STATE OF LAKE WINNIPEG

2nd EDITION

HIGHLIGHTS

Manitoba

Canada

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INTRODUCTION

Lake Winnipeg is a valuable freshwater resource known for its fisheries, its plentiful beaches, and its importance to the traditional livelihood of many First Nations and Métis communities. The lake supports both commercial and angling fisheries that add significantly to Manitoba's economy through recreational spending and through commercial sales to domestic and international markets. The beaches are a strong economic driver for local communities attracting visitors, cottagers and permanent residents alike. Beaches in the south basin of Lake Winnipeg are easily accessible, only a short drive from Winnipeg and can exceed 30,000 visitors per day, especially during the busy summer months. The lake is also an important part of Manitoba's hydroelectric system. Its outflow is regulated allowing the production of electricity at northern generating stations.

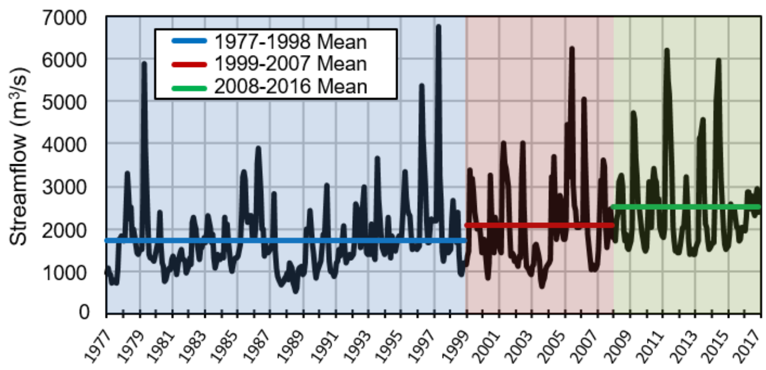
Lake Winnipeg

Growing concerns over the increase in large and sustained algal blooms in the 1990s, especially following the flood of 1997, led to the development of a multilateral partnership with a focus on monitoring and understanding the state of the lake's aquatic ecosystem. In addition to commitments of the Government of Canada and the Manitoba government, academic institutions and non-government organizations have been pivotal in supporting the research and monitoring activities that have significantly improved our knowledge of the lake over the past twenty years. The inaugural State of the Lake report, published in 2011, was the first comprehensive assessment of Lake Winnipeg and documented the physical, chemical and biological characteristics of the lake between 1999 and 2007. The 2011 report laid the foundation for future lake assessments and presented key information that supported the development of ecologically relevant nutrient objectives and loading targets for Lake Winnipeg. Continued and ongoing support for monitoring and research has not only improved our knowledge of the lake and its basin, but also provided a greater understanding of the threats to the lake. Climate change, invasive species, changes in land use, changes to land and water management, and fishing pressures all present challenges in managing the lake to achieve a healthy aquatic ecosystem. This report, available as both a highlights and extended technical document, presents updated information on the lake's chemistry and aquatic ecosystem that will help guide decision making for the management and protection of the lake.

CLIMATE AND HYDROLOGY

Lake Winnipeg is the 11th largest freshwater lake in the world and extends 436 km from north to south, covering an area of 23,750 km^2. Air temperatures can vary considerably between its north and south basins and its east and west shores. Within the immediate region around the lake, mean annual temperatures range from -0.7°C in the north to 1.6°C in the south, and from to 1.1°C in the west to 0.6°C in the east. Due in part to its latitude and continentality, the climate around Lake Winnipeg, along with the rest of the Prairie Provinces, is warming much faster than the global average. Since 1970, the region surrounding Lake Winnipeg has been warming at twice the rate per decade for the globe. Furthermore, by the 2051–2080 period, temperatures are projected to be 3°C higher under a low-carbon scenario and 4-5°C higher under a high carbon scenario. Although there is an expectation that these increasing air temperatures would affect mean lake temperatures, this has not yet been observed, likely because of high annual variability in temperatures. However, over the last ten years, there have been more examples of vertical thermal stratification in the north basin of the lake, meaning there are more instances where temperature gradients exist that allow warmer water to sit above cooler bottom waters. The cause of the increased frequency of these observed temperature gradients has not been explored, and the effects of higher air temperatures on their development must be better understood to determine whether the increase is related to climate change.

Drainage basin of Lake Winnipeg



Monthly mean gauged inflow to Lake Winnipeg in cubic meters per second (m^3/sec). Average streamflow over each of the three time periods (1977–1998, 1999–2007, 2008–2016) is indicated by the blue (1977–1998), red (1999–2007) and green (2008–2016) lines. A gradual increase in inflow to the lake among the three time periods is evident.

Lake Winnipeg lies within a watershed of nearly 1,000,000 km^2. Precipitation varies across the basin and strongly influences the hydrology of the lake. An average of 498 mm of precipitation, of which 76% is rain, falls across the region around Lake Winnipeg annually. Between November and February, most of the precipitation is snow, with an average snowfall of 132 cm for the region. Annual variability in the amount of precipitation is common across the Lake Winnipeg basin, resulting in periods of drought and flooding.

Over the last several decades, the hydrology of the lake and the rivers flowing into the lake appears to be changing. The time that it takes for water to move through the lake, known as the residence time, has varied over the last 50 years from 2.5 to almost eight years. From 1967 to 1998 the average residence time was 4.5 years, which decreased to 4.1 years from 1999 to 2007, and further decreased to 3.1 years during the current reporting period of 2008 to 2016.

The average streamflow of gauged streams flowing into Lake Winnipeg was almost 20% higher in the 2008–2016 period when compared to the 1999–2007 period, and 44% higher in the 2008-2016 period compared to the historical average from 1977 to 1998. The greatest increases in flow between the 2008–2016 and 1999–2007 periods were in the Dauphin (125%) and Assiniboine (85%) rivers. The Winnipeg River, which accounts for the majority of flow into the lake (43% from 2008 to 2016), was the only river where no change was noted between the 2008–2016 and 1999–2007 periods. Similar to the inflows to Lake Winnipeg, the average outflow consistently increased over time and was 24% higher in the 2008–2016 period over the 1999–2007 period, and 53% higher in the 2008–2016 period than over the 1977–1998 historical period.

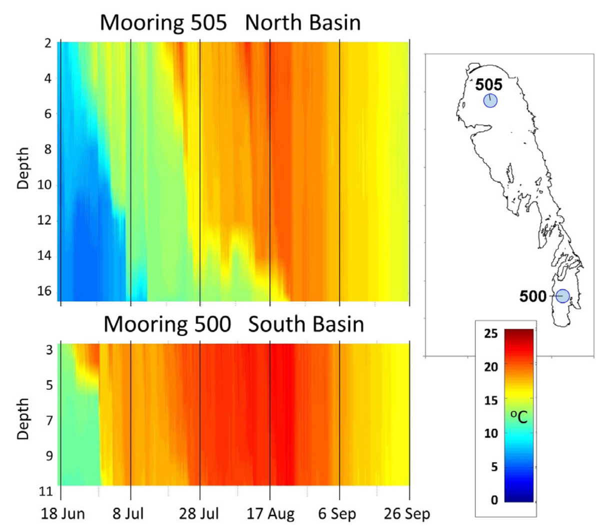
Water levels on Lake Winnipeg have been regulated for hydroelectric power generation since 1976 and vary throughout the season in response to regulation. Similar to the inflows, water levels appear to have increased over time despite increased outflows in the most recent period. From 2008 to 2016, the lake had an average lake level of 217.77 m, which is 0.25 m higher than the average water level of the previous reporting period from 1999 to 2007, and 0.32 m higher than the post-1977 historical average. Climate models suggest that by the 2051–2080 period, under both low and high-carbon scenarios, winter, spring and fall seasons will all become wetter, which could further change the hydrology of the lake.

WATER QUALITY

The north and south basins are unique from each other in physical characteristics, which influences the water chemistry of each basin. The south basin is shallower, smaller and generally warmer than the north basin. The water quality of the two basins is also impacted by differences in the inflows to each basin. Water chemistry in the south basin and narrows is controlled in part by the water chemistries of the Red and Winnipeg rivers, whereas the Saskatchewan and Dauphin rivers affect water chemistry in the north basin.

TEMPERATURE

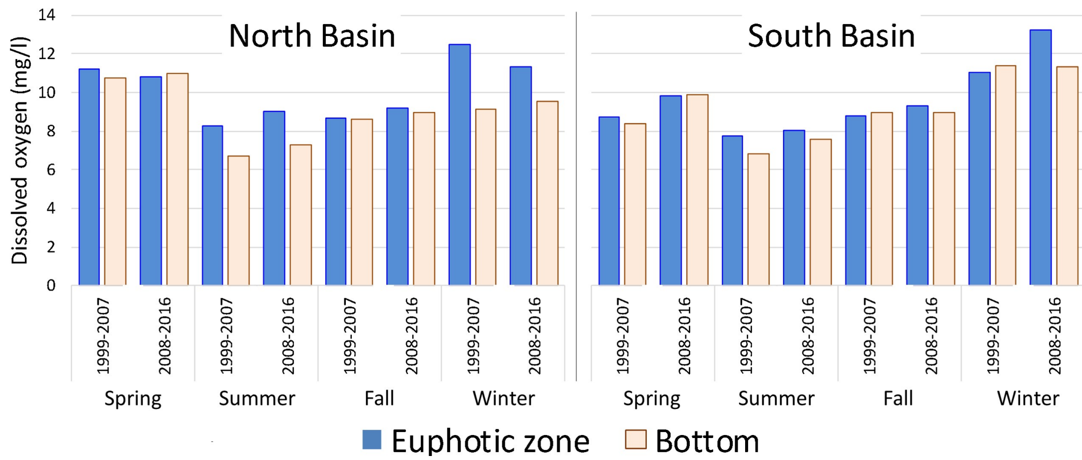
Water temperature influences the water quality of the lake because it affects the solubility of some compounds, such as oxygen, and also influences biological activity, for example algal growth. From 1999 to 2016, the daily mean surface water temperatures of the north and south basins were generally within 7°C of one another. Though generally the south basin warms sooner in the spring, and remains warmer through to mid-summer, it also cools faster than the north basin. The two basins often freeze within a few days of each other. Ice melt and breakup occur, on average, about two weeks earlier in the south basin, where surface water temperatures can reach 5°C or higher before ice has cleared off the north basin.



Temperature profiles of the north and south basins of Lake Winnipeg in 2008. The development of a thermal gradient extending from the surface to the bottom in the north basin from mid-June through mid-August is seen in the top panel. The bottom panel illustrates the mixed nature of the south basin, where generally no temperature gradient exists. This 2008 record is typical of most years where records exist. Charts produced by R. Yerubandi, Environment and Climate Change Canada.

Between late June and mid-July, the water of the south basin tends to warm to over 20°C and becomes isothermal, meaning there is little difference in temperature from the surface to the bottom. After that, a weak, short-lived vertical temperature gradient between the surface and bottom might develop on rare occasions. Warming in the north basin lags the south, especially below the surface. Unlike the south basin, the north basin is more likely to develop a vertical temperature gradient, usually in early summer, that lasts for as little as a week to more than a month. More examples of vertical temperature gradients were observed in mid-summer surveys of the lake in the 2008–2016 period when compared to the 1999–2007 period. Most of these temperature gradients were recorded over the deeper parts of the north basin.

DISSOLVED OXYGEN



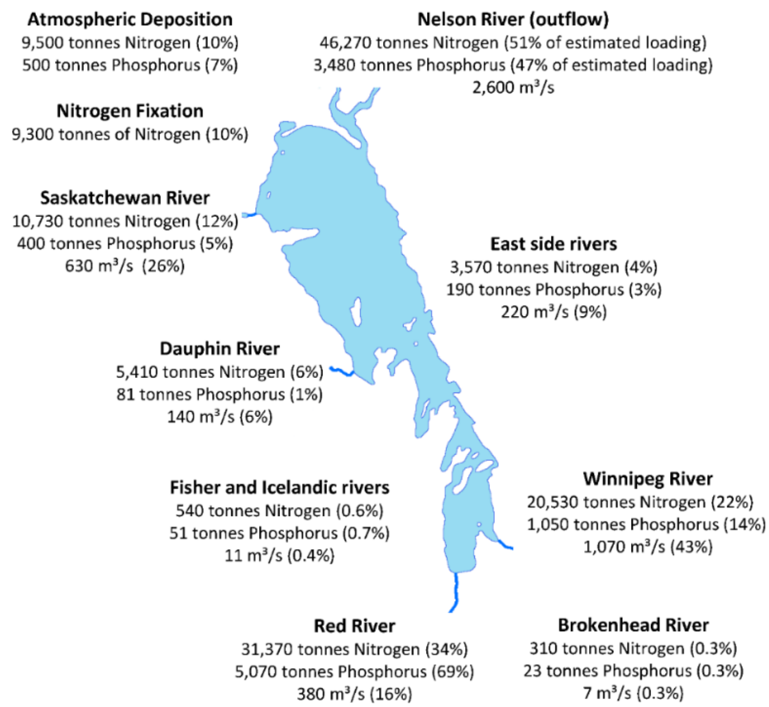
Euphotic zone and bottom seasonal mean dissolved oxygen concentration in Lake Winnipeg for the periods 1999–2007 and 2008–2016. Lake oxygen levels are good; generally well above 5 mg/L, which is Manitoba's water quality objective for the protection of aquatic life at temperatures above 5 °C.

Dissolved oxygen is a measure of the amount of oxygen that is dissolved in the water and is important for the survival of many aquatic organisms. The amount of oxygen needed by different aquatic organisms varies. Generally, dissolved oxygen levels above 5 mg/L are preferred, although water temperature is an important consideration since the solubility of oxygen and the metabolic rate of many organisms vary with temperature. Manitoba's water quality objective for protection of aquatic life for dissolved oxygen is temperature dependent — at temperatures above 5 °C, the lower limit for dissolved oxygen is 5 mg/L, whereas at temperatures of 5 °C or below, the limit is 3 mg/L. In the 2008–2016 period, dissolved oxygen concentrations were usually higher in the north basin than in the south basin in spring and summer, higher in the south in winter and similar in each basin in the fall. In both basins, average dissolved oxygen concentrations of both the euphotic zone (the surface zone where enough light penetrates for algal growth) and bottom waters were greater than 9 mg/L in spring, fall and winter and greater than 7 mg/L in summer.

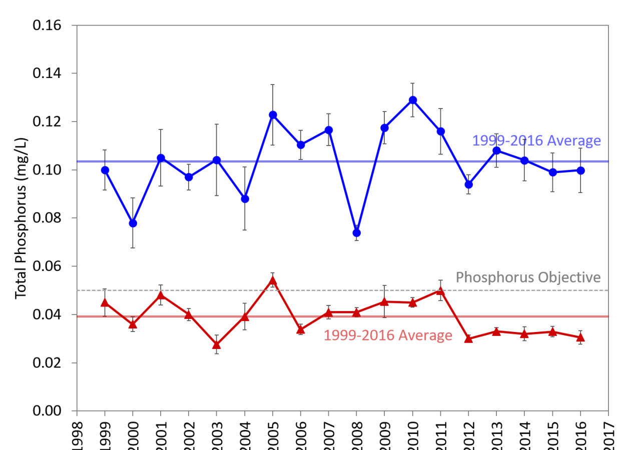
From 1999 to 2016, fewer than 2.5% of measured dissolved oxygen concentrations were below 5.0 mg/L; because temperature is not considered in this statistic, it is likely that the number of samples that did not meet the objective is even lower. Approximately two-thirds of these observations were recorded in summer or winter bottom samples, and most of the remaining third occurred near the surface under ice in winter. Many of the cases of severe oxygen depletion that were recorded during summer in the north basin developed in the bottom waters under steep temperature gradients that persisted for weeks or more. Steep temperature gradients limit the ability of oxygen to diffuse from surface waters to the bottom waters. This means that once the oxygen in the bottom waters is used, it cannot be replenished until the thermal gradient disappears. Given the frequency of temperature gradient formation (every year from 2013 to 2016), it is perhaps surprising that low oxygen levels were not observed more often in the recent years.

NUTRIENTS

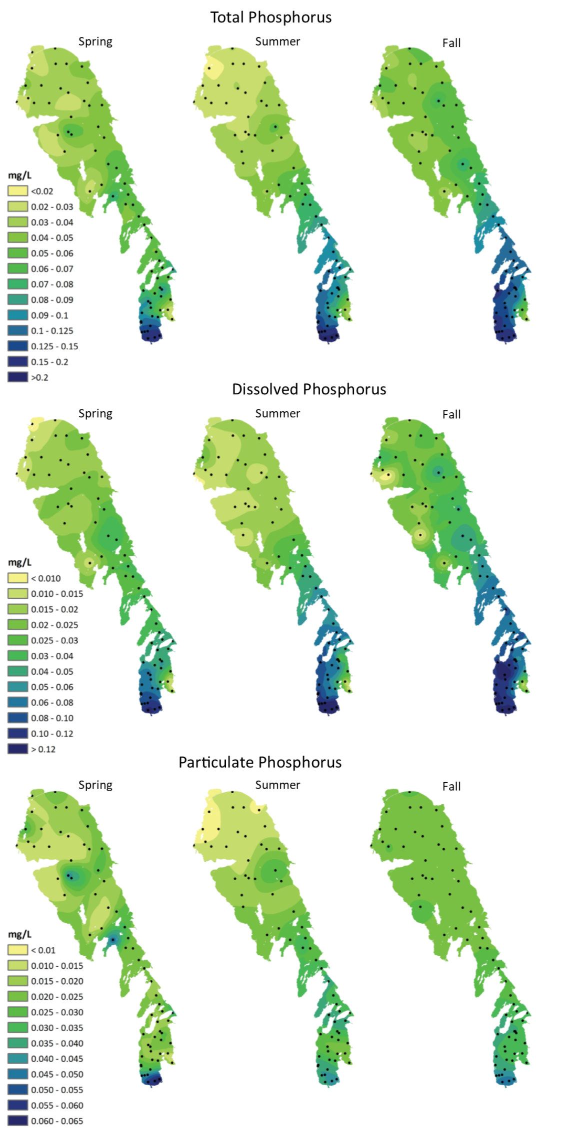
Nitrogen and phosphorus are important nutrients for aquatic organisms, but too much of either one or both will negatively affect the aquatic ecosystem. The total amount of a nutrient entering Lake Winnipeg is referred to as the nutrient load. This load varies annually, largely in response to changes in streamflow. From 1994 to 2016 the phosphorus loads varied between just over 3,000 tonnes per year to just under 11,000 tonnes per year, and in the last five years have been near the average (7,368 tonnes/year) or below. Phosphorus concentrations in the south basin, which averaged 0.104 mg/L from 1999 to 2016, continue to be high in comparison to estimated historical concentrations, and are double the phosphorus objective for the lake. In the north basin, phosphorus concentrations averaged 0.039 mg/L over the 1999–2016 period, and appear slightly lower in the last five years of the period of record.



Estimated Loading of Nitrogen and Phosphorus to Lake Winnipeg (annual averages 1994-2016).



Annual open water mean TP concentrations (± standard error) in the north basin and the south basin and narrows of Lake Winnipeg from 1999 to 2016.

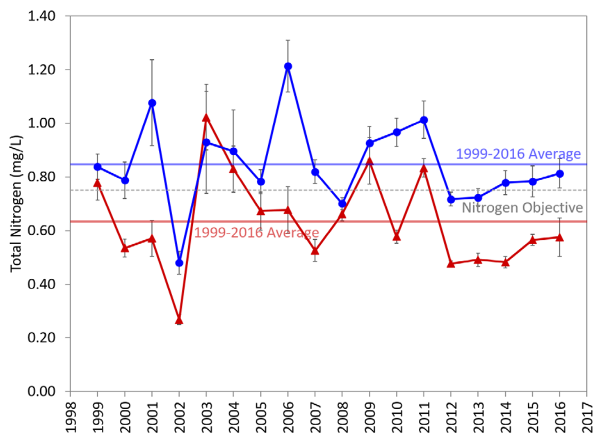


Average total, dissolved and particulate phosphorus concentrations measured in surface and euphotic water samples in Lake Winnipeg during spring, summer, fall and winter from 2008 to 2016. Concentrations are typically highest at the very south end of the lake near the inflow of the Red River. Concentrations in the south basin tend to increase from spring through fall, whereas in the north basin, concentrations are the lowest in the summer and highest in the fall.

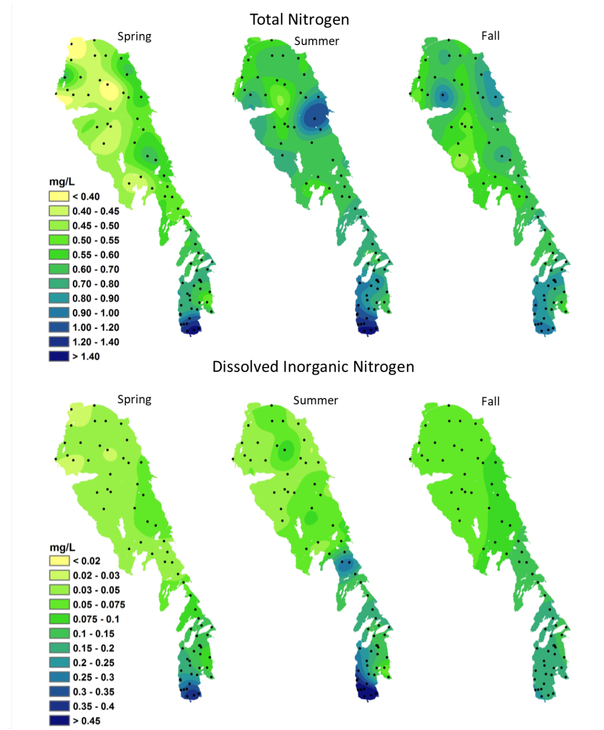
In both basins, from 1999 to 2016, phosphorus concentrations tended to be higher in the bottom waters than near the surface of the lake, although the difference between the surface and the bottom was greatest in the north basin. The internal phosphorus loading to the lake from the combined effect of diffusion of dissolved phosphorus from sediments and wind-induced resuspension of particulate phosphorus in lake sediments is estimated to be equal to or higher than phosphorus entering the lake from streams. Further knowledge on the influence of this internal phosphorus loading is needed to improve the understanding of the phosphorus cycle and phosphorus balance of the lake.

Additional monitoring of nutrient concentrations in the nearshore areas of Lake Winnipeg was implemented in 2014 to assess potential changes from the presence of Zebra Mussels. From 2014 to 2016, the concentration of particulate phosphorus was found to be higher in nearshore areas of Lake Winnipeg compared to offshore regions. Unlike particulate phosphorus, dissolved phosphorus concentrations did not differ between the two regions. The higher concentrations of particulate phosphorus in the nearshore regions is likely from resuspended sediment and sediment associated nutrients from the shallow nearshore areas that are subject to intense wave action during sustained wind events on the lake.

From 1994 to 2016, nitrogen loads to the lake varied between 52,470 tonnes/year to 136,676 tonnes/year. The loading to the lake has been below the average (91,263 tonnes/year) in three of the last five years, mainly attributable to lower loads than average from the Red and Winnipeg rivers. Nitrogen concentrations are typically highest at the very south end of the lake near the inflow of the Red River. Concentrations in the south basin tend to peak in the summer and decline in the fall, whereas in the north basin, nitrogen concentrations remain similar in summer and fall. Nitrogen concentrations from 2012 to 2016 appear to be lower than earlier in the period of record. The average total nitrogen concentration of the south basin (0.85 mg/L) from 1999 to 2016 is slightly above the objective, while that of the north basin (0.63 mg/L) is below the objective. Nitrogen fixation and denitrification rates are not well studied and more research would improve understanding of the nitrogen cycle and nitrogen balance of the lake.



Annual open-water mean TN concentrations (± standard error) in the north basin and the south basin and narrows of Lake Winnipeg from 1999 to 2016.



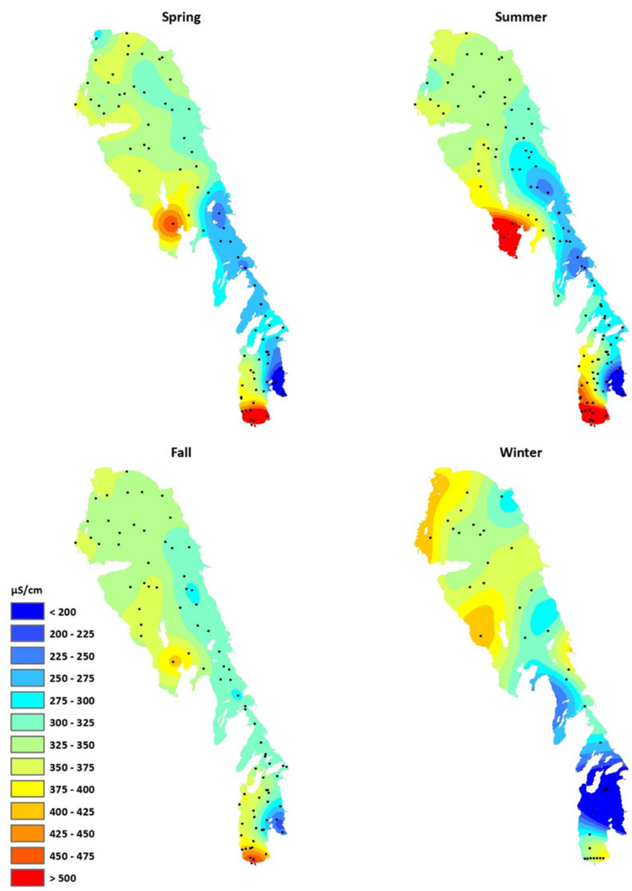
Average total and dissolved inorganic nitrogen measured in surface and euphotic water samples in Lake Winnipeg during spring, summer, fall and winter from 2008 to 2016. Concentrations are typically highest at the very south end of the lake near the inflow of the Red River. Concentrations in the south basin tend to peak in the summer and decline in the fall, whereas in the north basin, concentrations remain similar in summer and fall.

OTHER WATER CHEMISTRY CONSTITUENTS AND CONTAMINANTS

Several chemical constituents were routinely monitored in Lake Winnipeg over the 1999–2016 period. As with temperature, dissolved oxygen and nutrients, concentrations of many of these constituents differed between the two basins of the lake. In general, concentrations of potassium, total suspended solids, turbidity, total organic carbon, and the majority of trace elements were significantly higher in the south basin and narrows compared to the north basin. In contrast, conductivity, alkalinity, sodium, chloride, total dissolved solids, and total inorganic carbon were higher in the north basin compared to the south basin and narrows. Lake pH and concentrations of calcium, magnesium, and hardness were similar between basins.

Concentrations of trace elements in Lake Winnipeg over the 1999–2016 period were low and many were often below detection. Most metals other than aluminum and iron, which have naturally high concentrations in most Manitoba freshwaters, rarely exceeded the guidelines for the protection of aquatic life. Between 1999 and 2016, the concentration of most trace elements in Lake Winnipeg were similar to typical concentrations measured in other Manitoba freshwaters.

Although the primary focus of the water chemistry programs has been on tracking nutrient concentrations and general lake chemistry, the levels of some man-made pollutants in the lake have also been explored. Chemical compounds such as pesticides, pharmaceuticals, and legacy contaminants (chemicals no longer used but persisting in the environment) do not seem to pose an acute or chronic risk to the Lake Winnipeg ecosystem. Pesticide detections are low in the lake and no samples exceeded Manitoba's guidelines for the protection of aquatic life. However, additional research on long-term exposure scenarios would fill an information gap for some pesticides that are commonly used in the basin. Concentrations of microplastics



Average conductivity (µS/cm) measured in surface and euphotic water samples in Lake Winnipeg during spring, summer, fall and winter from 1999 to 2016. With the exception of some localized inputs around the inflow from the Red River in the south basin, conductivity tends to be higher in the north basin than in the south basin and narrows.

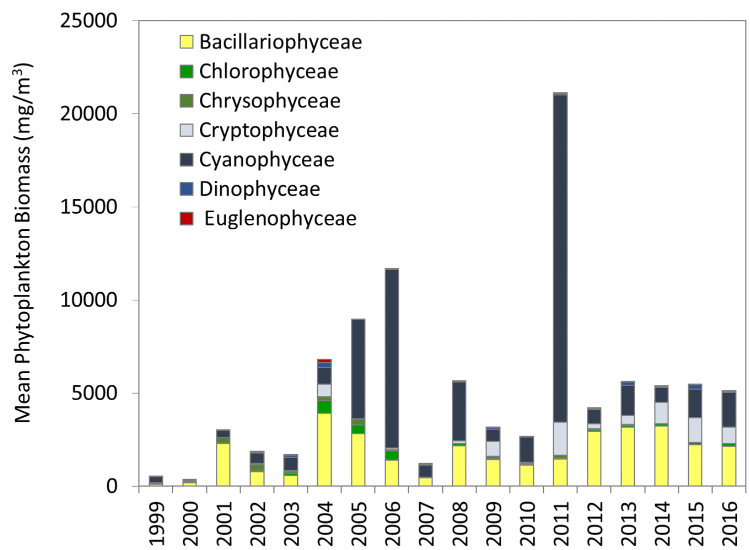
appear elevated in Lake Winnipeg relative to Lake Huron and Superior, but are similar to concentrations found in Lake Erie. Unlike the Laurentian Great Lakes, where fragments and pellets are the dominant type of microplastics, the majority of particles identified in Lake Winnipeg are fibers. The impacts of microplastics to the aquatic ecosystem of Lake Winnipeg are currently unknown and require more research.

BIOLOGY

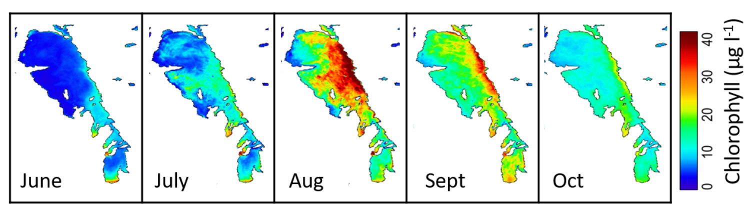
Lake Winnipeg supports a diverse biological community. Primary producers, like plants and algae, and higher order organisms like insects, fish and waterfowl all make up part of the lake's aquatic ecosystem. While algae are part of a natural freshwater ecosystem, excess algae, particularly large amounts of cyanobacteria, are a concern for their potential impacts to recreation, fisheries and drinking water. Cyanobacteria are actually bacteria and are often included with measures of algae because like algae, they derive their energy from photosynthesis. Cyanobacteria are of concern because they have the potential to produce compounds that are toxic to animals and humans. When excess algae form blooms in Lake Winnipeg they can cover large areas, sometimes much of an entire basin. These algal blooms can cause considerable concern to the public, particularly when the algae washes up along beaches in the south basin.

Over the last two decades, the types of algae (phytoplankton) and total amount of algae present (reported as biomass) have varied considerably, responding to changes in lake nutrients, temperature and light among other factors. There was more than a 60-fold difference in the algae biomass in Lake Winnipeg between years with low amounts (e.g. 319 mg/m^3 in 2002) and years with high amounts (e.g. 21,098 mg/m^3 in 2011). However, in the last five years, the total amount of algae has been stable and similar to the 1999–2016 average.

Although there is significant year-to-year variation in the relative proportions of the different types of algae, on average, cyanobacteria (*Cyanophyceae*) have accounted for approximately half (51%) of the total biomass in Lake Winnipeg from spring to fall. Diatoms (*Bacillariophyceae*) were the next largest group, comprising 34% of the total biomass over the same period. For the cyanobacteria, three specific types (*Aphanizomenon*, *Anabaena* and *Microcystis*) accounted for the majority of the total cyanobacteria biomass in Lake Winnipeg. Microcystin, a cyanobacterial toxin, was rarely detected in the offshore areas of Lake Winnipeg but was found more frequently in the nearshore areas of the south basin. Although microcystin was detected, concentrations in the nearshore areas were quite low and exceeded the recreational guideline in less than 1% of samples, and the drinking water guideline in less than 5% of samples.

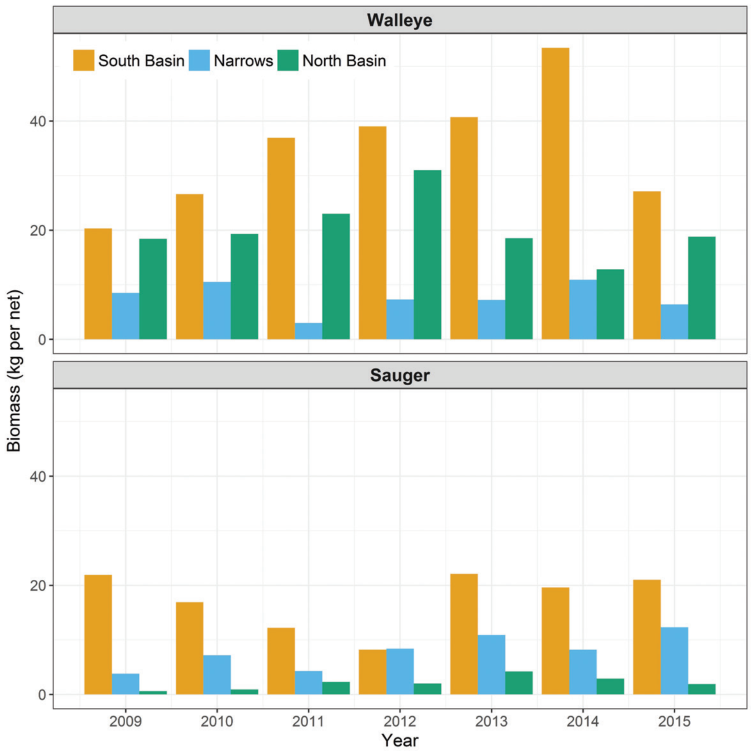


Average annual biomass of different groups of algae (*phytoplankton*) in Lake Winnipeg, 1999–2016. In most years diatoms (*Bacillariophyceae*) and cyanobacteria (*Cyanophyceae*) make up the largest fractions of the total algae biomass.



Variability in chlorophyll from June to October averaged over 2003–2011. Typically, chlorophyll concentrations are lowest in June, peak in August and remain high in September. Widespread blooms occur in the summer and fall in both basins.

Satellite imagery can help identify algal blooms in areas of the lake that are not sampled or at times when the lake is not sampled. Sensors measure chlorophyll, a pigment in algae. The concentration of chlorophyll in water is related to the amount of algae in the water. Imagery available from 2003 to 2011 and from 2017 to 2018 was used to describe how algal blooms in Lake Winnipeg varied in space and time. Over these years, blooms lasted on average from 40 days to 80 days over a season. In some locations blooms lasted up to 150 days. The amount of algae varied the most from month to month in the north basin, where it was usually low in the spring and increased progressively through the summer and early fall. The years that had the most severe blooms in terms of amount, size and duration were 2005, 2006 and 2011.



Biomass (weight) of walleye and sauger in Lake Winnipeg from 2009 to 2015, by basin (south basin, north basin, and narrows).

Other components of the aquatic food web are under pressure or have undergone changes that are more pronounced over the recent years. Six aquatic species in Lake Winnipeg (three fish, one mollusc, one reptile and one amphibian) are either considered at risk or are of special concern, including: Lake Sturgeon, Chestnut Lamprey, Bigmouth Buffalo, Mapleleaf Mussel, Snapping Turtle and Northern Leopard Frog. Within the last decade, two new invasive species have established a presence in the lake that will likely impact invertebrate and fish populations. The Spiny Water Flea, native to large areas of Eurasia, was first found in Lake Winnipeg in 2011 in the stomachs of fish captured in the south basin of the lake. By the fall of 2012, this species had colonized the north basin. In the fall of 2013, Zebra Mussels, native to Europe, were detected in several harbours in the south basin of the lake and have since spread to the north basin. The changes that may occur to the lake's ecosystem due to the presence of both these invasive species are unclear because of the complexity of various physical and biological interactions.

The Lake Winnipeg fishery has also undergone recent changes. Over the last decade, the abundance of Rainbow Smelt (another invasive species) declined drastically, although the reasons for the decline are unclear. From 2013 to 2014, the relative abundance of Walleye decreased in the north basin where the Rainbow Smelt were their main diet, but increased in the south basin where other prey fish make up their diet. However, since 2015, Walleye biomass has decreased in both basins. In fact, the overall lake-wide status of Walleye is now rated fair and the current trend is deteriorating, as relative abundance and commercial landings have decreased following at least several years of high mortality rates attributed to intensive fishing pressure. The status of the Sauger population is poor and deteriorating. The Sauger population has been in decline for more than two decades, with commercial yields having fallen to less than 90% of peak yields. Recent increases in Sauger mortality rates are of concern with respect to the future status of the population. Measurements of the mercury content of Lake Winnipeg fish from 2010 to 2016 indicated that levels were among the lowest for water bodies monitored in Manitoba and were consistently below the Health Canada guideline for retail fish.

Water quality monitoring of the indicator bacteria E. coli at Lake Winnipeg beaches from 2004 to 2018 showed that in the majority of cases most beaches were within recreational water quality objectives and showed no major changes over that time. Studies to determine the sources of E. coli at Lake Winnipeg beaches indicated that much of the indicator E. coli bacteria came from animal sources, mostly shorebirds and geese.

SUMMARY

Lake Winnipeg is a complex system. Over the past two decades our knowledge of its function and structure has improved, but many knowledge gaps still exist. Some of the gaps identified in the first State of Lake Winnipeg Report have been addressed in this update (*e.g.* fish populations, temperature and oxygen profiles, spatial variability in chemical constituents), while others are currently under study (*e.g.* littoral zones, internal nutrient loading/sediment resuspension). A significant gap remains in efforts to include indigenous knowledge along with western science to inform better our understanding of the state of the lake. Furthermore, new questions have emerged regarding the impacts of invasive species, climate change and uncertainty around the effects of microplastics on different biota.

The management of the lake remains a challenging task. Improvement will take time given the large watershed, the many small and diffuse sources of nutrients, and internal loading from legacy nutrients in the lake sediments. In the meantime, information from this report will be used to develop indicators of lake health that can be updated and reported on regularly. Efforts to improve the health of Lake Winnipeg will continue throughout the Lake Winnipeg basin including: wastewater treatment facility upgrades, implementing beneficial management practices to reduce nutrient loading, and actions to limit the spread of aquatic invasive species. With multilateral partnerships established and a keen stakeholder interest, a key next step in achieving the goal of a healthy aquatic ecosystem in Lake Winnipeg should include consideration of an adaptive management approach. Adaptive management uses the best available data and information for lake management and allows adjustments to be made as additional knowledge in areas such as climate change, invasive species and in-lake processes become known.