The State of Lake Winnipeg

Elaine Page and Lucie Lévesque

An Overview of Nutrients and Algae

At nearly 25,000 square kilometers, Lake Winnipeg (Manitoba, Canada) is the tenth-largest freshwater lake in the world and the sixth-largest lake in Canada by surface area (Figure 1). Lake Winnipeg is the largest of the three great lakes in the Province of Manitoba and is a prominent water feature on the landscape. Despite its large surface area, Lake Winnipeg is unique among the world’s largest lakes because it is comparatively shallow, with a mean depth of only 12 meters. Lake Winnipeg consists of a large, deeper north basin and a smaller, relatively shallow south basin. The watershed is the second-largest in Canada encompassing almost 1 million square kilometers, and much of the land in the watershed is cropland and pastureland for agricultural production. The lake sustains a productive commercial and recreational fishery, with walleye being the most commercially important species in the lake. The lake is also of great recreational value to the many permanent and seasonal communities along the shoreline. The lake is also a primary drinking water source for several communities around the lake.

Although Lake Winnipeg is naturally productive, the lake has experienced accelerated nutrient enrichment over the past several decades. Nutrient concentrations are increasing in the major tributaries that flow into Lake Winnipeg (Jones and Armstrong 2001) and algal blooms have been increasing in frequency and extent on the lake, with the most noticeable changes occurring since the mid 1990s. Surface blooms of cyanobacteria have, in some years, covered greater than 10,000 square kilometers of the north basin of the lake and have washed up along shorelines and beaches in the lake’s south basin.
Many agencies have been involved in monitoring and research activities on Lake Winnipeg over the years. Much of the intensive lake monitoring has occurred since 1999 following a major flood in 1997 and evidence of deteriorating water quality. Although much information had been gathered over the years since intensive monitoring began on Lake Winnipeg, there had been no single comprehensive document that summarized the current scientific information for the lake. Thus, Manitoba Water Stewardship and Environment Canada partnered to produce a State of Lake Winnipeg report that summarized the major spatial and temporal characteristics of the lake from 1999 to 2007.

Released in July 2011, the report was a collaborative effort of the many agencies and individuals involved in research and monitoring on Lake Winnipeg. The report serves as a baseline for future science and research on the lake and will assist in efforts to measure progress toward reducing nutrient loading to Lake Winnipeg. While the State of Lake Winnipeg report includes information on climate and hydrology, fish and zoobenthos, aquatic invasive species, general chemistry, and recreational water quality, given the concerns regarding accelerated eutrophication and algal blooms, much of the focus of the report is on nutrients and algal blooms.

**Nutrients**

Phosphorus concentrations are spatially variable in Lake Winnipeg with strong latitudinal gradients driven by phosphorus loads from river sources. Highest concentrations are typically observed at the south end of the lake where the Red River flows into the south basin (Figure 3). The Red River is rich in phosphorus (mean = 0.354 mg/L) and on average contributes nearly 70 percent of the total phosphorus load to Lake Winnipeg. Phosphorus concentrations are lowest at the very north end of the lake where phosphorus concentrations from the Saskatchewan River are relatively low (mean = 0.019 mg/L) in comparison to phosphorus concentrations in the Red River. Five percent of the total phosphorus load to Lake Winnipeg is contributed by the Saskatchewan River. From 1999 to 2007, phosphorus concentrations in Lake Winnipeg were greatest in 2005, a year characterized by above-average river flows and rainfall, and above-average nutrient loads from the Red River. Strong seasonal increases in total phosphorus are evident in the south basin and the highest phosphorus concentrations are normally observed in the fall in both lake basins. Seasonal increases in phosphorus concentrations resembled patterns typical of shallow eutrophic lakes that are often attributed to internal phosphorus loading processes (James et al. 2009) and may help to explain elevated phosphorus concentrations during the fall months in Lake Winnipeg.

The geospatial pattern for total nitrogen concentrations in Lake Winnipeg resembled that of total phosphorus with the highest nitrogen concentrations at the very south end and the lowest concentrations at the north end of the lake. Nearly 60 percent of the total nitrogen load to Lake Winnipeg is contributed by the combined inputs of the Red and Winnipeg rivers that flow into the lake’s south basin. Atmospheric deposition and nitrogen fixation are other significant sources of total nitrogen, collectively contributing over 20 percent of the total nitrogen load to the lake. From 1999 to 2007, total nitrogen concentrations were quite variable from year to year with a maximum of a five-fold difference between years and no clear increasing or decreasing trends over time. The high degree of inter-annual variability in total nitrogen concentrations is, in part, related to the inter-annual variability in nitrogen-fixing cyanobacteria and rates of nitrogen fixation and denitrification in Lake Winnipeg. Although rates of nitrogen fixation have only been measured over a few years, rates may certainly vary depending on cyanobacteria bloom conditions and nitrogen deficiency in Lake Winnipeg. Cyanobacterial nitrogen fixation may also help to explain the higher concentrations of nitrogen observed along the east side of the north basin in the fall (Figure 4). This area of the lake is typically characterized by extensive blooms of cyanobacteria and the highest chlorophyll-a concentrations in the fall months (e.g., Figure 5).

**Chlorophyll-a and Phytoplankton Composition**

On average, chlorophyll-a concentrations in Lake Winnipeg were slightly higher in the north basin (mean = 14.4 µg/L) relative to the south basin (mean = 8 µg/L) for the 1999 to 2007 monitoring period. The north basin has much clearer water and allows for the development of higher algal biomass when nutrients are not limiting algal growth. Light constrains algal growth in the south basin of Lake Winnipeg because of the highly turbid inflow from the Red River and greater wind-induced resuspension of sediment in the comparatively shallow south basin. Seasonal patterns in chlorophyll-a varied from year to year in Lake Winnipeg, although chlorophyll-a tended to be highest overall during the fall. In 2007, the seasonal chlorophyll pattern in Lake Winnipeg generally resembled patterns observed in other eutrophic north temperate lakes with a spring bloom, a decline in biomass during the summer, followed by a fall bloom (Figure 5; Marshall and Peters 1989). This seasonal pattern was particularly apparent in the north basin of the lake, although the chlorophyll phenology is not consistent from year to year in Lake Winnipeg. Chlorophyll-a concentrations were greatest in the fall along the east side of the north basin where nutrients are typically higher and levels are most likely sufficient to support greater algal growth. Large algal blooms along the east side of the north basin may also be partly related to the prevailing north-westerly wind pattern that effectively concentrates surface blooms along the eastern shoreline.

From 1999 to 2007, chlorophyll-a was highest in 2006, which was the warmest year during the nine-year study period. The combined effect of elevated phosphorus loads in 2005 and above average air temperature in 2006 may partly explain the high chlorophyll-a biomass observed in 2006. Average chlorophyll-a concentrations were quite variable from year to year in Lake Winnipeg with a nearly nine-fold difference between the lowest concentrations observed in 2000 (4.1 µg/L) and the highest concentrations in 2006 (34.5 µg/L). Inter-annual variability...
Figure 2. Algal blooms covering much of the north basin of Lake Winnipeg (top left), along the shorelines in the south basin (top right), and algae attached to commercial gillnets (bottom).
in chlorophyll-a concentrations appear to be related to the variation in cyanobacteria biomass in Lake Winnipeg. Years with much higher chlorophyll-a concentrations (e.g., 2005 and 2006) generally had the highest cyanobacteria biomass and comprised a majority of the total phytoplankton biomass.

Much of the algal community composition of Lake Winnipeg is dominated by cyanobacteria and diatoms, and a large proportion of the total phytoplankton biomass is represented by very few genera. The bloom-forming cyanobacteria *Aphanizomenon*, *Anabaena*, and *Microcystis* and the large centric diatoms *Stephanodiscus* and *Aulacoseira* were the five dominant genera in the lake while most other genera contributed to less than five percent of the overall phytoplankton biomass. These genera are characteristic of eutrophic systems and often dominate the phytoplankton assemblages of other large shallow eutrophic lakes (Laugaste 1996). In the spring, the phytoplankton community was typically dominated by diatoms. The summer phytoplankton assemblage was dominated by either cyanobacteria or a mixed assemblage of cyanobacteria, diatoms, and chrysophytes, depending on the year. Cyanobacteria generally dominated the fall biomass in Lake Winnipeg although diatoms were an important component of the fall assemblage in some years in the north basin of the lake.

From 1999 to 2007, the annual phytoplankton assemblage in Lake Winnipeg shifted from cyanobacteria to diatom dominance and appeared to be linked in part to climate (Figure 6). Diatoms tended to predominate in cooler years and cyanobacteria were generally dominant in warmer years. Diatoms comprised nearly 80 percent of the total phytoplankton biomass in 2001, a relatively wet and cool year. In 2006, almost 82 percent of the total phytoplankton biomass was comprised of cyanobacteria and appeared to be related to the elevated nutrient loads in 2005 and the warm conditions that followed in 2006. Cyanobacteria capable of fixing atmospheric nitrogen (*Aphanizomenon* and *Anabaena*) predominated the cyanobacteria biomass in most years. However, in certain years, non-nitrogen fixing genera also comprised a large proportion of the cyanobacteria. For instance, in 2007, prolific blooms of *Microcystis* were observed in the south basin and contributed to more than 90 percent of the cyanobacteria biomass. These large *Microcystis* blooms appear to be a phenomenon of the south basin of Lake Winnipeg and may be favoured by the lower water transparency in the south basin of the lake. Since 1999, all recorded large blooms of *Microcystis* (> 10,000 mg/m³ or > 20,000 cells/mL) have occurred in the south basin of Lake Winnipeg. The biomass of *Microcystis* remained relatively low in the north basin (< 750 mg/m³) and was found in approximately...
10 percent of the phytoplankton samples collected from the north basin.

**Algal Toxins**

Large blooms of cyanobacteria are a concern on Lake Winnipeg because of their potential to produce algal toxins like the liver toxin microcystin-LR. The three dominant genera of cyanobacteria found in Lake Winnipeg (Aphanizomenon, Anabaena, and Microcystis) are capable of microcystin-LR production under favourable environmental conditions. Algae samples were collected both from the nearshore (beach) areas and from the offshore areas of Lake Winnipeg during algal bloom events. Although microcystin-LR was detected occasionally during these blooms events, microcystin-LR concentrations were below the analytical detection limit in the majority of samples. Where microcystin was detected in algae samples, concentrations from the offshore areas remained relatively low and well below the Manitoba Water Quality Objective for recreation (20 µg/L) and the Canadian Drinking Water Quality Guideline (1.5 µg/L). Occasionally, samples collected from the nearshore areas of the lake contained elevated concentrations of microcystin-LR that exceeded the recreational objective. It is not well understood why microcystin concentrations are occasionally elevated in the nearshore blooms but not in the prolific offshore blooms of cyanobacteria observed in the north basin of Lake Winnipeg. Further studies of the phytoplankton composition and genetic studies of the species capable of producing microcystin in the lake will be required to fully understand the cyanotoxin dynamics in Lake Winnipeg.

**Conclusion**

The *State of Lake Winnipeg* report has helped to inform science and research and will serve as a reference in assessments of change over time in Lake Winnipeg. Monitoring from 1999 to 2007 has provided critical information on the environmental characteristics of Lake Winnipeg, and monitoring and research efforts will continue through federal, provincial, and independent research initiatives in an effort to address the critical knowledge gaps. Both the full technical report and a summary highlights...
individuals would normally not take, the difference in perspectives becomes evident during the discussion. Most individuals realize that each perspective (i.e., color of the rainbow) needs to be addressed in order to develop a successful solution to the problem (i.e., the rainbow). In addition to being an active learning activity, this exercise fosters critical thinking and conflict resolution, components that are integral tools to success in solving real-life problems (Canfield and Canfield 1994).

The Skittles® Lake Management activity has been successful with university students. For the last two years, this activity was used in an undergraduate/graduate introduction of fishery science course. Each year, about half of the students specifically reported on their course evaluations that the Skittles® activity was their favorite class of the semester. Their reasons being, but were not limited to, “it taught me how to apply what I have learned,” “the Skittles® class made me want to become a lake manager,” or “it was fun.”

The Skittles® Lake Management activity is applicable to other venues of learning outside of academic institutions as well, like lake association meetings or meetings with citizen volunteer monitors. Frequently, these types of meetings include a group of individuals that are experiencing a lake management problem. The Skittles® Lake Management activity would be useful in such a situation, as the individuals would potentially be assigned a different role to play in regards to the lake management issue. The discussion among others may spark that individual to retain knowledge and do so with excitement. Although the proposed active learning method could be tailored in any manner to better fit a situation, the basis of this activity fills the ubiquitous need for new teaching tools to keep learners engaged. But, it is not only the learners that benefit from this activity. The teacher benefits as well. The Skittles® Lake Management activity is fun for all and never transpires quite the same. Both the learner and teacher gain new knowledge and perspectives that expedite practical solutions to real-world situations. Most importantly, who would want to pass up the chance to eat some candy?

References


Elaine Page is a water quality modelling specialist in the Water Science and Management Branch at Manitoba Water Stewardship in Winnipeg, Manitoba.

Lucie Lévesque is an aquatic scientist in the Prairie and Northern Water Quality Monitoring and Surveillance office at Environment Canada in Saskatoon, Saskatchewan.

( . . . STUDENTS CORNER, continued from page 62)