



STATE OF LAKE WINNIPEG:

1999^{to} 2007 HIGHLIGHTS



State of Lake Winnipeg: 1999 to 2007 Highlights

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State of Lake Winnipeg: 1999 to 2007 Highlights

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State of Lake Winnipeg: 1999 to 2007 is a first-of-its-kind compilation of physical, chemical and biological information on Lake Winnipeg, and would not have been possible without the hard work and coordination efforts of Lucie Lévesque (Environment Canada) and Elaine Page (Manitoba Water Stewardship).

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INTRODUCTION

Water quality in Lake Winnipeg has deteriorated over time, as evidenced by the increasing frequency and intensity of algal blooms in the lake in recent years. Increased nutrient (phosphorous and nitrogen) loading to Lake Winnipeg from the watershed is one of the key reasons for these algal blooms. While some scientific data had been collected on Lake Winnipeg over the years, much of the intensive monitoring on the lake has occurred since 1999. Knowledge of the structure and function of Lake Winnipeg has been advanced through intensive federal, provincial, joint, and independent research and monitoring programs. Research and monitoring programs have improved our understanding of the physical, chemical and biological characteristics of the lake and the sources and fate of nutrients transported to Lake Winnipeg. Until now, there has been no systematic attempt to summarize these data to establish a better understanding of the current state of the lake. To address this issue, Environment Canada and Manitoba Water Stewardship, along with many others conducting research and monitoring on the lake, have worked together to produce a State of the Lake report for Lake Winnipeg to summarize the current scientific knowledge on the lake, focusing on the period from 1999 to 2007. The report, which is available as both a highlights and extended technical document, is intended to serve as a baseline for future lake assessments and presents key information that will help to support the development of performance indicators and ecologically relevant nutrient objectives for Lake Winnipeg.

Lake Winnipeg Watershed

The Lake Winnipeg watershed extends from the Rocky Mountains to within a few kilometres of Lake Superior, and from the northern tip of the lake south to South Dakota. The watershed is the second largest in Canada and spans approximately one million square kilometres including parts of four Canadian provinces and four U.S. states. Of the roughly 7 million people in the watershed, nearly 80% live in large cities such as Calgary, Edmonton, Saskatoon, Regina, Winnipeg and Fargo. The watershed is dominated by agricultural land use, which has implications for the quantity and quality of water entering the lake. The western part of the watershed is predominantly cropland while forested areas dominate the eastern side of the lake in the Boreal Shield region.



Lake Winnipeg watershed

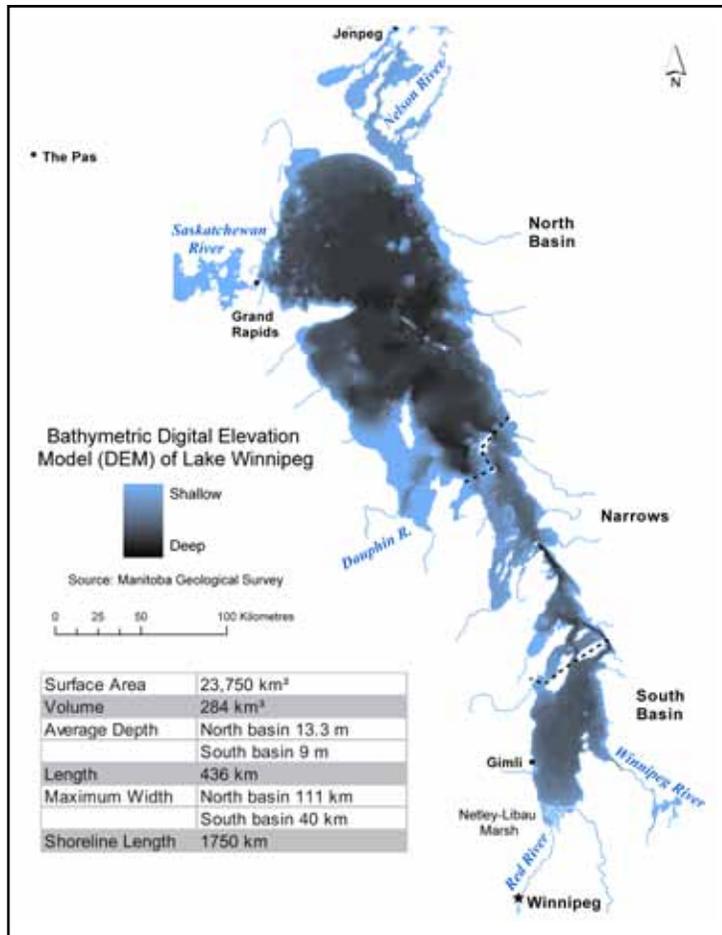
The three major rivers feeding Lake Winnipeg are the Saskatchewan, Red (including the Assiniboine) and Winnipeg rivers. Hydrology within the watershed is highly regulated, with numerous dams and diversions,

which alter the natural flow in rivers draining to Lake Winnipeg. Research has indicated that the abundant lakes and reservoirs upstream of Lake Winnipeg sequester nutrients, reducing their transport downstream. The size, geographical diversity, and the inter-jurisdictional and international nature of waters within the watershed present unique challenges to water resource management, including measures to reduce nutrient loading to Lake Winnipeg.

Lake Winnipeg

At 23 750 square kilometres in area, Lake Winnipeg is the tenth-largest freshwater lake in the world, and the sixth-largest lake in Canada. Lake Winnipeg consists of a large, deeper north basin, and a smaller, comparatively shallow south basin. Lake Winnipeg is shallow relative to other large lakes, with an average

depth of 9 m in the south basin and 13.3 m in the north basin. The two basins are separated by the narrows through which waters from the south basin ultimately flow northward. The north and south basins differ not only in size and depth, but also in water quality and biological characteristics. The Nelson River is the only outlet from the lake, flowing northward to Hudson Bay. The outflow of the lake has been regulated for hydroelectric power generation since 1976, making Lake Winnipeg the third-largest hydroelectric reservoir in the world. The lake is of substantial socio-economic and cultural importance, supporting numerous shoreline communities and sustaining a variety of uses including fisheries, recreation and hydroelectric power, which are key components of the provincial economy.



Dominant features and bathymetry of Lake Winnipeg

CLIMATE CONDITIONS

Given that Lake Winnipeg extends about 436 kilometres from its southern point near Netley-Libau marsh to the far north, the lake experiences different climate conditions across the south and north basins. The climate of the Lake Winnipeg watershed is classified as cold continental, with arid conditions throughout, particularly over the warm season through the prairies and plains to the west and south of the lake.

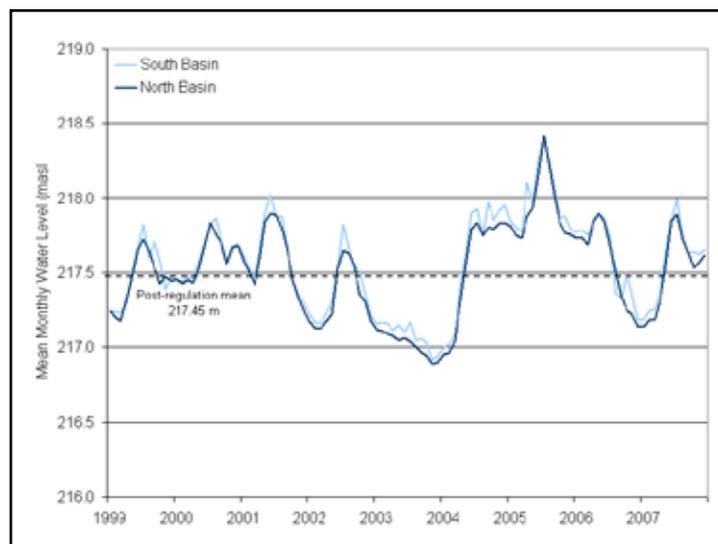
Air temperatures over Lake Winnipeg vary over a north-south gradient. For the period of 1999 to 2007, mean air temperature was 0.8°C at The Pas in the north, nearly two degrees lower than that at Gimli (2.5°C), located near the south end of Lake Winnipeg. Over the nine-year period, the warmest year was 2006 (The Pas 2.0°C, Gimli 3.7°C) and the coolest 2004 (The Pas -0.8°C, Gimli 0.9°C). The occurrence of air temperatures above or below what might normally be expected has implications for Lake Winnipeg. For example, in years where temperatures are higher than normal, water losses from the lake and the length of the open water season may be expected to increase, and rates of biological productivity (including the formation of algal blooms) may rise.

Annual mean precipitation in the Lake Winnipeg watershed is for the most part between 400 and 600 mm, but as low as 200 mm in some areas. Precipitation in the immediate vicinity of Lake Winnipeg was at or below the normal of 488 mm in most years from 1999 to 2007. The driest year was in 2006 (275 mm) and the wettest in 2004 (576 mm), the latter of which followed a strong and persistent drought that affected much of the Lake Winnipeg watershed in 2002 and 2003. Total precipitation occurs primarily in the form of rainfall between May and September. Snowfall, which represents between approximately 15 and 20% of the total precipitation in the south basin and up to twice that percentage in the north basin, contributes to sediment- and nutrient-laden flows during the spring melt in rivers upstream of Lake Winnipeg.

HYDROLOGY

River flow is the most significant source of water to Lake Winnipeg. Of the major tributaries, the Winnipeg River contributes nearly 50% of the total inflow to Lake Winnipeg, followed by the Saskatchewan River (25%), the Red River (16%), unmetered flows (6%) and the Dauphin River (4%). Compared to records from 1964 to 2005, the Winnipeg and Red rivers contributed proportionately more to the total inflow to Lake Winnipeg in recent years than in earlier decades (Winnipeg River 45%, Red River 11%). Flow from tributaries to

Lake Winnipeg accounts for a large proportion of the input to the lake's water balance, with precipitation contributing as well. Water loss occurs primarily via discharge through the Nelson River outflow, although evaporation also plays a role. From 1999 to 2007, average monthly tributary discharge to Lake Winnipeg was highest in 2005 (6854 m³/s) following a period of high rainfall, with the lowest discharges in 2003 (537 m³/s) following below normal precipitation and drought in the watershed.



Mean monthly water levels of Lake Winnipeg from 1999 to 2007

Data source: Water Survey of Canada, G. McCullough

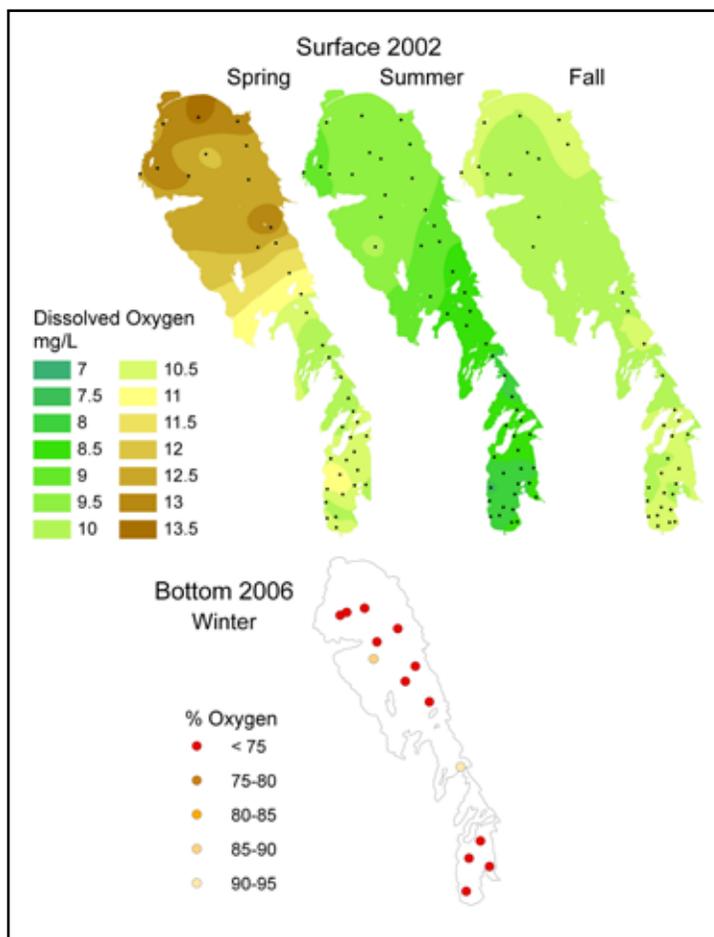
Water levels in Lake Winnipeg have been regulated for hydroelectric power generation since 1976. Since the onset of regulation, mean water levels have not changed but natural extremes in high and low water levels have been dampened by regulation. Prior to lake regulation, outflow was typically greatest in the spring and early summer and lowest in the winter. However, since regulation, the seasonal outflow pattern can be reversed with greater outflow typically occurring during the fall and winter, during periods of peak hydroelectric power demand. However, from 1999 to 2007 there were many wet years with high inflows to Lake Winnipeg causing a more natural seasonal outflow pattern. Water levels also vary in response to “wind-setup” or “storm surges.” Corresponding with tributary flows from 1999 to 2007, lake water levels were highest in 2005 and lowest in 2003, as were water residence times. Water residence times have implications for the storage and release of nutrients and contaminants in the lake, and from 1999 to 2007 averaged 4.3 years for the lake as a whole, 1.3 years for the south basin and 3.5 years for the north basin.

Water ultimately flows from south to north in Lake Winnipeg, affecting in part the distribution of water and nutrients through the lake. Hydrodynamic modelling of water circulation in Lake Winnipeg indicated that water generally flowed north or north-eastward in the north basin and north through the narrows region of the lake. Water circulation in the south basin was more complex, with water flowing southward along the west side of the lake and in a northerly direction along the east side of the lake.

WATER QUALITY

Water Temperature and Dissolved Oxygen

Water temperature affects the energy available for biological productivity and chemical processing in lakes, including the availability of dissolved oxygen for sustaining aquatic life. Water temperatures are typically higher in the smaller, shallow south basin and lower in the large, deeper north basin. Water in the north basin takes longer to warm in the spring than that in the south basin because of its large volume. The open water season, during which waters warm and light availability increases, driving biological productivity, is approximately 180 days in the south

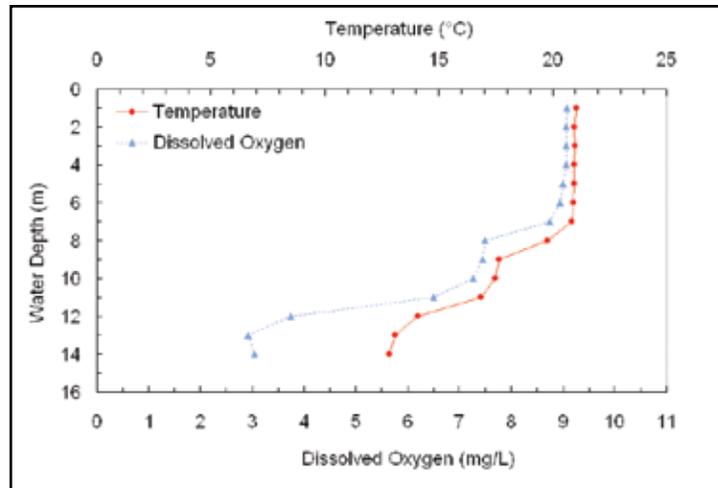


Seasonal dissolved oxygen concentrations in Lake Winnipeg surface (2002) and bottom (2006) waters

Data source: Environment Canada

basin and about 14 days shorter in the north basin. Climate change has the potential to alter water temperatures and associated lake characteristics.

Summer water temperatures in the south basin from 1999 to 2007 were typically 2.0 to 3.0°C higher than those in the north basin. The lowest was in 2004 (17.1°C) and highest in 2007 (22.9°C). Computer modelling based on air temperatures indicates that mean monthly water temperatures from 1999 to 2007 were not markedly cooler or warmer than any other decade since the mid-20th century. It is interesting to note that the water column of Lake Winnipeg is typically well mixed with bottom waters within 1.0 to 2.0°C of surface water temperatures. This has implications for dissolved oxygen levels and therefore the health of the lake.



Stratification of water temperature and dissolved oxygen in the north basin in the summer of 2007

Data source: Manitoba Water Stewardship

Dissolved oxygen in lakes, which is critical to sustain aquatic life, originates from the atmosphere and phytoplankton productivity, and is consumed by biological activity and decay. In addition, dissolved oxygen concentrations are strongly related to water temperature. Recent observations in Lake Winnipeg have indicated that there may be complex spatial and temporal variation in dissolved oxygen concentrations including the occurrence of oxygen-depleted conditions.

Dissolved oxygen concentrations in the surface waters of Lake Winnipeg from 1999 to 2007 were slightly lower in the south basin compared to the north basin, with only very small differences between concentrations in surface and bottom waters. Approximately 2% of dissolved oxygen measurements in surface waters in both basins were below the Manitoba Water Quality Objective for the protection of aquatic life (5 mg/L), with up to 6% below the objective in bottom waters of the north basin, indicating the potential for detrimental effects on aquatic biota.

Although waters in Lake Winnipeg are thought to be well mixed, temperature stratification from top to bottom has been observed on occasion in the north basin. Declines in water temperatures at the bottom of the lake can result in reduced availability of dissolved oxygen, which may threaten the survival of biota and increase the release of nutrients from sediments in the lake. Low dissolved oxygen concentrations were measured in bottom waters associated with temperature stratification, or a thermocline, in the summers of 2003, 2005 and 2007, as well as below ice in the winter of 2006. It is likely that the thermocline was eroded in the summer by strong winds that mixed the water column. The spatial extent and duration of low oxygen zones in Lake Winnipeg are not known and are undergoing further investigation.

Suspended Solids

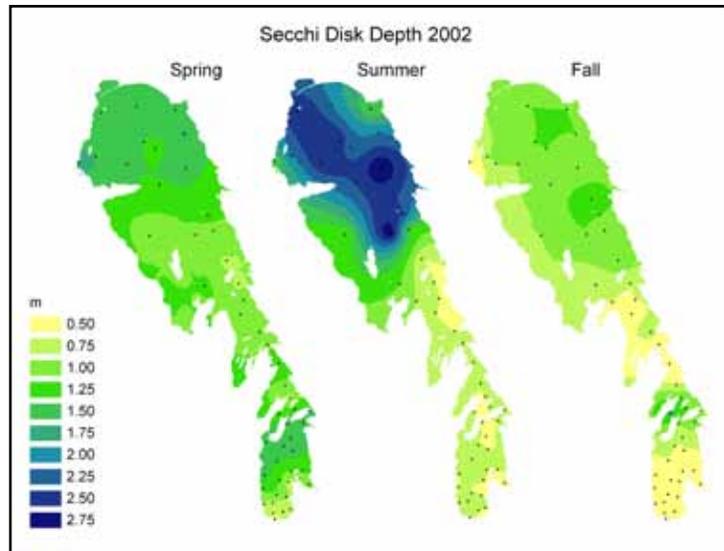
Suspended solids are mineral and organic materials derived from both within the lake and through its tributaries, from erosion, biological activity in the water, re-suspension of lake bottom materials, and to a lesser degree from atmospheric deposition. The mineral component of total suspended solids may carry adsorbed nutrients, and the biological component is itself composed largely of nutrients. Therefore, deposition and re-suspension of particles can affect nutrient storage and availability in the lake. In addition to impacting nutrients

in lakes, suspended solids play a large role in limiting the transmission of light through the water column, thereby limiting biological productivity and affecting the types and abundance of biota in the lake. For example, cyanobacteria, which often form a large component of the algae biomass in Lake Winnipeg, thrive in waters high in suspended solids.

Suspended solid concentrations in Lake Winnipeg's north basin were typically two to three times lower than those in the south basin from 1999 to 2007, averaging 5.2 mg/L for the north and 11.8 mg/L for the south. Light penetrated to greater depths in the clearer waters of the large, deep north basin. Secchi depth in the north basin was on average 0.8 m greater than that in the south basin. Higher total suspended solid concentrations late in the open water season in the north basin of Lake Winnipeg are generally the consequence of phytoplankton growth over the summer. Higher sediment concentrations in the south basin can be attributed to the high sediment loads carried by the Red River and to the greater susceptibility of the bottom sediments to wind-driven re-suspension in shallower waters. Wind-driven re-suspension of the sediments in the lake, thought to be a significant process in Lake Winnipeg's shallow waters, has implications for biological productivity, as well as for the release of nutrients from the lake bottom into the water column.

Nutrients

Phosphorus and nitrogen are the two major nutrients required for plant growth and occur naturally in soils, rocks and vegetation. Accelerated phosphorous and nitrogen loading from anthropogenic sources can lead to nuisance algal blooms, and is a problem facing many countries worldwide. Historical records indicate more pronounced rates of phosphorous and nitrogen deposition in Lake Winnipeg in the second half of the 20th century, attributable to anthropogenic inputs. Recent studies on the lake have shown that phosphorous concentrations in lake bottom sediments in the late 1990s and the 2000s were elevated and that a portion of these nutrients is available for biological activity such as algae growth.



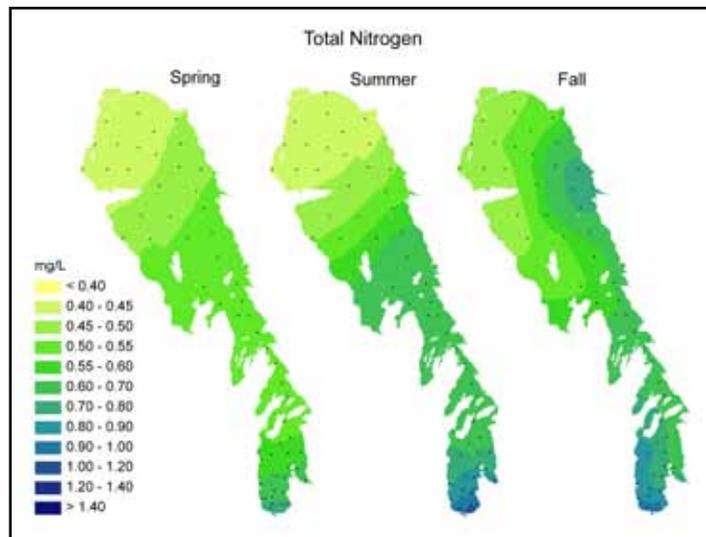
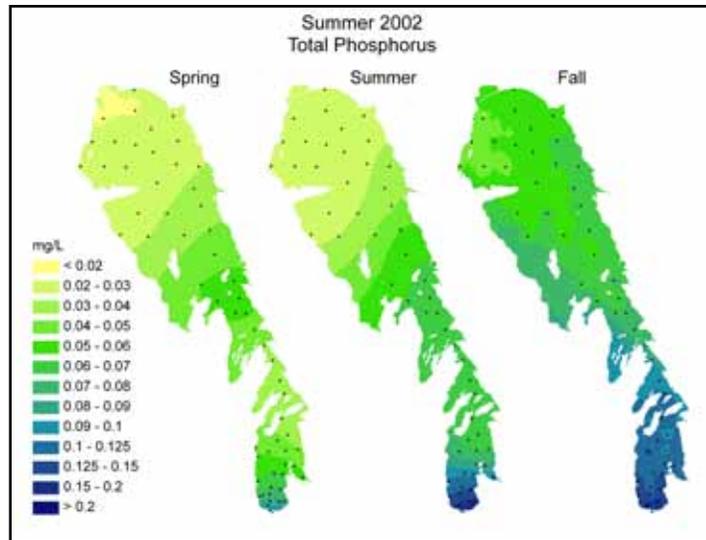
Seasonal secchi disk depth in Lake Winnipeg in 2002

Data source: Manitoba Water Stewardship

Recent water quality monitoring has indicated that Lake Winnipeg is generally classified as eutrophic or hypereutrophic, meaning that the lake is highly enriched with plant nutrients. From 1999 to 2007, the average total phosphorous concentration in Lake Winnipeg was almost three times higher in the south basin and narrows (0.113 mg/L) compared to the north basin (0.044 mg/L). Total nitrogen was also highest in the south basin (0.869 mg/L) compared to the north basin (0.653 mg/L). Higher nutrient concentrations generally occurred at the very south end of the lake and declined moving northward. Elevated nutrient concentrations at the southern end of Lake Winnipeg were likely associated with the nutrient-rich inflow of the Red River. Total phosphorus was generally greatest in the fall and may be partly related to the internal nutrient load from the lake.

Phosphorous concentrations did not appear to vary greatly in the north basin of Lake Winnipeg from 1999 to 2007. However, over the same time period, phosphorous concentrations in the south basin appeared to increase with higher

concentrations observed in 2005 to 2007. Mean annual phosphorous concentration was highest in Lake Winnipeg in 2005 when flow, total phosphorous concentrations and phosphorous loading from tributaries were greatest (between 1994 and 2007). Total nitrogen concentrations in Lake Winnipeg were variable, with no apparent change or trends since 1999. Large inter-annual variation in total nitrogen concentrations may be partly related to inter-annual variability in the biomass of nitrogen-fixing cyanobacteria. When compared to historical data collected during a lake-wide cruise in 1969, average phosphorous and nitrogen concentrations observed during the period from 1999 through 2007 were in the same range as in 1969. However, nutrient concentrations observed in 1969 were generally at the low end of the range observed in the recent decade, suggesting a possible increase between 1969 and the present. A paleolimnological study, a study of cores of lake bottom sediments deposited over centuries, is currently under way and is expected to provide additional information on historical water quality changes in Lake Winnipeg since the early 1800s.



Seasonal total phosphorous and nitrogen concentrations in Lake Winnipeg in 2002

Data source: Fisheries and Oceans Canada

The Red River is the largest source of total phosphorus and nitrogen to Lake Winnipeg, while the Winnipeg River contributed the second-largest load of phosphorus and nitrogen to the lake. On average, about 60% of the phosphorus and 54% of the nitrogen transported to Lake Winnipeg by tributaries and atmospheric deposition was retained in the lake. Phosphorous loads to Lake Winnipeg from the Red River were higher in high flow years and contributed as much as three quarters of the total phosphorous load to Lake Winnipeg. Rates of nitrogen and phosphorus export per hectare were also highest in the Red River and its tributaries compared to other major tributaries to Lake Winnipeg.

An understanding of both the sources and in-lake processing of phosphorus and nitrogen is required to better manage and adapt remediation strategies. A study has been undertaken to identify the various sources of phosphorus through the use of isotopes. Different sources of phosphorus with distinct “fingerprints” can potentially be identified, supporting future management decisions with regards to nutrient sources to the lake.

Source	% Total Phosphorous Load	% Total Nitrogen Load
Red River (at Selkirk)	68	34
Winnipeg River (at Pine Falls)	15	25
Saskatchewan River	5	10
Dauphin River	1	4
East Side rivers	3	4
Brokenhead, Fisher and Icelandic rivers	1	1
Atmospheric deposition	7	11
Nitrogen fixation	-	11

Average annual percentage contribution of rivers, atmospheric deposition and fixation to the total phosphorous and nitrogen load in Lake Winnipeg from 1994 to 2007

Data source: Manitoba Water Stewardship

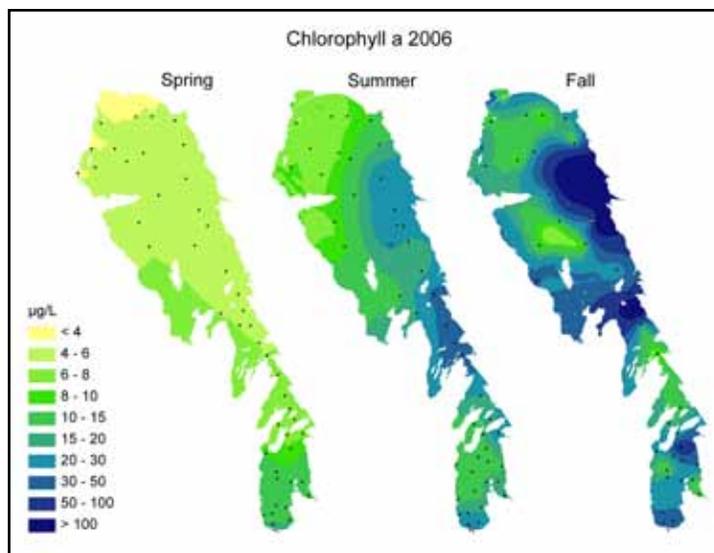
BIOLOGY

Phytoplankton

Phytoplankton are useful indicators of nutrient enrichment in aquatic ecosystems because of their relatively short life cycles that are integrative of water chemistry conditions. An indication of the recent nutrient enrichment of Lake Winnipeg has been the development of large blooms of cyanobacteria during the summer months. Noticeable changes have also occurred during the ice cover season with diatoms coating fishers’ nets, making the nets more visible to fish.

Average annual chlorophyll a concentrations, which are a common measure of the amount of algae, were almost two times higher in the north basin (14.4 µg/L) compared to the south basin (8 µg/L) from 1999 to 2007. In the fall of 2006 and 2007, prolific blooms were observed along the eastern shoreline of the north basin and through parts of the narrows where light and nutrients were likely favourable for phytoplankton

growth. Algal blooms in the south basin of Lake Winnipeg were apparent in the fall of 2006 but were not observed the following year. In the turbid south basin of Lake Winnipeg, phytoplankton biomass is often constrained by light, which may help to explain inter-annual variability in algal bloom formation. From 1999 to 2007, both phytoplankton biomass and chlorophyll a concentrations were highest in 2006 and may have been partly attributed to the high nutrient loads in 2005 and above-average air temperatures in 2006.



Seasonal chlorophyll a in Lake Winnipeg in 2006

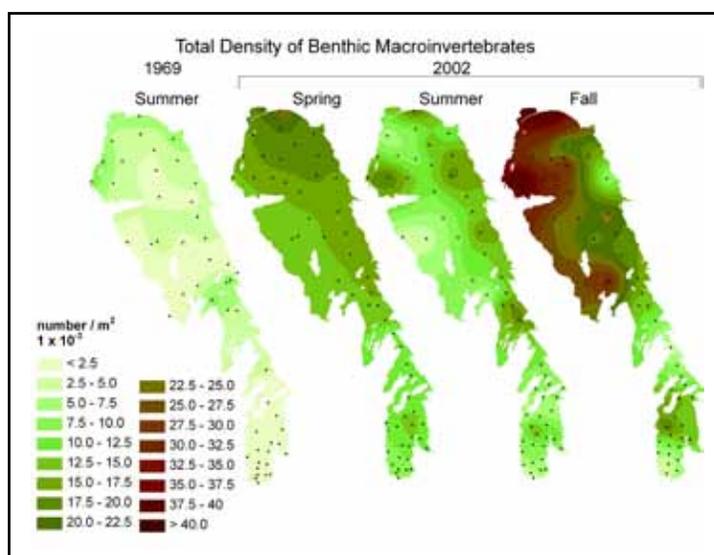
Data source: Manitoba Water Stewardship

A large proportion (>80%) of the total phytoplankton biomass in Lake Winnipeg during the ice-free season from 1999 to 2007 was represented by blue-green algae or cyanobacteria (*Aphanizomenon*, *Anabaena*, *Microcystis*) and diatoms (*Aulacoseira*, *Stephanodiscus*). Cyanobacteria capable of nitrogen fixation (*Aphanizomenon*, *Anabaena*) were dominant during the summer and fall in most years from 1999 to 2007 in Lake Winnipeg. However, in certain years, large blooms of non-nitrogen-fixing cyanobacteria also comprised a significant fraction of the total cyanobacteria biomass in Lake Winnipeg. Large blooms of *Microcystis* contributed to increases in non-nitrogen-fixing cyanobacteria biomass and occurred primarily in the south basin.

Invertebrates

Benthic macroinvertebrates are organisms that inhabit the bottom sediments of lakes for at least part of their life cycle. Examples include freshwater shrimp, insect larvae, midges and worms. Benthic macroinvertebrates play a critical role in the aquatic food web in lakes, serving as a major component of the diet of many fish.

Benthic organisms in Lake Winnipeg as a whole have undergone substantial increases in density in recent decades. Mean density in 2002 was more



Total density (numbers per m²) of benthic macroinvertebrates in Lake Winnipeg

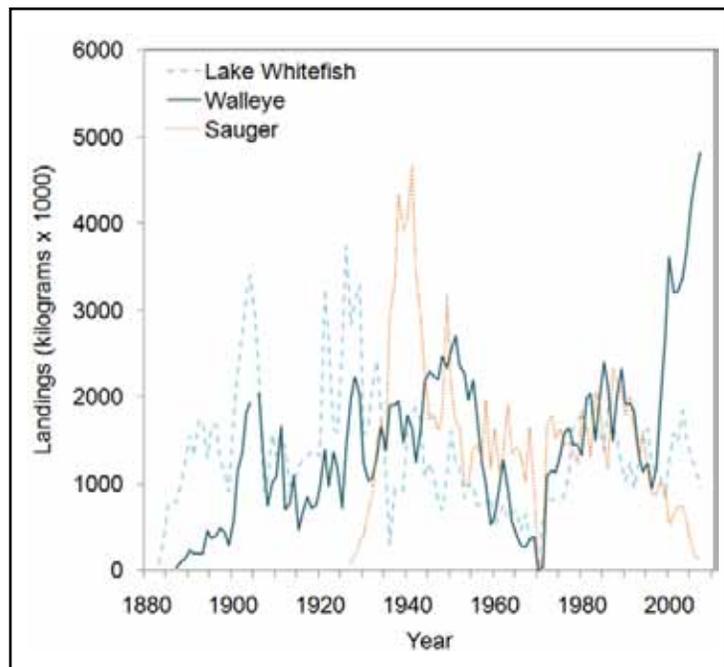
Data source: Fisheries and Oceans Canada, University of Manitoba, B. Hann

than triple that in 1969, particularly in the north basin of Lake Winnipeg. Both midges and aquatic worms comprised a substantial component of the benthic macroinvertebrate community. The abundance and types of benthic macroinvertebrates may respond both directly and indirectly to the increased availability of food resources as a consequence of nutrient enrichment. For example, aquatic worms, which tend to dominate sediments in stressed waters, increased markedly in abundance from 1969 to 2002 in the north basin of Lake Winnipeg, which may be a response to increased nutrient loading to Lake Winnipeg in recent years.

Fish

Lake Winnipeg has long supported important domestic, recreational and commercial fisheries. The commercial fishery began as a gill net

fishery for Lake Whitefish in the late 1800s. Lake Whitefish decreased in the 1930s, and Sauger and Walleye began to dominate the commercial fishery. Walleye harvest fluctuated over the decades, and increased until the mid-1980s, then declined in the mid-1990s. Since the mid-1990s, Walleye harvest has increased and is nearly double any historical Walleye harvest for Lake Winnipeg. Increases in total phosphorus, chlorophyll a and zooplankton densities in recent years may help to explain the increased Walleye harvest. Potential future changes in climate may bring about further change to Lake Winnipeg fishes, with projected increases in the length of the growing season and



Annual landings of Lake Winnipeg commercial fishery by species
Data source: Manitoba Freshwater Fish Marketing Corporation

warmer water temperatures potentially having detrimental effects on some coldwater species.

Since 2002, 25 prey fish species were collected in fish trawl tows from the *MV Namao*. Emerald Shiner, Rainbow Smelt and Cisco were the dominant species by mass in all years. Biomass of Emerald Shiner and Cisco was greater in the south basin and narrows compared to the north basin. Non-native Rainbow Smelt are now the dominant prey fish species in the north basin of the lake. It is unknown to what extent Rainbow Smelt have affected the food web and Walleye production in Lake Winnipeg. Adult Rainbow Smelt may be predators of zooplankton and early year classes of native fish species, and may compete with native fish species for food resources. A recent food web isotope model indicated that Rainbow Smelt occupied the lower forage fish trophic position that is typically used by Walleye. Baseline isotopic studies on Lake Winnipeg have provided information that can be used to readily define sources of water and attendant nutrient inputs to the Lake Winnipeg food web. Trace metal concentrations in fish, with an emphasis

on mercury, will be examined to see how food web isotope patterns can inform the transport of these contaminants from fish to birds.

CURRENT AND EMERGING ISSUES

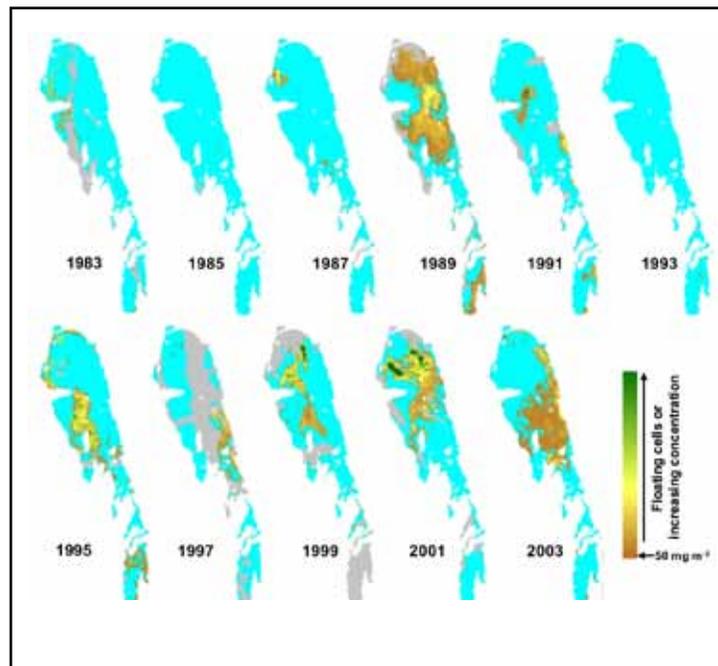
Algal Blooms and Toxins

Algal blooms have occurred historically in Lake Winnipeg. However, since the early 1990s, phytoplankton biomass and the intensity and frequency of algal blooms have increased, and phytoplankton composition has shifted to cyanobacteria dominance. Paleolimnological analysis of sediment cores from the south basin of Lake Winnipeg indicated that total algal abundance has increased 300 to 500% during the 20th century and that all algal groups have increased during the past 70 years. Phytoplankton surveys in 1969 revealed that in that year, average biomass was less than 2000 milligrams per cubic metre and comprised a diversity of taxonomic groups. Since 1999, there has been a progressive increase in mean biomass to over 4000 milligrams per cubic metre (2007), accompanied by a shift to a predominance of cyanobacteria.

Cyanobacteria blooms are of particular concern because of their potential to produce potent algal toxins that may pose health risks to humans and other animals. The algal toxin microcystin-LR is produced by certain species of cyanobacteria. Microcystin has been detected in nearshore and beach areas as well as in the offshore areas of Lake Winnipeg. From 1999 to 2007, concentrations of microcystin in the offshore areas of the lake generally remained very low and were well below the recreational and drinking water quality guidelines. However, in the nearshore and beach samples collected from Lake Winnipeg since 2000, elevated concentrations of microcystin were found to occur occasionally in the lake, potentially representing a health risk to recreational users.

Beaches

Beaches in the south basin of Lake Winnipeg are monitored for the fecal indicator bacteria *Escherichia coli* (*E. coli*). *Escherichia coli* is a bacteria found in large numbers in all warm-blooded animals including humans, livestock, wildlife and birds. While *E. coli* itself does not generally cause illness, when it is present in large numbers, the risk of becoming ill from other organisms is elevated. The most common illnesses contracted by bathers are infections of the eyes,



Satellite imagery of historic occurrence of algal cells (blooms) in Lake Winnipeg

Data source: AVHRR band optical data, G. McCullough

ears, nose and throat as well as stomach upsets. From 2004 to 2009 densities of *E. coli* bacteria at Lake Winnipeg beaches occasionally exceeded the Manitoba Water Quality Objective for recreation. However, densities usually returned to within acceptable limits within 24 hours. Beaches on the east side of Lake Winnipeg tended to have fewer occurrences of *E. coli* densities over the objective. Results of extensive sampling indicated that *E. coli* in beach sand is transferred to inshore bathing water when lake levels rise during strong northerly wind events. Genetic analyses suggest that the largest known source of *E. coli* in beach sand is from shorebirds and geese.

Aquatic Invasive Species

Aquatic invasive species are non-native organisms that have been introduced by humans into areas outside of their natural ranges. Aquatic invasive species can out-compete native species for food and other resources and significantly affect ecosystem function, the economic value of ecosystems and human health. Five aquatic invasive species are known to occur in Lake Winnipeg. These are Common Carp, Rainbow Smelt, White Bass, the cladoceran *Eusubomina coregoni* and Asian tapeworm. Of potential future concern are zebra mussels, which have recently been found in the United States portion of the Red River watershed. The spiny water flea was identified downstream from Pointe du Bois Dam on the Winnipeg River in 2010 and has the potential to be transported into Lake Winnipeg within the next few years if it is not already present in the lake. Other potential threats to Lake Winnipeg include the rusty crayfish, Koi Herpes virus, black algae and quagga mussels. Although it is difficult to predict impacts on Lake Winnipeg, these species may potentially alter ecological relationships among native species, affect ecosystem health and function, the economic value of ecosystems, and human health.

Climate Change

Computer modelling predicts that air temperatures in the Lake Winnipeg area will increase significantly over the next century and that surface water temperatures will increase accordingly. A 2.0°C increase in mid-summer water temperatures could negatively impact as many as 12 fish species common to Lake Winnipeg including Lake Sturgeon, Lake Trout and Burbot. Warm-water species such as Walleye, Yellow Perch and White Bass would be expected to benefit. In addition, earlier spring melt and later freeze-up would lengthen the duration of the open water season, hence potentially increasing biological productivity and nutrient processing in the lake, and affecting the availability of water as evaporation losses change.

CONCLUSION

Eutrophication of Lake Winnipeg has become increasingly pronounced over the past decade and is the main concern regarding the health of Lake Winnipeg. Periodic research and monitoring on the lake from the 1930s to the 1990s provide some indication as to past conditions in Lake Winnipeg and, when supported by paleolimnological research, has pointed to deteriorating water quality in Lake Winnipeg since the early 1900s. More rigorous and continuous monitoring on the lake in response to the increase in the intensity and frequency of algal blooms in Lake Winnipeg over the past 10 years has provided information on the chemical, physical and biological characteristics of Lake Winnipeg, and has highlighted the highly variable nature of water quality in the lake.

Knowledge of Lake Winnipeg has been further enhanced by focused research that has provided crucial information on topics such as nutrient dynamics and balance, trophic structure and interactions, responses of biological communities to nutrients, range and nature of physical and hydrodynamic conditions in the lake, nutrient sources, stressors to the lake, and response of the lake to these stressors. Recent examinations of changes in the lake over the long term have also provided new insights into the structure and function of the lake. However, further information is needed for a more complete understanding of the lake, the sources and nature of stressors, and the response of the lake to these stressors. Additional information will also help to facilitate the development of nutrient objectives for the lake.

Environment Canada and Manitoba Water Stewardship are committed to continuing collaborative work with others involved in research on Lake Winnipeg, including the Lake Winnipeg Research Consortium, universities and their students, private consultants, and others, to better understand Lake Winnipeg and to monitor long-term changes in its physical, biological and chemical condition. In September of 2010, Environment Canada and Manitoba Water Stewardship signed a Memorandum of Understanding Respecting Lake Winnipeg and Its Basin. The Memorandum provides a framework for:

- Identifying joint priorities for coordinated scientific activities;
- Coordinating information sharing between federal and provincial programs and activities; and
- Providing a forum for communication, consensus building and coordination of activities.

The Memorandum of Understanding will help to guide future research and monitoring on Lake Winnipeg and its large watershed, and will also help to identify and implement the solutions required to reduce nutrient loading and halt eutrophication.

GLOSSARY OF TERMS

Anthropogenic – of, relating to, or resulting from the influence of human activities.

Aquatic invasive species – non-native plants, animals or micro-organisms that have been intentionally or unintentionally introduced by humans into an area outside of their natural range.

Benthic – refers to the bottom of a body of water or organisms that live at the bottom of a water body.

Biological productivity – the productivity of organisms and ecosystems, including growth and associated processes and activities of plants, animals and bacteria.

Biomass – the amount of living matter by area or volume.

Chlorophyll a – green photosynthetic pigments found in all plants, algae and cyanobacteria that are responsible for converting light into energy for plant growth.

Concentration – the quantity of a component or substance in a given area or volume.

Continental climate – relating to the interior of a landmass, typically characterized by large temperature ranges and relatively low precipitation.

Cyanobacteria – a major group of algae that are typically characteristic of nutrient-enriched lakes and may form large blooms in the summer. Several species may form floating scums across the surface of a water body, and some produce algae toxins. Cyanobacteria are also known as *blue-green algae*.

Diatom – a major group of algae that are encased in a cell wall made up of silica.

Discharge – stream flow or volumetric rate of water flow.

Escherichia coli (E. coli) – bacteria found in all warm-blooded animals including humans, livestock, wildlife and birds.

Eutrophic – used to describe a productive water body enriched with nutrients that support a dense growth of algae and other organisms, the decay of which depletes the shallow waters of oxygen in summer.

Fecal indicator bacteria – bacteria used to measure the sanitary quality of water, as they are associated with fecal contamination and the possible presence of waterborne pathogens.

Forage fish – small fish that are preyed on by larger predators for food.

Hypereutrophic – a term used to describe a water body that is the most biologically productive, highly enriched with nutrients, and has low water clarity. Hypereutrophic lakes experience frequent and intense algal blooms and support large amounts of aquatic life.

Internal nutrient load – reintroduction of nutrients into the water column through mechanisms including re-suspension from the lake bed or dissolution into the overlying water.

Isotope – a chemical element with a distinct signature used to track the source, movement and distribution of an element in a water body. For example, isotopes are often used to identify the major nutrient sources of water bodies.

Macroinvertebrate – an animal lacking a spinal column that is often found at the bottom of a water body and is large enough to be seen without the use of a microscope. Examples include aquatic snails and worms.

Microcystin-LR – a liver toxin produced by some species of cyanobacteria.

Nitrogen – a chemical that constitutes approximately 78% of the atmosphere, is one of the major nutrients required for plant growth, and is found in all living tissues. In excess, nitrogen contributes to eutrophication.

Nitrogen fixation – the process by which certain species of cyanobacteria are able to harness or “fix” nitrogen from the atmosphere during periods of nitrogen deficiency and convert it to forms of nitrogen required for growth.

Nitrogen-fixing cyanobacteria – cyanobacteria with differentiated cells called heterocysts that allow for nitrogen fixation from the atmosphere when nitrogen is not otherwise available for growth. Examples of cyanobacteria that are capable of atmospheric nitrogen fixation include *Aphanizomenon* sp. and *Anabeana* sp.

Non-nitrogen-fixing cyanobacteria – cyanobacteria that do not have specialized cells (heterocysts) and therefore cannot fix nitrogen from the atmosphere. Cyanobacteria that do not fix atmospheric nitrogen rely on other sources of nitrogen for growth (e.g., nitrogen from rivers and runoff).

Nutrient enrichment or eutrophication – a condition that results when a water body receives more nutrients than the organisms within it need for normal life, growth and reproduction.

Performance indicator – a measure or criterion by which performance, efficiency, achievement, etc. can be assessed, typically measured against a target.

Phosphorus – a chemical that originates from both natural and anthropogenic sources, occurs in solid and dissolved forms, and is essential to plant growth.

Phytoplankton – plants and plant-like organisms in the water column.

Remediation – to remedy or reverse environmental damage.

Residence time – average length of time that water or a substance spends in a water body.

Re-suspension – mechanism, typically associated with sediments, by which particles or substances are reintroduced into the water.

Secchi depth – the depth at which a Secchi disk is no longer visible from the surface of water, also a proxy for the depth to which light penetrates the water column.

Sequester – retain particles or substances, such as sediments and nutrients, often occurring via deposition and sedimentation in lakes and reservoirs.

Storm surge – a rise in water level above normal due to the action of wind on a water body.

Thermal stratification (Thermally stratified) – the separation of warmer surface water from cooler bottom water.

Thermocline – region of water where the temperature gradient between the two layers is greater than 1°C m^{-1} , separating warmer surface water from cooler deep water.

Trophic position – level of an organism in the food chain.

Watershed – the region from which water drains to a water body.

Wind-setup – see “Storm surge.”

Zooplankton – animals and organisms found in the water column, including macroinvertebrates.

Abbreviations

m – metres

masl – meters above sea level

mg/L – milligrams per litre

µg/L – micrograms per litre

