMAP; McDonald, 2000; McDonald et al., 2004). Sampling protocols defined by the USEPA's Rapid Biological Assessment Protocol (Barbour, 1999). Data was obtained from the MPCA's Environmental Data Access (EDA; http://www.pca.state.mn.us/data/edaWater/index.cfm). **NOTE:** This table is continued on the next page.

Station Name	Latitude (decimal degrees)	Longitude (decimal degrees)	County	Substrate	EPT no.	HBI	Intolerant Families	Pollution Tolerant Taxa (%)	Dominant Taxa (%)
Little Fork R.	475930	931331	Koochiching	--	10	5.6	2	26.2	25.3
Sturgeon R.	481248	935332	Koochiching	gravel	18	5.1	9	2.2	47.2
Black R.	482749	934844	Koochiching	sand	12	6.4	3	5.0	71.8
Trib. to E. Branch Warroad R.	484606	951404	Roseau	gravel	7	4.7	3	2.3	38.9
North Branch Rapid R.	483148	943649	Lake of the Woods	gravel	15	5.1	2	11.5	21.3
Beaver Brook	482127	932155	Koochiching	clay	9	4.2	1	5.8	28.5
Little Fork R.	480756	932749	Koochiching	--	12	4.4	4	12.4	30.9
Beaver Brook	482418	933102	Koochiching	gravel	10	4.0	3	5.8	20.1
Rapid R.	483453	942631	Lake of the Woods	sand	10	5.5	4	0.0	56.7
Little Fork R.	481052	932904	Koochiching	--	9	5.8	2	32.8	27.2
Little Fork R.	475811	931033	Koochiching	--	10	5.1	4	18.0	24.0
Black R.	482800	935848	Koochiching	sand	8	5.6	3	0.0	48.5
Big Fork R.	481237	935256	Koochiching	gravel	17	4.4	7	1.2	29.8
Rapid R.	484052	942533	Koochiching	--	12	5.1	3	1.8	49.1
West Branch Black R.	483124	934924	Koochiching	sand	8	5.8	2	14.0	38.1
East Fork Rapid R.	482817	941935	Koochiching	sand	10	5.9	1	1.9	68.1
Little Fork R.	482360	933355	Koochiching	--	12	4.4	5	1.0	38.7
Plum Creek	475642	934751	Koochiching	sand	7	4.7	2	1.8	43.4
Moose Creek	482948	943605	Lake of the Woods	gravel	9	5.6	1	0.8	59.7
Baudette R.	484152	943530	Lake of the Woods	--	7	2.0	1	12.6	67.1
Barton's Brook	483223	942758	Lake of the Woods	sand	7	5.3	2	0.8	61.2
Rapid R.	483111	943733	Lake of the Woods	sand	13	5.3	2	0.9	47.0
Trib. to Baudette R.	483740	943737	Lake of the Woods	sand	8	5.4	1	1.2	30.8
Peppermint Creek	484132	944253	Lake of the Woods	gravel	12	5.3	6	2.7	43.2
West Fork Baudette R.	483950	943857	Lake of the Woods	silt	9	5.1	1	17.9	21.8
Winter Road R.	484258	944151	Lake of the Woods	gravel	15	3.8	6	1.3	39.0
North Branch Rapid R.	482853	945738	Lake of the Woods	sand	8	4.4	1	6.4	26.8
Nett Lake R.	489109	931848	Koochiching	sand	8	5.3	2	6.0	38.3
East Branch Warroad R.	484508	950758	Roseau	sand	8	5.3	3	0.4	60.2
Warroad R.	485314	951934	Roseau	--	4	2.3	1	8.2	60.3
Tomato Creek	484644	950124	Lake of the Woods	--	6	5.5	2	5.7	71.1
West Branch Warroad R.	485122	952227	Roseau	sand	10	5.0	2	7.5	53.7
Beaver Brook	481804	931602	Koochiching	sand	13	5.0	2	3.7	37.5
Silver Creek	484032	942906	Lake of the Woods	gravel	13	4.5	5	2.5	21.2

TABLE 5.5 continued

Code	Dominant 2 Taxa (%)	Filterers (%)	Gatherers (%)	Scrapers (%)	Chironomidae (%)	Diptera (%)	Hydropsychidae (%)	Ephemeroptera Taxa	Plecoptera Families	Trichoptera Families	Total Families
1	38.7	4.4	58.7	18.0	25.3	27.0	0.0	5	0.0	5	29
2	58.1	18.8	63.8	3.1	47.2	52.8	5.6	7	2.0	9	32
3	74.8	1.5	80.7	4.5	71.8	72.7	0.0	6	1.0	5	26
4	60.6	12.4	75.5	2.8	38.9	48.2	11.0	2	1.0	4	25
5	38.1	12.2	53.5	27.1	21.3	26.7	8.8	8	1.0	6	29
6	47.9	1.2	55.8	36.7	28.5	29.7	1.2	4	0.0	5	26
7	48.5	3.3	70.3	17.0	30.9	32.7	0.0	7	0.0	5	28
8	35.1	0.6	75.0	13.6	20.1	21.1	0.0	5	1.0	4	24
9	70.8	14.8	66.2	9.5	56.7	61.0	14.1	5	2.0	3	18
10	39.8	3.7	42.5	28.6	12.6	17.5	0.0	5	0.0	4	32
11	38.9	3.7	61.7	20.9	24.0	26.0	0.3	5	1.0	4	31
12	62.4	14.2	66.8	10.5	48.5	64.1	0.3	5	1.0	2	17
13	46.6	51.0	40.6	3.0	21.8	27.8	17.9	6	3.0	8	25
14	68.0	0.9	68.0	20.1	49.1	51.5	0.3	5	3.0	4	24
15	56.7	40.1	37.2	3.2	18.6	56.7	0.0	6	0.0	2	20
16	74.7	1.3	84.7	4.2	68.1	70.9	0.3	5	0.0	5	29
17	62.3	1.0	74.1	20.9	38.7	39.4	1.0	6	2.0	4	20
18	69.6	0.6	83.4	10.8	43.4	46.4	0.0	4	0.0	3	19
19	77.2	18.0	75.8	5.1	59.7	60.0	17.5	5	0.0	4	19
20	77.2	0.8	76.7	5.8	3.3	3.3	0.0	4	0.0	3	24
21	71.9	7.0	84.9	4.4	61.2	63.5	5.2	4	0.0	3	19
22	65.9	2.2	62.8	22.4	47.0	53.3	1.3	6	2.0	5	24
23	54.9	39.0	53.3	6.3	24.2	56.6	7.3	5	0.0	3	20
24	58.3	17.5	64.2	12.1	43.2	45.0	15.1	3	2.0	7	28
25	39.1	4.5	55.4	20.5	17.3	22.1	0.3	5	0.0	4	29
26	61.8	24.3	26.3	46.4	9.3	10.4	22.8	4	4.0	7	27
27	51.5	1.5	86.0	9.1	26.8	29.0	1.2	4	0.0	4	19
28	57.9	3.3	69.9	22.7	38.3	39.0	0.0	4	0.0	4	24
29	79.1	20.9	69.4	7.0	60.2	63.3	18.9	3	0.0	5	24
30	69.3	0.0	77.3	17.8	6.3	6.3	0.0	3	0.0	1	18
31	82.7	0.6	83.0	6.3	71.1	76.1	0.3	2	0.0	4	24
32	77.3	4.7	80.6	8.2	23.6	26.9	0.5	3	1.0	6	28
33	58.8	1.1	78.5	11.4	37.5	41.0	0.3	6	0.0	7	30
34	40.5	33.7	45.7	16.9	5.2	25.5	12.9	5	1.0	7	27

significant). In addition, the sand and gravel sites exhibited significant differences in their HBI and EPT scores (Parametric t-test, $P < 0.05$), while there were no significant differences between sites with the two substrate types based on the other environmental variables (Parametric t-test or Non-parametric Mann-Whitney rank sum test, $P > 0.05$). These results demonstrate that benthic macroinvertebrate communities in the Rainy River 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 (Figure 5.2). Sites on the left side of the biplot have higher HBI scores and thus may be more perturbed by disturbances such as organic pollution as compared to sites on the left side of the biplot. Axis 2 represents a gradient of substrate type and ion concentration, including conductivity, turbidity, and pH. Sites in the upper portion of the biplot are typically sandy and turbid with low conductivity, whereas sites in the lower portion of the biplot have higher conductivity and pH (Figure 5.2). These results are consistent with other literature demonstrating that substrate composition is important in influencing invertebrate communities (e.g., Erman & Erman, 1984; Richards et al., 1993), although other factors related to stream morphology, flow, macrophytes, and predation are likely important as well (e.g., Hawkins et al., 1982).

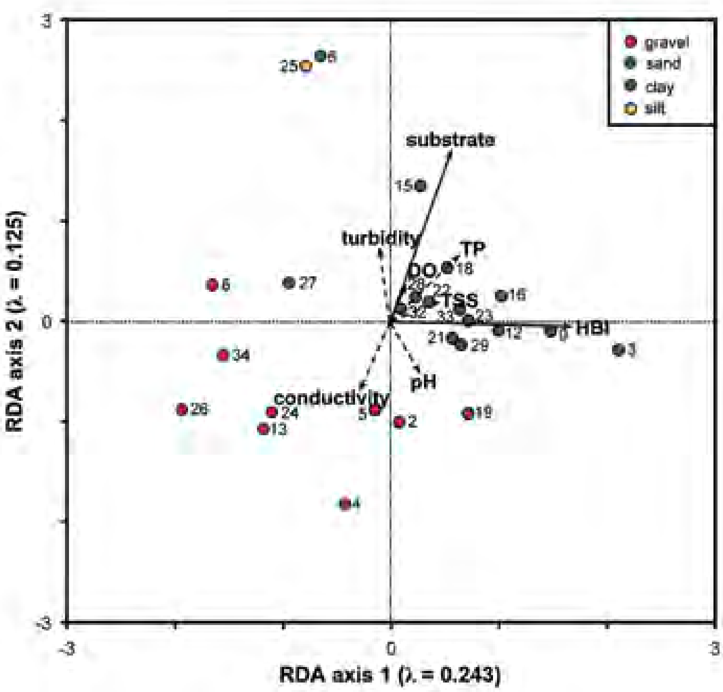

FIGURE 5.2. Redundancy analysis (RDA) ordination plot showing the site scores in relation to the environmental variables from 24 stream, tributary, and river locations sampled by the Minnesota Pollution Control Agency (MPCA) in 2005. The solid arrows represent the environmental variables that significantly (Monte Carlo Permutation Test, 999 Permutations, $P < 0.05$) influenced macroinvertebrate assemblages. Macroinvertebrate data used in this analysis is located in Table 5.5 (note: sites in which substrate composition was not specified were eliminated from the RDA).

5.4 Aquatic Macrophytes

It is well known that the aquatic macrophytes are affected by changes in their environment. From a management perspective, macrophytes have important limnological effects on aquatic ecosystems. They are important in stabilizing lake and river sediment, they influence the chemical conditions of the sediment and water, they are involved in nutrient cycling as well as the production and processing of organic matter, and the provide structured habitat for fish and their prey (i.e., invertebrates) (Carpenter & Lodge, 1986).

Despite their importance to ecosystem processes, macrophytes have not been surveyed in LOW or the Rainy River Basin. However, several macrophyte surveys have been conducted on Shoal Lake near Clearwater Bay, LOW (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).

5.5 Fish Communities and Fisheries

The ecological and economical importance of the LOW and Rainy River fisheries have made them the core of many research programs in the region. Fisheries responsibilities for the Ontario portion of LOW fall upon the LOW area manager at the OMNR-FAU in Kenora, Ontario. This office has been conducting ongoing long-term monitoring on LOW since 1984, the results from which are used in local fisheries management programs and in comparisons to other fish communities in Ontario. The Ontario portion of LOW has been divided into seven sectors based on differences in water chemistry, limnology, fish communities, and user group patterns (OMNR/MNDNR, 2004). The FAU monitors these sectors on a rotation of every two years as follows: North and Central sectors in 2003/04; Whitefish and Sabaskong Bays in 2005/06; and South Sectors 5 and 6 in 2007/08. The Rainy River/Manitou area managers at the OMNR Fort Frances, Ontario office are responsible for fisheries within the Rainy River.

The ecological and economical importance of the LOW and Rainy River fisheries have made them the core of many research programs in the region.

Fisheries management for the Minnesota portion of LOW and the lower extent of the Rainy River are under jurisdiction of the Area Fisheries Managers and staff at the MNDNR office in Baudette, Minnesota, while the upper reach of the Rainy River is the responsibility of the MNDNR 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 walleye lakes and has been in effect since 1983.


LAKE OF THE WOODS MUSEUM

Sport fishing on Lake of the Woods.


LAKE OF THE WOODS MUSEUM

Pulling up nets through the ice —commercial fishing on Lake of the Woods.

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/MNDNR, 2004) and are summarized in Table 5.6. This document is published every five 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). For the purposes of this report, general background information on the fisheries of LOW are provided. In addition, some specifics of three recreationally and economically important fish populations, sturgeon (*Acipenser fulvescens*), walleye/sauger (*Stizostedion vitreum / Sander canadensis*), and lake trout (*Salvelinus namaycush*) are included. Further details can be obtained in the *Fisheries Atlas* (OMNR/MNDNR, 2004).

Since the 1800s, the fisheries industry on LOW and Rainy River has been intense and has grown rapidly on both the American and Canadian sides of the border (Schupp & Macins, 1977). For many years, the theoretical yields of some commercially harvested fish (including cisco, white sucker, sturgeon) were exceeded, and sportfishing and angling increased this pressure. Exploitation of fisheries, especially walleye, was the primary influence on percid yields through 1888-1973, and continued 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. At the time, waste deposits from pulp and paper mills at International Falls and Fort Frances were likely impacting fish.

Lake Sturgeon
(Acipenser fulvescens)

Lake sturgeon are the largest fish found in both Ontario and Minnesota waters. Their mean age at maturity 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 Big Traverse Bay and the Rainy River (Rusak & Mosindy, 1997). These fish are specialized bottom feeders and use their long snouts

Keeping the harvest limits [for lake sturgeon] below the potential yield would allow the population to continue to recover to a healthy size and age structure.

to stir up the lake and river bottoms. Using their barbells they can detect and feed on small fish, crustaceans, mollusks, and other benthic organisms.

Lake sturgeon were 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 resulted in drastic declines in lake sturgeon on LOW and the Rainy River. Pollution from pulp and paper mills at International Falls and Fort Frances in addition to municipal discharges during the 1800s to mid-1900s caused water quality and nursing and spawning habitats to deteriorate. This led to further declines in fish populations. Since the passage of the Clean Water Act in the late 1960s, and legislation involving limits on sturgeon harvest, water quality in the Rainy River has improved and sturgeon recovery has been slow and gradual (Mosindy & Rusak, 1991).

A management plan for lake sturgeon has been developed by Ontario, Minnesota, and Rainy River First Nation biologists (Ontario-Minnesota Fisheries Committee). 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 (OMNR/MNDNR, 2004). The goals of this program are outlined in the *Ontario–Minnesota Boundary Waters Fisheries Atlas* (OMNR/MNDNR, 2004). The objective is to provide a subsistence recreational and commercial fishery and some trophy fishing for fish greater than 183 cm in length. 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/MNDNR, 2004). Today, harvest through sport fishing is minimal in Ontario due to the high minimum harvest length of approximately 165 cm total length (114 cm from opening to posterior edge of dorsal fin; Topp & Stewing, 2005). In Minnesota, the primary harvest pressure is through sport-angling, where only one sturgeon per license year between 45 and 50 inches or over 75 inches total length can currently be harvested. 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. However, mean annual harvest decreased to 3,062 kg in 2004 and 2005 (Topp & Stewig, 2005). 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). May 8 – May 15 2007 and October 1 2007 – April 23, 2008, only catch-and-release was permitted.

To assess recovery of the sturgeon population, an intensive tagging survey was performed in 2004 as a collaboration between the MNDNR, OMNR, and the Rainy River First Nation (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).

In general, 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. It has been recommended that the present level of harvest be maintained for at least 5-10 years (Stewig, 2005) to allow the sturgeon population to continue to expand. Short-range (next 5 to 10 years) and long-range (next 20 to 30 years) goals are outlined in the *Ontario–Minnesota Boundary Waters Fisheries Atlas* (OMNR/MNDNR, 2004). In order to reduce angling pressure on sturgeon populations, the harvest limits were made more restrictive in 2001 and 2002 in Minnesota (Heinrich, 2006). This would allow fish greater than 152 cm (60 inches) and 30 years, which were still below recovery goals at the time of this study, to subsist, for although the population is recovering, it has few individuals over 40-50 years of age (Heinrich, 2006). Keeping the harvest limits below the potential yield would allow the population to continue to recover to a healthy size and age structure (Heinrich, 2006; OMNR/MNDNR, 2004). The sturgeon tagging effort was reduced in 2006 and included only the Rapid River and Sturgeon River (Ontario) spawning sites. As well, the RRFN tagged wild-caught fish used in their sturgeon culture program and the U.S. Fish and Wildlife Service tagged fish captured in Four Mile Bay to collected tissue samples used in a disease study.

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

TABLE 5.6. Details of the fisheries sampling methodologies employed by the Minnesota Department of Natural Resources and the Ontario Ministry of Natural Resources on Lake of the Woods and the Rainy River. This information is detailed in the Ontario – Minnesota Boundary Waters Fisheries Atlas (OMNR/MNDNR, 2004).

	Minnesota Department of Natural Resources (MNDNR), Baudette and International Falls, Minnesota	Ontario Ministry of Natural Resources (OMNR) Fisheries Assessment Unit (FAU), Kenora, Ontario
Jurisdiction	- Baudette, MN office: Minnesota portion of LOW and lower reach of Rainy River - International Falls, MN office: upper reach of Rainy River	- Ontario portion of LOW; divided into seven sectors that are sampled on a 2-year rotational basis
Sampling methodologies/strategies	- follows Large Lake Sampling Guide (Wingate and Schupp, 1983) - young-of-the-year [walleye (*Sander vitreus*), sauger (*Sander canadensis*), and yellow perch (*Perca flavescens*)] and forage abundance assessments with seines and/or trawls during July and August - fall gill net assessments for walleye, sauger, and yellow perch during September - spring electrofishing assessments for spaqning walleye at Long Sault Rapids (Baudette office) - spring lake sturgeon (*Acipenser fulvescens*) tagging and assessments in Four Mile Bay, the Inside Channel, and Rainy River (Baudette office) - northern pike (*Esox lucius*) spawning assessment after ice-out in tributaries on south shore of LOW and Rainy River (Baudette office) - spring electrofishing assessment for walleye and smallmouth bass (*Micropterus dolomieu*); fall electrofishing for walleye (International Falls office) - spring assessments for black crappie (*Pomoxis nigromaculatus*) and rainbow smelt (*Osmerus mordax*) (International Falls office)	- index gill netting - spring littoral index netting to assess lake trout (*Salvelinus namaycush*) - fall walleye index netting - spring and fall trap netting to assess important spawning populations - commercial fish sampling to monitor commercial harvest - shoreline seining for forage and young-of-the-year fish
Fisheries assessments	- Rainy River: 1997 and 2000; summer 2001 and 2002 - Northwest Angle fishery: two-year out of six-year rotation, last surveyed summer 2002 - LOW winter fishery: sampled annually 1998-98 through to winter 2002-03 - spring northern pike fishery assessment from 1997-98 as part of experimental northern pike regulation evaluation	- North and Central sectors in 1997-98 and 2003/04; Whitefish and Sabaskong Bays in 1999/2000 and 2005/06; and South Sectors 5 and 6 in 2002/02 and 2007/08.
Creel surveys	- Annual spring and summer surveys in LOW and the Rainy River	- Lakewide in 1999 and 2002 to assess openwater angling - Winter surveys in Whitefish Bay (1997, 1999, 2000, 2003), Sabaskong Bay (1997, 1999, 2000, 2001, 2002), and the North and Central Sector (2001, 2002)

> Variation in water chemistry, dissolved oxygen, and temperature between sites and years makes it difficult to predict the quality of [lake trout] habitat a site will have from year to year.

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 (Ruskak & 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).

Walleye / Sauger
(Stizostedion vitreum / Sander canadensis)

Walleye and sauger are commercially important piscivorous fish, although their diet will include invertebrates (copepods and crustaceans) and small fish during the first few months of their life. One study on LOW 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 (Swenson, 1977).

Walleye have been tagged at several spawning sites in LOW and the Rainy River to determine movement patterns, and it was determined that most walleye travel within 10-15 km of their spawning area, including across jurisdictional boundaries (OMNR/MNDNR, 2004). Spring walleye electrofishing is performed by the MNDNR to assess whether the walleye populations are becoming stressed from overharvesting. This is done by monitoring the abundance of large walleye and the size distribution of the spawning stock in the Rainy River (Heinrich, 2006).

The Canadian resident daily catch/possession limit for walleye and sauger was reduced from six to four with a Conservation Licence, and only one greater than 46 cm (18 inches) in total length (OMNR/MNDNR, 2004). Non-Canadian residents fishing in the region are limited to two walleye or sauger with four in possession, and only one greater than 46 cm (OMNR/MNDNR, 2004). For the Rainy River, the daily catch/possession limit is two walleye or sauger from March 1 to April 14, with no larger than 46 cm (18 inches; OMNR/MNDNR, 2004). Daily catch and possession limits in the Minnesota portion of LOW during the opening of the season in May to November 30 is eight fish, and not more than six can be walleye.

Lake Trout
(Salvelinus namaycush)

Clearwater Bay, located in the northwestern region of LOW, is unique because of its deep, cool, and clear bays that are ideal lake trout habitat. This region of LOW was known for its trophy lake trout fishery. 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 oxygen levels, and above average nutrient levels, including total phosphorus and chlorophyll-a (Mosindy, 1987). More specifically, declining deepwater dissolved hypolimnetic oxygen levels and deteriorating spawning sites due to shoreline residential development and increased nearshore macrophytes and algal material were targeted as the main causes of lake trout decline.

Clearwater Bay had been developed for cottages, residences, and other tourism-related properties since the early 1900s. This development went unchecked until the early 1990s when guidelines were put in place. These guidelines, outlined by the Clearwater Bay Restricted Area Order, were recommended by the OMNR to halt further development of the Clearwater Bay region and preserve lake trout habitat and other important ecosystems. In addition, a Clearwater Bay Lake Trout Strategy was developed by the OMNR in consultation with Clearwater Bay Advisory Committee and stakeholders in late 1980's. Based on the results of Mosindy (1987), the OMNR and the Clearwater Bay Fisheries Advisory Committee recommended the closure of the winter lake trout fishery on Clearwater Bay, Echo Bay, and Cul de Sac in LOW in 1988, and a tag system was adopted for harvesting lake trout. This tag system limits one lake trout per angler per tag, and tags are awarded based on a lottery system. In addition, fish cannot be used as bait for lake trout; 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 attempt to minimize nutrient additions.

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, 1984 would serve as baseline for future studies. Four sites were monitored within this region (Clearwater Bay East, Clearwater Bay West, Deception Bay, and Echo Bay) every 5 years from 1984-2007. In 2002, two additional sites were included in the sampling (White Partridge Bay and Cul de Sac).

Although there is spatial and temporal variation in water quality in Clearwater and Echo Bays, there were no significant trends in nutrients or chlorophyll-a concentrations at sites in this region (e.g., Section 4.2, Figure 4.16). However, studies have demonstrated that there is considerable variation in optimal lake trout habitat (based on dissolved hypolimnetic oxygen levels) between sites and years in LOW (Mosindy, 2006). Mosindy (2006) determined the amount of available lake trout habitat for each of the six OMNR sampling sites within Clearwater Bay. Lake trout habitat quality was classified into three categories based on temperature and dissolved oxygen concentrations during mid-September, as defined by Evans (2007) (Figure 5.3). This is the critical period for lake trout because the temperatures above the thermocline have not yet fallen below 15ºC. Although there was considerable temporal and spatial variation among sites, the deepest site, Clearwater Bay at ~50 m, and Deception Bay at 32 m, had the most lake trout habitat of all sites based on dissolved oxygen and temperature (Figure 5.3; Mosindy, 2006). However, two other deep sites, Clearwater Bay East (~32 m) and Echo Bay (37 m) had the least amount of optimal lake trout habitat (Figure 5.3; Mosindy, 2006). Overall, there was a general long-term trend showing an increasing amount of good quality late-summer lake trout habitat at most sites in Clearwater Bay from 1984 to 2004 (Mosindy, 2006). However, it is important to note that lake trout in the Clearwater Bay area are still vulnerable to temporal changes in water quality. Variation in water chemistry, dissolved oxygen, and temperature between sites and years makes it difficult to predict the quality of habitat a site will have from year to year (Mosindy, 2006).

Ten years following 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 (Mosindy, 2006). In fact, there were increases in both spawning and the recruitment of young trout (Mosindy, 2006). Declines in lake trout mortality to less than or equal to 20% in Echo Bay, Clearwater Bays, and Cul de Sac signified the success of the tag system. However, the lake trout populations of Echo Bay are still a concern (Mosindy, 2006). The low abundance and large fork lengths of lake trout in Echo Bay and Granite Lake sampling locations indicate

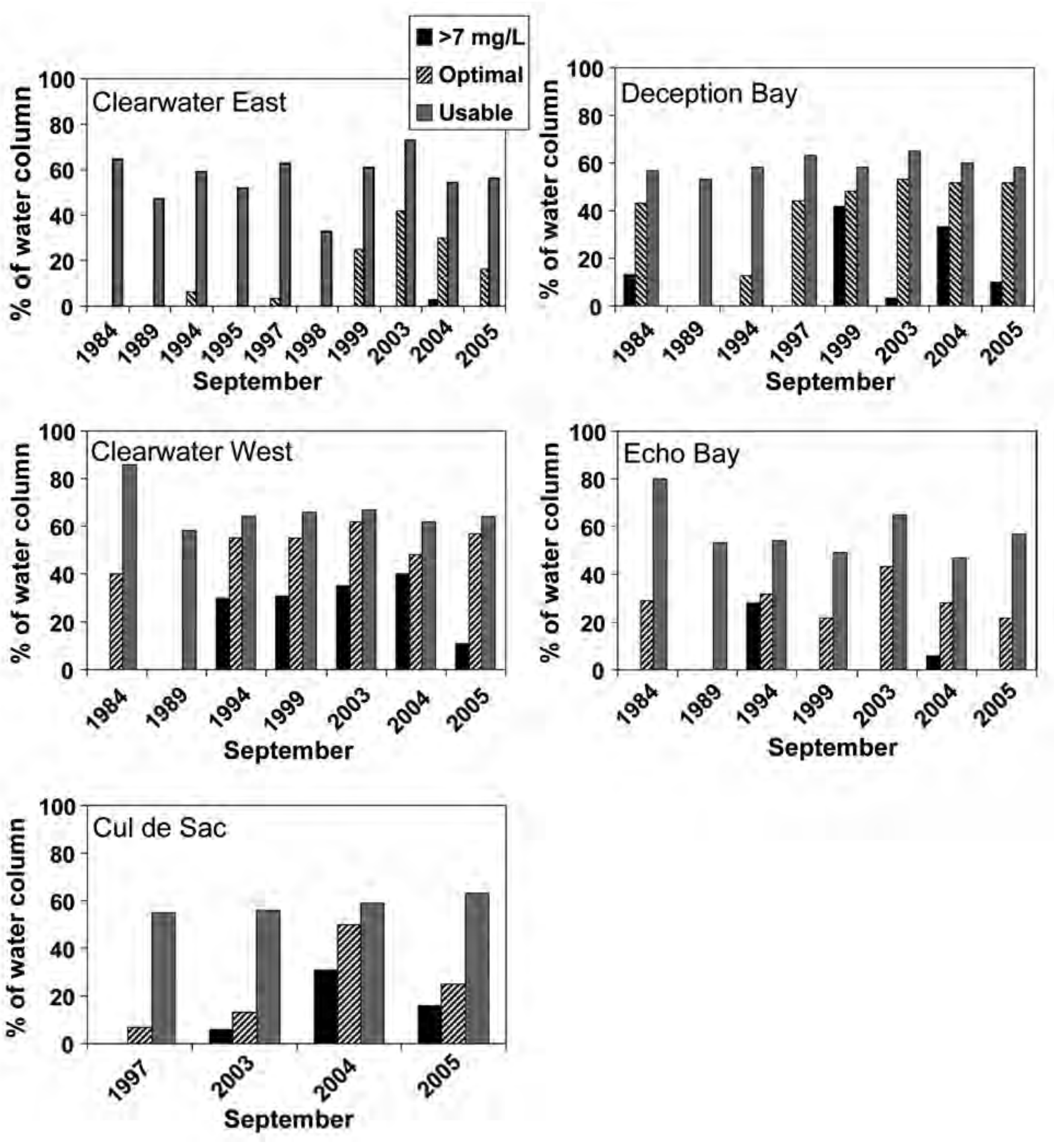

FIGURE 5.3. Proportion of available lake trout (*Salvelinus namaycush*) habitat at five sampling locations within the Clearwater/Echo bay region of Lake of the Woods, Ontario, 1984-2005. The % water column value represents the amount of useable habitat for lake trout. This habitat quality was based upon observed temperatures and dissolved oxygen concentrations ([DO]) during mid-September, since this is the most critical period for lake trout (i.e., before water temperatures above the thermocline have cooled below 15ºC). Lake trout habitat quality and requirements were described by Evans (2007) as follows: useable habitat (grey bars): temperature <15ºC and [DO] > 4 mg/L; optimal habitat (hatched bars): temperature < 10ºC and [DO] > 6 mg/L; >7 mg/L (solid bars): temperature < 10ºC and [DO] > 7mg/L. There was considerable spatial and temporal variation at these sites. Deception Bay and Clearwater Bay West showed an increase in the proportion of available lake trout habitat over time. Clearwater Bay East had the lowest proportion of available lake trout habitat. Overall, this demonstrates an increasing amount of high quality lake trout habitat over time at many sites in the Clearwater/Echo Bay region of Lake of the Woods.

This figure was modified from Mosindy (2006). Data is from the Ministry of Natural Resources Fisheries Assessment Unit in Kenora, Ontario.

that the fishery is dominated by a small number of older adults (Mosindy, 2006). This slow recruitment could be attributed to the continued exploitation of the fish population or other habitat problems, such as low hypolimnetic oxygen (Mosindy, 2006). Maintaining control of the fish harvest in Clearwater and Echo Bays would allow smaller individuals to move into a larger fish category (OMNR, 2001).

TABLES 5.7. List of sightings of amphibians and reptiles from the Lake of the Woods and Rainy River region of Ontario, as listed in the Ontario Ministry of Natural Resources' Natural Heritage Information Centre database (http://nhic.mnr.gov.on.ca/nhic_cfm).

Common Name	Taxonomic Name
Turtles	
common snapping turtle	*Chelydra serpentina serpentina*
western painted turtle	*Chrysemys picta belli*
Snakes	
eastern garter snake	*Thamnophis sirtalis sirtalis*
red-sided garter snake	*Thamnophis sirtalis parietalis*
northern redbelly snake	*Storeria occipitomaculata occipitomaculata*
Salamander	
Jefferson-blue spotted salamander complex	*Ambystoma jeffersonianum-laterale* "complex"
Frogs and Toads	
eastern American toad	*Bufo americanus americanus*
Nortnern spring peeper	*Pseudacris crucifer cruciver*
boreal chorus frog	*Pseudacris maculata*
grey treefrog	*Hyla versicolor*
wood frog	*Rana sylvatica*
northern leopard frong	*Rana pipiens*
mink frog	*Rana septentrionalis*

TABLES 5.8. a and b. Maximum calling indices for frogs and toads along two routes (Peppermint, near Baudette, and Northwest Angle) in Lake of the Woods County, Minnesota, 1998-2007. Scoring was as follows: 1 = Individuals can be counted with space between calls; 2 = Individuals can be distinguished but there is some overlapping of calls; 3 = Calls are constant, continuous, and overlapping. This data was obtained from the U.S. Geological Survey's North American Amphibian Monitoring Program calling survey's public access page (http://www.pwrc.usgs.gov/naamp/data/public/index.cfm). Surveys are volunteer-based and organized by the Minnesota Department of Natural Resources as part of Minnesota's Frog and Toad Calling Survey.

a) Peppermint, Minnesota (Route 500306)

	1998	1999	2000	2001	2003	2004	2005	2007
American toad	3	3	3	2	3	3	0	3
Gray treefrog	3	2	3	2	2	2	0	3
Spring peeper	3	3	3	3	3	3	3	3
Western chorus frog	3	3	2	2	2	3	3	3
Wood frog	1	3	3	3	2	3	3	3
Northern leopard frog	3	3	2	3	3	2	3	2

b) Northwest Angle, Minnesota (Route 500402)

	2005	2006	2007
American toad	1	1	2
Gray treefrog	2	0	3
Spring peeper	3	3	3
Western chorus frog	2	2	2
Wood frog	2	1	3
Northern leopard frog	1	1	1
Cope's gray treefrog	0	1	1

5.6 Reptile and Amphibian Communities

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 LOW and Rainy River Basin. Despite their value as indicator species, studies of the herpetofauna of LOW and the Rainy River Basin have been very limited. The OMNR's 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). The reptiles and amphibians in the LOW region of Ontario are listed in Table 5.7. In addition, 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 meant to identify trends in Minnesota's frog and toad populations over time and each volunteer is certified prior to contributing data to the program. As part of the MFTCS program, a volunteer must pass a difficult test before they can participate in the survey. Frog and toad calls are counted and scored three times per year in the early spring, late spring, and summer. Frogs and toads are surveyed at 10 sites along one route near Peppermint Creek near Baudette in Lake of the Woods County, and has been studied almost annually since 1998 (Table 5.8). Frog and toad species at this site that have been detected during this time include:

There are two areas in LOW that receive a large number of migratory birds each year, but are sensitive to environmental changes. These two regions ... have been designated as Important Bird Areas (IBAs) in Canada. The first is Three Sisters Island IBA, which is a nesting colony for the American white pelican. The second is the Lake of the Woods Sand Spit Archipelago IBA, which includes the LOW shoreline from Rainy River to Windy Point and areas inland.

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 of at least three 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 Minnesota and has been included in subsequent surveys (Table 5.8.; 2005-2007; MNDNR, 2007a). These data are included in NAAMP's eastern U.S. regional monitoring program (MNDNR, 2007b). Similarly, the MNDNR has a program called the Minnesota County Biological Survey which enlists volunteers to contribute data on a scheduled basis, and includes information on amphibians and reptiles. However, neither Roseau, Lake of the Woods, nor Koochiching Counties are included in this, nor are there plans for them to be included in the near future (MNDNR, 2007b).

Amphibian research has been minimal in the LOW/Rainy River region of Ontario as well. Canada has a community-based volunteer monitoring effort as part of their FrogWatch Program, that is 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 monitor their local wetlands for frogs and toads via sightings and calls and submit their results to FrogWatch (FrogWatch, 2007).

5.7 Waterbirds

A variety of waterbirds occupy the waters and shorelines of LOW and the Rainy River, including waterfowl, wading birds, and other birds that utilize the shoreline. Some birds are present year-round, while others are migratory and make their breeding grounds there. LOW is also a common stopover for migratory birds. 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.
There are two areas in LOW that receive a large number of migratory birds each year, but are sensitive to environmental changes. These two regions on LOW have been designated as Important Birds Areas (IBAs) in Canada (http://www.ibacanada.com/). The first is Three Sisters Island IBA, which is a nesting colony for the American white pelican. The second is the Lake of the Woods Sand Spit Archipelago IBA, which includes the LOW shoreline from Rainy River to Windy Point and areas inland (Harris et al., 2001). The 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). The Ontario portion of the Sandspit Archipelago IBA consists of the Sable Islands, Windy Point, and Burton Island, which are located approximately 25 km 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, and Thunder Bay, Ontario) 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*). This section will outline recent research pertaining to different aquatic shorebirds in LOW.

American White Pelican
(Pelecanus erythrorhynchos)

The American white pelican is the largest colonially nesting bird in Ontario with a body length of approximately 1.3 m and a wing span of 2.4-3.0 m (Ratcliff, 2005). White pelicans breed in various locations in Canada and the United States and overwinter mainly on the Gulf of Mexico. Their preferred breeding sites are remote islands away from mammalian predators and human disturbances (Ratcliff, 2005).

LOW is home to the oldest historical white pelican nesting site in Ontario and is considered to be one of the largest in Canada. Most of the occurrences of white pelican 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 designation (Ratcliff, 2005). In the Ontario portion of LOW, white pelicans inhabitated Dream Island, but this site was abandoned in the 1960s and the largest colonies are currently located on the Three Sisters Islands, located west of Bigsby Island. These sites are less accessible to humans due to the presence of submerged rocks and boulders. The islands' deep soils support trees and vegetation that shelter young birds (Trottier et al., 1980). In the Minnesota portion of LOW, White Pelicans nest on Crowduck Island, although they historically occupied Odell Island as well (Macins, 1991).White pelicans are also known to dramatically alter the landscape through their nesting and colonial behaviours, and vegetation and trees in the colony location often becomes impeded over time (Lockhart & Macins, 2001; Ratcliff, 2005).

White pelicans have been known to forage for food in areas up to 300 km away in search of abundant food supplies (Ratcliff, 2005). The feeding ranges of LOW white pelicans 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 north (Macins, 1991). Since they do not dive to forage for food, white pelicans tend to forage in small groups. In deeper water, white pelicans feed in association with double-crested cormorants (see next section). They normally target a variety of schooling fish of minimal economic value such as yellow perch, shiners, and bullheads. Occasionally, sauger, pike, walleye, and bass are consumed but in very small quantities (Lockhart &

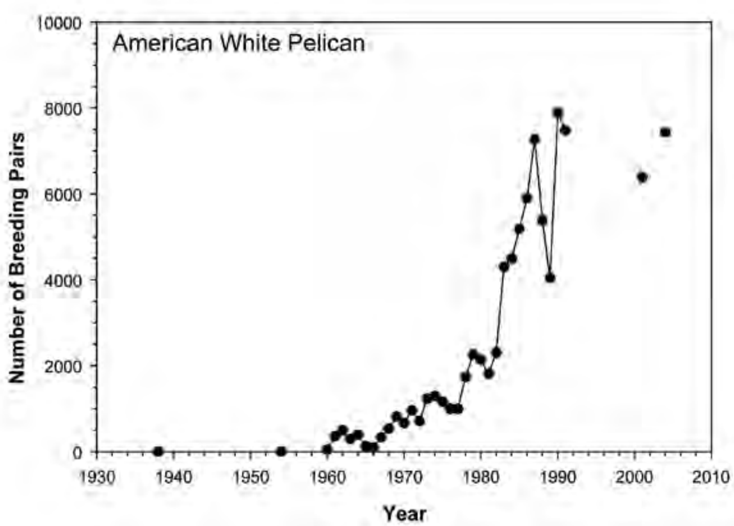

FIGURE 5.4. Historical trends in of numbers of breeding pairs of American white pelicans (Pelecanus erythrorhynchos) on Lake of the Woods, Ontario (1938, 1954, 1960-1991, 2001, 2004). Data are from Macins (1991) and Ratcliff (2005).

Macins, 2001). They are known to consume an average of 1.4 kg (3 lbs) of fish per day. Populations of the American white pelican have increased dramatically since the 1960s in many portions of their ranges (Figure 5.4; Wires et al., 2001a; Evans & Knopf, 1993). The Ontario portion of LOW was estimated to have 7,432 breeding pairs in 2004, which is 92% of the breeding pairs in the province (Ratcliff, 2005). The Ontario

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population is considered to be stable or slightly increased. In the Minnesota portion of LOW, populations have also increased from 29 breeding pairs in 1973 to 832 pairs in 1997 (Macins, 1991; K. Haws, MNDNR, Bemidji, MN, unpublished data). Since historical consensus on breeding pairs is not available in Minnesota, it is not possible to determine if populations are continuing to increase in this state. The white pelican is currently listed as Endangered and is protected under Canada's Species at Risk Act and Ontario's Endangered Species Act and is a species that is Specially Protected under Ontario's Fish and Wildlife Conservation Act. In Minnesota, the white pelican is listed as a species of Special Concern (i.e., not endangered or threatened but extremely uncommon and/or has unique and specific habitat requirements) by the MNDNR. Recent studies have recommended that significant white pelican colonies (> 100 pairs) in Minnesota, including those on LOW, be monitored at regular intervals of every three years (Wires et al., 2005). White pelicans populations are influenced by factors such as water level fluctuations, disease, human harassing, pesticides, and hunting in wintering areas (Ratcliff, 2005). 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 pelican count from 6454 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 as much as 90% or 1000s of young pelican mortalities in several U.S. Sates (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). In addition, human presence on or near the breeding colonies may cause the adults to abandon their nests. Pelicans nest in association with double-crested cormorants (see next section), and thus controls of cormorants in regions where they cohabitate will directly effect pelican breeding success (Ratcliff, 2005). Since there are no specific management plans implemented in Ontario for the double-crested cormorants, illegal cormorant control would cause major disturbances to the pelican populations. There has also been concern in recent years on their effects on recreation, aquaculture, and fisheries (Wires & Cuthbert, 2001a). 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 (herein referred to as cormorants) are a large, fish-eating birds whose populations have experienced many changes over the past 100 years. Cormorants occur in many inland lakes and coastal areas of North America, and have nested on islands in LOW for hundreds of years (Environment Canada, 2005), with reports dating back to 1798 (Peck and James, 1983; Wires et al., 2005). Most adult cormorants inhabit LOW colonies from about mid-April to late August or early September. Cormorants nesting in islands in LOW tend to form large ground colonies, although cormorants are known to nest in trees as well (Wires et al., 2005). Similar to white pelicans (who they cohabitate with in LOW), this nesting behaviour is known to impact vegetation communities on nesting islands (S. Lockhart, OMNR, Kenora, ON, Pers. Comm.).

Like White Pelicans, cormorants are fish-eating birds. On average, they weigh approximately 2.0 kg (4.4 lbs) and can consume approximately 25% of their weight in fish each day, or approximately 0.5 kg (1.1 lbs) (Dunn, 1975; Schramm, 1984; Glahn & Brugger, 1995, Hatch & Weseloh 1999). This has raised controversy with many people involved in fisheries and aquaculture who believe they consume large numbers of commercially and recreationally-important fish species and compete for their prey. However, studies have demonstrated that cormorants 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% taken by sport fish (Environment Canada, 2005).

By the 1920s, LOW contained some of the last known breeding colonies of double-crested cormorants 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-1970s, cormorants were experiencing reproductive failure due to eggshell thinning caused by organochlorine contaminants (such as DDT) in the environment (Environment Canada, 2005). Cormorant populations are considered to be sensitive to organochlorine contamination (i.e., p,p'-DDE, PCBs, mercury; Bishop et al., 1992) which caused reproductive and growth impairments.

Several events have occurred over the past 30 years that led to resurgence of cormorant 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, preventing killing or harassment of cormorants during their annual cycle; 3) reduction in human harassment and other changes, such as overfishing; 4) the introduction of alewife in the Great Lakes regions; and 5) creation of additional nesting and foraging habitat (Environment Canada, 2005).

The presence of large numbers of cormorants has caused hostility in some commercial and recreational anglers who believed that they threaten economically important fish stocks and aquaculture (Glahn & Brugger, 1995). They are also known to impact the vegetation on nesting islands (Hebert et al., 2005).

Accurate historical data are not available and historical numbers are mostly based on qualitative descriptions of flocks of cormorants (Wires et al., 2001b). 62% of Minnesota's breeding pairs are located at six sites in Minnesota (including O'Dell and Little Massacre Islands, LOW; Wires et al., 2005). In the Minnesota portion of LOW, colonies of cormorants currently occur on Crowduck Island, Gull Rock, Little Massacre Island, O'Dell Island, and Techout Island (Wires et al., 2005). In 2004, LOW was reported to have an estimated 4,370 cormorant nests at these five sites in the Minnesota portion of LOW (Wires et al., 2005). This was estimated by counting birds from aerial photos taken in June 2004 by the Ontario Ministry of Natural Resources.

Cormorants presently nest at a number of island sites in the Ontario portion of LOW. Currently, the cormorant populations that nest on the Ontario portion of LOW are considered to be stable or slightly decreasing, and increases over the past several decades are a reflection of 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 cormorants in the Ontario waters of LOW.

This concentration of cormorants at a small number of sites in LOW makes them extremely vulnerable to random events such as extreme weather, disease, human disturbances, and hydrological changes. Therefore, it has been recommended that large colonies of cormorants be monitored at regular 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.

Because of its high waterbird diversity (sites with ≥ 4 nesting colonies of waterbird species), it has been recommended that the colonies on the Minnesota portion of LOW be considered for special designations and protection and have been nominated for Important Bird Area (IBA) status (Wires et al., 2005). Listing these sites as protected would also have positive effects on non-target bird species. For example, 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).

TABLE 5.9. Population summary of adult piping plovers at Minnesota and Ontario sites in LOW from 1938-2007. Data was obtained from Haws (2005) and Heyens (2007).

	Minnesota (Haws, 2005)					Ontario (Heyens, 2007)		
	Pine and Curry Island SNA	Morris Point	Zippel Bay	Rocky Point	Stony Point	Sable Islands	Windy Point	Total
1938						6		6
1974						5		5
1978						5		5
1979						2	4	6
1980						3		3
1981						4		4
1982	24	4	0	2				30
1983	32	6	2	2		2		44
1984	36	8	0	0				44
1985	19-36	4	0					4
1986	18	4	0	1		6		29
1987	12	2	0			5	5	24
1988	18	4	0	4		3		29
1989	14	2	0	4		6	2	28
1990	8	2		2		4	0	16
1991	12	0	0	0		5	0	17
1992	10	0	0	0		0	2	12
1993	9	0	0	0		1	0	10
1994	10	2	0	0		3	0	15
1995	11	2	0	0		0	3	16
1996	10	0	0	0		0	3	13
1997	4	0	0	2		1	4	11
1998	6	0	0	2		0	5	13
1999	6	0	0	2		0	4	12
2000	8	0	0	2		0	3	13
2001	0	2	0	4		0	1	7
2002	2	2	0	0		1	5	10
2003	0	0	0	0	2	0	3	5
2004	0	0	0	0	0	0	1	1
2005						0	0	0
2006						0	2	2
2007	0	0	0	2		2	5	9

Common Tern *(Sterna hirundo)*

Common terns (herein referred to as 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 Minnesota 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 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, south shore of Four Mile Bay, Sandy Shores (east of Rocky Point), and the shoreline between Rocky and Long Points (Cuthburt & McKearnan, 1985; Herb et al., 2004; Haws, 2005). For example, 2003 was considered a good year for terns, as more than 200 adults were observed with 40-50 nests in July and 140 young fledged (Haws, 2005). This success was attributed to the unusually low water levels of 2003

(Haws, 2005). Alternatively, high water years, such as 2002, tend to result in lower numbers of fledged young (Haws, 2005). In 2003, a new nesting site was also observed west of Crowduck Island, at a site named Joshua's reef. 153 tern nests were observed in July at this site, with the likely success of this colony (Haws, 2005).

Predation and competition for breeding space tend to have negative effects on tern success (e.g., Haws, 2005). For example, terns compete with Ring-Billed gulls and plovers for breeding space, and these competitors may predate upon tern chicks and eggs. A federal permit has been obtained by the MNDNR to remove these gulls where they are present in tern and plover nesting sites. Additionally, trapping of mammalian predators in the regions of nesting sites has been done in the past, but this is ineffective in low water years where land bridges are formed, such as a landbridge between Tern Island and Morris Point. In 2004, for example, one colony located on Morris Point on Pine/Curry Island had 109 tern nests with eggs, but there was complete nest failure at this site due to predation (Haws, 2005). Based on the results from Haws (2005), a future monitoring and management plan for common terns on Pine and Curry Island has been recommended.

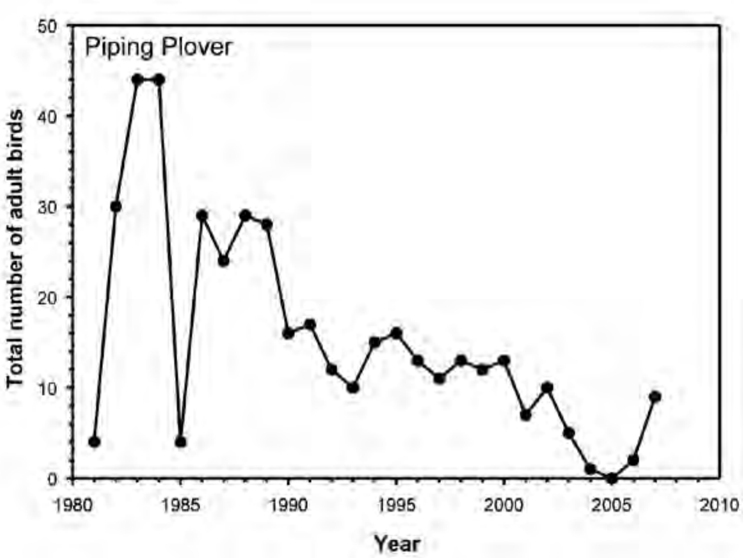

FIGURE 5.5. Historical trends in of numbers of adult piping plovers (*Charadrius melodus*) on Lake of the Woods. Data are from the Minnesota Department of Natural Resources Nongame Wildlife Program (Haws, 2007) and the Ontario Ministry of Natural Resources (Heyens, 2007). Data are listed in Table 5.8.

Piping Plover
(Charadrius melodus circumcinctus)

Piping plover are small migratory shorebirds who live along shorelines and make their nests on sparsely vegetated sand or gravel areas. 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). This subspecies is listed as either threatened or endangered throughout its entire range in North America. The Sand Spit Archipelago IBA is the last nesting site for this species in Ontario (Harris et al., 2001). When present, they are seen on the sandy beaches of the Sable Islands and Windy Point in Ontario, and at Pine and Curry Island, Zippel Bay, and Rocky Point in Minnesota.

Piping plovers also have many interspecific interactions with many species in LOW, mainly the common tern, ring-billed gull (*Larus delawarensis*), spotted sandpiper (*Actitis macularia*), semipalmated sandpiper (*Calidris pusilla*) and killdeer (*Charadrius vociferous*), which account for approximately 90% of the interactions (Maxson, 2000). Several of these species had a low direct effect on reproduction, but others were potential predators and the plovers react intensely to them [e.g., ring-billed gull, American crow (*Corvus brachyrhynchos*), and common grackle (*Quiscalus quiscula*)] (Maxson, 2000).

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, 2007c). 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 Four Mile 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 shorelines and plover and tern nesting habitat (Haws, 2005). Egg and chick losses also result from predation by mammalian predators (i.e., Wiens & Cuthbert, 1984; Maxson & Haws, 2000).

Despite intensive management efforts since the 1980s on LOW, the reproductive success of piping plovers is low in LOW, and its populations are in decline (Table 5.9, Figure 5.5). In the 1980s, approximately 50 birds were recorded at one location on the Minnesota portion of LOW (Maxson & Haws, 2000). However, in the Minnesota and Ontario 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). In fact, LOW populations have been declining steadily since 1988 (Maxson & Haws, 2000; Heyens, 2006). One reason why this is concerning is because this remnant plover population at LOW in Ontario and Minnesota serves as the only geographical link between the populations of the Northern Great Plains/Prairies and the Great Lakes.

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). Despite these management efforts, piping plovers continue to decrease (Maxson & Haws, 2000; Haws, 2005; Heyens, 2007). For example, in 2007, no hatchlings fledged from the nests located in the Ontario portion of LOW, while one pair fledged three young at Rocky Point on the Minnesota side of LOW (Heyens, 2007). Nonetheless, monitoring and management efforts will be continued. For example, 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 done by the MNDNR Nongame Wildlife Program and Wetland Wildlife Populations and Research Group and OMNR (Haws, 2005; Heyens, 2006). In addition, advice to the Lake of the Woods Control Board (LWCB) will continue to be given regarding lake level management on LOW (Heyens, 2007).

Bald Eagle *(Haliaeetus leucocephalus)*

Bald eagles are large, strong, predatory birds that occur near large bodies of open water where fish are plentiful and there are tall trees for nesting and roosting. In addition to fish, they predate on waterfowl, shorebirds, and small mammals, and are also scavengers of the shoreline areas. They occur across North America, including LOW and are significant for a number of reasons. They are considered to be an ambassador species for other species in the ecosystem, indicators

Bald eagle populations in northwestern Ontario tend to be successful in part because most human activity near nests occurs after the young have hatched.

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 ranges, 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, PCP, dioxins) throughout the 1900s severely depleted their populations. 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, as well as 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 such as the territorial behaviour of adult eagles (Grier et al., 2003). For the LOW (and all of Northern Ontario), bald eagles are classified as Special Concern from a former Endangered classification. The Special Concern classification withdraws bald eagles from Endangered Species Act legislation and regulations, but they remain a Species at Risk in 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 eagle populations in northwestern Ontario tend to be successful in part because most human activity near nests occurs after the young have hatched, which is contrary to southern Ontario where human presence is constant and successful nests are normally 1 km away from human activity (Grier et al, 2003). Bald eagle populations in LOW have been relatively well studied. Based on a 33-year (1966-1998) summary of bald eagle reproduction at LOW and Red Lake/Lac Seul Areas, Ontario, bald eagle populations have steadily increased throughout this period (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 the future status of these species, since there are a still number of factors that are considered to be threatening to bald eagle 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 (AVM) and West Nile Virus (WNV) (Grier et al., 2003).

Other Waterbirds

A number of waterbirds nest on or near the shores of LOW 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 lake 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.).

6 EMERGING THREATS TO WATER QUALITY & BIOLOGICAL COMMUNITIES

6.1 Contaminants

The bioaccumulation of persistent, organic substances in aquatic biota through biological sequestration has been well studied throughout the world. However, the current state of knowledge about the transport and fate of mercury and other contaminants in Lake of the Woods and the Rainy River is minimal. Although contamination of food webs by persistant pollutants, such as PCBs, do not pose immediate threats to biota in the lake and river, the presence of mercury in the aquatic food webs in this region continues to be the main culprit of food consumption advisories in both Ontario and Minnesota (OMOE, 2007; Minnesota Department of Health, 2007). This section provides a brief overview of previous research pertaining to contaminants in this region.

Mercury

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 Provincial 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 are important in storing and transforming mercury to 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). The majority of mercury inputs to lakes and their watersheds occurs through wet and dry atmospheric deposition. In Canada, the major contribution of atmospheric anthropogenic mercury until the 1980's was the chloralkali industry. However, all chloralkali plants are now closed in Ontario. The decline in emissions by chloralkali plants in combination with improvements in mining and smelting industries throughout the 1990s has resulted in an overall decline in the amount of mercury emitted to the atmosphere through anthropogenic sources. In 2003, Canada emitted under 7 tonnes of mercury, 73% of which was attributed to electricity generation (34%) including coal fired power plants, incineration (20%), and non-ferrous mining and smelting industries (19%) (Environment Canada, 2004).

In general, when mercury is present in the aquatic environment, it may bioaccumulate in aquatic biota and biomagnify in aquatic food chains (i.e., become more concentrated as it moves up in the food chain). Mercury concentrations in fish are positively correlated with body size so that larger fish purportedly have higher concentrations of mercury due to their higher trophic position in the food chain and a longer time spent accumulating mercury (Scott & Armstrong, 1972). In an examination of forage fish in 25 central 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 traditional indices of trophic position (i.e., adjusted-$\delta 15N$) in predicting mercury concentrations of fish within trophic guilds or communities.

Few published data exist on mercury contamination in fish in Lake of the Woods and the Rainy River and there are no new data on mercury concentrations in water in these systems. The OMOE, based on annual sampling, has made recommendations as to the amount of fish from LOW and the Rainy River one should consume each month; however, this is based solely on fish caught in the region of LOW that falls within the Kenora District in Ontario (Ontario Ministry of the Environment, 2007). Similarly, the Minnesota Department of Health (MDH), in collaboration with the MNDNR and the MPCA, develops guidelines on an annual basis for fish consumption from Minnesota waters, including the Rainy River and the southern portion of LOW (Minnesota Department of Health, 2007). Based on these published guidelines, consumption advice based on contaminant levels are generally more restrictive for Minnesota waters than they are for Ontario waters (Minnesota Department of Health, 2007; Ontario Ministry of the Environment, 2007). For example, the MDH recommends that walleye from LOW that are 38-51 cm (15-25 inches) in length be consumed no more than one time per week and walleye 51-64 cm (25-30 inches) in length be consumed no more than once per month. Alternatively, the Ontario OMOE recommends eating no more than 8 walleye per month in the range of 15-60 cm (6-24 inches) and only four walleye per month in the 60-70 cm (24-28 inches) range (OMOE, 2007).

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 their elevated level in the food chain compared to other forage fish, and their importance as a prey item in piscivore diets. However, they indicated that piscivores increased in size following the addition of smelt to their diets, which might have contributed to a growth dilution effect.

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 due to the human health risk associated with the consumption of mercury-contaminated fish (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). They concluded that most bioaccumulated mercury in fish is anthropogenically-derived and that atmospheric deposition was the primary contributor of mercury in fish in lakes in this drainage basin. In addition, annual water fluctuations have significant effects on mercury levels of young-of-the-year yellow perch in several Minnesota lakes, including Rainy and Namakan.

Although anthropogenic emissions of mercury have declined considerably over the past 30 years, there continue to be previously existing pools of mercury that may impede the recovery of mercury levels in fish and other biota. Current research has demonstrated that the observed reductions in atmospheric loadings of mercury described above may lead to rapid declines in fish methylmercury concentrations in a matter of years, although this may be delayed by the remaining pools of previously existing mercury in the watershed export (Harris et al., 2007). Based on the assumption that LOW receives mercury both from the atmosphere and from its watershed, a lake and its biota may experience a gradual response to reductions in mercury input. Under this assumption, reductions in direct atmospheric deposition to a lake may result in an initial rapid decline in mercury content of fish followed by a secondary response from the wetland peat and upland soils which slowly (over centuries) return to equilibrium (Harris et al., 2007).

The hydrological complexity of LOW calls for more elaborate mercury and contaminant testing of fish from the different regions of the lake that are under pressure from angling, as well as standardized guidelines for fish consumption for these border waters.

Other Contaminants

Contaminants other than mercury, including industrial chemicals (polychlorinated biphenyls (PCBs), dioxins, furans, mirex, photomirex) and pesticides (DDT, toxaphene) are released as by-products of 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 release is 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) that was established under the Emergency Planning and Community Right-to-Know Act of 1986 and was expanded by the Pollution Prevention Act of 1990. The activities for both countries are reported annually.

Compared to other regions of North America, such as the Great Lakes region, these contaminants are released at lower concentrations to LOW and the Rainy River. Although there are currently no studies demonstrating the levels of these contaminants in fish, the contaminant effects on birds have been studied. 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, since 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. LOW is considered to be an uncontaminated "reference" area, and is far removed from major sources of contamination (Donaldson et al., 1999).

6.2 Invasive Species

LOW and the Rainy River are part of the Winnipeg River drainage basin, residing within the immense Nelson River watershed 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. In addition, it provides habitat and water quality that provide suitable habitat for several invasive species.

In general, there has been a recent increase in awareness from public and government that aquatic invasive species pose major threats to aquatic systems. This is the result of enhanced education programs, including signage at public access points to LOW and the Rainy River. In addition, Ontario (Department of Fisheries and Oceans Canada) and Minnesota (Minnesota Department of Natural Resources) have included watercraft inspection at international borders, regulation, and enforcement as part of their educational program (efforts) 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 Lake of the Woods basin.

Several non-native flora and fauna have invaded LOW and the Rainy River 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 five confirmed invaders in parts of LOW and the Rainy River. However, the possibility of future invasions by non-native species, such as the zebra mussel (*Dreissena polymorpha*) and the benthic diatom *Didymosphenia geminata*, require attention and assessment. Both the impacts and implications of current and potential invasive species on biological communities in this region are discussed below.

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).


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Spiny water flea

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, located in the Minnesota portion of the Upper Rainy River watershed (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).

Fort Frances OMNR staff first detected the spiny water flea in their sturgeon larval drift nets in the Rainy River in June, 2007, and continued to observe them for the rest of the summer. It is suspected that this invader arrived from Rainy Lake, where it was discovered in the summer of 2006.

Spiny water flea
(Bythotrephes longimanus)

The spiny waterflea (*Bythotrephes longimanus*) is an invasive predatory zooplankton. *Bythotrephes'* predate 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). They may also clog fishing rods making it difficult to land fish.

Fort Frances OMNR staff first detected the spiny water flea in their sturgeon larval drift nets in the Rainy River in June, 2007, and continued to observe them for the rest of the summer (Clayton, 2007; J. Vandenbroeck, OMNR, Fort Frances, ON, Pers. Comm.). It is suspected that this invader arrived from Rainy Lake, where it was discovered in the summer of 2006. By late summer of 2007, *Bythotrephes* was detected in Wheeler's Point at the outflow of the Rainy River in LOW. It 2007, it was found in other portions of LOW including Zippel Bay to Zippel Creek and the Big Fork, Little Fork, and Warroad, and Baudette Rivers (MNDNR, 2007c).

As a result of this invasion in LOW, the MNDNR (Baudette Office) and OMNR (Fort Frances Office) plan to increase their zooplankton sampling effort in the Rainy River and the southern basin of LOW in future years (e.g., 2008-2009) with the intent of tracking and detecting potential shifts in the zooplankton community (T. Heinrich, MNDNR, Baudette, MN, Pers. Comm.; J. Vandenbroeck, OMNR, Fort Frances, ON, Pers. Comm.).

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, 1971). It was observed in Lake Winnipeg in 1994 (Salki, 1996). Suchy & Hann (2007) used paleolimnological 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 way of the Rainy River via the Laurentian Great Lakes or 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.

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 invasion can be problematic for many reasons as it poses a threat to native crayfish, fish, invertebrate, and macrophyte populations.

In 2006, [the OMNR-FAU] 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.

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 predated 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, insects), decaying plants and animals, fish eggs, and small fish. In addition, aquatic macrophyte beds are susceptible to rusty crayfish predation, which can 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.

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). Water depth and distance from the mainland did not seem to influence the colonization of the rusty crayfish on islands in LOW (Geard, 2007). There are currently no reports of Rusty Crayfish in Shoal Lake, the Ptarmigan and Clearwater Bay area, and the area south of the Aulneau Peninsula. However, in 2007, the MNDNR (Baudette Office) reported the first sighting of this species in the Minnesota portion of LOW (Lake of the Woods 4th International Water Quality Forum Proceedings, 2007). It is currently being monitored by the Ontario OMNR's Fisheries Assessment Unit 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.).

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). The OMNR's Invasive Species Monitoring Program, coordinated by the Fisheries Assessment Unit in Kenora, is currently assessing the possibility of its invasion to the Winnipeg River. The MNDNR does not have any sampling program directed at finding incidences of the rusty crayfish in Minnesota waters.

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 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). Although the colonization of this species on islands in LOW is limited by water depths greater than 12 m (Geard, 2007), the OMNR-FAU has identified potential fronts for invasion into other areas of LOW, including Ptarmigan-Clearwater Bay area in the north, the Northwest Angle and Bishop Bay, Sabaskong Bay, and Miles Bay (Lake of the Woods 4th International Water Quality Forum Proceedings, 2007).

Rainbow smelt *(Osmerus mordax)*

Rainbow smelt were accidentally introduced into upper reaches of the LOW drainage basin from Lake Superior in 1960's. They have since spread throughout LOW where coldwater basins are present because adults seek refuge below the thermocline in summer. Smelt were first detected in Namakan and Rainy Lakes in 1990 and LOW in 1991 (Franzin et al., 1994). They were likely introduced by anglers, downstream migrations, or downstream movements in the Rainy River (Franzin et al., 1994). In 1996 there was a peak in the rainbow smelt populations in Rainy Lake. However, during 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. In fact, walleye numbers increased significantly during the 1990s following the invasion of rainbow smelt (Kallemeyn et al., 2008). However, they are also known to displace some members of whitefish family such as cisco, as well as eliminate or cause declines in some fish species. It also causes shifts in fish community structure by competing with other fish by feeding on young fish and invertebrates. 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 most predatory fish (Swanson et al., 2003; Swanson et al., 2006).

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 (such as another invasive species, the round goby, whose diet consists of significant amounts of zebra mussels), 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). Based on this calcium threshold, the majority of LOW is not vulnerable to invasion since all sectors have ambient calcium concentrations below 20 mg/L, and most are below 15 mg/L (Section 4, Figure 4.5; with the exception of one outlier in the Whitefish Bay Sector, Index Island in July 2007, 20.8 mg Ca/L). Alternatively, based on analyses by Neary & Leach (1992) of Ontario lakes, LOW falls within the appropriate pH (> 7.3), calcium (12->20 mg/L), and temperature ranges (mean annual: $>0^{\circ}C$; mean January: $>-15^{\circ}C$) and the bedrock and soils have a high potential to neutralize acidity to warrant susceptibility to invasion. In addition, there is good road access to the lake with a high number of tourists visiting the lake each year (Neary & Leach, 1992).

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Didymo *(Didymosphenia geminata)*

Didymosphenia geminata (commonly referred to as Didymo) is a golden brown diatom that is large in size (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 by occupying higher nutrient, lower altitude environments (Spaulding & Elwell, 2007). Although its trophic interactions are not yet understood, it is known to impact streams in many ways by causing nuisance blooms and deteriorations in water quality as demonstrated by 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 of the North to the west of Lake of the Woods. Currently, there is an expanding effort to expand outreach and education efforts to inform the public and government agencies and to develop research initiatives to address the behaviour and impacts of this organism (Spaulding & Elwell, 2007).

BEV CLARK

6.3 Climate change

Changing weather patterns will affect lakes in complex ways that are not fully understood. In general, we know that climatic changes will directly effect lake thermal habitats and indirectly effect watershed processes that will in turn influence the thermal, chemical, and biological characteristics of boreal shield lakes (Keller, 2007). This section highlights recent developments in climate change research in the Lake of the Woods and Rainy River basin region with respect to changing weather patterns and its effects on physical, chemical, and biological (specifically, phytoplankton) properties of lakes.
Several climate warming models predict increased mean summer temperatures in the northern temperate zone over the next century. In fact, in Canada, annual temperatures have increased by 1.3 °C from 1948 to 2006, the period for which data are available in northern as well as southern regions of the country. Over the same time period, annual average temperatures in Ontario increased between 0 and 1.4 °C, with the largest increases observed in the winter (December - February) and spring (March - May) seasons in northwestern Ontario. Temperature records from Kenora airport, for example, show a rise in mean annual air temperatures of approximately 2.5 °C since 1899, with the highest temperature increases measured over the past three decades in the winter months. As noted earlier (Chapter 3), warmer air temperatures have resulted in a lengthening of the frost-free season by 15 days since the 1920s, and an increase in the ice-free period in LOW by more than two weeks since measurements began in the mid-1960s.

Long-term changes in annual precipitation have been more variable than changes in temperature within and among meteorological stations (Chapter 3). In general, however, 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). Moreover, recent decades have seen a switch from more frequent, smaller convective storms during the summer that provided relatively stable summer flows in local streams, to fewer, but larger convective storms. This change in weather pattern has resulted in short periods with very high flows, interspersed among long periods with very low flows. The most damaging of these events in recent history were the series of intense thunderstorms between June 8th and 11th, 2002 that dropped up to 400 mm of rain in northwestern Ontario and northern Minnesota (Chiotti and Lavender, 2008). There has also been a shift in the cause and timing of flood events from events that were more commonly associated with spring runoff to those that are caused by heavy rainfall throughout the year, rain-on-snow conditions associated with warmer winter temperatures, and ice jamming. Chiotti and Lavender (2008) report 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).

Increases in mean summer and autumn precipitation (Section 2.0, Climate, Figure 3.6), and winter temperatures (Section 2.0, Climate, Figure 3.2) may result in increased runoff from the surrounding watershed, and thus, elevated discharge from the lake outflow during the winter months. St. George (2007), for example, reported that increased winter discharge may be the cause behind a 58% increase in mean annual flows in the Winnipeg River Basin since 1924. However, this record is also punctuated with unusually low periods of 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). Indeed, extreme events of low and high discharge are predicted to be more common under most climate change scenarios.

Depending on the emissions scenario considered, and the region examined, air temperatures in Ontario are expected to increase by 3 to 8 °C over the next half century. Seasonal projections predict that maximum warming will occur in the winter in the far northern regions of the province, and in the spring and winter in northwestern Ontario. Global circulation models (GCMs) also predict increases in total annual precipitation over the next 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.

Effects of climatic warming and drought on physical, chemical and biological characteristics in boreal lakes

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 have been studied intensively for more than three decades. During the drought, annual air temperatures warmed by approximately 2°C, resulting in declines in mean annual runoff of approximately 50%. The increase in air temperature observed at ELA during this time period was less then half of 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 Lake of the Woods and Rainy River Basin over the next few decades.

During the drought period, ELA scientists observed an increase in the number of days without flow for many streams, a severalfold 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). 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

Studies have shown that fisheries management should include maintenance of a certain range of fluctuation in water levels.

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).

Recent studies have found that warming temperatures may exacerbate the severity of blue-green (cyanobacteria) blooms in enriched lakes, because blue-greens have been shown to out-compete other algae 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 blue-greens 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) 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).

6.4 Water level fluctuations

As discussed previously (Section 3.3. Hydrology), the water levels of LOW and the Rainy River are controlled by the Lake of the Woods Control Board (LWCB), the International Rainy Lake Board of Control (IRLBC), and the International Lake of the Woods Control Board (ILWCB). These agencies aim to balance the needs of parties with diverse interests, such as cottagers, boaters, anglers, residents, water suppliers, sewage disposal, farmers, hydroelectric power industries, and other commercial and industrial companies.

In recent years, these agencies have been under pressure to maintain water levels of LOW and of the Rainy River within a range that will minimize water fluctuations. Fluctuating water levels are caused by many factors, such as extreme weather events (i.e., intense rainfall or snowmelt, drought), variation in spring lake fill-ups, alterations in flow regime of nearby reservoirs and dams (i.e., Namakan Lake), and peaking by hydroelectric companies. Hydropower 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 properties (i.e., resorts, cottages, houses, land, docks) located near the shore. Some important fish, such as perch, walleye, and sturgeon, are sensitive to fluctuating water levels. These shifts in water levels alter fish spawning habitat and 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).

Studies have shown that fisheries management should include maintenance of a certain range of fluctuation in water levels. In fact, it has been determined that peak habitat conditions occur at 340 m^3/s for walleye and 170 m^3/s for sturgeon (O'Shea, 2005). Therefore, it has been recommended that a minimum flow of 340 m3/s at Manitou Rapids is required to maintain the availability of suitable fish spawning habitat in the Rainy River (O'Shea, 2005). 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

An aqueduct at the far west end of Shoal Lake in Indian Bay flows by gravity to the City of Winnipeg. Currently, there are no threats to water quality and levels in Shoal Lake.

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).

A work group on the Environmental Effects of Peaking on the Rainy River was established in 2002 by the Ontario/Minnesota Fisheries Committee to examine the issue of peaking. 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, Minnesota Pollution Control Agency, Minnesota Department of Natural Resources, 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 period that normally occurs from April 15 to June 30. In 2007, studies on sturgeon spawning below the Rainy Lake dam and water temperatures along the Rainy River were commenced by the MNDNR, the OMNR, the Department of Fisheries & Oceans Canada (IRLBC/IRRWPB, 2006).

It has also 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: 1) 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; 2) stream flow allow biological and physical conditions to be maintained; 3) the natural hydrograph for the Rainy River be determined; and 4) that regular assessments of water quality and connectivity be performed (O'Shea, 2005).

Shoal Lake – Winnipeg's water resource

Shoal Lake is part of the Lake of the Woods-Rainy River drainage basin, and is connected to LOW by Ash Rapids at its far eastern point. Shoal Lake currently supplies water to the City of Winnipeg, the First Nations communities of Iskatewizaagegan #39 and Shoal Lake # 40, and the town of Falcon Lake, as well as local camps, cottages, and resorts. Although low-lift pumps have been installed, Shoal Lake normally transports water to these areas via gravity alone. Under high water demands, Shoal Lake can draw water from LOW through the narrow channel at Ash Rapids. An aqueduct at the far west end of Shoal Lake in Indian Bay flows by gravity to the City of Winnipeg. Currently, there are no threats to water quantity and levels in Shoal Lake (TetrES Consultants, 2000). However, as Winnipeg's water requirements increase with ongoing development pressures coupled with impending climate warming which is predicted to lower water levels in this region (Magnuson et al., 1997), Shoal Lake's water resources may be threatened. Based on a water balance analysis by TetrES Consultants (2000), current Winnipeg water demands exceed Shoal Lake's natural water renewal 50% of the time. This lack of water replacement is sustained by LOW, which is authorized by the International Joint Commission and controlled by the Lake of the Woods Control Board. Under increasing low water scenarios, Shoal Lake may come to rely on LOW for continued water supply. It has been recommended that the potential impacts of Shoal Lake drawdown on LOW be monitored regularly (TetrES Consultants, 2000).

7 MONITORING NEEDS AND DATA GAPS

7.1 Why should we monitor?

Lovett et al. (2007) define 'environmental monitoring' as a time series of measurements of physical, chemical, and/or biological variables that are designed to answer questions about environmental change. This is a useful definition, because it reminds us that monitoring serves a specific purpose: to answer questions or to support research objectives. Centered on sound research questions and objectives, well designed monitoring programs form the base on which defensible management and policy decisions can be built (Yan et al. 2008).

There is no better source of status and trend information than long-term records from well designed and managed monitoring programs (Field et al. 2007; Lovett et al. 2007). Long-term monitoring allows us to validate appropriate sampling methodologies and experimental designs, to generate data for model development and testing, and to understand the natural variability of ecosystems over time.
As indicated by Weatherhead (1986), monitoring allows us to answer the question: "how unusual are unusual events"? For example, when meteorologists report an unusually large rainfall event in the region, they are able to make this assessment based on more than 100 years of historical data. In contrast, when an algal bloom forms in Lake of the Woods (LOW) in late summer or early fall, we must rely solely on anecdotal reports to determine how severe the event is relative to the historical norm, because no long-term data exist. While there is certainly value in anecdotal reporting, the development of a long-term monitoring program for assessing algal species abundance, composition, and the concentrations of algal toxins over space and time would provide us with an objective means of assessing trends, and for determining whether or not a specific event is "unusual".

Despite their importance, long-term monitoring programs for aquatic ecosystems are rare. In part, this reflects a lack of public funding (e.g., Krajnc 2000; Schindler 2001), but it is also because the majority of research programs are fixed to the duration of graduate student projects (Weatherhead 1986), and these rarely extend beyond three years of monitoring. Albeit scarce, well designed long-term monitoring programs have made enormous contributions to environmental policy development and evaluation (e.g., Yan et al. 2008).

> In our view, the next three to five years represents a critical period for the development of a core monitoring program for the region ...

We are at an exciting juncture for monitoring in the Lake of the Woods and Rainy River Basin. While there are significant challenges to be overcome because of the geographical and jurisdictional complexity of the basin, there is also a tremendous opportunity for developing an integrative monitoring program that addresses research and management questions of local interest. Indeed, some of these efforts already are underway in the basin. In our view, the next three to five years represents a critical period for the development of a core monitoring program for the region, and the allocation of additional funds will be required for this program to be sustainable over the long-term. However, relative to the value of resources it protects and the policy it may inform, long-term monitoring is extremely cost-effective (Yan et al. 2008).

7.2 Challenges to monitoring in the Lake of the Woods and Rainy River Basin

Physical, hydrological and limnological complexity

Challenges: As the eagle flies, the distance from the outflow of Rainy Lake, along the Rainy River, and north through LOW to the Winnipeg River is nearly 250 km. To complicate matters, LOW is nearly as wide, from west to east, and it is long, from south to north, and contains hundreds of separate bays, and more than 14,000 islands. The lake is one of the most hydrologically complex waterbodies in northwestern Ontario, if not Canada. It would be more aptly named the Lakes of the Woods, as many of the bays experience water quality and ecological conditions that are unique. For example, the range in total phosphorus concentrations observed among several bays in LOW (Pla et al. 2005) is similar in magnitude to the variation in phosphorus that is observed among hundreds of lakes in central Ontario, Canada (Ontario Ministry of the Environment's Lake Partner Program: www.ene.gov.on.ca/envision/water/lake_partner/index.htm).

The variation in water quality that has been observed among bays in LOW is a result of many factors, including:

- the proximity of each bay to the main direction of flow in the lake, which is from the mouth of the Rainy River to LOW outflows near Kenora, Ontario;
- variation in water depth across the lake, with more shallow areas found in the large southern basin, and deeper bays that are more typical of the Precambrian Shield found in northern regions of the lake;
- the degree of water column mixing that occurs at the site, reflecting both differences in water depth and fetch;
- variation in surficial geology across the landscape; and
- local environmental pressures and disturbances (e.g., the degree and intensity of shoreline residential development), that may affect individual bays to varying degrees.

This variation introduces challenges to the design of a long-term monitoring program for the Lake of the Woods and Rainy River 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.

Considerations: 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 (i.e., they include physical, chemical and biological variables), 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. Moreover, 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 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). Chemical trends may even be reversed over time. Because the changes we observe in water quality are being affected by an increasing number of environmental stressors (Yan et al. 2008), it is plausible to expect that continued monitoring will reveal additional changes over time.

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). An informative list of the key characteristics for successful monitoring is provided by Lovett et al. (2007):

1. Design the monitoring program around compelling scientific questions. This is the central tenant of any monitoring program. Ideally, these questions should be generated by a scientific advisory committee of varied expertise, taking into consideration the interests of the many stakeholders within the basin.
2. Allow flexibility to review, provide feedback on, and to adapt the monitoring design as research questions evolve. Again, this should be a primary

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.

function of the scientific advisory committee, as they determine whether or not the scientific questions are still relevant, and/or the data being collected are still addressing the questions. We recommend that a synthesis report, similar in focus to this State of the Basin report, be written every five to seven years to track long-term changes relative to the baseline data presented here, and to serve as a means for re-focusing the scientific objectives.

3. 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. 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. Fortunately, there are historical precedents for long-term sampling routines that can be mirrored in the Lake of the Woods and Rainy River Basin. Lessons learned from sampling at other monitoring sites (e.g., the Great Lakes, Lake Simcoe, Lake Winnipeg, Experimental Lakes Area) can be used to refine the monitoring design for the Lake of the Woods and Rainy River Basin. Importantly, these measurements should be as inexpensive as possible, because the cost will ultimately determine the long-term stability of the program.
4. Maintain quality and consistency of the data. This is a critical point, because data of low quality, or data where methods or collection sites have changed frequently through the record, may be of limited value. Lovett et al. (2007) emphasize that sample collections should be rigorous, repeatable, well documented and should employ acceptable methods. Furthermore, 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. Generally defined, the goal of QA/QC is to identify and implement sampling and analytical methodologies that limit the introduction of error into datasets. A more formal definition is provided by the Intergovernmental Panel on Climate Change (IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Chapter 8. Quality Assurance and Quality Control; www.ipcc-nggip.iges.or.jp/public/gp/english/8_QC-QC.pdf), where QC is defined as a program for providing routine and consistent checks to ensure data integrity, correctness and completeness, to identify and address errors and omissions, and to document and archive inventory material and all QC initiatives. Within agencies working in the basin, these procedures currently exist in some form. However, field and analytical procedures may also vary among agencies, as stated above, and thus uncertainty may be introduced regarding the interpretation of data, particularly for variables that are being collected by more than one agency. QA, which is defined in the IPCC report as a planned system of review procedures preferably conducted by third parties, should be performed after the implementation of QC procedures. The development of QA/QC procedures requires resources, expertise and time, and should be a topic of discussion for the scientific advisory committee.
5. Plan for long-term data accessibility and sample archiving. 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. At the very least, however, metadata should be archived, and

should include detailed information on sampling methodologies, analyses and data reduction procedures that are publicly accessible. Also, a list of primary contacts for agency-specific datasets should be maintained and updated. In the Lake of the Woods and Rainy River Basin, the Rainy River Water Resources Centre (www.rainybasinwater.org) has begun to serve this purpose.

6. Continually examine and present the monitoring data. The Lake of the Woods International Water Quality Forum is 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.
7. 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.

Political and jurisdictional challenges

Challenges: Multiple agencies, including government departments working at municipal, state/provincial and federal levels, non-governmental organizations, volunteer groups that include the general public, and First Nations, have an interest in the lake, and are or have been monitoring in the basin. Added to this complexity, the basin spans inter-provincial and well as national jurisdictional boundaries. Furthermore, these agencies have both varied and overlapping responsibilities, particularly when it comes to the protection of water quality. Jurisdictional complexity may translate into a duplication and/or fragmentation of monitoring efforts, designs, and delivery which could easily lead to ineffective programs that lack comprehensive or integrated coverage.

Considerations: In addition to the creation of a scientific 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. These agreements can vary in content, from simple statements of intent for collaboration, to more formal agreements that include provisions for standardizing data collection, requirements for QA/QC, data sharing protocols, and possibly stipulations for financial contributions from one or more of the partners. Recently, an initiative among government agencies and the Lake of the Woods Water Sustainability Foundation (LOWWSF) has resulted in a draft Multi-agency Agreement for collaboration that includes as members Environment Canada, LOWWSF, Minnesota Department of Natural Resources, Minnesota Pollution Control Agency (MPCA), Ontario Ministry of the Environment, Ontario Ministry of Natural Resources, Manitoba Water Stewardship, and the US Environmental Protection Agency. The draft agreement outlines, generally, that these groups agree to coordinate and collaborate on monitoring and management activities in the LOW watershed.

At a broader political level, a formal submission by the LOWWSF is being developed to seek the involvement of the International Joint Commission (IJC) to: 1) create a Water Pollution Board for LOW (possibly as an expansion of the Rainy River Water Pollution Board); and 2) to create an ad hoc task force to coordinate complimentary research and phosphorus management plans for LOW that would benefit both the LOW and Lake Winnipeg.

Effective monitoring must be centered on clear and compelling scientific questions or objectives.

The Province of Ontario has shown support for this submission by way of a letter from Premier Dalton McGuinty to the Canadian Minister of Foreign Affairs.

The IJC currently plays a significant oversight role with respect to water quantity and quality in other regions of the LOW watershed, through its creation and management of the International Lake of the Woods Control Board, the International Rainy Lake Board of Control, and the International Rainy River Water Pollution Board.

Funding challenges

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 (e.g., increased property values with improved water quality). In the United States, for example, it has been estimated that the costs of broadscale monitoring programs associated with the implementation of the Clean Water Act in 1972 were no more than ~2% of the costs of complying with the Act (Lovett et al. 2007). Similarly, programs for monitoring acid rain deposition and impacts, required under the 1990 amendments to the Clean Air Act (Title IV), have been costed at 0.4% of the implementation costs of the Act, and at only 0.01% of the estimated benefits of this implementation (Chestnut & Mills 2005). Furthermore, the absence of monitoring programs greatly hinders the evaluation of the effectiveness of policy decisions or remediation. For example, as the MPCA embarks on a detailed Total Daily Maximum Load study for phosphorus in the southern of LOW, monitoring will be required to calibrate their models, and to track nutrient levels over time in response to any remediation activity that is proposed.

As discussed above, the complexity of this basin, and the shared responsibilities of multiple agencies for its management require that core funding be generated from multiple sources. The continued development of working agreements between the partner agencies is recommended.

7.3 Data gaps: A case study—development of a nutrient budget and nutrient modeling in the Lake of the Woods watershed

General Gaps

Effective monitoring must be centered on clear and compelling scientific questions or objectives. To illustrate where specific data gaps exist in the basin, we discuss the state of monitoring with respect to the development of a total phosphorus nutrient budget and nutrient management models for use in the LOW watershed. Possible research questions for this initiative may include:

- What are the relative sources of phosphorus to the Rainy River and LOW? (nutrient budget)
- In terms of nutrient response within LOW, how sensitive is the lake to increases in shoreline development? To long-term changes in climate? And how do these sensitivities vary spatially in the lake? (nutrient modeling)
- 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? (applied nutrient modeling)

When assessing possible data gaps, we begin by creating a list of variables that would be required to address these research questions (please see Table 7.1). In Table 7.1, the variables have been categorized along two axes. The horizontal axis broadly divides the variables by ecosystem type (e.g., lake, watershed, airshed), and the vertical axis separates the variables into scientific domains (e.g., physical, chemical, and biological variables).

We can also rate the quality of the existing monitoring data. In our example, we evaluate quality based on the temporal frequency and the spatial range across which the data have been collected. Using this approach, data that have been collected at regular sampling intervals, over multiple years, and that cover a broad geographic range in terms of site location, are assigned a rating of 'overall good quality'. As can be seen in Table 7.1, based on this criterion alone (and not yet considering quality associated with the type and precision of analyses, or other factors) we note that there are very few variables that we can classify as having good quality. On a more positive note, however, we can similarly state that there are few variables that are very limited or have no data. Most variables are limited somewhat by spatial or temporal coverage. Furthermore, with one exception (e.g. fish data) the data coverage appears to decrease with scientific domain (from physical to biological variables). This means that data on key variables of interest, such as algal species abundance and composition and algal toxins, are very limited.

Specific Gaps

With on-going work in the development of a total phosphorus budget for the Rainy River and LOW, and in recent phosphorus modeling efforts in LOW, the following specific data gaps have been noted [For further details on data gaps, please also see: 1) Gartner Lee Limited. 2007. Lake of the Woods Baseline Nutrient Compilation and Guidance Document. GLL Report 70-068 – 70-069; and 2) Watson, S. and Yerubandi, R. 2008. Scenario-based assessment of modelling approaches to Lake of the Woods nutrient management. Environment Canada.]:

- An enhancement of meteorological monitoring is recommended, including the collection of short and long-wave radiation and photosynthetically active radiation (PAR): these additional data are necessary input variables into dynamic nutrient, physical-biologically coupled, and climate models.
- Spatial coverage for the collection of deposition chemistry should be improved: there are presently no sites within the boundaries of LOW where

TABLE 7.1 Monitoring variables required to develop a nutrient (i.e., phosphorus) budget, and to perform nutrient modeling, in the Lake of the Woods and the Rainy River basin. The variables are categorized along a horizontal axis of ecosystem type (lake, watershed or airshed), and a vertical axis of scientific domain (physical, chemical or biological). Data quality has also been assessed as being of high (green), medium (red) or low (grey) quality based on the spatial and temporal extent of data that are currently available.

	Lake	Watershed	Airshed
Biological	- algal biomass and composition - algal toxin data - other biological data (e.g. fish) - paleoecological data	= very limited or no data = data limited by temporal/spatial scale = overall good quality	
Chemical	- nutrient chemistry - general chemistry - sediment nutrient loading data	- tributary chemistry - point and non-point source P sources	- deposition chemistry
Physical	- lake morphometry - lake bathymetry - water balance - profile data - internal water movements	- tributary flow data - runoff data - sub-watershed areas - land-use information	- precipitation - temperature - solar radiation - PAR

There should be continued discussion regarding the location and sampling frequency of core monitoring sites in LOW, along the Rainy River, and into its tributaries.

precipitation depths and chemistry are being collected. Thus, atmospheric nutrient loads are currently being estimated from data collected at remote sites, such as the Experimental Lakes Area, or sites in northern Minnesota.

- Bathymetric maps and water circulation/internal water movement data are lacking: Apart from detailed bathymetries of a few isolated bays in LOW, detailed bathymetric maps are not available for the lake, but are required for some models (e.g., hydrodynamic and fisheries optimal habitat management models). There are on-going efforts to improve this deficiency, particularly for Big Traverse Bay.
- There are no data on internal loading and release rates of nutrients (i.e., phosphorus) from lake sediments: There are currently no data on nutrient loads from lake sediments in LOW. Big Traverse Bay, in particular, is a large, shallow bay that may experience internal loading via re-suspension from wave activity, or other processes. The contribution of internal loading to the total nutrient budget cannot be determined at the present time, although it is potentially an important contributor. On a related note, there are limited dissolved oxygen profile data for regions outside of the Clearwater Bay area. This has implications for internal phosphorus loading and other biological processes.
- There are very few data quantifying the tributary load of nutrients to the Rainy River and LOW: Apart from detailed loading data that have been collected for the Rainy River, and for some of the tributaries feeding the Rainy on the U.S. side of the international border, there are few data on nutrient concentrations or flows of other major tributaries to the Rainy River or LOW. Although it is likely that the Rainy River contributes the majority of the tributary load to LOW (it contributes approximately 70% of the tributary flow), other tributaries cannot be ignored in a calculation of the whole-lake nutrient budget. Efforts are underway, through multiple partners, to begin some limited tributary monitoring in 2009 on both sides of the international border.
- Non-point source anthropogenic contributions to the nutrient budget have not been quantified: For example, detailed data regarding the number of shoreline residential developments, their annual usage rates, and their location across the basin do not exist. These data will be required to refine any nutrient budget or modeling estimate.
- There need to be improvements regarding the spatial distribution of water quality monitoring sites: There should be continued discussion regarding the location and sampling frequency of core monitoring sites in LOW, along the Rainy River, and into its tributaries. For example, prior to 2008, there were no monitoring sites located immediately above or below the LOW outflows. These data are required to calculate a preliminary mass-balance for total phosphorus and other elements in LOW, a necessary step in the development of a nutrient budget.
- There are limited GIS data (land-use, % wetlands, etc): The development of empirical equations for predicting nutrient loads from smaller tributaries, and upland and wetland areas of the watershed require detailed land-use data, most of which can now be generated using GIS tools. There exists a major challenge in integrating GIS base layers from U.S. and Canadian delineated watersheds, although some efforts have been made recently to integrate these databases.
- We know little about algal abundance and composition, and algal toxins in LOW: Severe algal blooms have been identified as the primary concern to local resource users. However, apart from some limited algal identifications (H. Kling, Algal Taxonomy and Ecology Inc. & B. Kotak, Miette Environmental

Consulting, pers. comm.), and some recent monitoring tied to a graduate student project (Chen et al. 2007), there are few data regarding the abundance and composition of major algal groups, and the concentrations and occurrence of major algal toxins.

7.4 Core and value-added monitoring

A successful core monitoring program, as described in detail above, 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. For example, if we consider the list of variables presented in Table 7.1, and determine the degree of overlap for a program designed to examine the impacts of climatic change on aquatic ecosystems, we estimate that ~90% of the variables would be transferable to the new research program (Table 7.2). Thus, although we have provided a long list of specific data gaps for a project related to phosphorus management in the basin, filling these gaps would also be beneficial for future research objectives.

7.5 Summary

In conclusion, the monitoring data that are summarized in this report were collected by many capable scientists and resource managers working on specific issues of interest to their agencies or affiliates. We suggest that the renewed interest in monitoring in the Lake of the Woods and Rainy River Basin should be strengthened through the development of a Basin-wide Technical Advisory Committee, and agreements that formalize current inter-agency partnerships. These initiatives would help resource managers to focus their scientific objectives, and to coordinate and collaborate on new monitoring initiatives.

TABLE 7.2 A list of common monitoring variables that would be required for 1) the development of a nutrient (i.e., phosphorus) budget, and to perform nutrient modeling; and 2) a program to measure and to assess the impacts of climatic change in the Lake of the Woods and the Rainy River Basin. There is significant overlap in the variables that would be required for these programs.

	Lake	Watershed	Airshed
Biological	- algal biomass and composition - algal toxin data - other biological data (e.g. fish) - paleoecological data	■ = variables in common	
Chemical	- nutrient chemistry - general chemistry - sediment nutrient loading data	- tributary chemistry - point and non-point source P sources	- deposition chemistry
Physical	- lake morphometry - lake bathymetry - water balance - profile data - internal water movements	- tributary flow data - runoff data - sub-watershed areas - land-use information	- precipitation - temperature - solar radiation - PAR

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10 GLOSSARY

Basin – see 'Drainage basin'

Catchment area – see 'Drainage basin'

Drainage basin – An area of land drained by a river or lake and its tributaries. Each dranage basin is composed of smaller units called watersheds which correspond to the drainage of a tributary or lake system (MPCA, 2007; MNDNR, 2007).

Fetch – distance (of lake) over which the wind has blown uninterrupted by land without appreciable change in direction.

Island shoreline – land situated on the edge of an island.

Lake surface area – the extent of the surface area of a lake enclosed within the lake shoreline or edge.

Maximum lake depth – The greatest depth of a lake.

Mean lake depth – The average depth of water in a lake. It is equal to the cross-sectional area divided by the surface width.

Perimeter – The distance around a lake or river. Can be considered the shoreline length.

Secchi depth – an estimate of water clarity of surface water. It is the depth at which a Secchi disk is no longer visible.

Shoreline development factor – an estimate of the degree of irregularity of a shoreline. It is calculated as the ratio of shoreline length to the circumference of a circle with the same area. A perfectly circular lake will have a value of 1 while lakes with very irregular shorelines will have values greater than 3.5. Lakes with high irregularity have more shoreline available and are generally more susceptible to development and its related impacts on water quality and habitat.

Trophic status – a measure of a lake's biological productivity. It is normally defined by total phosphorus (TP) concentrations, although chlorophyll-a concentrations can also be considered. In general, there are three main categories of trophic status (as defined by the Ontario Ministry of Environment standards): Oligotrophic lakes have TP concentrations of less than 10 μg/L are less productive and nutrient poor; mesotrophic lakes have TP concentrations of 10-20 μg/L and are moderately productive; and eutrophic lakes have TP concentrations of >20 μg/L and are very productive.

Watershed – see 'Drainage basin'

11 ABBREVIATIONS

Chl-a – Chlorophyll-a
CLMP – Minnesota's Citizen Lake Monitoring Program
DDT – Dichloro-Diphenyl-Trichloroethane
DOC – Dissolved organic carbon
EC – Environment Canada
EDA – Environmental Data Access
EEM – Environmental Effects Monitoring Program
EMAN – Ecological Monitoring and Assessment Network (Environment Canada)
EMAP – Environmental Monitoring and Assessment Program
EPT – Ephemeroptera-Plecoptera-Trichoptera Index
HBI – Hilsenhoff Biotic Index
IBA – Important Birds Area
IJC – International Joint Commission
ILWBC – International Lake of the Woods Control Board
IRLBC – International Rainy Lake Board of Control
LA – Lake area
LOW – Lake of the Woods
LOW FAU – Lake of the Woods Fisheries Assessment Unit (OMNR; in Kenora, Ontario)
LOWDPOA – Lake of the Woods District Property Owners Association
LOWWSF – Lake of the Woods Water Sustainability Foundation
LPP – Lake Partner Program
LWBC – (Canadian) Lake of the Woods Board of Control
MFTCS – Minnesota's Frog and Toad Calling Survey
MN – Minnesota
MNDNR – Minnesota Department of Natural Resources
MPCA – Minnesota Pollution Control Agency
N – Nitrogen
NAAMP – North American Amphibian Monitoring Program
NLF – Northern Lakes and Forests Ecoregion
NOAA – National Oceanic and Atmospheric Administration
OMNR – Ontario Ministry of Natural Resources
OMOE – Ontario Ministry of the Environment
ON – Ontario
P – Phosphorus
PCA – Principal Components Analysis
PCB – Polychlorinated biphenyl
PCP – Pentachlorophenyl
PWQMP – Provincial Water Quality Monitoring Program
RRFN – Rainy River First Nations
SWCD – Soil and Water Conservation District
TKN – Total Kjeldahl Nitrogen
TMDL – Total Maximum Daily Load
TP – Total Phosphorus
U.S. – United States
USEPA – United States Environmental Protection Agency
USGS – United States Geological Survey
WA – Watershed area
WHO – World Health Organization
WSC – Water Survey of Canada