Restoring the Health of Lake Winnipeg

Technical Annex

CANADA'S SIXTH GREAT LAKE

A Report by the Lake Winnipeg Implementation Committee

Technical Annex to

Report of
Lake Winnipeg Implementation Committee

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1. Introduction

This Technical Annex supplements and supports the report of the Lake Winnipeg Implementation Committee (LWIC)[1] "Restoring the Health of Lake Winnipeg: Canada's Sixth Great Lake" transmitted to The Honourable Reg Alcock, President of the Treasury Board, Government of Canada, and The Honourable Steve Ashton, Minister of Water Stewardship, Province of Manitoba. The LWIC report includes a draft Federal/Provincial framework agreement on scientific research and basin-wide action to improve Lake Winnipeg water quality and a draft Healthy Lake Winnipeg Charter.

The Annex provides fuller technical information on the environmental and socio-economic aspects of Lake Winnipeg and on the range of human impacts on the lake. It gives an overview of the history of scientific study on the lake, a brief description of the current state of research activity on the lake, and a list of scientific publications and presentations. It summarizes results from the Lake Winnipeg Science Workshop held in November, 2004. It gives a brief overview of the lessons learned from managing human impacts in the eastern Great Lakes[2]. It lists some of the many governmental and non-governmental bodies and organizations with jurisdiction over and/or interest in Lake Winnipeg, summarizes current initiatives, and stakeholder concerns and advice on steps to be taken to improve the health of Lake Winnipeg.

A HEALTHY ECOSYSTEM

A healthy ecosystem has been defined as a "socio-ecological unit" that is "stable and sustainable", maintaining its organization and autonomy over time and its resilience to stress, while being capable of remaining economically viable and able to sustain human communities[3]. More simply, ecosystem health is the state that allows an ecological natural system to sustain itself while meeting social and economic needs of people that are an integral part of it.

Decades ago, it was popular to believe that ecosystems were "out there", separate from people and their societies and that the systems of the natural world were primarily resources for human use. With accelerating environmental pollution and degradation and loss of biodiversity, this view evolved to acknowledgement of the need for management and regulation of human impacts. In the 1970s, evolution continued with the emergence of the ecosystem approach[4]. This recognizes that humans are part of and inseparable from ecosystems. For example, toxic chemicals emitted by industry end up in the food chains of humans just as surely as in those of fish, birds, or other wildlife. The ecosystem approach was inherent in the Great Lakes Water Quality Agreement of 1978. The father of the ecosystem approach, Dr. Jack Vallentyne described the necessity for a complete change in viewpoint, a paradigm shift, from "people managing ecosystems" to "people managing their own activities within ecosystems". The connectedness between the state of Lake Winnipeg and people and activities as far away from the lake as western Alberta, North Dakota and Minnesota, and northwestern Ontario is one theme of this project. The goal of the Lake Winnipeg Implementation Committee is to be a catalyst in the implementation of effective watershed-based action to restore Lake Winnipeg to a healthy state. This does not mean attempting to return the lake to a former pristine state but rather permitting the lake to return to a stable and sustainable ecological state that can provide predictable social and economic benefits to those who live, or earn their livings, around the lake or visit it.

METHODOLOGY

This report was largely based on reviews of existing information and data, including primary scientific literature, scientific reports, conference presentations, presentations to public hearings and other written advice, and information published on web sites. These materials included scientific data and results, other statistics and facts, narrative descriptions, recommendations from a wide range of stakeholders, and proposals for further study or action. In addition, personal interviews were undertaken with individual stakeholders and information was gained at meetings with the LWIC Advisory Board, federal and provincial officials, and selected citizens' advisory groups. The project was intended to take advantage of existing information, including public results from prior consultations. This project was not charged with nor resourced with time or funds to conduct original research or consultation.

Analysis was performed by considering the weight of evidence, consistency among diverse sources, credibility of trends through time, synthesis of facts, perspectives and opinions, recognizing knowledge and data gaps and inconsistencies, and bringing to bear long-term personal experience with aquatic science and environmental issues. The Technical Annex supports the Conclusions, Recommendations, Draft Federal/Provincial Agreement and Draft Lake Winnipeg Charter.

2. Lake Winnipeg – Canada's Sixth Great Lake

A TIME FOR ACTION

Like highly-stressed Lake Erie in the 1960s before concerted action improved it, Lake Winnipeg is at a critical point in its history. The seriousness of the situation surprises many Canadians. After all, how is it that Lake Winnipeg, far from major centers of population and industry, is in environmental trouble?

This Annex explores circumstances of Lake Winnipeg's geography and the interplay of factors that allowed it to decline silently to the point today where the impact of human activity on the lake is visible from space. Three levels of government, industry, and communities are rallying to the cause of restoring the health of Lake Winnipeg.

It is important to put Lake Winnipeg into context as one of Canada's great lakes. Canada has 20 per cent of the world's fresh water and seven per cent of the world's renewable fresh water[5]. Almost nine per cent, or 891,163 square kilometers, of Canada's total area is covered by fresh water[6]. In fact, Canada has 94,000 cubic meters of fresh water per person compared with 7,400 cubic meters per person in the continental U.S. and 4,600 cubic meters per person in Mexico[7]. Water stress begins when there is less than 1 700 cubic meters of water per person per year for all major functions[8].

This rich natural endowment is mostly held in a string of "great lakes" running from north-west to south-east along the division between granitic Precambrian Shield on the east and glacial till and sedimentary geology on the west. From north to south, Great Bear and Great Slave are followed by Lake Manitoba and Lake Winnipeg, then by the five eastern Great Lakes along the Canada – U.S. border.

Geographically, these lakes divide into two groups. The "northern" Great Bear and Great Slave lakes are in relatively unpopulated areas, and until the last few decades, in areas with little industrial development. Human influences historically on these lakes are comparatively low.

The "southern" Great Lakes, Superior, Ontario, Michigan, Huron and Erie, on the other hand, lie along the Canadian population belt north of the U.S. border. An estimated 40 million people on both sides of the international border live within the watershed, about 31 per cent of the population of Canada and ten per cent of the population of the U.S.[9]. These lakes have served the needs of the populations for water consumption, transportation, fisheries, and recreation for centuries. Consequently, human impacts on these lakes, especially in the past hundred years, have been considerable, resulting in a high level of scientific, political, social and economic attention.

Fig. 1. Map showing the extent of the Lake Winnipeg sub-basin of the Nelson River Drainage Basin[14]

Between the "northerly" lakes and the" southerly" (eastern) Great Lakes lies Lake Winnipeg (Fig. 1). In public perception, it is "northern". Although 23,000 residents live along its shores and the residents of Manitoba and tourists have visited the beaches of the South Basin since the early 1900s, Lake Winnipeg has until recently attracted little attention.

Contrary to the perception of Lake Winnipeg as "northern" and consequently remote and environmentally undisturbed, the lake receives most of its water from populated "southern" portions of Canada. In fact, the Lake Winnipeg sub-basin is the second largest watershed in North America (Fig. 1), receiving flows from four U.S. states and four Canadian provinces[10]. It stretches from near the Rockies in the west to a few kilometers from the eastern Great Lakes in the east. The sub-basin is nearly 40 times greater in area than Lake Winnipeg, the largest ratio for any large lake in the world[11]. The Lake Winnipeg sub-basin is home to six million people, 17 million livestock[12] and includes 55 million ha of agricultural land[13].

Silent Impacts on Lake Winnipeg

Lake Winnipeg is "northern", isolated, and undisturbed in public perception, but actually "southern" in position. It has been subjected to decades of increasingly serious human impacts before these have received public attention.

Without the early warning function of long-term, periodic monitoring and scientific programs on the lake, the nutrient pollution of Lake Winnipeg came to political and public attention unexpectedly from satellite photos from space. In one of those rare occasions in science, where small, invisible but cumulative impacts reach a point that is highly visible and undeniable, these photos show marked concentrations of chlorophyll over large areas of the North Basin (Fig. 2). The green in the center of the North Basin indicates the presence of thick mats of blue-green algae, more accurately known as cyanophytes or cyanobacteria. These algae are signs of phosphorus over-enrichment. The blue-green algae are favoured when the supply of nitrogen is deficient relative to the supply of phosphorus. They are known to produce toxins that can be a risk to aquatic organisms and human health[15].

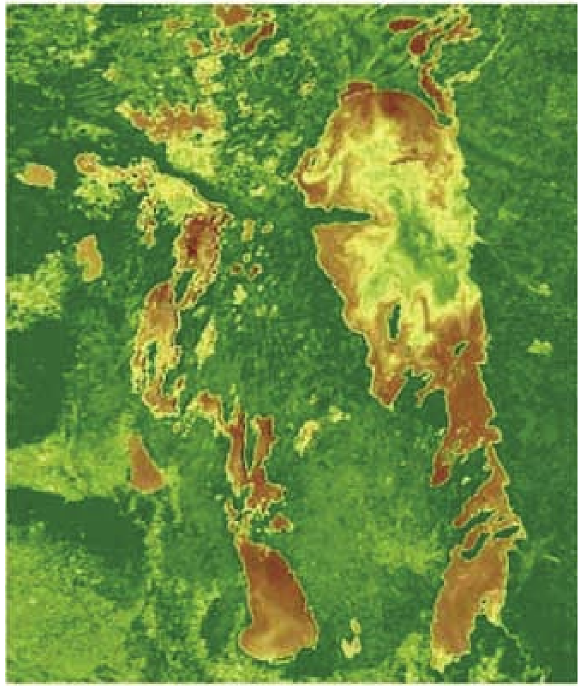


Fig. 2. Satellite photo of Lake Winnipeg on 26 September, 2001.[16]

Scientists attribute the dramatic response of the North Basin of Lake Winnipeg to the interaction of three anthropogenic factors:

- excess quantities of phosphorus entering the lake from the sub-basin
- regulation of the lake as a hydroelectric generation reservoir leading to retention of nutrient-rich water and algal populations during the productive summer season
- damming of the Saskatchewan River upstream of the North Basin causing the sediment load to be deposited before reaching Lake Winnipeg, resulting in increased light availability for algal growth.

Increasingly in Canada, aquatic research dollars are allocated to water bodies perceived by the public to have high-profile problems. Although the paucity of long-term scientific information on the Lake Winnipeg has considerably delayed recognition that the lake is in trouble, that awareness is now widespread. Governments are ready to act, and numerous stakeholders from a wide variety of sectors are lined up to be partners.

> **"Water…is not just part of our reality, it's also part of our identity"**
> **Hon. Steve Ashton**[17]
> **Manitoba Minister of**
> **Water Stewardship**

THE GEOGRAPHY OF LAKE WINNIPEG

Lying in the center of North America (Fig. 3), Lake Winnipeg is the tenth largest freshwater lake in the world. With a surface area of 23,750 square kilometers[18], it is the seventh largest lake in North America, and the third largest wholly in Canada. It is larger than Lake Ontario, but slightly smaller than Lake Erie. Lake Winnipeg receives run-off water from a large part of the immense Nelson River drainage basin, a major hydrological system of central North America, second in size only to the Mackenzie River drainage basin. Waters of the Nelson River Drainage Basin pass through Lake Winnipeg and flow out as the Nelson River, reaching the sea in Hudson Bay.

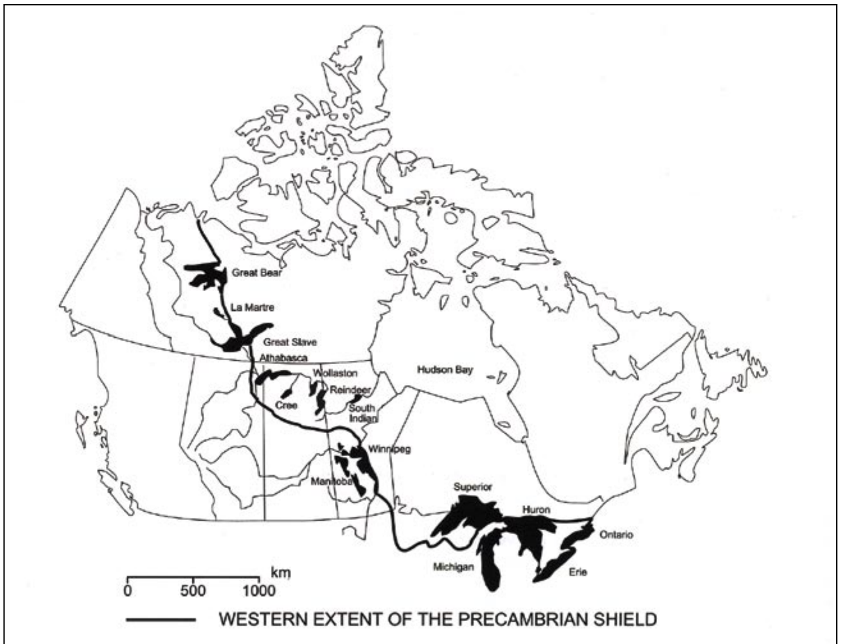


Fig. 3. The Great Lakes of Canada lying along the divide between the southwestern Precambrian Shield to the east and north and the low-relief Interior Plains with Paleozoic rocks to the west and south[19,20]

The Nelson River drainage basin covers more than one million square kilometers of the interior of North America[21] (Table 1). It extends from the Canadian Rockies in western Canada to within 19 kilometres of Lake Superior in eastern Canada[22]. The total distance from the headwaters of the Bow River to the Hudson Bay is greater than 3,000 kilometers[23].

The Lake Winnipeg sub-basin, also termed Lake Winnipeg watershed in many publications, occupies all of the area of the Nelson River Drainage Basin to the outlet of Lake Winnipeg into the Nelson River for a total area of about 950,000 square kilometers (Table 1). The Lake Winnipeg sub-basin is international and inter-provincial, involving four provinces and four states. It crosses Alberta, Saskatchewan, Manitoba and northwestern Ontario. In the U.S., waters derive from small portions of Montana and South Dakota, and from North Dakota and Minnesota. Three major rivers flow into Lake Winnipeg, the Saskatchewan River with headwaters in the west and Montana, the Red River of the North with headwaters in Minnesota and the Dakotas, and the Winnipeg River from northwestern Ontario (Table 1).

Lake Winnipeg serves multiple purposes, including recreation, commercial fisheries, and acts as the third largest hydroelectric power generation reservoir in the world[24]. It is a source of drinking water for some communities on the lake and on the Nelson River. Water passing through the lake has served 5.5 to 6 million people, their urban and rural centers, 55 million ha of agricultural land in Canada, and 17 to 20 million livestock[25]. The natural landscape of the sub-basin is about 40 per cent woody vegetation (381,000 square kilometers), ten per cent wetlands (95,000 square kilometers), and 50 per cent agricultural land (477,000 square kilometers)[26].

Table 1. Statistics on the Nelson River Drainage Basin,Lake Winnipeg and its sub-basin[27]

	Parameter	Value
Lake Winnipeg	Location	96º20' to 99º20' W. longitude and 50º20' to 53º51' N. latitude [28]
	Surface area	23,750 km^2, ~ 3.7 % of Manitoba's surface area
	Water depth	12 m mean in South Basin; 16-17 m mean in North Basin; irregular in the Narrows with maximum of 61 m[29]
	Maximum Length	Total 430 km; South Basin 90 km; North Basin 240 km[30, 31]
	Maximum width	40 km, South Basin, 100 km, North Basin [32]
	Length of shoreline	1,750 km
	Volume	284 km^3 [33]
	Altitude	Mean lake level 217.4 m above mean sea level [34]
	River inflows, mean monthly flow	Winnipeg River: 771 m^3s^{-1} Saskatchewan River: 667 m^3s^{-1} Red River: 159 m^3s^{-1} Dauphin River: 57 m^3s^{-1} [35]
	River outflow, mean	Nelson River: 2045 m^3s^{-1} [36]; 62.4 – 98.9 m^3 y^{-1} x 10^9 (1969 – 1974)[37]
	Residence time	Whole lake: 2.9 – 4.3 y (1969 – 1974) South basin: 0.43 – 0.83 y (1969 – 1974)[38]
	Evaporation and storage	3.6 – 28.1 m^3 y^{-1} x 10^9 (1969 – 1974)[39]
Lake Winnipeg drainage sub-basin	Area	953,250 km^2 [40], second largest watershed in Canada
	Population	5.5 million people and 20 million livestock[41]
	Natural Landscape	40 % woody vegetation (381,000 km^2), 10% wetlands (95,000 km^2), 50 % agricultural land (477,000 km^2)
Nelson River Drainage Basin	Area	> 1 million km^2, 892,300 km^2 in Canada and 180,000 km^2 in the U.S.[42]
	Location	~45.5º to 57º N. latitude and ~90º to 117.5º' W. longitude[43]

GEOLOGICAL HISTORY OF LAKE WINNIPEG

Geologically, Lake Winnipeg is a young lake. Like the eastern Great Lakes and the other large lakes of North America, Great Bear, Great Slave and Athabasca, it is an ice-scour lake on the border of the Canadian Shield. It is a result of repeated glaciation and the scraping away of relatively soft Paleozoic sediments along the margin of the Canadian Shield. Lake Winnipeg is flanked by Precambrian (Kenoran Orogeny >2.5 Ga) rocks on its eastern and northern shores and Paleozoic carbonate rocks (primarily Ordovician, Silurian and Devonian dolomite, limestone and sandstones) of the Williston Basin to the west and south. The axis of the lake lies to the west of the contact between the Precambrian and Paleozoic rocks[44].

Lake Winnipeg and the other large Manitoba lakes, Manitoba, Dauphin, Winnipegosis and Cedar, to the west are all remnants of glacial Lake Agassiz. Lake Agassiz was the largest of all of the glacial lakes in North America, extending over a total area of almost 950,000 square kilometers in Saskatchewan, Manitoba and Ontario, and south into North Dakota and Minnesota, although not all at any one time[45]. Lake Agassiz began forming 12,000 to 11,000 years before present because the northward-draining rivers of the Prairies were dammed by the Laurentide ice sheet. As the glaciers melted, the waters of Lake Agassiz first flowed to the south, then east giving rise to the Eastern Great Lakes, and finally north into the Hudson Bay by about 8,000 to 7,000 years before present[46] (Fig. 4).

Lake Winnipeg continues to evolve with changes in water flow and regional tilting of the Earth's crust from glacial isostatic rebound. Lake Winnipeg initially formed as a much smaller body of water in the north. It then enlarged towards the south as the outlet at the head of the Nelson River rose in altitude and the land tilted. About 8,000 years ago, the southern and northern basins were two separate lakes and it was not until about 2,500 years ago that the north, south and central basins coalesced into a single lake. Models predict that in 2,000 years time water levels at the current southern shore of the South Basin will be 6.5 meters higher than at present[47]. Glacial rebounding is relevant today as a process involved in the problematic issue of shoreline erosion in Lake Winnipeg.

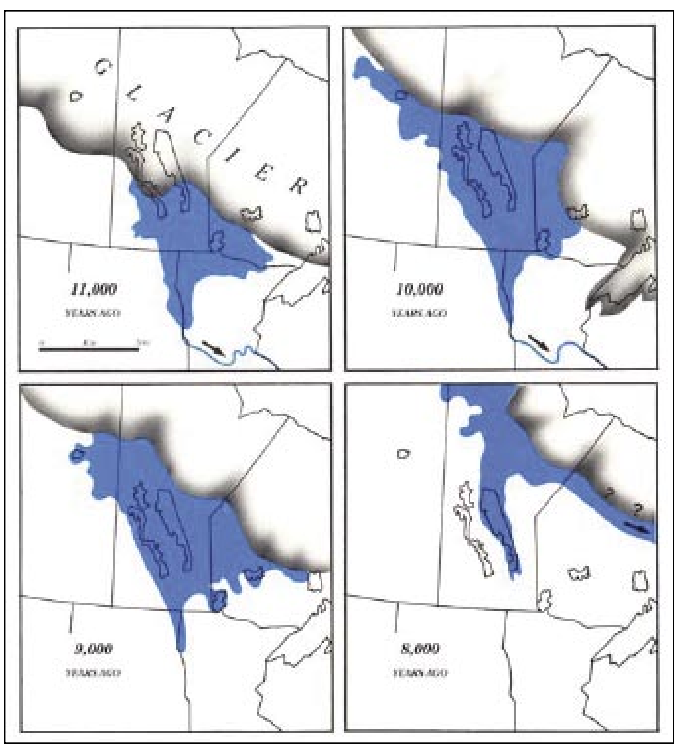


Fig. 4. The retreat of Lake Agassiz (blue) from 11,000 to 8,000 years before present[48]

MORPHOLOGY AND HYDROLOGY OF LAKE WINNIPEG

At our present geological time, Lake Winnipeg is 430 kilometers in length and divided into South and North Basins, separated by the Narrows comprised of islands and constricted passages reaching 61 meters in depth (Table 1). The South Basin has a flat lake floor with water depth averaging a mere 12 meters[49]. The North Basin has an average water depth of 16 to17 meters and a generally flat floor[50]. A disproportionate fraction of the lake's shoreline is found in the Narrows, whereas the North and South Basins have relatively smooth outlines[51]. Mean lake level is 217.4 meters above mean sea level. Lake morphology and depth are a result of its geological history and location as described above and these in turn influence the physics, chemistry and biology of the lake and how the lake responds to human impacts.

Among lakes of its size, Lake Winnipeg is unusual in being so shallow[52]. With a large fetch, abundant wind energy, and shallow water depths, Lake Winnipeg water masses are usually well mixed vertically. Little or no stratification of temperature, oxygen, or dissolved elements occurs in the lake[53, 54].

Lake Winnipeg is known for its surges and seiches of unusually high amplitudes. The length and breadth of the Lake Winnipeg basins allows the prairie wind to drive surface water currents of 20 to 90 centimeters per second and to cause water levels to increase by one to two meters at downwind locations[55]. The frictional influence of the very shallow bathymetry and the restricted flow between the South and North basins is clear when these events are modeled. The earth's rotation causes a counterclockwise rotation of high water around the shoreline of the lake. Water level is most elevated when winds are along the northwest axis of the lake and the effect is greatest in the South Basin[56]. These dynamic features of the lake influence its safe use for boating, whether for commercial or sport fishing, or recreational boating. They also impact shoreline stability.

Shoreline recession is widespread in Lake Winnipeg often impacting residential property, public areas and beaches. Erosion, flooding and dynamic beach changes at the shoreline are primarily, or at least to a great extent, the result of naturally-occurring processes related to the geology and lake history. Shoreline retreat at local rates of as much as one meter or more per year is promoted by long-term rising of lake level due to uplift of the northern lake outlet and southward tilting of the basin. Erosion is highly variable with some shores lightly impacted and a very few showing accretion. Over a 40-year period, some locations showed erosion of over 100 meters. The local impact is a function of exposure (orientation, fetch, and wave energy) and the nature of substrate[57]. The eroding shores are cohesive shores that have a thin layer of sand over clay or glacial till. The erosion of the cohesive nearshore is ongoing and irreversible. Once eroded, the clay and silts are transported into deep water and are never returned to the shore[58]. Lake regulation affects the extent of erosion, flooding and beach changes to a much lesser degree than natural processes. Infrequent and unpredictable storm events at high water levels can cause very significant erosion[59].

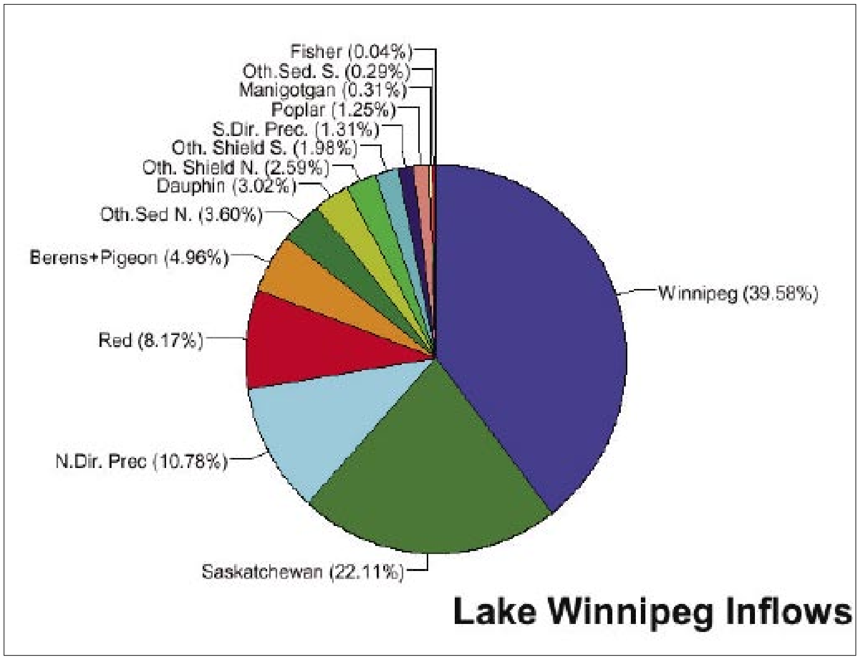


Fig. 5. Relative inflow volume contribution by major rivers to Lake Winnipeg[60]

Although the Nelson River is the only outlet of Lake Winnipeg, there are a number of inflowing rivers. In terms of water flow, the main tributaries are Winnipeg and Saskatchewan Rivers (Fig. 5). The next largest input is precipitation, followed by inflows of the Red, Dauphin and Berens rivers (Table 1). Other smaller tributaries make up the remaining 25 per cent[61] (Fig. 5). Some of the other rivers that flow into Lake Winnipeg include the Poplar, Pigeon, Manigotagan, Dauphin, Fisher, and Icelandic rivers.

The natural inflows to Lake Winnipeg are greatest in the spring and summer, due to the snow melt during warming weather combining with the naturally heavier rainfalls in spring and early summer. By fall, the tributary waters abate as a result of drier conditions. With the onset of winter, precipitation falling as snow does not contribute to the runoff. Because of its large surface area, Lake Winnipeg's level will rise or fall very slowly as a result of the difference between inflow and outflow. Similarly, it takes a long time for the lake's level to drop after flood inflows have receded[62].

The Lake Winnipeg Regulation Project

In the 1960s, the benefits of using Lake Winnipeg as a reservoir to enhance hydroelectric generating capacity of Manitoba were considered. As well, it was thought to be advantageous to prevent the extreme levels brought about by weather. The lowest levels were considered undesirable to swimming, recreational boating, navigation and thought at that time to be undesirable for marsh habitat. Highest levels threatened to damage beaches, cottages, and agricultural land. Flood levels were known from 1880 and 1901 that exceeded those in 1950 and 1960. During the 60 years before 1972, the lowest level recorded was 215.98 meters (708.61 feet) and the highest level was 218.71 meters (717.54 feet). It was recognized "that any interference with natural environmental conditions, whilst offering benefits, may also create problems". Nevertheless, "Although the flushing rates of the Lake will be decreased slightly as result of regulation no serious detrimental effect to the minute free floating plant organisms in the Lake, which form the primary component of the food chain, will result" [63].

In February 1966, the province of Manitoba and the government of Canada agreed to allow Manitoba Hydro to use Lake Winnipeg as a natural reservoir for hydroelectric development on the Nelson River. Work on the Lake Winnipeg Regulation project began in 1970 with the construction of three channels and the Jenpeg Generating Station and Control Structure, which were completed in late 1976.

Regulation enhances hydroelectric power generation potential because the natural flow pattern from Lake Winnipeg into the Nelson River is opposite to the energy needs of the province. Greater power generation is required in winter than in summer. Regulation decreases the water outflow from Lake Winnipeg in the spring and early summer in order to make available more outflow in the fall and winter (Fig. 6).

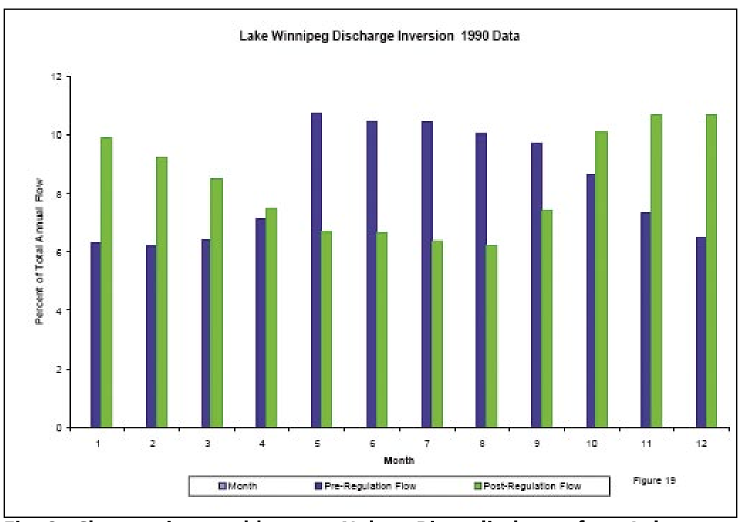


Fig. 6. Changes in monthly mean Nelson River discharge from Lake Winnipeg pre- and post regulation[64]

In 1970, Manitoba Hydro was granted a licence to regulate Lake Winnipeg. While the level of the lake is regulated between 216.7 meters (711 feet) and 217.9 meters (715 feet) above sea level (ASL), the licence allows Manitoba Hydro to set the outflows as required for power production purposes along the Nelson River. Sometimes the lake level will rise above or drop below these levels, such as during high or low runoff periods. Under such extremes, the lake will be operated to return to the licensed operating range as quickly as inflow conditions will permit.

During times of high inflow, when the level of the lake rises above an elevation of 217.9 meters above sea level, Manitoba Hydro must maintain maximum outflow in order to return the level of the lake to below 217.9 meters as soon as possible. During drought periods, the level of the lake may fall below 216.7 meters. If this should occur, outflows from the lake will be determined by the Minister of Conservation.

Weather conditions, such as wind and barometric pressure, can cause levels to differ substantially at various points on the lake. Manitoba Hydro uses the daily average level readings from eight gauges to determine the lake's level. Since the Lake Winnipeg Regulation project was built, the average level of the lake has remained virtually the same as the average level prior to regulation. In addition, the wide fluctuations between the highest and lowest levels have been substantially reduced (Fig. 7). Because of the project, the risk of devastating high water levels, such as those that occurred in 1966 and 1974, have been eliminated. As well, regulation has brought protection against extreme low levels (Fig. 7) that would naturally occur in dry years such as in 1932, 1941, and 1962[65]

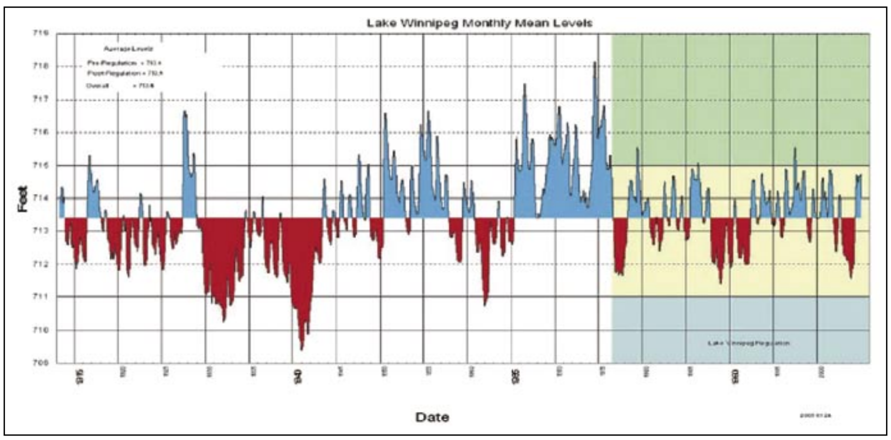


Fig. 7. Lake Winnipeg monthly mean water levels (1912 – 2004)[66]

LAND AND LAND USE

Lake Winnipeg lies entirely within the Boreal natural province (Fig. 8) in the area that is predominantly forest.

Water chemistry and other characteristics of Lake Winnipeg reflect its geographical location at the divide between two distinctly different geological formations, the softer sedimentary Paleozoic areas to the west and the harder, granitic Precambrian rocks to the east. The three major rivers drain distinct areas:

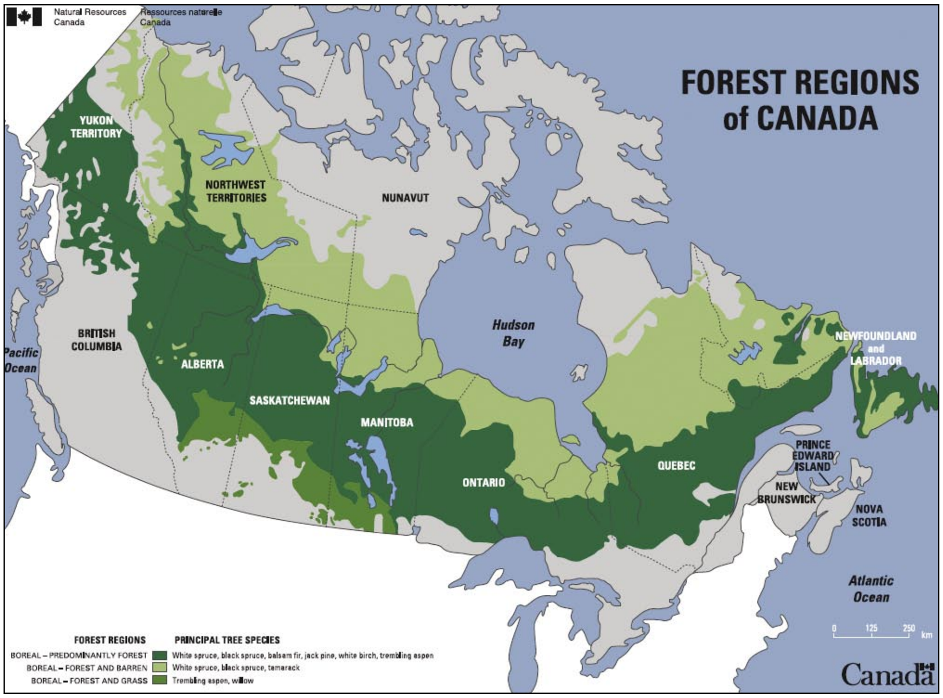


Fig. 8. The boreal natural province extending across Canada. Three major subdivisions are represented by the three shades of green. Source[67]

- Winnipeg River drains the eastern and south-eastern watersheds on the Precambrian Shield that are part of the Boreal Shield Ecozone
- Red River drains the Prairies Ecozone to the south and south-west of Lake Winnipeg, and its watershed extends well into North Dakota and Minnesota
- Saskatchewan River watersheds to the west and north-west of Lake Winnipeg are part of the Boreal Plains Ecozone and the Prairies Ecozone.

The eastern watersheds of Lake Winnipeg are overlain with variable thicknesses of glacial Lake Agassiz-derived soils, muskegs, and boreal forests. The southern, western and north-western watersheds are overlain with considerable thickness of glacial Lake Agassiz sediments, well-developed chernozemic soils, originally prairie grasses in the south, and mixed deciduous and coniferous forests to the west and north-west. The prairie watersheds, the most human-altered region in Canada, now support agricultural activities and a number of cities, whereas the Precambrian Shield supports mining and forest industries, little agriculture, and few large communities (Table 2).

Table 2. Characteristics of the three ecozones drained by major rivers flowing into Lake Winnipeg

Watershed	Eastern and south-eastern	South and South-west	West and north-west
Ecozone	Boreal Shield	Prairies, 138,600 km^2 in Canada, 148,900 km^2 in U.S.	Boreal Plains and Prairies
River	Winnipeg River	Red River	Saskatchewan
Geology	Igneous bedrock of Precambrian Shield	Sedimentary (Palaeozoic and Mesozoic shales, limestones, dolomites, and sandstones)	Sedimentary (Palaeozoic and Mesozoic shales, limestones, dolomites, and sandstones)
Soils	Glacial Lake Agassiz-derived soils: acidic, sandy, granitic tills and glaciolacustrine deposits; Canadian Shield bedrock and barecrop outcrops; clay deposits and fluvioglacial outwash deposits	Glacial Lake Agassiz sediments, well-developed Chernozemic soils	Glacial Lake Agassiz sediments, well-developed Chernozemic soils
Terrestrial	muskegs, and boreal forests, coniferous forest with some aspen and poplar to mixed forest; wetlands cover about 25 per cent of the Lac Seul Upland Ecoregion;	Prairie grasses in Lake Manitoba Plain ecoregion; includes also Aspen Parkland ecoregion and Moist Mixed Grassland ecoregion	Mid-boreal Lowlands ecoregion; Interlake Plains ecoregion; Poorly drained fens, bogs with conifers, permafrost in patches; mixed deciduous and coniferous forests, grasslands
Mean annual temperature	0.5 °C	2 °C in the north to 3 °C in the south	-1 °C in the north to 1.5 – 3.5 °C in the south depending on location
Climate		Warmest and most humid	Water deficits common
Activities	Mining, forestry, water-based recreation, hunting; little agriculture and industrial activity	Agriculture (corn, spring wheat, oilseeds, hay) and livestock production; hunting and water-based recreation	Forestry, sport fishing; wildlife trapping and hunting; agriculture (60 per cent of Canada's cropland), livestock (80 per cent of Canada's rangeland and pasture), mining, oil and gas production
Population	75,000	800,000	3 million
Population Centres	Few large centers	Winnipeg, Grand Forks, Fargo-Moorehead	Various

WETLANDS

Wetlands are critical components of the freshwater resources of North America and one of the components most vulnerable to changes imposed by industry, agriculture, society in general[68] and climate change[69]. It is estimated that 14 per cent of Canada's surface, about 1,270,000 square kilometers, are wetlands. These include the world's second largest peatlands resource base, forming one of the principal water storage reservoirs in the northern hemisphere[70]. Peatlands are essential to the global environment because they retain, purify and deliver fresh water, store carbon, absorb pollutants and support numerous species of plants and wildlife, many of them identified as endangered.

As North America was settled by Europeans, wetlands were valued for the space they provided when there were drained or filled[71]. It is only over the last few decades that wetlands have been recognized as ecosystems that provide vital ecosystem services.

Manitoba is home to two of the largest lacustrine lagoon marshes, or river delta marshes, in North America. Delta Marsh located at the south end of Lake Manitoba covers approximately 150 square kilometers, while the Netley-Libau Marsh on the Red River at Lake Winnipeg, approximately 65 kilometers north of Winnipeg, covers approximately 200 square kilometers[72]. The Netley-Libau Marsh was officially dedicated as a Canadian Important Bird Area on October 1st, 2000. The Netley-Libau Marsh is also a candidate Heritage Marsh under the Manitoba Heritage Marsh Program. Historically, the Netley-Libau Marsh has produced and supported extremely high muskrat and waterfowl populations. This marsh has greater than one per cent of global, biogeographical, or national population in terms of nests or concentrations of numbers of Forster's Tern, Franklin's Gulls, Black-crowned Night-Herons, Yellow-headed and Red-winged Blackbirds, Swallows[73].

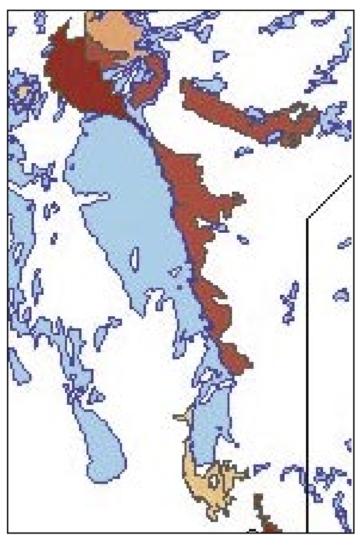


Fig. 9. Areas (in two shades of brown) around Lake Winnipeg where 35-50 per cent of the land is occupied by peatlands.

In the province of Manitoba, wetlands cover 233,340 square kilometers or 43 per cent of the province[74]. Although there are large lacustrine wetlands in Manitoba, peatlands concentrated in the boreal forest region of the province, particularly around the north basin of Lake Winnipeg, and in the Hudson Bay Lowlands region compose approximately 90 per cent of all of Manitoba's wetlands (Fig. 9). For the most part, peatlands have been maintained in a relatively pristine and unaltered state due to the lack of human activity in these areas.

A 2.5 million hectare portion of the east side of Lake Winnipeg, including the peatlands in the vicinity of the Narrows (Part of the brown area in Fig. 9) has been nominated as a future World Heritage Site for the boreal ecozone[75],[76]. The site is comprised of traditional land of four First Nations in Manitoba and one First Nation in Ontario, as well as Atikaki Wilderness Park in Manitoba and Woodland Caribou Park in Ontario. The World Heritage designation would provide protection of traditional lands from development and conserve significant boreal forest biodiversity.

CHEMISTRY AND BIOLOGY OF LAKE WINNIPEG

From the descriptions above, Lake Winnipeg can be imagined to be a large depression in a system of rivers draining an immense part of Canada and a portion of the northern U.S. We therefore expect that Lake Winnipeg is more influenced by the magnitude of flow and the chemical composition of the water sources than is the case for most other great lakes. It is 1/100th the depth of Lake Baikal and 1/18th the depth of Lakes Superior and Huron[77]. Because of its location at the boundary of two different geological provinces, it receives flows of two distinctive types of water quality.

Water chemistry of a lake reflects the characteristics of the watershed. The two geological zones drained, on the one hand, by the Winnipeg River, and on the other hand, by the Red River and Saskatchewan Rivers differ markedly in geology, soils, vegetation, and human activities (Table 2). The Precambrian Shield drainage area is 173,750 square kilometers, whereas the sedimentary area drained is 779,500 square kilometers[78].

Table 3. Representative water parameters and chemistry of the three major rivers flowing into Lake Winnipeg, mid-summer, 1969[79]

River	Secchi visibility (m)	Conductivity umhos cm^{-1} at 25 °C	pH mol m^{-3}	Ca mol m^{-3}	Mg mol m^{-3}	Na mol m^{-3}	K mol m^{-3}	SO_4 mol m^{-3}
Winnipeg	0.8	100	7.65	0.32	0.16	0.074	0.023	0.083
Saskatchewan	1.5 – 2.0	380	8.38	1.0	0.64	0.62	0.059	-
Red	0.35	675	8.30	1.40	1.28	1.57	0.20	1.16

River	Total dissolved P mol m^{-3}	Particulate P mol m^{-3}	Total dissolved N mol m^{-3}	Particulate N mol m^{-3}	Particulate C mol m^{-3}
Winnipeg	0.13	0.87	32.8	12.1	55.0
Saskatchewan	0.45	0.55	27.8	5.28	57.5
Red	0.16	3.68	7.14	16.7	168.0

The rivers have very different chemical (Table 3) and biological characteristics and have different effects on the limnology of the lake[80]. The inflows from the south and southwesterly portion of the sedimentary sub-basin are of greater alkalinity (higher pH) and dissolved mineral content than those of the east and the north. The waters from the Precambrian Shield are neutral or slightly acid in pH and low in mineral content[81]. Nevertheless, the Winnipeg River in 1969 delivered as much or more of some elements than the Red River because of its greater flows. As much as 99 per cent of the large sediment load carried by the Saskatchewan River since the 1960s is deposited in Cedar Lake and the reservoir at Grand Rapids, and does not reach Lake Winnipeg. During low water years, the Red and Winnipeg Rivers carry about the same sediment load to Lake Winnipeg but in moderate to high water years, the Red River can carry ten times more sediment than does the Winnipeg River[82].

Species and communities are found where they are because they are able to survive, reproduce and sustain or expand populations in the particular set of physical, chemical, ecological, and climatic conditions that operate over time. Furthermore, species as components of communities vary from rare to common or dominant depending upon their ability to access the resources they require in the environment and avoid mortality such as from predation, disease, or human exploitation. In the face of seasonal, short and long-term natural variability in environmental factors, biodiversity within the community is important for overall ecological sustainability and stability. All the species in a geologically-young environment such as Lake Winnipeg have been invaders to have reached where they are and are potentially invaders in the future. Invasion is a natural, opportunistic expansion of range as appropriate environmental conditions are available and the species is successful in competing for resources and space.

The biology of Lake Winnipeg reflects the post-glacial connection that Lake Agassiz had for a time with the Mississippi River system. Southern species of fish, mollusks, crustaceans and other zooplankters and phytoplankton are thus represented in Lake Winnipeg today. In fact, no endemic species are known in Lake Winnipeg, a fact attributed to its geologically young age. The oldest fish species is an ancient relict species, the sturgeon, *Acipenser fulvescens*. Lake Agassiz was an important route of dispersal for the southern zooplankton species throughout central and northern Canada[83].

Present-day biology of Lake Winnipeg was first studied intensively between 1927 and 1933. The flat, muddy bottom of the lake supports a rich fauna dominated by insect larvae, molluscs, and amphipods. Generally, a few species dominate with large numbers of individuals. In the 1929 survey, 310 species of phytoplankton and 143 species of zooplankton were reported. All of these, with rare exception, occur as well in the Great Lakes region or in the Mississippi drainage[84].

The lake was next studied from June to October 1969. Distribution of crustacean zooplankton species was seen to be related to differences in receiving water chemistry between the eastern Precambrian Shield and the southern and western sedimentary areas[85]. Also, the influence of climatic differences within this lake that extends over 3° 30′ of latitude and 3° of longitude were documented. A total of 34 species of crustacean zooplankton were identified. Of these, only 12 were distributed throughout the main body of the lake, the remaining 22 species were restricted to areas near the river inflows in which they presumably entered. Thus, there is a core 12 species, and a group of 22 marginal, yet unsuccessful invaders. Although the Red River supplies only 20 per cent of the water inflow, it has a stronger influence on the character of the zooplankton communities within the South Basin than does the Winnipeg River that supplies 80 per cent of the inflow to the South Basin.

As for the zooplankton, special distribution of phytoplankton in Lake Winnipeg can be explained by the diverse geology of the basin, variations in inflow water, river flows, and climate differences between the North and South Basins[86].

It was estimated that the total phosphorus concentration in Lake Winnipeg at the time of the 1929 study was 50 milligrams per cubic meter or about half the 1970 level. The average transparency of the South Basin decreased from 1.5 meters in 1929 to 0.75 meters in 1969. Transparency in 1969 was higher in the North Basin attributed to the sediment and nutrient trapping by Cedar Lake. Temperature differences between the South and North Basins related to the natural climatic differences between latitudes and the phosphorus loading explained almost all of the differences in abundance of the zooplankton within the lake[87].

ECONOMIC AND SOCIAL VALUES

Hydroelectric Power Generation

Lake Winnipeg is used as a storage reservoir for the generation of hydropower on the Nelson River. Exports of electricity contributed an average of $365 million per year over the past 10 years[88] and as much as $588 million per year to the provincial economy[89]. Of the total generating capability of 5480 megawatts in 2005, 75.8 per cent was generated in the Nelson River system[90]. Over the past 30 years, electricity exports to the U.S. are equated to a reduction in greenhouse gas emissions by about 155 millions tones[91].

Manitoba and Ontario recently signed an agreement for a sale of power from Manitoba to Ontario valued at over $500 million starting in 2006[92] that will require further hydroelectric development.

Recreation and Tourism

Recreation and tourism along the Red River and surrounding Lake Winnipeg generate an estimated $110 million per year.[93] Lake Winnipeg beaches are a Manitoban and a Canadian tourist attraction. Eight Provincial Parks and Provincial Recreation Parks are located along the South Basin, including Hecla/Grindstone, Winnipeg Beach, and Grand Beach.

Winnipeg Beach has attracted day users and cottagers since its beginnings as a Canadian Pacific Railway resort destination in 1901. Grand Beach is famous for bird-watching, its marsh trail, and its 8-meter tall white sand dunes as well as numerous water-contact activities [94].

Beach safety staff estimate that 395,100 people visited Grand Beach during the summer of 2002 while 87,800 made the trip to Winnipeg Beach. Over 460,000 people visited Grand Beach Provincial Park during the summer of 2002. In 2003, that number increased to over 609,000 people, up by 32 per cent[95]. More than 15 small craft harbours provide service to many sail and power boats on Lake Winnipeg.

Settlements

More than 23,000 permanent residents live in 30 communities along the shores of Lake Winnipeg. These include 11 First Nations communities.[96] The Municipality of Gimli has a permanent population base of about 5000. Its taxable assessment base of $180 million makes it one of the highest per capita assessment areas in Manitoba, mostly relating to permanent and cottage subdivisions, resort development, and industry. Winnipeg Beach has a total taxable assessment of $27 million, almost all of which is lake-related[97].

Growing numbers of people are building cottages along the shores of Lake Winnipeg, many of which are winterized. Most cottage communities are concentrated along the shore of the South Basin, and cottages number over 10,000.

A few small communities primarily on the east shore draw and treat water from the lake for community use. Most First Nations communities access tributary streams entering Lake Winnipeg or local aquifers for water supplies[98].

> **World Class Water Source on the Shores of Lake Winnipeg**
> **The global company, Diageo, maker of world-famous drinks employs over 20,000 people in around 80 countries. The company chose Gimli with world class quality of ground water from artesian wells as the site for producing several brands, including its Canadian product.**

Fisheries

Of all the Canadian provinces, Manitoba has the highest commercial production of freshwater fish with 49 per cent of the total value in Canada and 39 per cent of the total weight, based on 2002 data. Lake Winnipeg comprises Manitoba's largest commercial fishery thereby contributing substantially to freshwater fish production and employment. In 2001 - 2002, about 42 per cent of the total weight and 62 per cent of the total value of fish production in Manitoba came from Lake Winnipeg. During the same period, 1,073 licensed fishers and their helpers were employed in the commercial fishery on Lake Winnipeg. The total value of commercial fish production on Lake Winnipeg in 2001 - 2002 was $20,380,350[99].

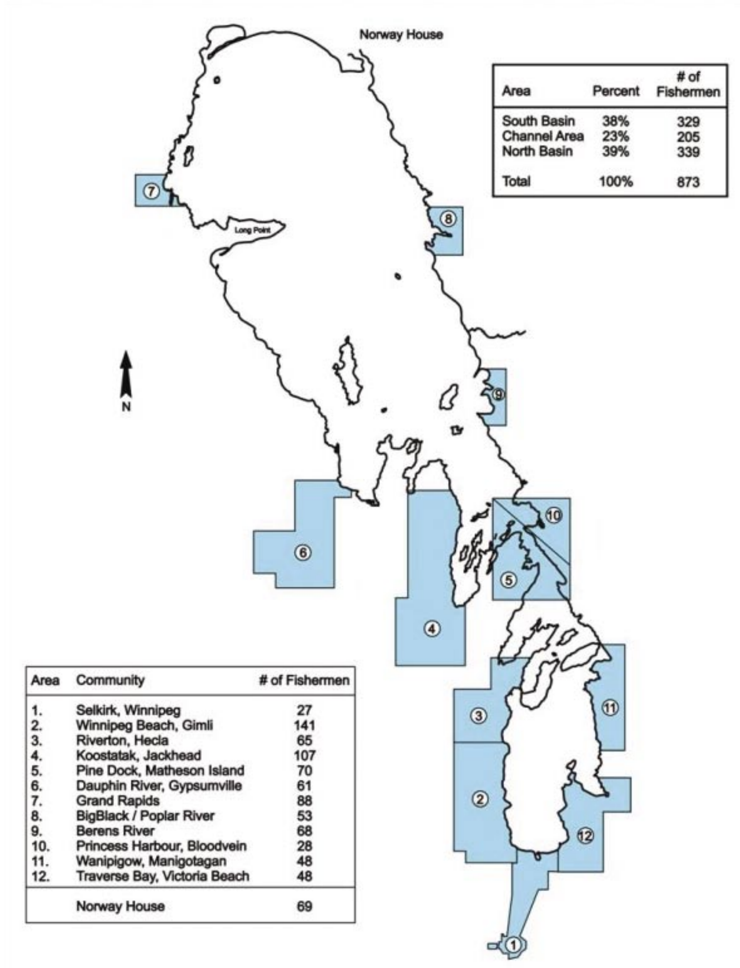


Fig. 10. Lake Winnipeg community licensing areas[100]

The fishers are largely located in the South Basin and the Narrows (Fig. 10). The majority of fishers are First Nations or Metis. Quota entitlements were created in 1985. There are about 1650 quota entitlements on Lake Winnipeg for the summer, fall and winter commercial fisheries. Some quotas are for individuals, others for communities.

Gear has changed over time and since the early 1990s, monofilament nets has quadrupled the efficiency of a typical gillnet compared with pre-1950[101]. The total annual quota for the combined commercial fishery of walleye (pickerel), sauger and whitefish is currently 6.4 million kilograms. This quota has never been formally attained, nevertheless, domestic and illegal catches are unknown and not included. Walleye bring the greatest financial return and whitefish the least[102].

During the 2002 - 2003 season, 3,212,700 kilograms (round weight) of pickerel (walleye) were caught by commercial fishers on Lake Winnipeg. Harvest of whitefish and sauger were also high at 1,597,700 and 739,000 kilograms (round weight), respectively (Fig. 11).

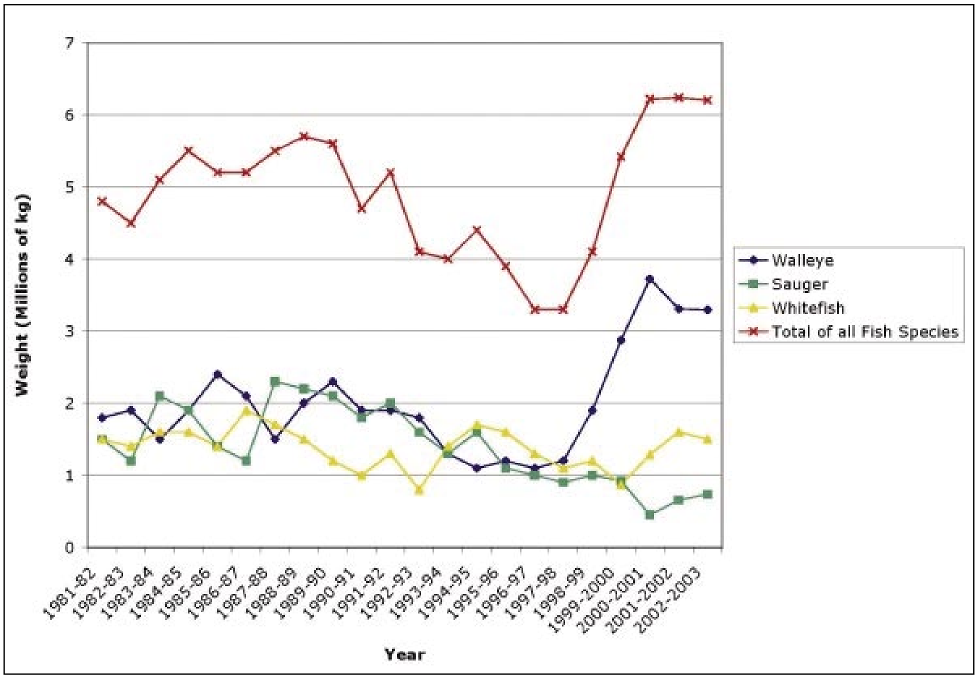


Fig. 11. Change in fish production (by weight) in Lake Winnipeg between 1981 and 2003[103]

History of the Fishery

Lake Agassiz, and then Lake Winnipeg have been the distribution center from which many of the fishes of the drainage basin dispersed. Lake Winnipeg still has the most diverse fish fauna of any water body in the basin. Although the fishes of Lake Winnipeg have great economic and ecological significance, the composition, abundance and dynamics of the fish community of Lake Winnipeg over time and space are not well understood[104]. According to reports in 2003, there are 52 species of fish in Lake Winnipeg[105] whereas a 1991 publication reported 48 species in the Lake Winnipeg fish community[106]. General information is available on the general habitat preferences and relative abundances of Lake Winnipeg fishes[107].

The first fishers were the aboriginal peoples using various species for thousands of years following human occupation of the Lake Winnipeg region. Fish catches began to be documented when the Europeans settled around the lake. Management of the fishery was under federal responsibility until the transfer of powers over natural resources to the province in 1930[108]. The commercial fishery began in the 1870s but the first records are available only from 1883 (Fig. 12).

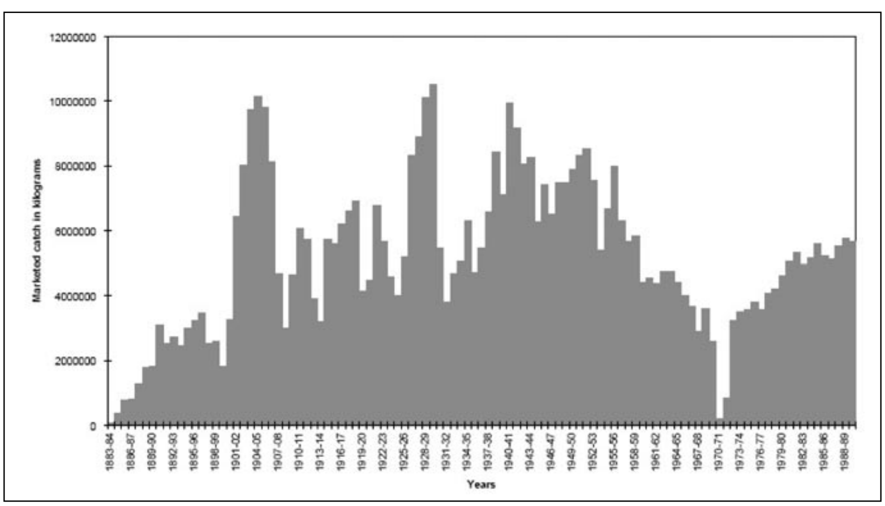


Fig. 12. Annual commercial landings of all species of fish from Lake Winnipeg, 1883 – 1990[109]

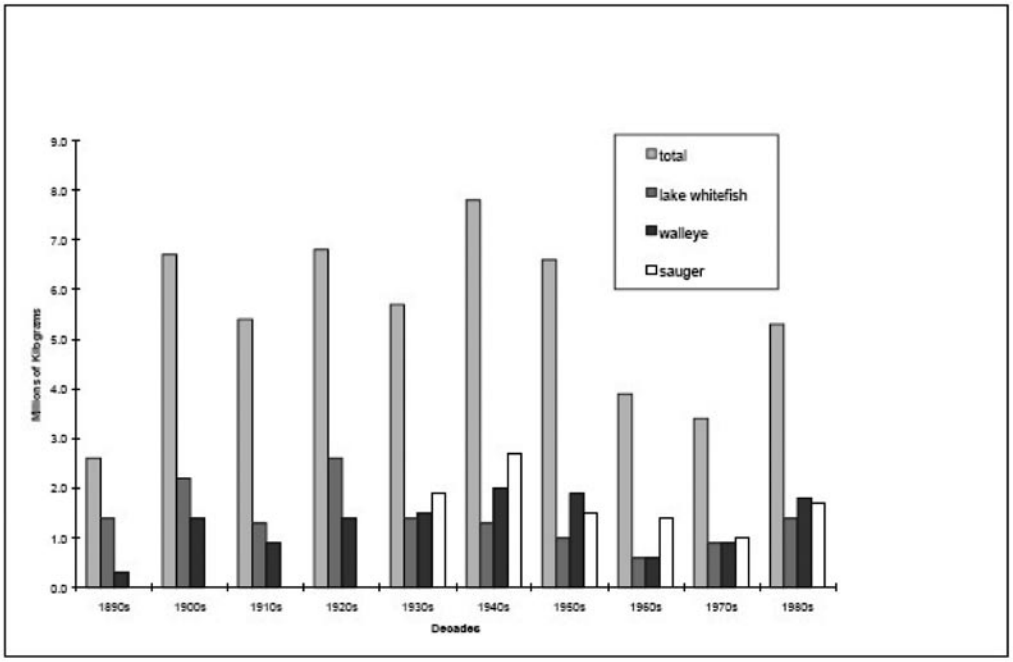


Fig. 13. Average annual commercial catches of the three major fish species harvested from Lake Winnipeg by decade from the 1890s to the 1980s[113]

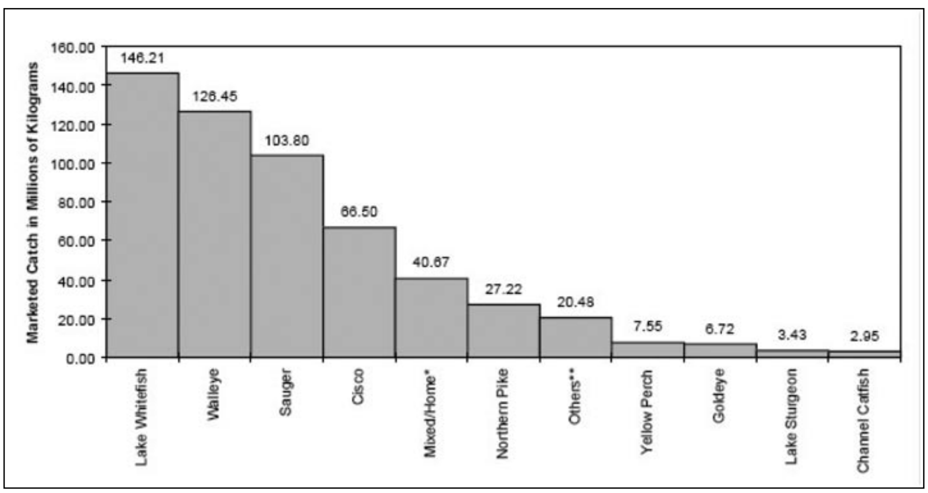


Fig. 14. Total commercially-harvested weights of the main fish species in fish catches from Lake Winnipeg: 1880-1990[114]

The interruption in catch in 1970-71 is related to the closure of some areas due to the contamination of the Winnipeg River by mercury. In the 1960s, the Grand Rapids hydroelectric generating station transformed Cedar Lake into a reservoir. In 1971, mercury levels were found to be elevated in whitefish in Cedar Lake and the commercial fishery was closed.

Subsistence harvest was most important in Lake Winnipeg from 1887 to 1909 when the mean annual harvest was 342,456 kilograms. Although the subsistence harvest later decreased, it is still important as a source of food and plays a central role in the traditional cultural life of First Nations peoples[110]. There was also a substantial use of fish as food for sled dogs until snowmobiles became common[111]. Bait and recreational fishing are other sources of fish harvest. Manitoba produces more than half of the Canadian catch of the common carp, mostly from Lake Manitoba, followed by Lake Winnipegosis. Lake Winnipeg produces about 50,000 kilograms of carp annually on average[112].

As indicated in Fig. 13 and 14, the fishery is dominated by lake whitefish, walleye (pickerel) and sauger.

Originally a whitefish and walleye fishery, as whitefish declined, sauger was included in the commercial fishery in the 1930s (Fig. 13) by which time the fishery was fully developed. An even more dramatic impact of fishing was on populations of sturgeon. The catch began in the 1890s and ended by the 1920s with the virtual extirpation of this species[115]. Remnants now contribute a few hundred to a few tens of kilograms to the annual harvest. Trout succumbed to overfishing by 1900.

The long-term mean commercial yield of Lake Winnipeg for the period 1931 to 1983 was estimated as 2.57 kilograms per hectare per year[116]. This is considerably lower than that from Lake Erie, in a slightly warmer climatic zone, of 9.72 kilograms per hectare per year [117]. Commercial landings represent only a portion of the total fish caught. Unmarketed species are culled from the commercial catch and an estimate of cullage could be as high as 1.7 million kilograms or 25 per cent of the total annual commercial harvest[118]. This suggests that a total of 139-186 million kilograms of several fish species have been harvested and culled over the history of the fishery, most returned to the lake[119].

Over the long-term, walleye yield density declined following each time it surpassed one kilogram per hectare per year, i.e. in 1950 and 1985. One estimate of sustainable yield is 0.66 kilograms per hectare per year. These are probably the upper limit of sustainable walleye yield in Lake Winnipeg[120]. Between 1976 and 1980, the commercial landings of whitefish, walleye and sauger averaged 4.59 million kilograms per year. An estimate of maximum sustained yield of whitefish, walleye, sauger, and northern pike made about 1984 was 3.8 million kilograms per year[121].

The commercial harvest yield in the past several years exceeds the performance of the past two decades (Fig. 11) although not the long-term performance (Fig. 13). This is related to the highly increased walleye harvest that is exceeding long-term records[122].

3. A Lake Under Stress

EUTROPHICATION

Lake Winnipeg is exhibiting extreme eutrophication with vast algal mats that are visible from satellites

> **"It will be difficult to control the acceleration of the rate of supply of nutrients, metals, and other deleterious substances to Lake Winnipeg, because of the diffuse source of many of these substances"**
> **- G.J. Brunskill, S.E.M. Elliott, and P. Campbell, 1980**

The condition of Lake Winnipeg most responsible for bringing national attention to its deteriorating health is the presence of highly visual mats of blue-green algae[123] (Fig. 15) that are particularly evident in the remote, relatively unpopulated North Basin. Excessively high biomass of algae is a general condition indicative of eutrophication, a state brought about by unnaturally high concentrations of nutrients[124] entering an aquatic ecosystem. In Lake Winnipeg, the algal blooms are thick enough to clog the nets of commercial fishers[125], increasing their physical efforts when hauling nets and reducing economic return. Recently, fishers report physical reactions to the algae including rashes and burning of the eyes[126]. Fouling of beaches with large mats of decomposing algae creates unpleasant conditions for cottagers and swimmers.

The ecological impacts are also serious, including the alteration of the structure and function of aquatic biotic communities, reduction in dissolved oxygen due to decomposition of senescing blooms, and production of toxins from the blue-green that may result in fish die-off and bathing advisories[127].

Fig. 15. Thick mats of blue-green algae that covered 8000 km^2 of the North Basin in 1999[128]

Satellite imagery has revealed larger and more frequent algal blooms in Lake Winnipeg in the last 10 years than in the 1980s.
- The Lake Winnipeg Research Consortium, Inc.

Scientists aboard the DFO/Coast Guard Vessel, the Namao, in August, 2004 estimated that the blooms covered about 4,000 square kilometers, or one-sixth of the North Basin's surface area. This was despite unusually cool weather. During the warmer previous year, 2003, the blooms covered close to 8,000 square kilometers, even affecting some southern beaches[129]. On August 29, 2005, the blooms are reported to have covered about 50 per cent of the lake or an estimated 13,000 to 14,000 square kilometers[130], a condition that has been attributed to the unusually heavy rains in Manitoba in 2005[131].

Causes of Eutrophication

Eutrophication is caused by a variety of human activities in the watershed

A Sea of Algae
"…nutrients that have been flowing into the lake in ever-increasing quantities over recent decades are almost certainly a major factor behind this year's blooms."
Alex Salki, DFO Researcher

Eutrophication is defined as the complex sequence of changes initiated by the enrichment of natural waters with plant nutrients. Increased primary production and abundance of photosynthetic plants are typically followed by increases in secondary biological production at all levels of the food chain, including fish[132]. Controlled eutrophication is sometimes undertaken to increase productivity in systems that are exploited for fish. For example, the Lake Enrichment Program of the Salmonid Enhancement Program of DFO fertilizes some British Columbia lakes to increase planktonic food for juvenile salmon. This practice replaces nutrients that naturally would have been available from the carcasses of returning salmon that now form the commercial catch and never reach the lakes[133]. The detrimental effects of eutrophication occur at nutrient supply levels well above natural levels.

Eutrophication is attributed to the increase in human populations, lack of tertiary sewage treatment, intensive cropping and increased use of fertilizers, increased cattle and hog production all of which increase the loads of biowastes to the watershed. As well, the 1997 flood resulted in the largest known transport of nutrients in a single event to the South Basin. The concentrations of nutrients in the South Basin in 1998 were the highest on record[134].

The impact of excess nutrient loading on a waterbody is dependent not only on the nutrient loads and resulting concentrations but also on the morphology and hydrology of the waterbody.[135, 136]. With respect to morphology, the mean depth is the important factor, and for hydrology, water renewal time is key. Water renewal time is the theoretical time it takes for the inflows from the tributaries and precipitation to equal the total volume of the lake. Given the volume of inflows and precipitation that exist, the shallowness of Lake Winnipeg causes the water renewal time to be short. Thus, it is more sensitive to excess phosphorus in inflowing water than are the deeper Lakes Michigan and Superior.

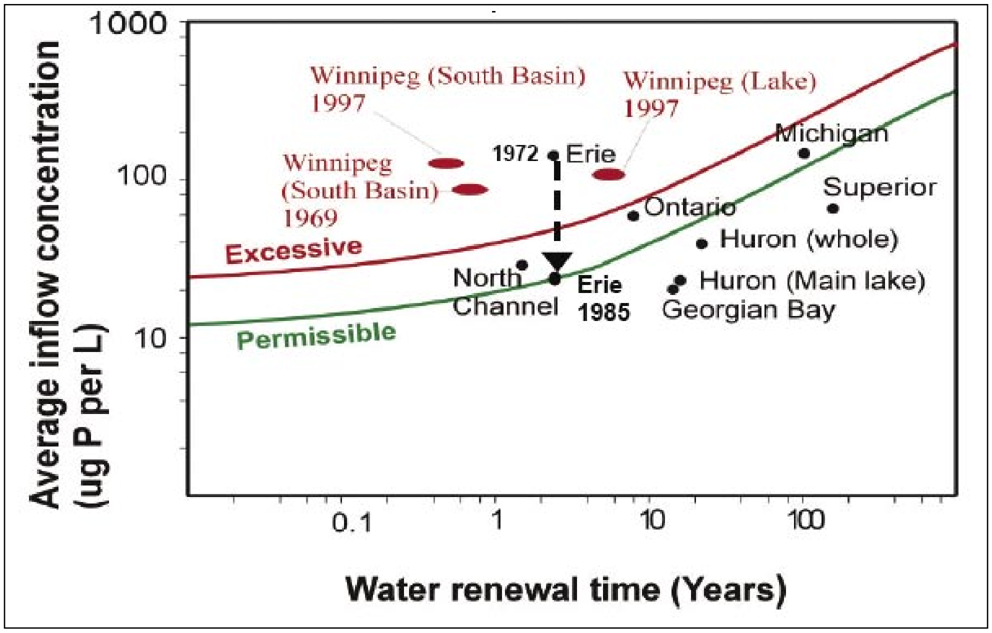


Fig. 16. Phosphorus concentrations in inflowing water as a function of water renewal time.[137]

Even by 1970, the loading of phosphorus to the South Basin was judged sufficient to produce a very eutrophic lake[138] using the original relationship developed by Vollenweider[139] between phosphorus loading and lake mean depth and shown in Fig. 16. Algal growth was apparently limited in the South Basin at that time by light penetration rather than by nutrients. The vast algal mats seen recently did not occur.

Phosphorus: The Critical Nutrient in Eutrophication

Excess phosphorus has been demonstrated to be the key nutrient causing eutrophication in fresh waters

> **"Since all the rivers in southern Manitoba drain into Lake Winnipeg, the state of P in the lake is a good barometer for the P problem in the province as a whole."**
> **- I. Halket, K. Snelgrove, and B. Wiebe[140], University of Manitoba**

Nutrients are essential elements required for all organisms. They include the macronutrients nitrogen, phosphorus, carbon, hydrogen, oxygen, potassium, sulfur, magnesium and calcium, and the micronutrients such as iron, copper, manganese, boron, molybdenum and chloride. These elements are all naturally present in air, water, and soil.

Unlike nitrogen, phosphorus does not exist in nature as the element. The largest reservoir of phosphorus is rock, such as apatite. Phosphorus in the environment occurs as inorganic or organic phosphorus but the only environmentally-reactive form is inorganic orthophosphate (PO_4^{-3})[141]. Prior to the mining of fertilizers, the primary source of phosphorus to aquatic and land plants was weathering of parent material and phosphorus from that source cycled through biological processes.

Although numerous elements are nutrients, including particularly nitrogen and phosphorus, usually one element or a physical parameter such as light limitation controls the level of algal productivity. In surface fresh waters, the availability of phosphorus determines the productivity[142], also termed trophic status, that is, the rate of algal growth that provides food for the higher levels of the food web. Supply of phosphorus is naturally more limited to the lakes of the Precambrian Shield than to those on the sedimentary areas, therefore, pristine Shield lakes have lower productivity. The species composition of algae present at various levels of phosphorus loading is determined by the ratio of nitrogen to phosphorus.

Scientific understanding of the key role of phosphorus in eutrophication began to come about when the International Joint Commission (IJC) was asked in 1964 to consider the causes of pollution in the eastern Great Lakes[143]. In 1969, IJC Advisory Boards of Lake Erie and Lake Ontario reported that phosphorus was the cause of the pollution and recommended a program to control phosphorus[144]. They concluded that in most natural waters the growth of algae is controlled more by the supply of phosphorus than by the supply of nitrogen and that the loading of phosphorus can be controlled more effectively than that of nitrogen. While nitrogen is a requirement for plant growth, it is available from a number of sources such as soils, sediments, precipitation, and the atmosphere. Under natural conditions, phosphorus is originally supplied by the weathering of rocks as are many of the micronutrients listed above, whereas nitrogen is a component of rocks and the major constituent of air.

The role of phosphorus was unequivocally and scientifically demonstrated by the experiments on small whole lakes at the Experimental Lakes Area (ELA), a DFO project in a pristine area of northwestern Ontario. The ELA program was established in 1968 as an ecological laboratory in which to study the causes of and the recovery from pollution in actual aquatic ecosystems. A 16- ha lake was separated into two basins by the installation of a curtain. One basin received additions of carbon and nitrogen, and the other received identical loadings of carbon and nitrogen, plus phosphorus[145]. As in the satellite image above, Fig. 17 captures the undeniable results. Phosphorus was necessary to produce eutrophication. Without phosphorus, the biological community on the side of the lake receiving nitrogen and carbon was indistinguishable from the natural pristine state.

Photosynthesis and growth require specific proportions of nutrients. For example, there is an approximate ratio between nitrogen and phosphorus of about 15 atoms nitrogen:1 atom phosphorus required by plants. When nitrogen:phosphorus is at a level of

Fig 17. The two basins of Lake 226 separated by a curtain. The lower basin received additions of carbon, nitrogen and phosphorus; the upper basin received carbon and nitrogen only. The bright green colour is from a surface scum of algae resulting from phosphorus additions.

about 15:1 or greater in the aquatic environment, the algal community is dominated by algae such as greens and diatoms that are edible to zooplankton, and form the base of the food web. When the nitrogen:phosphorus ratio falls below 15:1, nitrogen-fixing blue-green algae, always present in the community are favoured and can become dominant. In oligotrophic and mesotrophic lakes, usually the blue-green algae reside in the benthos and are present in very low abundance in the plankton. As nitrogen becomes increasingly depleted during the growing season, there is a succession of blue-green species. These algae obtain some of the nitrogen they need by taking it from the atmosphere, where there is an unlimited supply[146]. In non-eutrophic, lakes they play an important role by bringing needed nitrogen into the system. As they collapse and decompose, they release nitrogen and phosphorus for the fall succession of diatoms and greens that normally follows the blue green collapse.

Under excess phosphorus loading as a result of human activities, the blue-greens can become dominant at any time in growing season. These species are generally not consumed by zooplankton and the flow of energy from the blue-greens and the normal food web is disrupted. The biomass of the blue-greens accumulates and can become very large. After these organisms die, the decomposition consumes oxygen. These are the undesirable conditions that can produce fish kills.

Thus, the presence of excessive amounts of algae is a sign of oversupply of phosphorus. The presence of blue-green algae is a sign of an oversupply of phosphorus relative to nitrogen. The solution to the problem is the reduction of the supply of phosphorus relative to that of nitrogen to the point where nitrogen:phosphorus is >15:1, as well as the absolute reduction of supply of phosphorus to levels that are more natural for the type of aquatic ecosystem.

Although phosphorus is the nutrient limiting eutrophication in aquatic ecosystems, locally and over short time periods, other factors can be limiting. Some studies indicate that nitrogen has a more important role as a limiting nutrient than usually recognized [147]. It has been observed that phytoplankton responses to enrichment are enhanced when both N and phosphorus are added together. This seems to suggest that both nitrogen and phosphorus are limiting. In some studies limiting nutrients, i.e., available nitrogen and orthophosphate, are determined in a water body as the concentrations at maximum algal biomass. If the concentrations of available nitrogen or phosphorus are greater than growth-rate-limiting concentrations under these conditions, then that nutrient is not immediately limiting[148]. It is well-known that light can also limit algal production such as when there is high turbidity due to sediment load or humic acids, or shading such as by a heavy surface algal bloom or the presence of macrophytes. Other nutrients such as iron may limit productivity. In bottle experiments, carbon may be limiting. Results on factors limiting production from the field, bottle experiments, laboratory assays, or mesocosms, may be describing site-specific, relatively short-term, or experimental conditions. They do not contradict the statement that phosphorus is ultimately the limiting nutrient in the aquatic systems over the long-term. As long as lakes respond as does Lake Winnipeg to phosphorus by nitrogen–fixation, phosphorus reduction is the reliable means to achieve lower algal standing stocks[149].

It has been widely believed that, although phosphorus concentrations limit algal growth and biomass in freshwater, in the oceans nitrogen is limiting[150]. Recent evidence from marine and estuarine studies indicate that in the seas around Sweden, the input of nitrogen balances the availability of phosphorus and that both nitrogen and phosphorus are used for optimal biological production. Nevertheless, phosphorus is the overarching limiting factor. Reducing loading of nitrogen to the seas has been found to cause an increase in blue-green algae. Therefore, to limit production in the seas around Sweden, phosphorus loading has to be reduced[151]. A separate study of the Baltic Sea led to the conclusion that reduction of algal productivity and organic loading to the permanently stratified, anoxic deep waters will be effected by phosphorus removal from terrestrial sources. Reduction in nitrogen inputs are likely to be offset by increased nitrogen input by fixation[152]. Finally, recent reports solve the puzzle of how marine organisms in the tropical oceans obtain enough nitrogen to meet their needs. Decomposition of organic matter in deeper ocean water provides part of the needed nitrogen. Now there is firm evidence from a ten-year study on 150 stations sampled during six cruises that nitrogen fixation occurs at a greater rate than previously believed. One genus of the cyanobacterium, *Trichodesmium* spp. is a major source of new nitrogen in the tropical North Atlantic accounting for the previously-unidentified source of nitrogen[153]. These recent studies on nutrient limitation in the marine system significantly broaden the weight of evidence that productivity in aquatic ecosystems in general is primarily phosphorus limited and consequently reduction of phosphorus is the management choice to reduce eutrophication.

Excess Nitrogen, a Toxic Substance that Needs to be Controlled

Although the oversupply of the plant nutrient nitrogen to aquatic ecosystems is not the cause of eutrophication, excess nitrogen acts in other ways that are detrimental indirectly or directly to aquatic systems, aquatic life, and to livestock and human health. Excess nitrogen[154]:

- causes fish kills due to ammonia toxicity
- contaminates groundwaters causing exceedences of the drinking water guideline for nitrate
- leads to acidic deposition – acid rain
- contributes to decline in amphibian populations in southern Ontario due to elevated nitrate levels
- increases emissions of the potent greenhouse gas, nitrous oxide
- increases concentrations of nitrogen oxides contributing to the formation of photochemical smog in some cities
- leads to incipient nitrogen saturation is some forested watersheds.

Although all of these impacts of nitrogen are relevant to the Lake Winnipeg sub-basin, the first two relate more directly to the health of Lake Winnipeg and its tributaries. Ammonia is released into the environment by a variety of industries and other human activities, such as in effluents from wastewater treatment. About 60 per cent of the total nitrogen load in wastewater effluent is ammonia with the rest being organic nitrogen[155]. It is more difficult to quantify agricultural releases of ammonia to water. Intensive animal-rearing facilities with direct runoff to water bodies have the highest potential to impact aquatic ecosystems negatively.

Many studies document the toxicity of ammonia to aquatic organisms[156], including fish, invertebrates and aquatic plants. Sensitivity to ammonia varies with species and life stage. As well as causing mortality, ammonia may have chronic ecological impact on aquatic ecosystems, such as by reducing reproductive capacity and growth of young. Ammonia in the aquatic environment is on the Priority Substances List of the *Canadian Environmental Protection Act* (CEPA)[157]. A guideline has been published for the permissible levels of dissolved ammonia in wastewater effluents. The allowable concentrations are highly pH-dependent[158].

Nitrate in groundwater is one of the most problematic and widespread of groundwater contaminants and groundwater pollution is of increasing concern. Groundwater levels are declining in many areas due to overdrafts. Contamination puts this declining resource at further risk. In Canada, about eight million people, or 26 per cent of the population, depend on groundwater, five million of these live in rural areas[159]. In the U.S., groundwater is the source of drinking water to about 50 per cent of the overall population, and to about 90 per cent of the rural population. Common sources of nitrogen in the soil are fertilizers, livestock waste, and septic systems. Excess nitrate in the soil is most often found in rural and agricultural areas and may travel through the soil with rain or irrigation water to enter groundwater. Wells that tap groundwater may be affected. Shallow wells, wells in sandy soil, or wells that are improperly constructed or maintained are more likely to have nitrate contamination. Canadian drinking water guideline for nitrate is 10 milligrams of nitrate-nitrogen per liter. The U.S. drinking water quality standard is 45 milligrams per liter. Nitrate interferes with the blood's ability to transport oxygen. Infants and pregnant and nursing women are most at risk. Cattle, horses, sheep, piglets, and chicks are also susceptible to nitrate poisoning.

Control of nitrogen from a wide variety of industrial, municipal, and agricultural activities may be advisable or required. Because of the multiplicity of modes of toxicity of various chemical forms of nitrogen, the steps required to alleviate the problem will be problem-specific.

EUTROPHICATION OF LAKE WINNIPEG

Dominance of Blue-green Algae

Increasing biomass and changing species of algae signals that Lake Winnipeg has received increasing nutrient loadings over time

The biomass and production of algae in Lake Winnipeg over the past three decades are signaling that the watershed has been undergoing major changes. Compared with the state of the lake in 1969, already impacted by human activities, the lake in the last decade shows a marked trend towards increasing blooms of nuisance, harmful and toxin-producing cyanophytes (Fig. 18). The phytoplankton community in 1969 appeared to have lost several species recorded in 1929. By 1969, species typical of increased eutrophication, not found in the 1920s were present in significant numbers. By 1994, there was an increase in the number of nitrogen-fixing blue-greens and their biomass. In the 1999 to 2005 period, blue-green blooms were progressively larger and lasted longer[160].

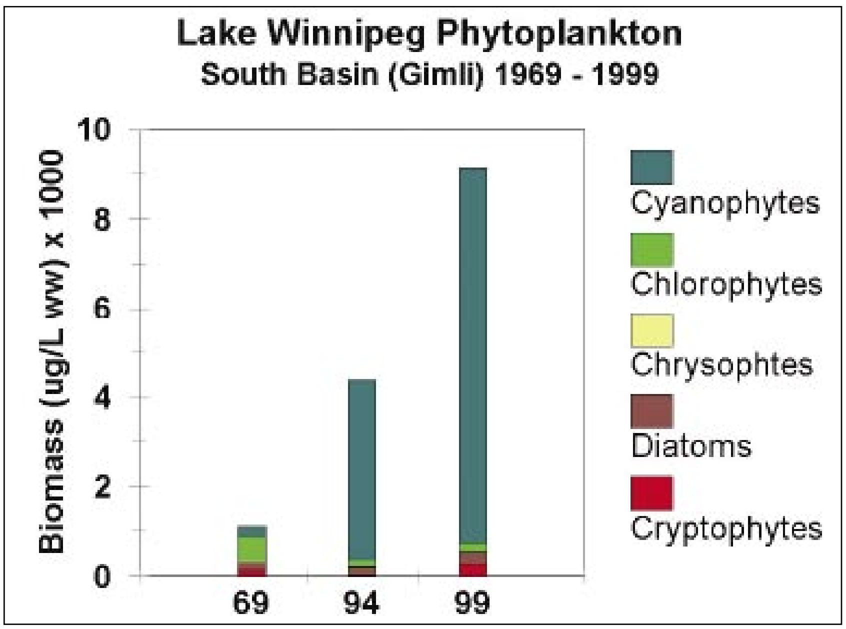


Fig. 18. Change in the average composition and biomass of phytoplankton in the South Basin over time[161]

In eutrophic Lake Winnipeg, the direct uptake of atmospheric nitrogen by the blue-green algal blooms was measured directly. During a single day in the summer of 2003, algal nitrogen fixation accounted for up to 100 tonnes of nitrogen being drawn into the North Basin per 24 hours[162].

Blue-green algal toxins

Species of blue-green algae contributing to the large blooms are known producers of toxins that may have serious implications for ecosystem health and the health of people using the lake and its waters.

The presence of toxins associated with the blue-green algal blooms was mentioned above. The dominant species in these blooms, such as *Microcystis flos-aquae* and *M. aeruginosa* in the South Basin and *Aphanizomenon flos-aquae*, *Anabaena flos-aquae, A. lemmermanii* and *A. mendotae* in the North Basin are often toxin producers [163]. Cyanobacterial toxins are a well-known risk to health of fish and shellfish and the human consumers of fish, shellfish, and drinking water[164,165].

Several types of algal toxins are produced by toxic algae, including microcystins and anatoxins. There are over 50 different microcystins[166]. A microcystin of concern in Manitoba and the only toxin routinely measured is Microcystin-LR, a relatively large heptapeptide molecule that is stable for weeks in the environment. Microcystins can be accumulated by humans consuming infected fish or shellfish or drinking contaminated water. Conventional water treatment processes do not completely remove microcystins from raw water[167]. They have been identified as promoters of hepatocellular carcinoma (liver cancer). High incidence of primary liver cancer in Haimen City and Fusui County in China was attributed in part to the presence of microcystins in pond, ditch and river water used for drinking[168]. The danger of inhaling Microcystin-LR and others that may be present or absorbing them during water sports is recognized[169]. Recreational use of water containing Microcystin-LR can cause as headaches, stomach cramps, vomiting, diarrhea, fever, headache, pains in muscles and joints, weakness, skin, eye and throat irritation and allergic reactions. The persistence of microcystin-LR has been studied in southern Finland as cyanobacterial blooms decreased at the end of the season. Dissolved microcystin was present about twice as long, 30 days, as microcystin associated with suspended particulates[170]. Despite much study of microcystins, their impacts and that of other toxins within the fresh water food chain are not well understood[171].

The other main group of algal toxins are anatoxins. These are neurotoxins responsible for rapid on-set symptoms and on occasion for rapid deaths. These chemicals are more volatile than microcystins and more short-lived in water. Their occurrence is therefore not well known. It is reported that *Aphanizomenon flos-aquae* produces saxitoxins. Saxotoxins are water-soluble neurotoxins that include paralytic shellfish toxins. Studies are underway to determine if these are present in Lake Winnipeg[172].

Recent initial studies on Lake Winnipeg fish, zooplankton and water indicate the presence of low levels of microcystins and anatoxins. Sophisticated methods for identifying and quantifying the chemical families of microcystins and anatoxins indicated that more than one form of microcystin occurred in the fish and the algae, with the most common not being Microcystin-LR[173]. For example, Microcystin-RR and YR were found along with unidentified microcystins[174].

Since 1993, the Province of Manitoba monitors surface waters for the presence of microcsytin-LR. A study in 1995 and 1996 focused on rural water quality. In 1995, the study surveyed 158 raw water sites, including dugouts and recreational sites. It found (detection limit 0.1 micrograms per litre) the Microcystin-LR in 70 per cent of the sites, including treated water samples for domestic consumption, many of which were between 0.5 and <1 micrograms per litre. In 1996, fewer sites were monitored for longer periods. In neither year did any samples exceed the proposed guideline for Microcystin-LR of 1.5 microgram per liter though many were close to one microgram per liter[175]. This proposed guideline is higher than that recommended by WHO for these substances that are accumulated in the body. Recreational water quality of beaches on Lake Winnipeg and other locations is reported regularly by the province, including the presence of algal blooms and associated Microcystin-LR[176].

Algal toxins are of significant concern around Lake Winnipeg as well as downstream in the major Nelson River to communities using the river and the lake as a source of drinking and domestic water. The outflow from the North Basin subject to the largest blooms of blue-green algae is at risk of containing algal toxins. Reservoirs down stream on the Nelson are expected to contain toxic algae and toxins due to the presence of blooms. A very large bloom of *Microcystis* occurred at Cross Lake on the Nelson in the late 1980s following the establishment of the reservoir at that community. Monitoring for these toxins is not yet taking place at these communities.

Other Effects of Eutrophication

In mid-2003, the North Basin showed thermal stratification resulting in bottom waters that were not mixing with the upper layers. The bottom waters were six to seven °C cooler than upper waters, were depleted in oxygen, and had higher than normal concentrations of carbon dioxide and ammonia. In the fall, as upper waters cooled, the whole column mixed re-oxygenating the bottom waters[177]. Some members of the bottom-dwelling invertebrates, part of the benthic community, were strongly impacted in areas where oxygen concentration was reduced. These organisms are a major component of the food supply of juvenile and adult fish in the lake. Densities of Tubificidae (worms) and Chironomidae (midges) were least reduced. On the other hand, Lumbriculidae (worms), Sphaeridae (fingernail clams), Planorbidae (snails), Lynceidae (clam shrimps) and Haustoriidae (amphipods) were severely reduced in August 2003. Although some populations recovered by August 2004, some did not[178].

In 2005, populations of the important commercial species, whitefish, had moved from their normal lake bottom habitat to mid-water depths presumably because of low oxygen conditions. As a consequence, they became more difficult to catch by commercial fishers[179].

Trends in Nutrient Loadings over Time to Lake Winnipeg

Comparison of river flows and their nutrient loads over time shows the Red River to be the most important source of nutrients to Lake Winnipeg

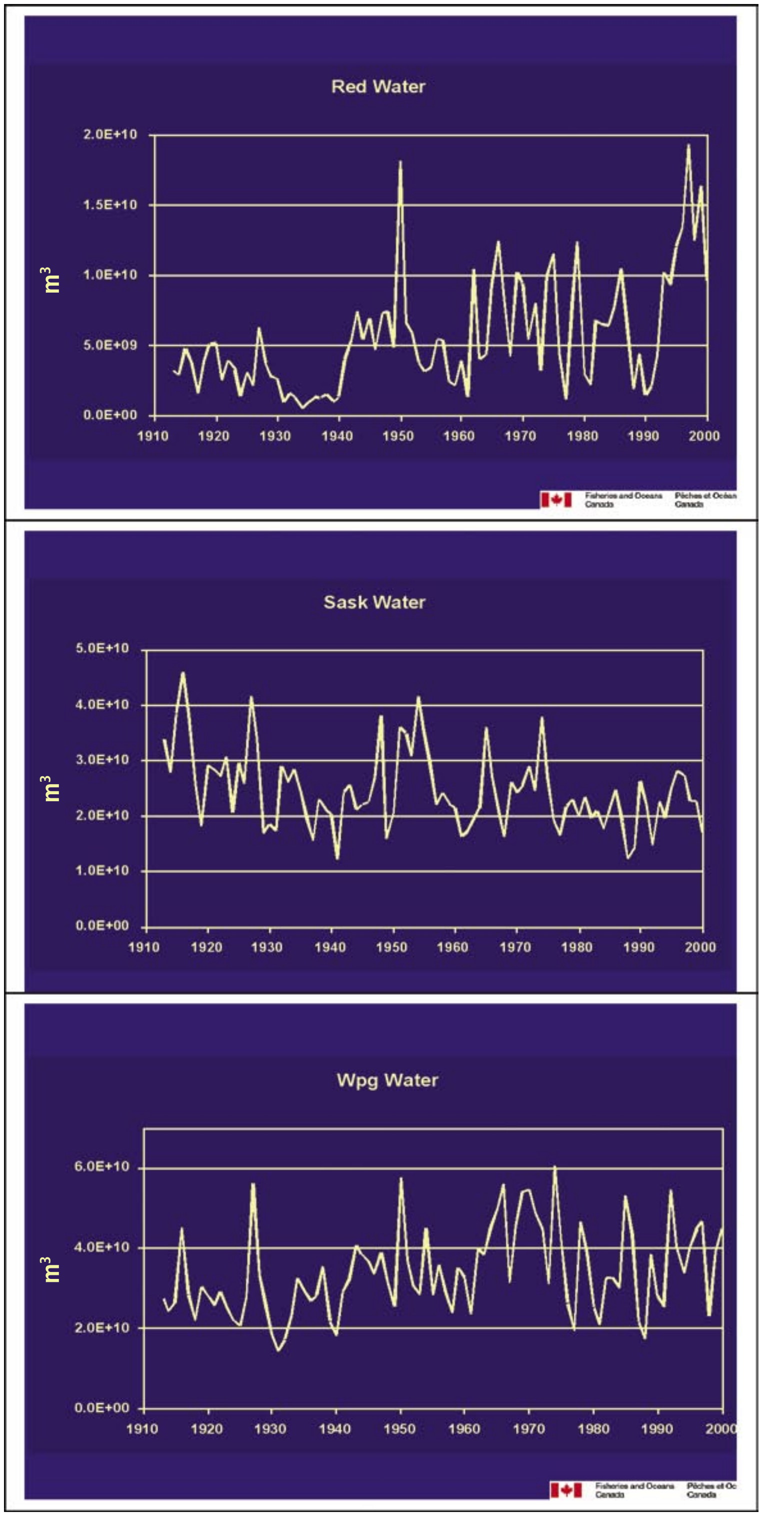


Fig. 19. Water flows for the three major tributaries to Lake Winnipeg, 1913 - 2000[180]

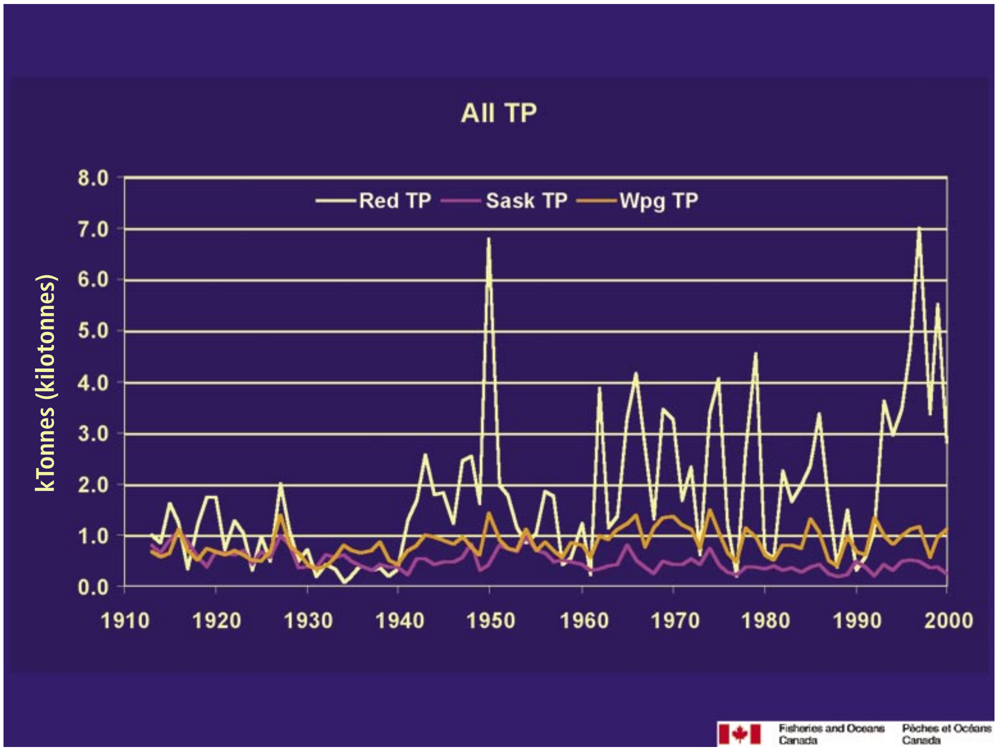


Fig. 20. Loading of total phosphorus to Lake Winnipeg from the three major tributaries, 1913 to 2000[181]

The long-term water flow data show that each of the three major rivers flowing into Lake Winnipeg showed different trends over time (Fig. 19). Flows in the Red River were particularly low in the 1930s, generally higher in the second half of the 20th century, and especially high during the flood years of 1950 and 1997. The Saskatchewan River flows generally declined over the 20th century, whereas flow in the Winnipeg River was variable but without trend towards increase or decrease.

Although nutrient concentrations in the three rivers have been measured from only 1960, the phosphorus loadings were estimated for 1913 to 1969 (Fig. 20). The largest loadings were from the Red River and again increased loading during flood periods is clear. Loading from the Saskatchewan River declined with time, and that from the Winnipeg River rose slightly over the century. At the beginning of the century, the Red River contributed about 30-40 per cent of total P load to Lake Winnipeg, whereas by the end of the century it was contributing as much as 80 per cent.

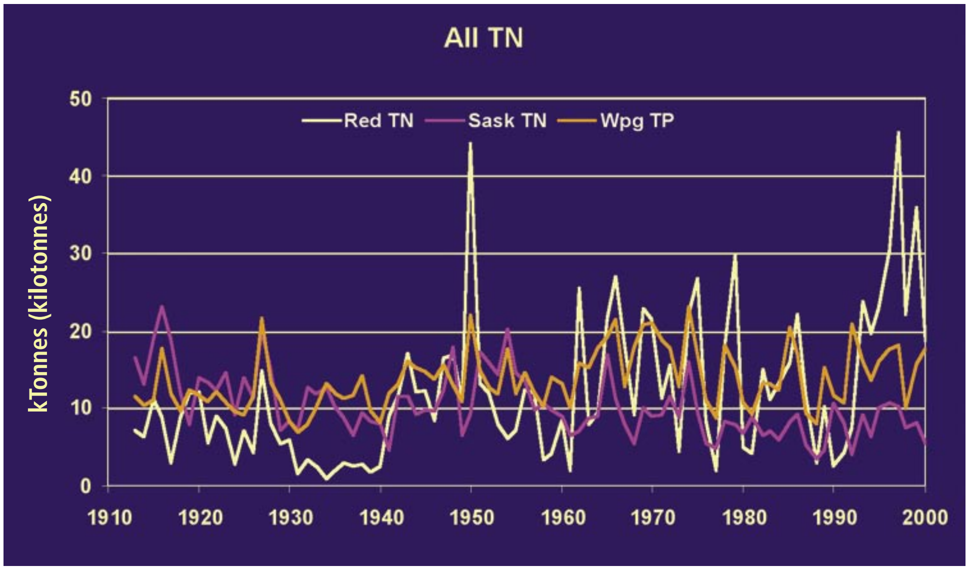


Fig. 21. Loading of total nitrogen to Lake Winnipeg from the three major tributaries, 1913 to 2000[182]

The trends through time for total nitrogen were similar for the three major rivers to those for total phosphorus (Fig. 21). Although the total loads of both nitrogen and phosphorus increased over the last century, total phosphorus increased more quickly resulting in a decline in nitrogen:phosphorus ratio over time.

The nitrogen:phosphorus ratio in Lake Winnipeg over this time period decreased with time (Fig. 22) in a trend that is consistent with the increase in cyanophytes in Fig. 18.

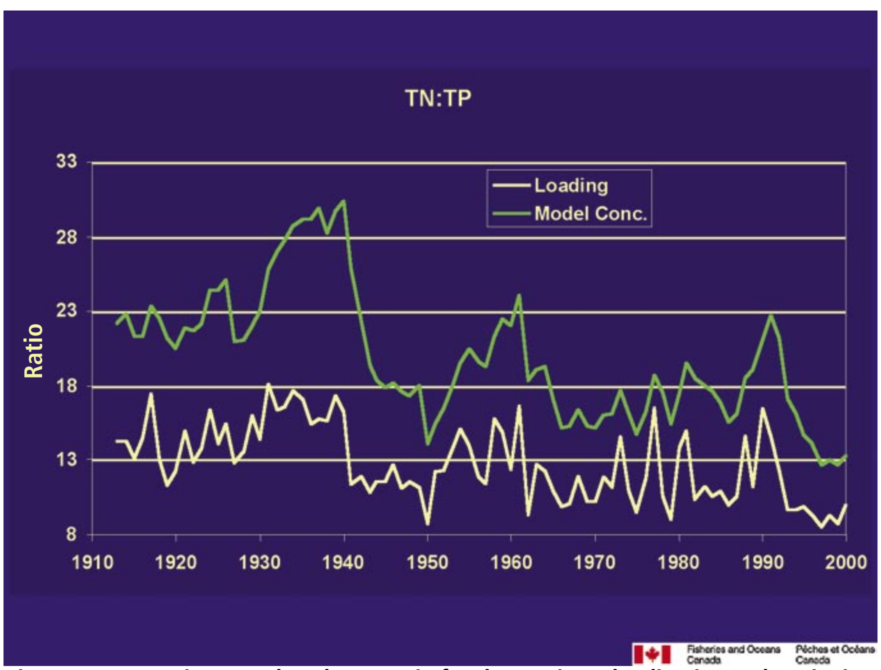


Fig. 22. Average nitrogen:phosphorus ratio for the nutrients loading into Lake Winnipeg from 1913 – 2000 (bottom) compared with modeled nitrogen:phosphorus ratio in the lake (top)[183]

Retention of Nutrients in Lake Winnipeg

Lake Winnipeg is retaining nutrients and chlorophyll as a result of lake level regulation

Following the onset of lake level regulation in 1976, concentrations of total phosphorus (Fig. 23) and total nitrogen (not shown) decreased in the Nelson River over time, whereas they would be expected to increase with increasing nutrient loadings. Knowing the rates of decline in total phosphorus over time allowed the rate of long-term loss of phosphorus to the sediment to be calculated as an average of 15 per cent per year[184]. Figure 24 shows the annual time course of phosphorus retention in the North Basin. Total retention of phosphorus in the North Basin is estimated at 230 tonnes per year[185]

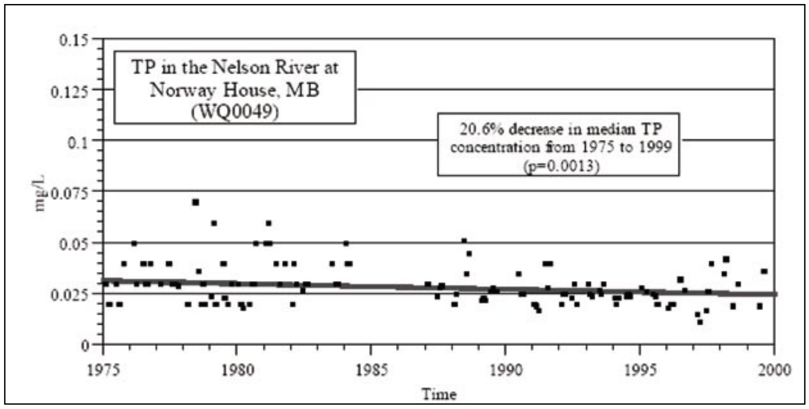


Fig. 23. Trend in total phosphorus in the Nelson River at Norway House, 1978-1999.
Dots are measured concentrations; the solid line is the trend in flow-adjusted concentrations. Per cent change in median concentration refers to the median concentration of the flow-adjusted trend line.
Source[186]

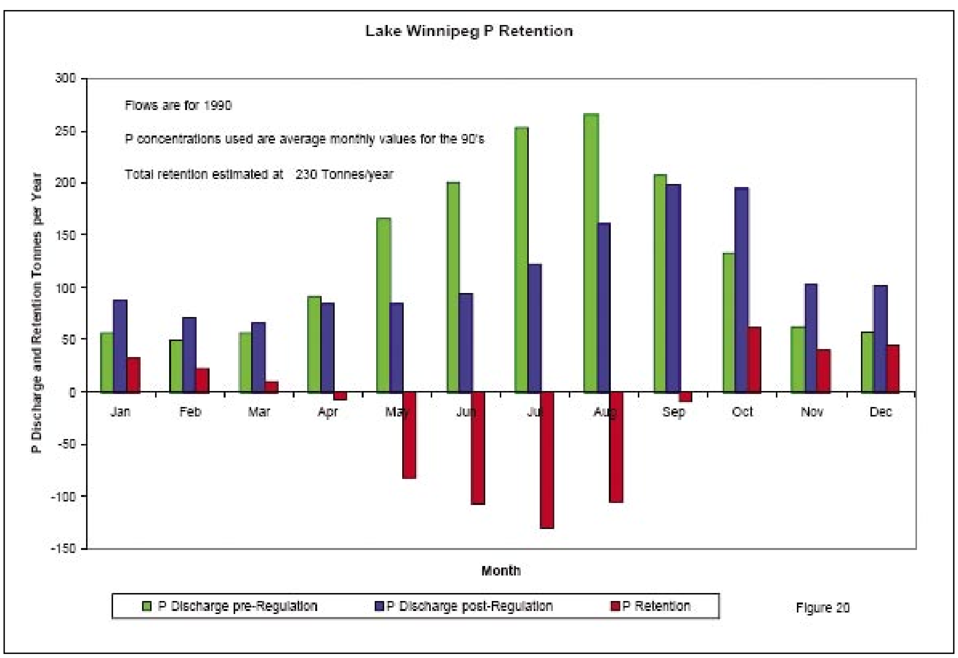


Fig 24. Comparison by month of the loss or retention of phosphorus in the North Basin of Lake Winnipeg before and after regulation of the lake as a hydroelectric reservoir[187].

Examination of the sediment record provides an independent, lake-based account of events in the lake. Fig. 25 shows that in a core from the middle of the North Basin the rate of phosphorus accumulation increased by 300 per cent after the mid 1970s[188]. At about 1975, the deposition rate exceeds the range of values for the previous 50 years. The same core showed corresponding increases in deposition of total nitrogen and chlorophyll (not shown). This is additional evidence of a major change in algal productivity of the North Basin. The figure shows that significant amounts of phosphorus are now at or near the surface of the sediments.

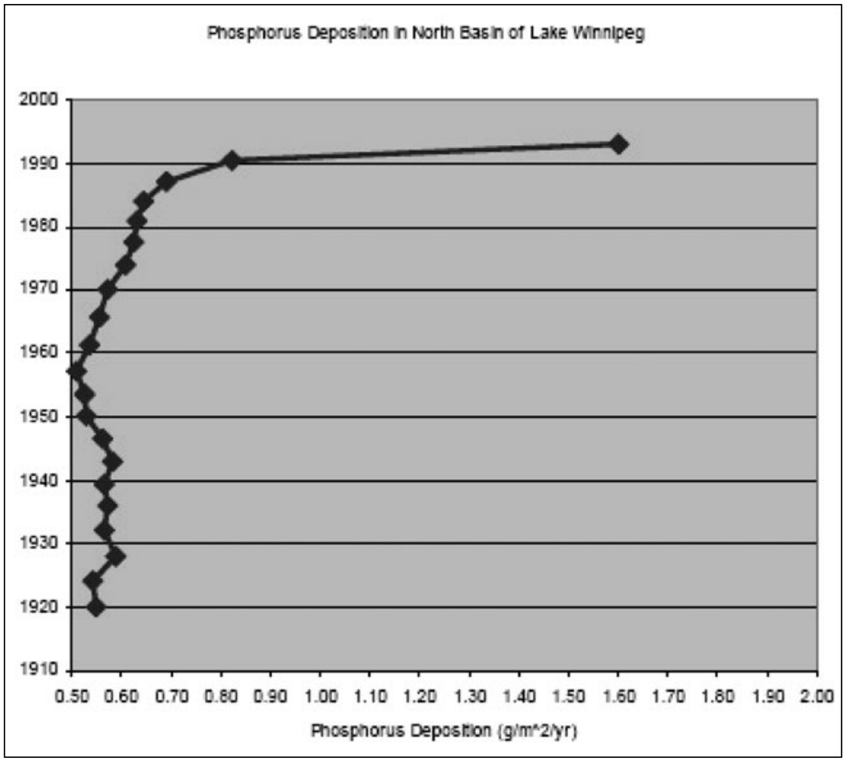


Fig. 25. Phosphorus deposition determined in a core from the middle of the North Basin in 1994[189]

The increases in phosphorus in the lake sediments are consistent with increased phosphorus concentrations in the Red River and the decreased concentrations in the outflowing Nelson River. Reduced summer outflow of the lake decreased the normal loss of summer plankton in the outflow into the Nelson River. This biomass was retained in the lake, eventually contributing phosphorus, nitrogen and chlorophyll to the sediments[190] (Fig. 25). The significance of the large amount of phosphorus in Lake Winnipeg sediments is that as external loading from the tributaries is decreased as controls are implemented on phosphorus loading to the lake, sediment phosphorus is available for resuspension and reintroduction into the water column[191] by a natural process termed internal loading. It is expected that internal loading will slow the rate of recovery of Lake Winnipeg from eutrophication.

Geochemical analysis of sediment cores from the South Basin of Lake Winnipeg including the same period as covered by the North Basin core also showed phosphorus enrichment in the sediment attributable to higher algal productivity. Increases started in the 1960s, a time of increased fertilizer use on the prairies. Uppermost sediments are enriched by a factor of up to two relative to background levels[192].

Non-point Sources of Nitrogen and Phosphorus

The largest source of nitrogen and phosphorus to Lake Winnipeg is from the Red River watershed with the largest contributions originating in the United States

In considering the most easily-implemented and cost-effective ways to reduce phosphorus loading to Lake Winnipeg, attention has been paid to identifying the geographical sources and significant point and non-point sources of phosphorus.

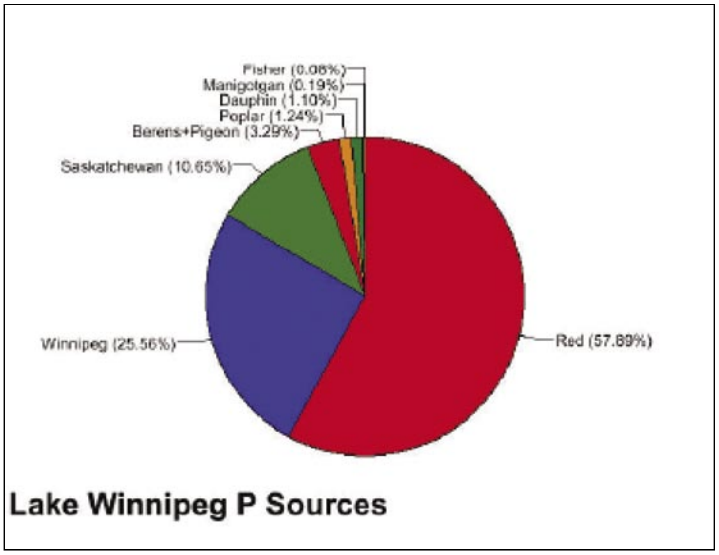


Fig. 26. Proportions of loading of phosphorus to Lake Winnipeg contributed by the Red River and other rivers[193]

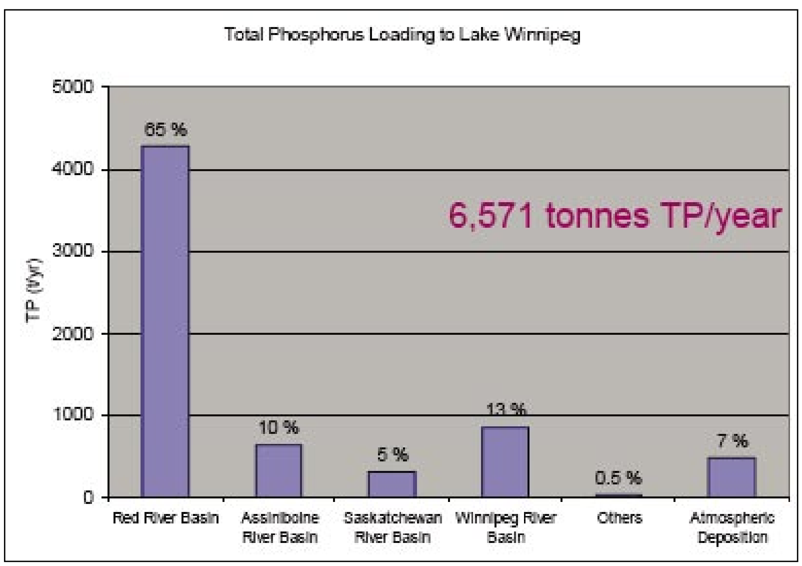


Fig 27. Loadings of phosphorus to Lake Winnipeg from rivers and the atmosphere[194]

Figures 26 and 27 indicate that of the three tributaries, the Red River is by far the largest contributor of phosphorus to Lake Winnipeg. Although the land area of the Red River watershed in the U.S. is 4 times greater than in Manitoba, the contribution of phosphorus from the U.S. is only 1.5 times greater for a significantly lower yield per unit area (Table 4). On the other hand, the U.S. yield per unit area of nitrogen is higher than in Canada. Thus, the nitrogen:phosphorus ratio of loadings in Manitoba is 12.9 vs 16.6 for those from the U.S. In comparison, the nitrogen:phosphorus ratio of loadings from the Saskatchewan River is 56.3, from the Winnipeg River is 47.3, and from atmospheric deposition is 44.3. Since 59 per cent of the phosphorus load in the Red

River originates outside the province[196] (Fig. 27), efforts to control phosphorus will involve international, inter- and intra-provincial actions.

Red River Basin Part	Area	P Load	N Load	P Yield per Unit Area	N Yield per Unit Area	N/P Ratio
	km^2	tonnes	tonnes	kg/km^2	kg/km^2	mole/mole
Total	127,000	4268	29083	33.6	6814	15.1
US (80%)	101,600	2537	18983	25	7482	16.6
Man. (20%)	25400	1731	10100	68.1	5834	12.9
Assiniboine		637	3682			12.8
Total at Selkirk		4905	32765			14.8
Total to Lake Winnipeg		5838	63207			24

Table 4. Nitrogen and phosphorus contributions from locations of the Red River Basin[195]

Within Manitoba, considerable amount of phosphorus load is contributed along the highly urbanized stretch between St. Norbert to the south of Winnipeg and Selkirk to the north. The phosphorus in the Red River is attributed to agriculture, 17 per cent, natural sources, 13 per cent, and direct wastewater effluent discharges, 11 per cent, within Manitoba (Fig. 28). Partitioning the loading by type of land use indicates the cropland is the major source of phosphorus in two Manitoba watersheds (Table 5). The yield from various land uses is calculated using nutrient export coefficients from the literature.

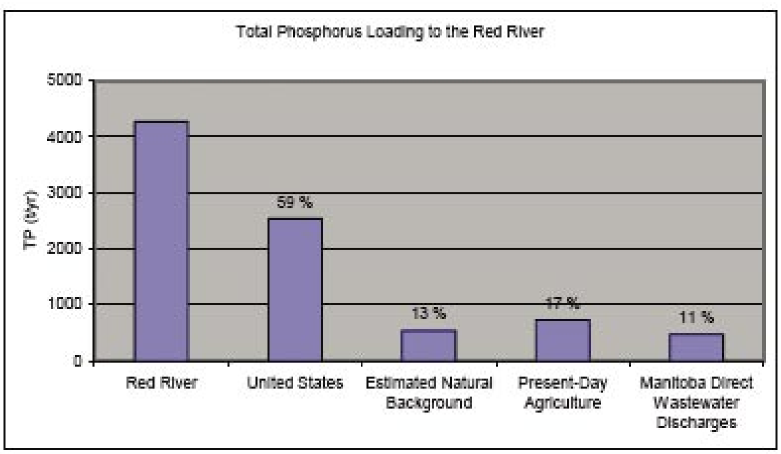


Fig. 28. Sources of phosphorus loading to Lake Winnipeg[197]

	Pasture	Cropland	Forest	Other	Total
Assiniboine River					
TP (tonnes/yr)	123	808	59	49	1039
%TP	11	73	5	4	
Red River					
TP (tonnes/yr)	81	1037	43	48	1209
%TP	5	62	3	3	

Table 5. Calculated yields of total phosphorus (TP) in the Assiniboine and Red River Watersheds associated with land uses[198]

The task of accurately attributing the total phosphorus load to a water body such as Lake Winnipeg to particular locations or to various types of land use in the watershed is a highly complex one. Some problems are lack of necessary data[199].

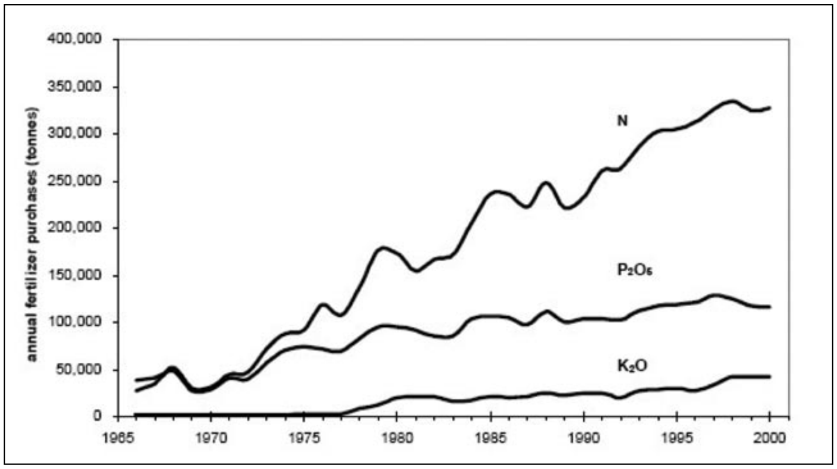
- While water flow in many streams and rivers is monitored continuously, concentrations of nutrients, sediments, or contaminants are generally monitored on a pre-set schedule, once a week, or once a month. This fails to measure concentrations at peak weather events so major nutrient loading events are not well measured.
- Snowmelt runoff is a dominant process in Manitoba, but our understanding of phosphorus transport from land to water during snowmelt is limited.
- Processes that temporarily retain phosphorus in rivers, streams and lakes such as sedimentation and biological immobilization are not well understood.

The main sources of phosphorus contamination in surface water include point sources from urban and industrial activities and non-point sources from agricultural activity and natural processes such as erosion, atmospheric deposition, and wildlife[200]. Atmospheric deposition is a significant source of phosphorus for lakes[201], contributed as dry deposition where phosphorus is bound to dust and particulate material, wet deposition along with rain or snow, and as phosphine gas. Phosphine gas is generated by wetlands. Terrestrial sources include urban point and non-point sources. Urban point sources include end-of-pipe municipal and industrial waste water sources. Non-point sources include run-off from lawns, parking lots, construction sites, septic systems, and developed areas that lack sewers[202]. Municipal waste water sources themselves include many industrial waste water. Furthermore, municipal waste water primary and secondary processes generate biosolids, that are often returned to cropland as an amendment. Also of concern in guiding application rates in addition to nitrogen or phosphorus are heavy metals, some of which are essential metals while others are toxic. Natural land sources of phosphorus include forest areas and riparian zones. Phosphorus export is generally low from forested lands compared with developed lands. Agricultural lands are also sources[203].

Understanding the factors controlling the amounts of phosphorus, chemical forms, and routes of transport from non-point sources to Lake Winnipeg is highly complex but necessary in order to plan effective alleviation of eutrophication

The risk of phosphorus loss from soil to water is determined by a complex of factors, including [204]:

- balance between input into and outputs from the agricultural systems
- soil phosphorus retention properties, related to iron and aluminum oxides and calcium carbonate
- forms, quantity, and availability of phosphorus in the soil
- runoff characteristics of the catchment area
- management practices, such as incorporating manure rather surface applying, conservation tillage, riparian or buffer strips.



Fig, 29. Annual fertilizer nutrient sales in Manitoba from 1965 to 2000[205]

Although the rate of increase in use of phosphorus fertilizer is less than that of nitrogen, it has more than doubled between 1965 and 2000 (Fig. 29). Additions of phosphorus to land have exceeded removal of phosphorus in harvested crops since the early 1990s. Yet, in one study 73 per cent of Manitoba's soils tested medium or lower in plant-available phosphorus in 2001[206]. In another analysis in 2000, fertilizer phosphorus applications met or exceeded crop removal in eight of twelve Manitoba regions. Five regions around Winnipeg draining into Lake Winnipeg via the Red River have substantial annual phosphorus excesses. These are regions with large livestock populations and/or potato production[207].

Animal manure is a significant source of phosphorus because most of the phosphorus consumed by livestock is excreted in the manure[208]. In one study, the average nitrogen:phosphorus ratio of 9.1 is considerably lower than agronomic requirements and manure application based on crop nitrogen requirements results in excess phosphorus application[209]. In fact, over the pump-out of hog manure stored in earthen ponds and subject to agitation during pump-out, total nitrogen varied 3.5 fold, but total phosphorus varied 20-fold. Nitrogen: phosphorus ratio varied widely during pump-out from 73 to 3.3 (Fig. 30) [210]. Thus, conventional manure application results in a large range of phosphorus being applied for constant nitrogen loading on the field. The high variability of phosphorus in hog manure is related to variability in the particulate content. Hog manure is difficult to agitate in earthen ponds because the heavy particulates settle to the bottom of the pond. The first manure drawn off is low in particulates and high in dissolved inorganic phosphorus, whereas at the end of the pump-out the manure is a slurry with a high particulate organic phosphorus content.

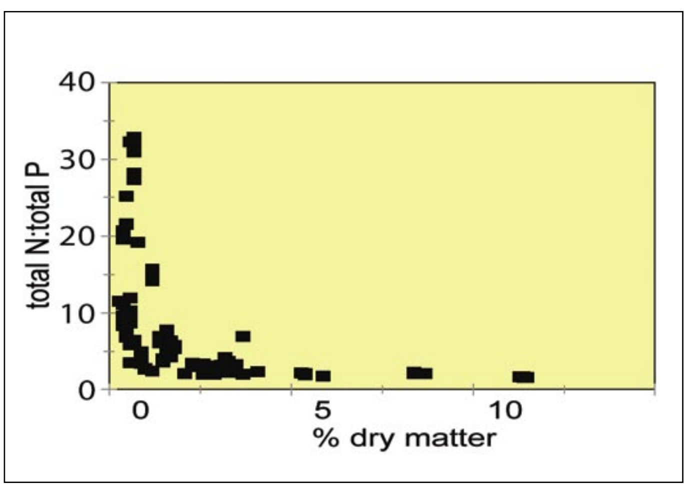


Fig. 30. Nitrogen:phosphorus (N:P) vs per cent dry matter in hog manure samples collected during land application [211] N:P varied from 33 to 1.5, expressed on a weight basis. This is equivalent to 73 to 3.3 expressed as atoms of N:atoms of P.

A variety of options are being suggested to avoid the over-application of phosphorus to soil[212]:

- matching soil available phosphorus plus phosphorus additions to crop needs; requires well-mixed manure of known phosphorus content, or on-the-go manure analysis and mapping of phosphorus loading; additional nitrogen can be applied as needed in a second pass
- growing high phosphorus demand crops such as canola in soil with excess phosphorus to mine the soil
- planting of effective buffer strips around manured fields to reduce soil and phosphorus transport to surface waters
- use of constructed wetlands for the treatment of feedlot runoff and dairy wastewater
- avoiding overgrazing of pastures
- treating manure to recover or immobilize phosphorus.

Other alternatives being explored are management of feed and feeding for phosphorus control. Grain is the primary ingredient in livestock feed. The phosphorus in grains is stored as phytate. Phytate is poorly digested by livestock with two results. Many feed formulations have a safety margin, that is, the animals are fed excess grain to make sure they digest a sufficient amount. Secondly, the animals receive inorganic phosphate as an additive to ensure their physiological requirements for phosphorus are met. Thus, the poorly digested phytate ends up in manure as particulate organic phosphorus, and the inorganic phosphate contributes to the dissolved inorganic phosphorus in the manure. Strategies to counteract the high loss of phosphorus by livestock include[213],[214]:

- improvements in feed efficiency to increase weight gain per unit of feed through genetic selection of animals, proper feed formulation and mixing of ingredients, feed processing methods, correct use of vitamins, and use of wet feeders
- addition of the enzyme, phytase, to feed formulations to allow the animals to digest more of the phytate
- highly-available phosphorus corn, soybean, and barley varieties are promising in improving dietary phosphorus availability
- better matching of feeding to the nutritional needs of growing livestock
- reduction of feed waste by feeder design and maintenance.

Point Sources of Nutrients to Lake Winnipeg

Some of the largest point sources of phosphorus in the Red River basin are municipal wastewater treatment facilities. For example, based on the values in Table 4, the contribution to phosphorus loading by the effluents from the City of Winnipeg's Pollution Control Centres is 390 tonnes per year total phosphorus [215] (Fig. 31). On the average this is seven per cent of the total Red River loading or 23 per cent of the Manitoba portion of the Red River phosphorus loading. Depending on the variability in the flows of the three rivers into Lake Winnipeg, the City of Winnipeg effluent may vary from five to 35 per cent of the total Red River phosphorus loading. Total nitrogen contributed by the City of Winnipeg is 3591 tonnes per year[216], resulting in an average nitrogen:phosphorus ratio for the City's input of 20.3.

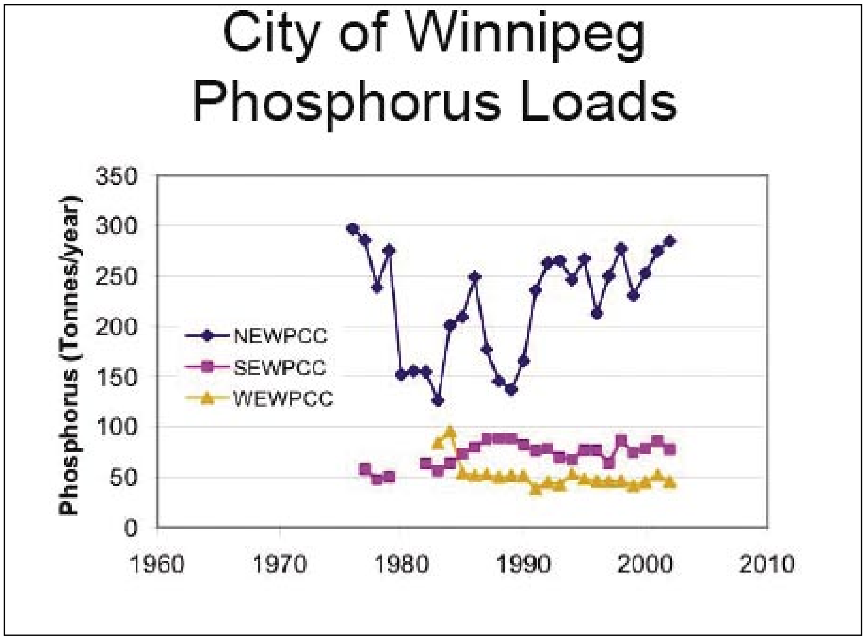


Fig. 31. Annual loading of total phosphorus to the Red River in the effluents from the three City of Winnipeg Wastewater Treatment Plants[217]. NEWPCC, North End Water Pollution Control Centre; SEWPCC, South End; WEWPCC, West End

The City of Winnipeg's contribution of total phosphorus to Lake Winnipeg is significant. Moreover, compared with phosphorus in runoff from natural landscapes where 25 to 40 per cent of the phosphorus is relatively unavailable mineral phosphorus, in treated sewage, 65 to 100 per cent of the total phosphorus has been found to be bioavailable[218,219]. As well, the City of Winnipeg adds more than 200 tonnes per year bioavailable phosphate as phosphoric acid to drinking water to control lead levels. It is estimated that 50 to 60 tonnes per year of this reaches Lake Winnipeg[220].

In addition to this, 13,000 dry tonnes per year biosolids from the processing of sludge at the North End Water Pollution Control Centre are applied to land around the City. These are applied in the City's WINGRO program on fallow land in which any parcel of land only ever receives one application of biosolids at a maximum of 56 dry tonnes per hectare. Unlike the phosphorus in wastewater effluent, phosphorus in biosolids is not predominantly bioavailable. Water extracted about ten per cent of the total phosphorus in biosolids compared with 30 to 40 per cent of the total phosphorus in hog and cattle manure[221]. Biosolids are incorporated into soil, avoiding land subject to flooding, slopes, and setbacks from waterways. Biosolids from the little-industrialized City of Winnipeg are relatively low in heavy metals. Except for copper that is slightly high, levels of cadmium, chromium, lead, nickel and zinc are well under the USEPA high quality pollutant limits[222]. Thus, the practice of recycling useful nitrogen, phosphorus and organic matter back to the land for agronomic use is favourable, providing the application rate of the available nitrogen and phosphorus are well within crop nutrient requirements. There are currently no field estimates of phosphorus runoff following the City of Winnipeg land application of biosolids[223].

The Clean Environmental Commission in 2003 recommended that the City of Winnipeg develop a plan to remove nitrogen and phosphorus from its municipal wastewaters with priority placed on phosphorus [224]. The City's move to tertiary treatment of sewage effluents to remove phosphorus is important in reducing loading of bioavailable phosphorus to Lake Winnipeg. Moreover, getting Manitoba's house in order will make it easier to negotiate with upstream U.S. municipalities in the Red River to undertake tertiary treatment and other controls on phosphorus loading in the River. Currently, the U.S. cities along the Red River, Grand Forks and Fargo[225]/Moorhead do not employ tertiary treatment of wastewater.

Nevertheless, if nitrogen is to be removed from the wastewater effluent to reduce the risk of ammonia toxicity in the receiving waters, it would reduce its nitrogen:phosphorus ratio, presently averaging 20.3." On the other hand, the risk from ammonia can be reduced by converting the ammonia to nitrate by nitrification. Removing nitrogen with or without reducing phosphorus will have little impact on the blue-green bloom in Lake Winnipeg. The algal community is capable of obtaining the nitrogen it needs from the atmosphere. It is estimated that an amount equivalent to the entire annual total nitrogen load to Lake Winnipeg from the City of Winnipeg can be captured by the algae from the atmosphere in 37 days[226].

> **This is clear and specific evidence of the futility of controlling N inputs as a means on limiting algal growth in the lake.**
> **- M. Stainton, A. Salki, L. Hendzel, and H. Kling.**
> **Freshwater Institute, Department of Fisheries and Oceans**

Limitation of the natural supply of phosphorus to water bodies explains its role in controlling eutrophication. Phosphorus is limited in another way. Rock phosphorite (P2O5) is a non-renewable fertilizer ore that is diminishing in global supply, particularly in North America, and for which there is no substitute[227]. Adequate supply of imported phosphorus is an absolute requirement for food security in Canada, since Canada contains virtually no phosphorite rock reserves. It is estimated that global, land-based reserves could be largely depleted within a century. Large reserves on continental shelves in tropical areas are generally outside the extended legal continental shelf of countries[228] and will be difficult to mine. Therefore, careful agricultural management of phosphorus to reduce the risk of eutrophication, will have the added benefit of efficient use of this limited resource and reduction in its loss to lake sediments and to the sea. At present, phosphorus is accumulating in the sediments of Lake Winnipeg at an estimated rate of 230 tonnes per year.

> **Careful stewardship of phosphorus on land could help avoid eutrophication and reduce the rate of loss of finite phosphorus fertilizer resources to lake and marine sediments.**

PERSISTENT ORGANIC POLLUTANTS

Persistent organic pollutants (POPs) from agricultural and industrial activities in the sub-basin eventually reach Lake Winnipeg

Little attention was given to determining levels of persistent organic contaminants in Lake Winnipeg until 1995. Sources of persistent organic pollutants (POPs) include agricultural and industrial activities in the sub-basin, such as hydroelectric developments on the Winnipeg and Saskatchewan Rivers, urban centers, and atmospheric transport[229]. Inventories of PCBs in South Basin sediments in 1995 exceeded those in remote lakes but were similar to those in other large lakes and reservoirs subject to industrial, agricultural, and urban activities. Inputs to the North Basin were more consistent with atmospheric than riverine sources. The organochlorine insecticides, DDT and hexachlorocyclohexane (HCH), represented the next largest inventories after PCB. The maximum concentrations for some POPS in cores were at strata dated at the late 1960s to early 1970s while others were at the surface of the cores[230].

Floods greatly accelerate the loading of POPs and nutrients to Lake Winnipeg

Severe weather events can cause departures from the normal trends in contaminant inputs into aquatic ecosystems. The 1997 Red River flood of the century was such an event. Floods have the potential to mobilize considerable amounts of contaminants such as POPs as well as nutrients. From 28 April to 18 June, 1997, approximately 2.5×10^8 kilograms of suspended solids carrying 2.4 kilograms PCBs, 1.7 kilogram DDT, and 0.21 kilogram HCH, and other contaminants were transported in the Red River into Lake Winnipeg[231]. Quantities of POPs were also transported dissolved in the floodwaters. These quantities did not significantly change the concentrations of the POPs in the sediment of the South Basin or in emerging mayflies. Concentrations of DDT and PCBs were modestly higher post-flood than pre-flood in top predators including walleye and burbot as well as in zooplankton and yellow perch. Nevertheless, this magnitude of change is believed also to occur due to natural variability in food webs[232].

Some chemicals in runoff and wastewater discharges exhibit endocrine-disrupting properties

There is increasing awareness that a number of chemicals in the environment such as dioxin, PCBs, DDT and other pesticides, plasticizers, and sex hormones such as phytoestrogens act as endocrine disruptors. They mimic or block hormones and disrupt normal physiological functioning even when they are present in the environment at extremely low levels. Fish in the Great Lakes contaminated by PCBs have reproductive problems and abnormal swelling of the thyroid glands. Sources of endocrine disruptors to the environment are industrial, agricultural and municipal wastes including incineration, landfills, agricultural runoff, atmospheric transport, harbours, industrial and municipal effluences, and pulp mill effluents[233]. While there are some studies that sufficiently connect contaminants and endocrine disruption in fish and invertebrate populations, in general, gathering this evidence is complex and relies on a strong field program[234]. Thus, while concentrations of POPs in Lake Winnipeg biota are relatively low, subtle impacts on the biota cannot be ruled out.

PHARMACEUTICALS AND PERSONAL CARE PRODUCTS

Pharmaceuticals and personal care products (PPCPs) are increasingly entering aquatic environments with largely unknown effects

Another group of chemicals of increasing concern are pharmaceuticals and personal care products, collectively known as PPCPs. Municipal sewage, direct dumping of excess or outdated medications, agricultural and aquaculture wastes are sources of PPCPs. These chemicals include antibiotics, blood lipid regulators, analgesics, anti-inflammatories, antiepileptics, natural and synthetic hormones, fragrances (musks), nonylphenol ethoxylates, disinfectants, and antiparasiticides[235]. Although most of these products are in municipal wastes and processed by wastewater treatment, 50 per cent of the tonnage of antibiotics used is Canada is administered to livestock[236] and much of these ends up in manure. Many cattle also routinely receive growth-promoting hormones[237].

Some of PPCPs have endocrine-disrupting impacts[238]. Evidence suggests that some of these may impact non-target species in the environment and possibly humans. Two particular concerns are disruption of development and reproduction, and enhancement of antibiotic resistant bacteria. Unlike persistent organic pollutants, POPs, PPCPs do not bioaccumulate in the environment. Nevertheless, they are constantly entering the environment, resulting in long-term exposure[239].

The Manitoba Clean Environment Commission recommended that the City of Winnipeg measure heavy metals, organochlorines, endocrine-disrupting substances and pharmaceuticals in its influent and effluent streams[240]. Impacts, if any, of these chemicals in Lake Winnipeg fish and other organisms are poorly known, as is the environmental fate of antibiotics and growth-promoting substances used in agriculture[241].

EXOTIC SPECIES - BIOLOGICAL CONTAMINATION

Non-indigenous/exotic species are a highly damaging form of "biological" contamination

Although humans have been introducing species of plants and animals to new environments for thousands of years, the rate of species introductions has increased dramatically with globalization. The worldwide spread of non-indigenous species (NIS), also termed exotics, is now considered one of the most serious conservation issues facing society. There are approximately 50,000 non-indigenous species (aquatic and terrestrial) in the United States. These are responsible for economic and environmental damages totalling an estimated $137 billion per year. Of these NIS, 138 are fish associated with losses and damages costing one billion[242]. Less precise data exist in Canada, nevertheless, it is estimated that cumulative costs of NIS in Canada are $5.5 billion for just nine species and over $22 million in on-going annual costs[243]. The Great Lakes are inhabited by 145 NIS and this number is increasing due to the release of ballast waters from Eurasia containing many exotics[244]. Although it is exceedingly rare that an introduced species will become established and invasive, the number of introductions is so large that numerous aquatic ecosystems worldwide are impacted by NIS.

After being introduced to aquatic systems, NIS that become established can cause extensive ecological and economic damage through a variety of mechanisms, including habitat change, competition, predation, herbivory, disease, and hybridization[245]. The direct impacts of habitat alteration, competition, predation, and herbivory on native species by NIS may be further compounded through hybridization between NIS and similar native species such that the NIS can overwhelm and assimilate the native genotype and possibly result in the genetic extinction of native flora and fauna.

The interaction between introductions of NIS, extirpation of native species, and habitat alteration is believed to result in the biotic homogenization of aquatic ecosystems[246]. In general, the biotic homogenization of an ecosystem results in reduced spatial diversity as endemic species are typically replaced with widespread exotic species[247]. Fish populations in the United States have become more similar to one another due to introductions such that, on average, pairs of states have 15.4 more species in common now compared to pre-European settlement times[248]. Through one or more and combinations of the above mechanisms, biological introductions are responsible for more extinctions than any other factor, excluding human land use changes[249]. While habitat destruction is endangering species at a greater rate than NIS, it is much easier to restore degraded habitats than it is to control biological pollutants such as NIS that can reproduce, grow, and disperse once introduced successfully[250].

At least eight species of fish and one crustacean zooplankton species have been introduced to Lake Winnipeg.

Recent additions to Lake Winnipeg's fish fauna include introduced exotic species and new range expansions for species formerly absent from the immediate drainage of Lake Winnipeg but present in the headwaters of the Red River drainage in the U.S. Exotic fish enter Manitoba largely through human introduction, such as authorized and unauthorized stocking of game species, accidental and intentional introduction of live bait or other non-game species, illegal release of tropical and temperate aquarium specimens and accidental escape from culture ponds. Exotic species also enter by natural dispersal within the drainage from headwaters within a drainage system[251].

At least eight introduced freshwater fish species occur in Lake Winnipeg[252], including common carp, *Cyprinus carpio*[253]; white bass, *Morone chrysops*); and rainbow smelt (*Osmerus mordax*). If inter-basin transfers occur in the future, introduction of the gizzard shad, *Dorosoma cepedianum*, and pike perch *Sander leuceoperca* would be of most concern.[254]. In addition to the common carp and rainbow smelt, other warm water fish species that have entered or been introduced to the Red River and Lake Winnipeg tributaries include the bigmouth buffalo. The stonecat used Lake Winnipeg to disperse to the Brokenhead River but has not been collected in the lake itself[255]. The exotic crustacean zooplanktor, *Eubosmina coregoni*, is well established in the lake, and another crustacean, *Bythotrephes cederstroemi,* was detected in Saganaga Lake in the Winnipeg River watershed.

The rainbow smelt, (*Osmerus mordax*) was introduced to several lakes in the upper portion of the Winnipeg River system in northwestern Ontario. It is not certain how they were introduced, but since 1991, Lake Winnipeg has contained an established population of rainbow smelt[256,257]. This introduction has resulted in declines in populations of several native fish species such as emerald shiners, *Notropis antherinoides*, and spottail shiners, *N. hudsonius*. It is reported that walleye, *Stizostedion vitreum* (Mitchell), that feed on smelt develop a greasy, bland quality to their flesh, and lake trout that feed on smelt acquire a strong cucumber-like odor that is not removed by cooking, diminishing the quality of the fish for human consumption. In addition, rainbow smelt feed on the young of larger fish like walleye, northern pike, *Esox lucius*, whitefish, and ciscoes. Moreover, fish such as such as lake trout, northern pike, whitefish, yellow perch, and walleye that consume rainbow smelt may contain higher concentrations of contaminants such as mercury through biomagnification[258]. It is too early to tell the magnitude of the impact of this introduction on the $20 million commercial fishery of Lake Winnipeg.

Compared with the Eastern Great Lakes, Lake Winnipeg is at an early stage with respect to the presence of NIS. In addition to problems of eutrophication and chemical contamination, the Great Lakes have been heavily impacted by the presence of exotic species[259]. An estimated 162 exotic aquatic species have been introduced into the Great Lakes[260], beginning in the late 1800s[261].

The main developments that account for this large number include the construction of the Welland Canal that opened the way for large ships, the opening of the St. Lawrence seaway, emptying of ship ballast water, ship fouling, aquarium release, and intentional release. Much less is known about bacterial, viral, protozoan and algal exotics[262], except where certain diseases have been identified. Some of the effects of the exotics have been reduction in phytoplankton biomass and productivity, changes in species and size composition of communities, increased water clarity, disappearance of the previously-dominant benthic amphipod, *Diporeiea*, and the decline and extirpation of commercially important fish species[263].

ENDANGERED OR THREATENED SPECIES

Lake Winnipeg has one species of snail and five species of fish designated as endangered, threatened or of special concern

The snail, *Physa winnipegensis*, found only in Lake Winnipeg is designated as endangered by COSEWIC[264] and is under consideration for addition to the *Species at Risk Act* (SARA)265. It is disappearing from two areas in the lake due to it sensitivity to pollution. It is mainly threatened by cottage and recreational development around the lakeshore, which results in habitat degradation. The snail is also thought to be sensitive to pollution from agricultural, municipal, logging and pulp-mill activities close to the rivers that drain into Lake Winnipeg. Increased shoreline erosion due to water-level regulation is also a concern.

A remnant population of shortjaw cisco, *Coregonus zenithicus,* is threatened as is the carmine shiner, *Notropis percobromus.* Species of special concern are bigmouth buffalo, *Ictiobus cyprinellus*, chestnut lamprey, *Icthyomyzon castaneus*, and silver chub, *Macrhybopsis storeriana*. The lake sturgeon, *Acipenser fulvescens*, is also under stress[266].

IMPACTS ON LAKE WINNIPEG WETLANDS

Wetlands are being altered by lake level regulation

Artificial stabilization of water levels on Lake Manitoba and Lake Winnipeg is causing the physical structure of these marshes to be altered, leading to the loss of wetland habitat. This alteration can be seen in the number of water bodies comprising Netley-Libau Marsh. In 1960, before stabilization of water levels on Lake Winnipeg, there were 50 individual waterbodies within the marsh, whereas in 1980 after stabilization, the number had decreased to 17 [267]. The capability of the marsh to support wildlife has been reduced since stabilized water levels are recognized as the principle factor affecting the marsh and its flora and fauna. Other impacts on the marsh include exotic species, large infestations of purple loosestrife and flowering rush. The common carp can be found throughout the marsh impacting water quality and increasing turbidity[268].

DEVILS LAKE, NORTH DAKOTA

Water from Devils Lake, North Dakota, a perched sub-basin of the Red River poses a poorly-known risk to Lake Winnipeg

Devils Lake Basin in North Dakota (Fig. 32), 6,131.6 kilometres (3,810 square miles) in area is a perched sub-basin of the Red River of the North Basin. This means the basin has no outlet. Subject to dramatic cyclical water level changes over time driven by climate, the level of the lake has risen 7.62 meters (25 feet) since 1993. This has damaged transportation, residential and commercial infrastructure built on land that is intermittently a lakebed. Damage is estimated at about U.S. $450 million and an additional U.S. $350 million has been spent on flood control infrastructure to protect local

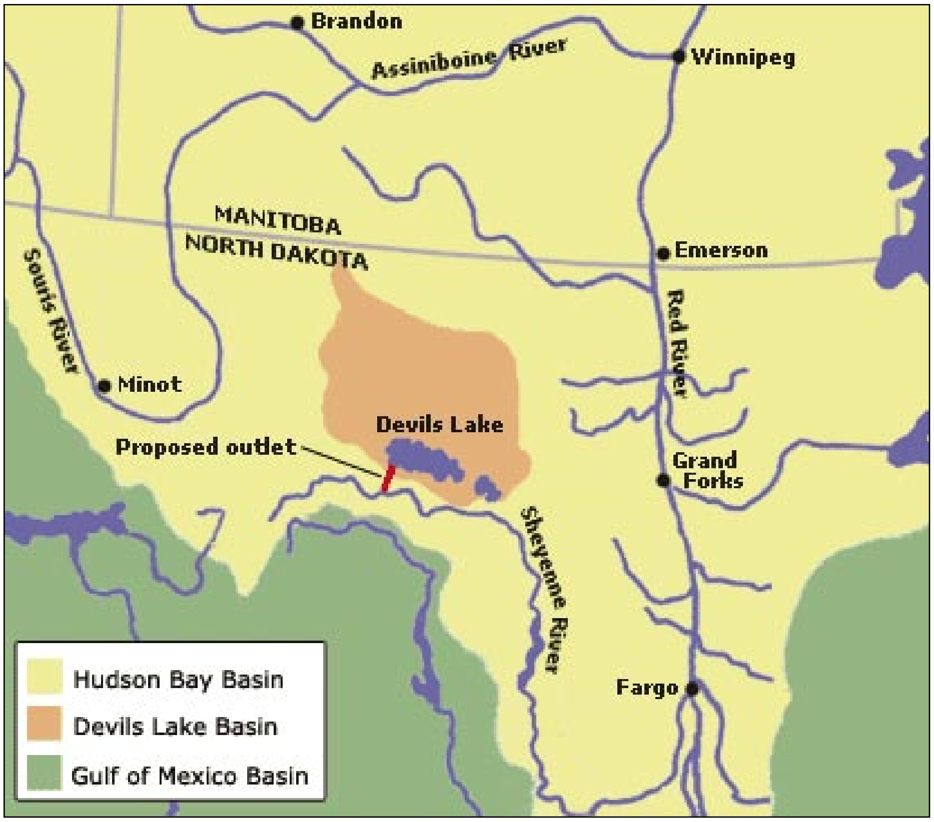


Fig. 32 Location of Devils Lake Basin within the Hudson Bay Drainage Basin[269]. Devils Lake is the larger of the two lakes within the Basin, Stump Lake is the smaller

communities, relocate homes and upgrade infrastructure[270]. As a solution to the present critical state of flooding, North Dakota constructed a 22 kilometre long pipeline to drain water from Devils Lake to the Sheyenne River. This project known as the Peterson Coulee temporary emergency outlet is estimated to cost $28 million. Water started to flow through this outlet on 15 August, 2005[271] and ceased about ten days later because the sulfate concentrations in the Sheyenne River upstream of the outlet exceeded the allowable limit due to low river levels[272].

As shown in Figure 32, Devils Lake is within the Lake Winnipeg portion of the Hudson Bay (i.e., Nelson River) Drainage Basin. Flows from the Devils Lake into the Sheyenne River drain east into the Red River and eventually to Lake Winnipeg. Concerns about the quality of the water flowing from Devils Lake and the possibility of undesirable erosion and transfers of biota have been expressed by a nonprofit, grassroots organization of people concerned with preserving the Sheyenne River[273] and by the Province of Manitoba[274] and others[275].

Devils Lake is subject to natural cycles of low and high water over geological time due to climatic variations

Devils Lake formed at the end of the last Ice Age, also known as the Pleistoene Epoch, about 12,000 years ago. One of the glaciers that covered North Dakota, the Late Wisconsinan glacier, as it advanced southward in the area of Devils Lake pushed materials beneath the leading edge of the glacier upward into the path of the glacier and left a source depression behind. This process of moving materials towards the leading edge of the glacier was enhanced by the fact that the glacier was moving over the Spiritwood Aquifer, pressurizing it. Escaping water from the aquifer assisted in the movement of materials deepening the depression that became the Devils Lake Basin. As the glacier retreated, a lake, then known as Lake Minnewaukan, formed in the basin. It was larger than the modern Devils Lake, included the modern Stump Lake and reached an elevation of up to or higher than 445 meters (1,460 feet). As Lake Minnewaukan shrank as the glaciers continued to melt and recede and the water level dropped to below 441.4 meters (1,448 feet), Stump Lake became isolated from Devils Lake. Throughout its history, Devils Lake has risen and fallen between two extremes. It has completely dried up several times, it has overflowed into the Sheyenne River drainage a number of times, and ranged between these extremes the remainder of the time[276].

> **Devils Lake**
> **"The lake is essentially always either rising or falling. That is its natural condition. And the reason for this is entirely the result of climatic cycles."**
> **- John P. Bluemle, North Dakota Geological Survey**

Over the past 10,000 years, it is estimated that Devils Lake has overflowed to the Sheyenne River eight to ten times. The most recent events are believed to have been 4,000 - 5,000, 2,500, and 1800 years ago. Devils Lake has overflowed into Stump Lake more frequently, including in the mid 1820s. Devils Lake completely dried up, particularly between 5,000 and 7,000 years ago. Although the lake's level is driven by climate, the relationship is not always synchronous. This fact is attributed to the presence of the underlying Spiritwood Aquifer that exchanges water with the lake, delaying the response of water level in the lake to natural drought and flood cycles. The North Dakota Geological Survey draws three conclusions about the water level fluctuations in Devils Lake:

- "Fluctuations in the levels of Devils and Stump Lakes are caused entirely by climatic changes – long-term cycles of wet and dry weather. These fluctuations are cyclic, extreme, and inevitable. Barring decisive action, such as construction of an inlet and an outlet, the fluctuations will continue
- The actions of humans during the past 120 years or so – since settlement – are not an important factor in determining the behavior of the lake. Even though agriculture, drainage of wetlands, road construction and all the rest may contribute to some minor, short-term effects, these things are definitely not responsible for the overall behavior of the lake. They do not determine whether the lake rises or falls, and they have only a very minor impact in determining how much the lake rises or falls.
- The natural condition for Devils Lake is to be either rising toward overflow or falling toward a dry lake bed. The lake should not be expected to maintain a stable level or to remain long at any given level"[277].

Water levels in Devils Lake are currently high and rising

Water level in Devils Lake on 3 September, 2005 was 441.57 meters (1,448.71 feet), well above the 440.74 meters (1,446 foot) level at which Devils Lake overflows to Stump Lake (Fig. 33). In fact, Devils Lake has been flowing into Stump Lake intermittently since 2001.

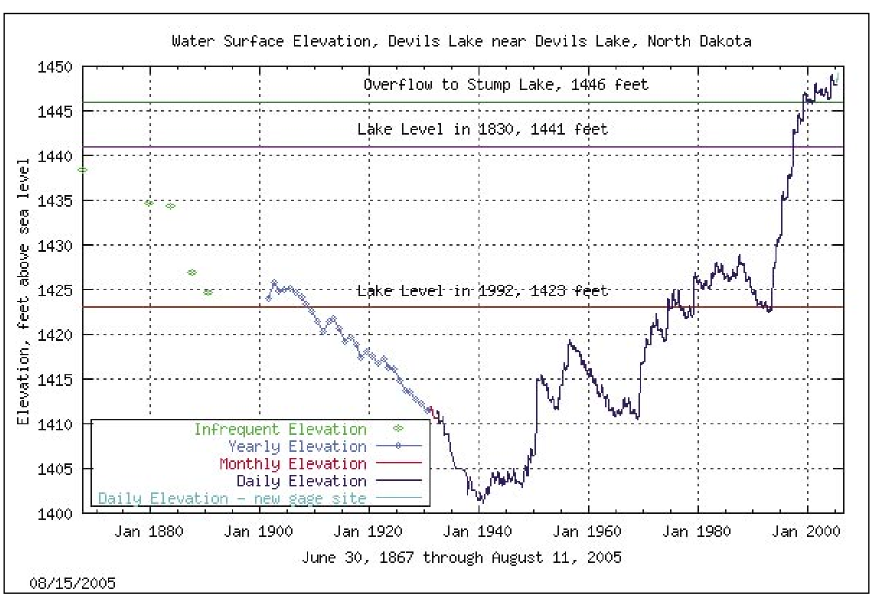


Fig. 33. Period of Record for Devils Lake near Devils Lake, North Dakota[278]

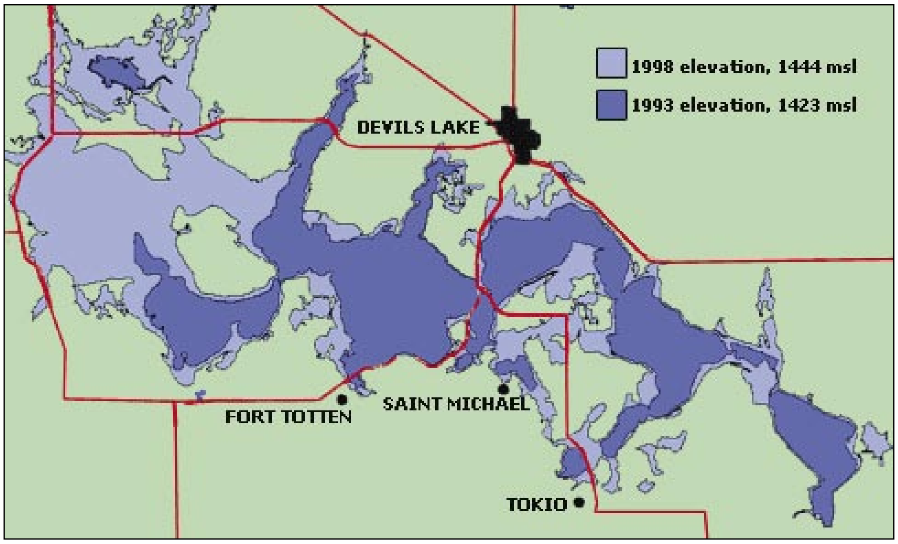


Fig. 34. Increase in areal extent of Devils Lake between 1993 and 1998[279]

Devils Lake water flows out to Lake Winnipeg

Flow of water from Devils Lake into the Red River of the North is a natural phenomenon, estimated to have occurred three times in the past 5,000 years. It does not constitute inter-basin transfer of water. The possibility that Devils Lake would flow into the Sheyenne River in this cycle has been estimated using a model that uses historical climate conditions and the storage available in Devils Lake. Assuming the recent wet conditions will continue through 2015, the model indicates about a two per cent chance that Devils Lake will reach the level (about 444.7 meters or 1,459 feet) to spill over into the Sheyenne River before 2015[280].

Although inflows from Devils Lake into the Red River and eventually into Lake Winnipeg occur naturally at long intervals, the Canadian concerns today about the water from Devils Lake lie largely with the possibility that exotic species may be present in Devils Lake that could be transferred to the Red River and into Lake Winnipeg. Furthermore, quality of the Devils Lake water reaching the Red River and eventually crossing the international border into Canada is also of concern.

A multi-jurisdictional, multi-agency biological study was undertaken in July, 2005 to gain a better understanding of whether or not species of concern may be present in Devils Lake or Stump Lake. Known exotics such as the zebra mussel, fish pathogens and parasites were sought. Phytoplankton, zooplankton and benthic invertebrates were also assessed. None of the 12 known species of concern identified in advance were found in the survey. Nevertheless, several phytoplankton species and one species of zooplankton, a calanoid copepod, were found in the lakes that are not in Lake Winnipeg. These prefer high salinity and are unlikely to survive in Lake Winnipeg. No taxa were found in the benthic communities of the lakes that were not found in Manitoba. Several species of the cyanobacteria, Microcystis, were found in Devils and Stump Lakes that are not reported to be in Lake Winnipeg. It is not known if these could become established in Lake Winnipeg and, if so, whether they would have negative impacts. The only fish pathogen detected was the agent causing a relatively-common bacterial kidney disease. Finally, three fish parasites were found that are potential species of concern for Manitoba[281]. These results indicate the importance of ensuring that microorganisms as well as macrorganisms are not transferred with Devils Lake water should the outflow of water to the Sheyenne River resume.

Whereas the flow of water from Devils Lake into Lake Winnipeg is an intra-basin transfer, an inter-basin transfer has received support. North Dakota's State Water Commission has endorsed a plan that would bring water from the Missouri River to Lake Ashtabula and the Sheyenne River. The project would be used to deliver water to eastern North Dakota in times of drought[282].

CLIMATE CHANGE

The present CO2 concentration in the global atmosphere may be higher than at any time during the past 20 million years

Climate change is an overarching reality that currently affects all ecosystems and human activities. The increase in global average temperature known as global warming has been 0.6 °C over the 20th century[283].

The atmospheric concentration of carbon dioxide (CO_2) has increased by 31 per cent since 1750. The present CO_2 concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years. The current rate of increase is unprecedented during at least the past 20,000 years[284].

It is believed that climate warming is caused by both natural forcings, such as variability in solar irradiance and volcanic eruptions, as well as by the dramatic increases in anthropogenic greenhouse gas[285] emissions of carbon dioxide, methane, and nitrous oxide. The best agreement between model simulations and observations over the last 140 years has been found when all of the anthropogenic and natural forcing factors are combined. They indicate that natural forcings may have contributed to the observed warming in the first half of the 20th century[286]. For example, Solanki[287] showed that total solar irradiance between 1850 and roughly 1980 correlated with Earth's temperature, consistent with a causal relationship. After 1980, the relationship breaks down and most of the warming over the past 50 years is correlated with increase in anthropogenic GHG emissions[288].

Global climate change will impact all Canadians. Aquatic ecosystems are among the resources at particular risk.

Climate change is expected to affect adversely the stability and productivity of Canada's water and coastal systems, food production, and forestry and fishing industries, among others[289]. Ecological impacts due to climate change are most evident at the highest latitudes in both hemispheres, as reported by the Arctic Climate Impact Assessment[290]. It is widely recognized that while striving to bring GHG emissions under control, countries, especially northern countries like Canada, will have to adapt.

Among the resources at risk in Canada is freshwater, particularly in areas of low supply and high demand. Recent studies are showing that summer (May to August) flows in several major rivers in Canada's western prairie provinces have declined by 30 to 85 per cent during the 20th century[291]. Climate warming is a confounding factor in addition to increasing human demand and human modification to natural flow patterns that are already impacting local water supplies. Warming increases evapotranspiration, reduces winter snowpacks, and is causing dramatic melting of the glaciers that feed the prairie rivers. The most affected is the South Saskatchewan River showing a reduction of almost 85 per cent in flow since the early part of the last century (Fig. 35). The tributaries, Oldman, Bow and Red Deer Rivers have multiple impoundments, and large withdrawals for irrigation, municipal, and industrial uses. Climate change has exacerbated the decrease in flow as evapotranspiration exceeds annual precipitation. Most of the irrigation in Alberta of 2.5 kilometres^3 water per year to irrigate 400,000 acres of land for 70 per cent of Canada's agriculture depends upon reservoirs that trap spring snowmelt runoff from the eastern Rocky Mountains[292]. All of the major rivers crossing the western prairie provinces originate in the Rocky Mountains, where deep snowpacks and melting glaciers maintain river and groundwater supplies. Glaciers have receded rapidly in the 20th century and some are now at a point where the glacial melt is declining[293]. Recognizing that the water supply to Lake Winnipeg particularly from the Saskatchewan River would be decreased by climate change, the Manitoba Climate Change Task Force recommended that Manitoba Hydro immediately sponsor research to address climate change impacts on reservoirs and water levels[294].

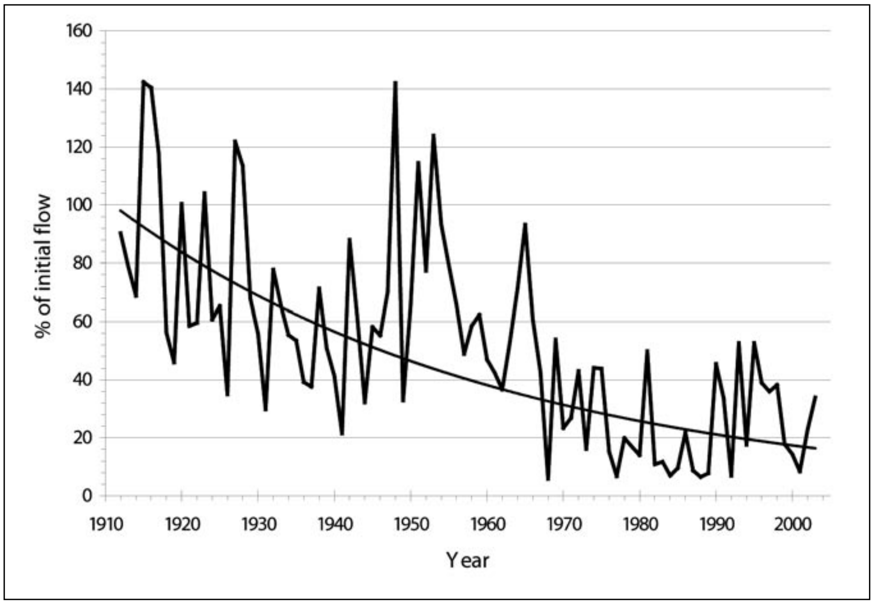


Fig. 35. Long-term relative change in summer flow (May-August) in the South Saskatchewan River at Saskatoon, Saskatchewan (-83.6 per cent from 1912-2003; $P < 0.0001$). The smooth lines are regressions representing the best fit to the data for the entire period. The percentage reduction in flow is the change in regressed flow during the period of record[295].

Climate change is the most overarching environmental condition to present itself to governments. It impacts the responsibilities of every federal and provincial government department.

Decreasing water quantity is one important effect of climate change on aquatic ecosystems. As well, climate change may increase biological rates of metabolism, growth, and reproduction and cause poleward shifts in ranges, including those of non-indigenous species. Acid deposition is expected to interact with climate-induced changes in delivery of dissolved organic carbon to boreal lakes. This may enhance transparency and permit damaging ultraviolet-B rays to penetrate to greater depths. Adaptation of freshwater ecosystems to climate change is expected to result in loss of biodiversity[296].

Lake Winnipeg is responding in subtle ways to climate change

Given the latitudinal distance from end to end of the north-south-oriented Lake Winnipeg, there is a clear climate difference between the South and North Basins. The northern most end of the lake is in the high boreal eco-climate, and the south end is in the low boreal eco-climate with mid-boreal climate in between. Mean annual temperatures range from about 0.5 ° C in the north and 1.9 ° C in the south. About one-quarter to one-third of the precipitation falls as snow, depending on the location[297].

Although air temperature has not been continuously monitored over the last century at any single station near Lake Winnipeg, temperature records have been pieced together and used to estimate mean surface water temperatures for the period 1909 to 2004. Temperature changes over the century appear not to have been dramatic. Nevertheless, significant long-term temperature trends for September in the North Basin showed an increase of 1° C over the century, and for August in the South Basin showed an increase of 1.9° C over that period[298]. Midsummer air temperature is predicted by one scenario of the Canadian Global Climate Model, Version 2 (CGCM2), to rise about 2° C by the middle of the 21st century, implying average July –Augusts surface water temperatures of 20 – 21 ° C in the middle of the century in the North Basin and about 23 ° C in the South Basin.

More extreme weather events are predicted such as an increase in the number of thunderstorms, dry periods of longer duration, more intense winter storms[299]

The timing of melt and break-up of the ice cover on Lake Winnipeg was investigated by examining satellite images. During the 20th century there were no significant trends towards either earlier break-up or later freeze-up. Nevertheless, using the CGCM2 model, break-up is predicted to be a week and a half earlier by the middle of the 21st century than during the last century in the North Basin, and a week earlier in the South Basin. On the other hand, no significant change in time of freeze-up was predicted for either the North or South Basin by the middle of the century[300]. The Lake Winnipeg sub-basin is south of the major areas of permafrost, nevertheless, changes to permafrost along the Nelson River are expected to be important to communities.

The dramatic increase in the distribution of one species of crustacean zooplankton, *Mesocyclops edax,* is hypothesized to be related to the temperature increase[301]. Generally a species that prefers warmer water[302], *M. edax,* present in small areas at the mouths of the Saskatchewan and Red Rivers in 1969 expanded to lakewide status by 1999[303].

> **Manitoba's climate change plan is the best of all the provincial and territorial plans.**
> **- David Suzuki Foundation, 3 October, 2005**[304]

Lake Winnipeg and its Sub-basin: Source or Sink for Carbon Dioxide?

While there is research interest in examining the sediments of Lake Winnipeg as a site of carbon sequestration, the primary natural systems of carbon sequestration are terrestrial systems, including forests, soils, and wetlands; the ocean; and geologic formations. The extensive peat areas on the north and east sides of the lake[305, 306] are representative carbon reserves[307] that could well be included in research and monitoring programs on Lake Winnipeg. Wetlands, including peatlands, contain the highest density of carbon of all land-based ecosystems. Canada has 24 per cent of the world's wetlands, including peatlands, and these cover approximately 14 per cent of Canada's land surface. They contain about 60 per cent of Canada's carbon stock[308].

Wetlands are a double-edged sword. On the one hand, they are immense sinks for greenhouse gases as indicated above. Wetlands, particularly peatlands, absorb and emit carbon but generally absorb more carbon than is given off. Nevertheless, wetlands can also be a source of the greenhouse gas, methane. More significant at this time in our history than their potential as further sinks is the possibility that under climate warming peatlands will become massive sources of greenhouse gases overwhelming energy conservation and technological advances both in Manitoba and Canada. A particular hazard is fire. Fire is a natural occurrence in wetlands but a drier climate will not only increase the incidence of forest fires but also the frequency, intensity, and duration of peat fires. Monitoring programs of changes to water content, hydrology, and carbon dynamics in peatlands can permit effective planning of where best to establish fire observation and to deploy fire-fighting capacities.

4. Our Scientific Understanding of the Lake Today

"It is clear that Lake Winnipeg is an aquatic ecosystem under stress. Although the causes of the problems are understood in general, our scientific knowledge of the Lake is limited and insufficient to answer some of the specific questions posed by Lake managers"
- G.B. Ayles and D.M. Rosenberg (2005)[309]

HISTORY OF RESEARCH AND REPORTING ON LAKE WINNIPEG

Of the world's great lakes, Lake Winnipeg has been remarkably poorly little studied

In part because it was assumed that Lake Winnipeg is remote and little impacted[310], the lake received remarkably little scientific study. Comparatively, the African Great Lakes, Victoria and Malawi, are considerably better known and the eastern Great Lakes very well studied (Fig 36).

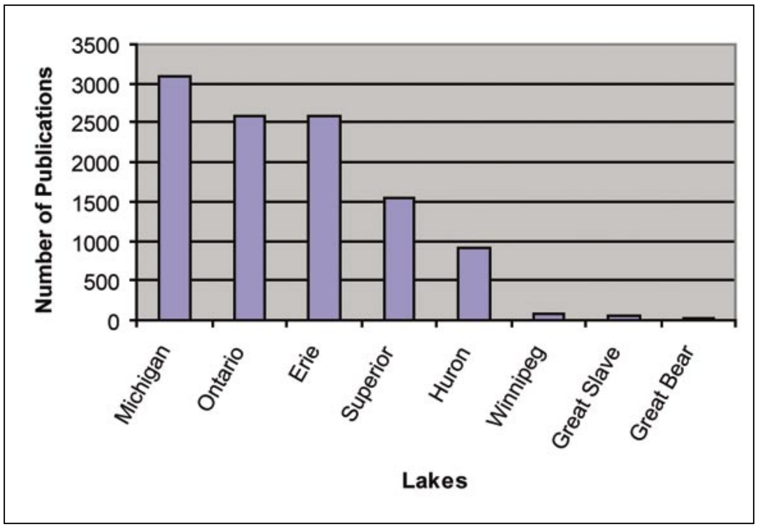


Fig. 36. Comparison of the number of scientific publications on fisheries and aquatic sciences from Canada's great lakes[311]

Comprehensive scientific study of Lake Winnipeg has been intermittent, with long periods of inactivity (Table 6) with a few exceptions[312, 313]. The lake was studied quite intensively in 1929 but did not receive scientific attention again until 1969. At that time scientists from the Freshwater Institute, that in 1972 would become the regional headquarters for the Department of Fisheries and Oceans' (DFO) Central and Arctic Region, undertook studies because of the lake's geographical importance and size rather than because of an institutional mandate. The next major study took place in 1994 and 1996, when the Geological Survey of Canada began to learn more about the geological history of post-glacial Lake Winnipeg, a remnant of Lake Agassiz.

Following the Red River flood in 1997, the "flood of the century", the International Red River Basin Task Force of the International Joint Commission funded a one-time study from 1997 to 1998 on the degree of contamination of the South Basin by the flood waters. With the formation of the Lake Winnipeg Research Consortium in 1998 by a group of researchers at the Freshwater Institute along with other stakeholders, on-going, whole ecosystem study of the lake was finally begun. In 2001, the Lake Winnipeg Research Consortium Inc. started annual reporting of the results of its whole ecosystem research studies.

Excellent scientific work has been carried out on Lake Winnipeg, providing a great deal of information on geology, paleolimnology (geological history of life in the lake), hydrology, and ecology of a number of trophic levels in the food chain. Yet, the lake remains one of the most poorly understood great lakes of the world with respect to its food web structure and function[314].

The small total scientific research over the decades plus its lack of continuity leaves large gaps in the understanding of the lake's natural variability in physical, chemical and biological processes across the lake and through time. This makes it much more difficult to know whether changes in fauna or flora populations are due to natural variability or to human influence.

Lake Winnipeg has been the subject of several conferences, workshops and meetings (Table 7). Recently reporting of research results and planning of whole lake research cruises takes place at annual Science meetings held by the Lake Winnipeg Research Consortium, Inc., usually in April.

Table 6. Periods of scientific study on Lake Winnipeg

Period	Purpose	Area Studied	Publications
1929 Work from auxiliary schooner "Breeze"	Study of physical and biological conditions to determine the sustainability of fisheries		Bajkov 1930[315] Bajkov 1934[316]
1969 Cruises on the SS Bradbury	Study of physical, chemical and biological parameters	Whole lake, 65 stations	Kling and Holmgren 1970[317] Kushnir 1971[318] Brunkskill 1973[319] Brunskill et al. 1979[320] Brunskill and Graham 1979[321] Brunskill et al. 1979[322] Brunskill et al. 1980[323] Brunskill et al.1980[324] Salki and Patalas 1992[325]
1994: Lake Winnipeg Project Phase 1; Cruises on the CCGC Namao	Regional geological study of the lake basin with respect to post-glacial and geologically recent lake history	Whole lake, 54 stations	Last 1996[326] Todd 1996[327] Todd and Lewis 1996[328] Todd et al. 1996[329] Salki 1996[330] Todd et al. 1998[331] Todd et al. 1998[332] Moran and Jarrett 1998[333] Rack et al. 1998[334] Henderson and Last 1998[335] Buhay and Betcher 1998[336] Kling 1998[337] Burbidge and Schröder-Adams 1998 [338] Vance and Telka 1998[339] Nielsen 1998[340] Lambert et al. 1998[341] Tackman et al. 1998[342]
1996: Lake Winnipeg Project Phase 2; Cruises on the CCGC Namao	Further geological study and shoreline component, post-glacial uplift	Whole lake, 21 stations	Lewis et al. 2000[343]
1997: Flood of the century: during the flood, summer of 1997; winter of 1997-98; summer of 1998	Evaluate the impacts of the flood, particularly the transport of contaminants in the Red River and their fate in the South Basin (funded by the IJC Red River Basin Task Force)	South Basin, 33 stations	Currie et al 1998[344] Stewart et al. 2000[345] Stewart et al. 2003[346]

Table 6. (continued from pg 53)

Period	Purpose	Area Studied	Publications
1998 – 2000, 2002-2004: Lake Winnipeg Research Consortium based on the CGC Namao.	Better understanding of the biological, chemical and physical processes that are critical to the well-being of the lake	1998: South Basin, 18 stations; 1999: whole lake, 98 stations; 2000: Gimli to George Island, 37 stations; 2002-2004: whole lake, 65 stations	LWRC 2005[347] Simpson et al[348] Wilkinson and Simpson 2003[349]
2005 record summer rainfall study, Sep			

Table 7. Scientific conferences, meetings, workshops, symposia and sessions focusing on Lake Winnipeg

Sponsor	**Topic**	**Date and Location**	**Publications**
Manitoba Energy and Mines	Lake Winnipeg Workshop	March 18-19, 1995, Winnipeg	Manitoba Energy and Mines 1995 Proceedings[350]
Geological Association of Canada	Physical Environment and History of the Lake Winnipeg Basin	May 27-29, 1996, Winnipeg	GAC/MAC 1996[351]
International Association for Great Lakes Research (IAGLR) (45th Annual Conference) and Aquatic Ecosystem Health and Management Society	IAGLR 2002: And the Other Great Lakes Session Topic: State of Lake Winnipeg Ecosystem: Food Web, Health and Management	June 2-6, 2002, University of Manitoba, Centre for Earth Observation Science, Winnipeg	IAGLR Abstracts[352],[353],[354],[355],[356],[357],[358],[359],[360],[361],[362],[363],[364],[365],[366],[367],[368],[369],[370],[371],[372],[373],[374],[375],[376],[377],[378],[379] Special Issue Aquatic Ecosystem Health and Management (in press or in prep.)[380],[381],[382],[383]
International Association for Great Lakes Research (46th Annual Conference) and International Lake Environment Committee (10th World Lakes Conference)	Global Threats to Lake Lakes: Managing in an Environment of Instability and Unpredictability	June 22 – 26, 2003, DePaul University, Chicago, IL	Abstracts[384],[385],[386],[387],[388]
Lake Winnipeg Research Consortium	Annual Science meeting	2002, 2003, 2004 in Winnipeg	Agenda[389]

Lake Winnipeg research lacks long-term government support

The record of scientific research on one of the world's great lakes prior to 1994 is astoundingly sparse by any standard (Table 1). The comprehensive study by a team of researchers from the Freshwater Institute in 1969 demonstrated capacity and interest. Yet, the bulk of the reports were not published for a decade and some of the important work not for more than 20 years. This is an indication of low priority by the organization for focus on northern Lake Winnipeg. In 1994, the initiative for basic geoscience research was taken by the Geological Survey of Canada, Ottawa; Manitoba Energy and Mines; the University of Manitoba; and the consulting sector, with some participation by the Freshwater Institute. Thus, the Freshwater Institute did not have a research presence on the Lake from 1969 until 1997 when the 1997 flood of the century prompted the IJC International Red River Basin Task Force[390] to initiate and fund a study of the movements of contaminants in the flood plain and receiving South Basin (Table 1). The first clear signs of eutrophication in 1992 were missed by researchers, although not by the local residents. Earlier in the 1960's, the entry of mercury into the ecosystem had also been missed because of lack of appropriate environmental and fish monitoring programs. Mercury contamination led to the abrupt closure of the commercial fishery on Lake Winnipeg from 1970 to 1971, impacting fishers and the market.

By 1996, DFO had cut freshwater research programs in Canada by 55 per cent, critically reducing scientific capacity in existing programs and reducing the staff available to give attention to non-core areas, such as Lake Winnipeg. Now, the unique multi-stakeholder consortium represented by the Lake Winnipeg Research Consortium established in 1998 has stepped into the void.

Not only has the federal government cut freshwater Science, the Province of Manitoba seriously reduced monitoring of fish populations in Lake Winnipeg. The annual stock monitoring program that was standardized in 1979, was reduced in the late 1990s, and stopped after 2003[391].

Although the Consortium's research programs are comprehensive, coordinated, and multi-disciplinary, as was the Lake Winnipeg Program in the mid 1990s, much of the research effort is necessarily being expended to obtain basic knowledge of the ecosystem. There is a large catch-up to do on Lake Winnipeg to bring our knowledge of variability in time and space of hydrology, water and sediment chemistry, biological community composition and function and other areas to the level in the Great Lakes.

Thus, the paucity of past research attention and the present lack of critical human resources capacity have serious implications for providing the knowledge to address Lake Winnipeg's problems most efficiently:

- much of the current research effort, ship time, and sample analysis is necessarily dedicated to obtaining baseline knowledge limiting the effort to gathering crucial information on present urgent, dynamic, and emerging issues
- a large back-log of samples, particularly from 2002 to 2004 cruises exists in storage; some samples back to 1969 are as yet unanalyzed because of staff/funding shortages
- a large body of data exists in databases that have not been analyzed because of staff/funding shortages
- much data has not been synthesized, published, and presented.

The publication of findings in peer-reviewed scientific journals is the best means we have of ensuring that research results are presented objectively, free of vested interest, and are available to all users world-wide. Publication of supporting data in widely-recognized data, manuscript and technical report series such as those published by DFO is a highly useful adjunct to primary publication. Primary publication can be a lengthy process, often requiring two to three years between data collection and final publication. In order to be timely to resource managers, policy setters, interest groups, and the public at large, data must normally be ready for presentation at meetings or conferences within one year or less. Long delays in the analysis of samples, data analysis and reporting compromises the ability to have up-to-date scientific information for decision-making concerning urgent, dynamic, ecologically-, socially- and economically-important issues.

THE LAKE WINNIPEG SCIENCE WORKSHOP

The Lake Winnipeg Science Workshop in November 2004 focused attention on knowledge gaps and proposals for future scientific research

In November, 2004, the Lake Winnipeg Science Workshop[392] (LWSW) was held in Winnipeg as an important step in the implementation of the Lake Winnipeg Action Plan. Organized through collaboration by Manitoba Water Stewardship, Fisheries and Oceans Canada, and Environment Canada[393], the workshop had the primary goal *To identify science priorities and research needs for*

- water quality and nutrients
- fish communities
- fish habitat

in Lake Winnipeg in support of current and emerging management issues as identified by the agencies directly responsible for the Lake's aquatic resources.

The major aquatic issues facing Lake Winnipeg were identified (in no particular order) as:

- climate change
- biological contaminants, e.g. fecal coliforms
- chemical contaminants
- endangered species
- eutrophication
- exotic species
- floods
- inter-basin transfers
- overfishing
- sediment levels
- shoreline disturbance
- water control

Workshop participants developed a number of research proposals in each of the themes (Table 8). These were prioritized by the participants at the workshop but do not necessarily reflect the priorities of the agencies sponsoring the workshop.

Table 8. Prioritized list of research proposals developed at the Lake Winnipeg Science Workshop[394]

Theme	Project Title	Brief Description
Fish 1	Fish community index sampling programs	Obtain relative abundance indices using standard bottom set multi-mesh gillnets to allow understanding of community structure and dynamics.
Water 7	Relating nutrients and biological endpoints for setting ecological objectives for Lake Winnipeg	Determine the relationships between critical biological endpoints with respect to algae, benthic invertebrates, fish and others and nitrogen and phosphorus concentrations.
Water 6	Physical model for Lake Winnipeg	Determine how water moves in Lake Winnipeg, including contributions of wind velocity, temperature, bathymetry, currents, and water velocity.
Habitat 1	Aerial inventory of North Basin and Channel areas of Lake Winnipeg	Use of current and historical satellite imagery and aerial photos of the North Basin and Channel areas to provide physical descriptions of various habitat types and classification and quantification.
Habitat 2	Fish habitat classification for the South Basin of Lake Winnipeg	Collect data such as bathymetry, fetch, and cover to apply existing fish habitat models developed for the Great Lake. Develop a good fish habitat suitability database.
Habitat 3	Assessment of use of tributaries and reefs by Lake Winnipeg fishes	Determine which tributaries and reefs are important habitats for Lake Winnipeg fishes, particularly species at risk.
Habitat 4	Decline of wetland habitat in Lake Winnipeg	Determine whether wetland decline is related to water regulation, nutrients and turbidity or exotic species.
Water 4	Watershed hydrology model	Develop a model for understanding of the quantity and timing of water flows into Lake Winnipeg.
Habitat 7	Develop a better understanding of the relative importance of nutrients (nitrogen and phosphorus), light (sediment load) and temperature to the algal community in Lake Winnipeg	Describe the current state of knowledge of nutrients, sediment load, and temperature to the algal community of the lake ecosystem. Develop models of algal productivity and use models to test sensitivity of the algal community to significant factors.
Fish 4	Effects of exotic species on the Lake Winnipeg ecosystem, including the commercial fishery	Address a number of critical issues regarding exotic fish, invertebrate, plants, viruses and others, such as routes and modes of transfer, effects of exotic species on the biological community structure and function, the impacts of exotics on contaminant/toxin transfer through the food chain, and the effect of exotics on quality, taste, texture, disease and condition of fish flesh.
Habitat 9	Invasion of exotics into Lake Winnipeg and consequences on fish community	Perform a risk assessment of potential exotic species on the Lake Winnipeg ecosystem by matching ecological requirements of potential exotics (fish, invertebrates, plants or viruses) with existing conditions in the lake.
Water 3	Land use: Lake Winnipeg sustainability	Address the relationship between land use and soil type and their contributions to nitrogen and phosphorus enrichment of Lake Winnipeg.
Habitat 5	Correlation of land use and watershed nutrient database	Assemble existing land use information and river nutrient concentrations and load information into an integrated GIS database. Test for correlation between land use and nutrient concentrations and loads in downstream runoff.

Table 8. (continued from pg 57)

Theme	Project Title	Brief Description
Fish 2	Partitioning sources of mortality other than the commercial harvest	Address all source of mortality including total harvest of fish and other sources of mortality including harmful algal blooms, toxins, oxygen depletion, starvation, foodweb interactions and others.
Habitat 8	Causes and consequences of the decline in zoobenthos communities in Lake Winnipeg	Explore hypotheses that the potential causes of zoobenthic decline are hypoxia in the North Basin related to changes in thermal stratification and eutrophication, sedimentation, and nutrients and contaminants.
Water 5	Nutrient loading estimates for the Lake Winnipeg basin	Develop a nutrient budget with known precision and accuracy.
Fish 5	Traditional and local knowledge	Collect local and traditional ecological knowledge (TEK) from fishers and local elders on what is known about the fisheries and the ecosystem of Lake Winnipeg.
Fish 3	Subpopulation structure of commercial species (walleye, sauger, whitefish)	Determine whether there are separate stocks of commercial species and if the discrete stocks show fidelity of spawning, i.e. return to spawn in the same area year after year.
Fish 6	Effect of climate and climate change on the aquatic ecosystem: Monitoring and analysis	Integration of historic water temperature data sets, including profiles, and air temperature in the lake and basin.
Habitat 6	Define and describe critical habitats for species at risk	Describe and locate critical habitat for SARA species.
Fish 7	Contaminant levels in Lake Winnipeg biota	Track changes in contaminant levels in fish, water and sediments as an early warning system for potential problems.
Fish 8	An ecosystem model to understand the impact of changes in food web structure on fisheries productivity	Accumulate data and develop an ecosystem model (e.g., ECOPATH) of the Lake Winnipeg food web to predict how changes in nutrient loading and exotic species will affect fisheries productivity; compare management strategies for managing the fisheries.
Water 1	Bacteria levels at recreational beaches	Develop a predictive model relating exposure/risk (source dependent) with wind/water and changing bacterial counts
Water 2	Carbon cycling/carbon sequestration	Provide an estimate of the relationship between nutrient loading and carbon deposition and an economic evaluation of changes in carbon sequestration.

"In the future, a whole-watershed approach will be necessary to develop the scientific knowledge and understanding to support aquatic ecosystem-based management for Lake Winnipeg"
- G.B. Ayles and D.M. Rosenberg[395]

THE GREAT LAKES EXPERIENCE AS A MODEL FOR LAKE WINNIPEG

The Eastern Great Lakes are of an even larger scale than Lake Winnipeg and have received attention for many decades. Therefore, management of the Great Lakes offers experience in and lessons for managing Lake Winnipeg issues such as eutrophication, exotics, and fish productivity.

Since 1972, much of the management of the Great Lakes has been guided by the Great Lakes Water Quality Agreement between Canada and the United States[396]. The agreement expresses the commitment of each country to restore and maintain the chemical, physical and biological integrity of the Great Lakes Basin Ecosystem and includes a number of objectives and guidelines to achieve these goals. It is a watershed-based agreement. The first agreement was signed in 1972. It was renewed in 1978, and amended by a Protocol in 1987 to strengthen programs and to increase accountability for their implementation. The agreement provides for two binational boards, the Great Lakes Water Quality Board and the Great Lakes Science Advisory Board, to advise the Commission[397]. It is interesting to note that the major issue at the time of the 1972 agreement was phosphorus over-enrichment. Three decades later, a milestone agreement is being presented for Lake Winnipeg for the same issue. As for the eastern Great Lakes, the solution will involve cooperative, concerted action by both Canada and the U.S.

Eutrophication began in the Great Lakes with increased inputs of phosphorus during the 1950s and 1960s. Loading of phosphorus to Lake Erie in 1968 was 28,000 tonnes/year. Unlike Lake Winnipeg, Lake Erie received most of its phosphorus load from municipal sewage. In particular, 25 per cent of its phosphorus load was from detergents. The largest sewage treatment plants were directed to reduce phosphorus in effluent to one milligram phosphorus per liter and attempts were made to control non-point sources. The result was that phosphorus loads were reduced by 50 per cent in Lake Erie and Lake Ontario and the phosphorus concentrations in shallow western Lake Erie and Lake Ontario decreased by 50 per cent. The improvement was achieved by tertiary treatment of sewage and not by control of non-point sources[398]. The main lesson learned in Lake Erie was the importance of phosphorus concentration and the bioavailability of phosphorus as causal factors in eutrophication and the target of its control. A marked difference between Lake Erie and Lake Winnipeg is that the Lake Winnipeg sub-basin is 40 times the area of the lake, compared with three times for Lake Erie. This and the higher population density around Lake Erie makes sewage the most important and controllable input of phosphorus. Non-point sources are considered to be proportionately much more important for Lake Winnipeg, and will need to be targeted for control of phosphorus as well as point sources.

The Great Lakes experience in fisheries management is also useful for Lake Winnipeg. Great Lakes regional fish habitat management plans are developed using layered GIS-based descriptions of habitat for (a) suitability of habitat for all species and life stages of the fish assembly, (b) identification of rare habitat types, (c) wetlands of various types, and (d) local expert identification of important habitat for particular fish species and life stages. The field data are then used to construct models of productive capacity of near-shore fish habitat. Finally, large scale, multi-partner projects are employed to predict impacts of such influences as climate changes and changes in water level to fish habitat. Two of the most important lessons are that multi-partner and multi-agency projects lead to synergistic products for ecosystem-based management and effective and continuing communication among management agencies are paramount[399].

The importance of lake-wide monitoring in the Great Lakes was recognized when it was lacking in the 1980s. As phytoplankton biomass declined in western Lake Erie and shifted in species composition, the lack of lake-wide monitoring made it impossible to determine whether the cause was P abatement or grazing by the exotic zebra mussel, *Dreissena polymorpha*[400]. Adequate and consistent monitoring over time and space are required for scientists to be able to tease out the relative importance of such factors as eutrophication, contamination, loss of wetlands, presence of exotics, and now climate change on ecosystems and their functions.

The science of environmental monitoring is now well developed in the Great Lakes and serves as a model for Lake Winnipeg. The State of the Lake Ecosystem Conferences (SOLEC) database contains over 800 indicators of ecosystem health, and about 80 are applied routinely. Indicators are categories of evidence that tell us about the condition of something of interest. Categories of ecosystem health indicators include[401]:

- state of the environment: these address state of the environment, quality and quantity of natural resources, and the state of human and ecological health; reflect the ultimate objective of environmental policy and implementation; are biological, chemical, physical variable, or ecological functions
- pressure: these describe natural processes and human activities that impact, stress or pose a threat to environmental quality
- human activities/response: These describe individual and collective actions to halt, mitigate, adapt to, or prevent damage to the environment; include actions for the preservation and the conservation of the environment and natural resources; examples are education, regulation, market incentives, technology changes.

Not only must there be indicators but there must also be general agreement on which indicators to use and how to use them. Indicators are measures of the effectiveness of specific mitigative and restorative efforts by society and can be applied to decide among competing priorities. Indicators are necessary when large expenditures of time, and taxpayers' and industry's dollars are being made.

Finally, an additional Great Lakes example for managing Lake Winnipeg has just been released. The Great Lakes Conservation Blueprint for Biodiversity[402] assembles, maps, and analyzes data on biodiversity in ecosystems in the Great Lakes region of Ontario. Sites identified in the process, if protected, could sustain essential elements of biodiversity. Conserving these sites comprises a vision or blue-print of maintenance of biodiversity. The Ontario Ministry of Natural Resources and the Nature Conservancy of Canada are cooperating in this effort.

ADDITIONAL LAKE WINNIPEG RESEARCH PRIORITIES

The Great Lakes experience puts into perspective the significance of the impoverished scientific record on Lake Winnipeg. There are no background data and trends through time for many processes, species, and ecosystem functions in the lake. Despite the challenges of measuring the effectiveness of action, it is absolutely essential to the people and the economies that depend on a healthy Lake Winnipeg that a serious start is made to reverse eutrophication and be proactive on other issues. In the meantime, we will need to invest more resources to develop a more complete understanding of natural processes in and human impacts on Lake Winnipeg.

The list of prioritized and cross-linked research proposals from the LWSW provides a starting point for expanding the research and monitoring programs already under way by the Province of Manitoba and the Lake Winnipeg Research Consortium.

Two areas are emerging that have strong public and ecosystem health and/or economic implications for Manitobans who depend upon the lake for water and livelihoods.

Research on Risks from Blue-green Algal Toxins

More knowledge is urgently needed about the toxins produced by the vast blooms of blue-green algae throughout the lake at certain seasons. A great deal is known about algal toxins and their effects on organisms from other systems and laboratory studies. Nevertheless, specific information is required for Lake Winnipeg. We need to[403]:

- identify accurately the morphotypes (genotypes) of algal species known to produce toxins
- determine exactly which toxins are produced by each species/morphotype
- determine the relationship of the stability of the toxins with environmental conditions in the lake
- isolate the morphotypes into media for culture and confirm the nature of the toxins produced by each
- determine the conditions favouring and limiting the production of species of toxic algae and of toxins
- measure accumulation of toxins in organs and tissues of food organisms, such as fish and ducks.

In the meantime, each community around the lake and on the Nelson River should have access to water monitoring for toxic algae as well as either an alternative water supply that is clean or an effective treatment system that can be used during periods of toxin production.

Ecological Study on Sustainability of Commercial Walleye Catches

For the past five years, the commercial catch of walleye in Lake Winnipeg has been well above the long-term performance (Fig. 11). It is well above the estimated maximum sustainable yield for the lake estimated in the 1980s and 1990s. Given the economic importance of the fishery to the Lake Winnipeg fishers, their communities, and the province, research is needed on the ecological basis of this increase. Whether the increased walleye production is attributed to eutrophication and increased secondary production, to the presence of the rainbow smelt as an additional food source, or other factors, knowledge is urgently needed to evaluate maximum sustained yield under current Lake Winnipeg conditions. Research needed is to:

- obtain trawling data on the abundances of young-of-the-year walleye, sauger, and whitefish to be used annually to adjust future quotas
- measure temporal changes in abundance of other gill-netted species
- analyze gut content data
- obtain catch and effort data from the special permit fishing
- obtain catch and effort data from the domestic fishery[404].

A Final Proposal: The First State of the Lake Report on Lake Winnipeg

Federal departments Environment Canada, Fisheries and Oceans, Health Canada, and Agriculture and Agri-Food Canada and the Province of Manitoba have now identified the need and value of a five-year science program of issue-targeted research on Lake Winnipeg and its watershed. For Lake Winnipeg, the central issue is eutrophication and the impact of blue-green algal biomass and toxins on the water quality, productive capacity of its fishery, and the recreational value of its shoreline.

Planning for efficient and effective research on Lake Winnipeg will require ready access to as much background information as possible. There is a large body of physical, chemical and biological information acquired by DFO researchers from 1969 to the present during the course of 18 whole lake cruises. In total, over 900 stations have been sampled, in most cases for a complete suite of physical, chemical and biological parameters in both the water column and in sediments. Nevertheless, much of these data is either unpublished, in dispersed reports, or represented as samples that have yet to be fully analyzed. The requirement for sample analysis is particularly true of material collected from 2002 to 2004.

A proposal has been made to prepare a state of the lake report for Lake Winnipeg by mid-2006 to integrate all of the physical, chemical and biological data available for Lake Winnipeg from 1969 – 2004[405]. This report will consist of text (describing the various sources of data, methodology used, and basic interpretations), a relational database, and maps of data using Arcview Geographical Information System (GIS) - Spatial Analyst. The report and associated database will be a primary resource, available to the scientific community, and publicly available. It will assist in assessing changes in lake health in general and more specifically, in identifying regions of the lake that are showing greatest impact so as to guide when and where research activities should be focused. Data in this report will represent the best estimate of time trends available and provide a present baseline for lake health against which the impact of remedial actions in the basin can be assessed. The estimated funding required for the state of the lake report is $225,000, comprised of $105,000 for sample analysis, $60,000 for the GIS database, and $60,000 for data analysis and report writing.

> **Lake Winnipeg is the least surveyed, least studied, and least understood of the world's great lakes.**
> **- Frances Russell, Author**

Species Identification – A Pending Crisis

Imagine trying to understand a book in a foreign language without the benefit of a dictionary and reading experience. Scientists "read" ecological communities by analyzing species composition. Species composition is the most basic parameter of communities. It influences such features as standing biomass, size structure, and productivity of communities and the ecosystems of which they are a part.

Taxonomy is the science of naming and describing species. The term is also used for the identification of species that have been described. The scientific literature contains species descriptions and characteristics that distinguish species from others. Taxonomic specialists initially recognize each species and life stage by the distinguishing features but after months and years of experience, identify organisms instantly from overall visual appearance. Rapid recognition is essential for the processing of samples from aquatic systems where the majority of the organisms are microscopic and numerous.

The skilled taxonomist readily detects the appearance of non-indigenous species or subtle changes in the morphology, size, or life cycle of existing species. These may be important early indications of change in ecosystem function or response to changing environmental conditions.

For the lower trophic levels of fresh waters, such as microbes, phytoplankton, zooplankton, and benthic invertebrates, the number of specialists in the world is quite small. In Canada and other countries, many specialists in these freshwater groups have retired from government, universities, or science-based businesses or are nearing retirement age. With increasingly-limited human resources and funding in bioscience laboratories, taxonomic skills are not being adequately passed on to the next generation of scientists. In recent decades, graduate students are not encouraged by universities to specialize in taxonomy. There is a looming crisis in the availability of specialists focusing on the freshwater lower trophic levels.

Consistent with the decline of taxonomy, few scientific journal and book publishers today publish primarily taxonomic works. An example of taxonomic data and associated analysis at risk of being lost is a monograph on the Crustacean Zooplankton of Canada. This is a compilation of the life work Dr. Kasimierz Patalas, now retired from the Freshwater Institute, DFO, Winnipeg, where he was Senior Scientist for many years. The work reports community composition of crustacean zooplankton from each of 921 lakes in all regions of Canada from Ellesmere Island to Lake Erie plus information on 2579 additional lakes from the scientific literature. The distributions of more than 80 species has been used to characterize regional zooplankton communities and to deduce the patterns of reinvasion of freshwater species following the last glaciation. All of the 921 lakes were sampled within a few years of 1970, thus providing point-in-time, historical data. They provide irreplaceable baseline data against which to measure the impacts of human activity. For example, since some of these species exhibit marked temperature or climate preferences, these organisms are biological indicators of climate change impact on Canada's lakes. Unless a concerted effort is made to find funding for the special publication of the Crustacean Zooplankton of Canada, this valuable resource may be lost from North America's scientific literature.

5. Organizations in the Lake Winnipeg Sub-basin and their Advice

Several levels of government, international bodies, and First Nations have responsibility for or interest in Lake Winnipeg and its sub-basin. Many from the private sector, from academia, and from non-governmental groups on both sides of the international border have interests in, concerns about, and advice to offer on Lake Winnipeg. Several innovative organizational structures have arisen spontaneously in this environment of concern about the health of Lake Winnipeg and determination to restore this significant resource to a healthy state.

This section reviews the range of organizational players in the sub-basin, institutional developments, and advice and proposals that are being offered to guide action. This list of organizations, departments, agencies, bodies, and groups is far from complete. *The Manitoba Water Directory*[406] lists almost 130 organizations involved with Manitoba alone.

INTERNATIONAL BODIES

International Joint Commission

The IJC is involved in the Red River in several ways. In 1964, the IJC was requested by the Canadian and U.S. governments to study and report on the extent and causes of pollution of the Red River at the international boundary and to recommend remedial measures. Following adoption of water quality objectives, the International Red River Pollution Board was established as a water quality supervision board in June 1969 and has provided continuous surveillance of the water quality of the Red River at the international boundary[407].

Following the flood of the spring of 1997, the International Red River Basin Task Force was formed to examine and report on the causes and effects of damaging floods in the Red River basin, and to make recommendations on means to reduce, mitigate and prevent harm from future flooding in the basin. It completed its work with the release of its report, *Living with the Red*[408].

In 2001, the International Red River Board (IRRB) combined ongoing activities and membership of the International Souris-Red Rivers Engineering Board and the International Red River Pollution Board. The Board helps the IJC prevent and resolve transboundary disputes by providing advice on matters affecting the quality, levels and integrity of the waters of the Red River ecosystem[409]. In mid-2004, the IRRB stated that "Participating Red River Basin jurisdictions and water management agencies will strive towards reducing Red River nutrient loading to meet the interim goal of reducing nutrient loading into Lake Winnipeg by ten per cent over the next five years"[410].

Red River Basin Commission

The Red River Basin Commission (RRBC) is an independent, international, broadly-representative[411] organization with charitable status providing timely advice on water-related events and developments, community-based educational and outreach programs, an annual international conference, and carrying out a number of locally-based projects and programs[412]. The organization has its roots in the 1979 Red River flood. Its predecessors were the International Coalition for Land and Water Stewardship in the Red River Basin (TIC), that formed formally in 1983 in recognition that floods and other water issues can best be managed by cooperation throughout the international watershed, and the Red River Basin Board formed in 1997 role was a way of vetting large complex water-related water-impacts projects. Formed in 2002, the RRBC now has as its means of achieving the mission to develop a Red River Basin integrated natural resources framework plan; to achieve commitment to implement the framework plan; and to work towards a unified voice for the Red River Basin. The vision is "A Red River Basin where residents, organizations and governments work together to achieve basin-wide commitment to comprehensive integrated watershed stewardship and management"[413].

The RRBC's Red River Basin Natural Resources Framework Plan[414] works toward:

- encouraging a basin-wide approach to the management of natural resources; managing within watershed boundaries.
- integration of diverse challenges such as flooding, water quality and supply, fragmentation of native prairie habitats, land use, and soil loss in natural resource management
- overcoming jurisdicational fragmentation and political barriers.

Using a set of guiding principles, teams work in nine areas:

- flood damage reduction
- hydrology
- water quantity
- fish, wildlife and outdoor recreation
- water institutions
- drainage/retention
- water quality
- conservation
- water law

Strengths of the RRBC are its long-term presence in the Red River Basin in both the U.S. and Manitoba, and its consistent efforts in outreach, education, and timely advice on projects.

> **The Red River Basin economy is influenced directly and indirectly by water. In return, the economy also influences the way we manage water-related problems…**
> **Red River Basin Natural Resources Framework Plan, Red River Basin Commission, May 2005**

International Water Institute (IWI)

The IWI [415] was conceived by the International Flood Mitigation Initiative for the Red River (IFMI)[416], itself an international response to the Red River flood of 1997. The IWI, based in Fargo ND, established a Management Board in 2001 comprised of representatives from Minnesota, North Dakota, Manitoba, and the U.S. Federal government. The purpose of IWI is flood research and watershed education for the Red River Basin or more specifically, to "provide a forum for research, public education, training, and information dissemination relating to flood damage reduction and water resource protection and enhancement in the Red River Basin"[417]. The organization has oversight of the Red River Center for Watershed Education[418] and the Center for Flood Damage and Natural Resources[419]. The IWI works with Tri-College University for administrative support and financial accounting. The partnership extends to numerous organizations and federal agencies[420]. In 2005, IWI held its Second International Water Conference and Lake Winnipeg[421],[422],[423] and Netley-Libau Marsh were two topics included.

IFMI created "River Watch", a media partnership with Prairie Public Broadcasting, and more than 28 local, state, federal and communication partners[424]. The mission of River Watch is to help people collect, understand, and use information about the health of their rivers so that rivers and their watersheds can be protected and restored.

The Red River Basin River Watch Monitoring Program began in Minnesota in 1995. It is now implemented in North Dakota and Manitoba through a partnership among the MN Pollution Control Agency, the ND Department of Health, the Red River Watershed Management Board and Oak Hammock Marsh. The basin-wide program provides hands-on "real world" science opportunities for students, teachers[425] and citizens and provides leadership experiences and greater awareness and understanding of baseline water quality in the Red River Basin.

International Institute for Sustainable Development (IISD)

Founded in 1990, the International Institute for Sustainable Development (IISD) is in the business of promoting change towards sustainable development through research and effective communication of its findings. The IISD contributes to sustainable development by advancing policy recommendations on international trade and investment, economic policy, climate change, measurement and assessment, and natural resources management.

The IISD has drafted a proposal for the revitalization of the Netley-Libau Marsh[426]. This proposal examines the feasibility of improving the ecological condition of the marsh, enhancing its nutrient removal capacity, providing a renewable bioenergy source, and mitigating climate change through the generation of carbon credits to offset consumption of fossil fuels.

GOVERNMENT OF CANADA

Environment Canada (DOE)

Aspects of the mandate of Environment Canada relating to water include:

- preserve and enhance the quality of the natural environment, including water, air and soil quality
- conserve and protect Canada's water resources
- carry out meteorology
- enforce the rules made by the Canada-United States International Joint Commission relating to boundary waters.[427]

A recent initiative of DOE is the development of the Competitiveness and Environmental Sustainability Framework (CESF). The CESF will take an integrated and comprehensive approach to a full range of sustainability challenges, linking policy with action in such areas as climate change, environmental stewardship, health and environment, and sustainable communities. The CESF has five pillars:

- Decision-making – inclusive and flexible, policy alignment across jurisdictions, results-focused collaboration, performance assessment and clear accountability
- Information – enabling sound decision-making, prediction, assurance and reporting
- Science and technology – coherent approach on priority challenges
- Performance promotion and enforcement – incentives to encourage compliance, fair enforcement regime, focused on outcomes
- Education and engagement – empowering citizens and decision-makers to make informed choices[428].

In May 2005, the Environment Minister Stéphane Dion announced the funding of $1.1 million a year to monitor the water quality of Lake Winnipeg. This represents about a ten-fold increase in federal expenditures devoted to Lake Winnipeg and is the largest federal commitment to a single Canadian lake outside the Great Lake, where funding is more than $10 million per year for monitoring and remedial action[429]

Environment Canada is developing a Federal Lake Winnipeg Action Plan. This plan, congruent with the CESF, for restoration and sustainable management of Lake Winnipeg in partnership has four goals:

- Understanding the ecology of the lake and watershed
  - physical, chemical, biological dimensions
  - drivers controlling the state of the lake such as climate variability and changing land use patterns
- Restore ecological integrity
  - Prioritize issues based on State of Lake Winnipeg Report
  - Develop monitoring program, incorporating climate change
  - Develop targets for restoration
  - Carry out restorative actions in an adaptive way through community involvement

- Long-term sustainability
  - Better understanding of resource demand/supply/allocation
  - Integrated knowledge for decision making
  - Watershed resource management
- Governance and communication
  - Federal-provincial *Canada Water Act* agreement
  - Federal inter-departmental agreement
  - Coordination, collaboration and partnerships (First Nations, universities, Prairie Provinces Water Board, IJC, Lake Winnipeg Research Consortium, ENGOs and others)
  - Communications and outreach[430]

Fisheries and Oceans Canada (DFO)

The mission of DFO is "to work toward safe, healthy, productive waters and aquatic ecosystems for the benefit of present and future generations by maintaining the highest possible standards of service to Canadians; and conservation and sustainable resource use, scientific excellence, and marine safety, and environmental protection" [431].

DFO has never formally operated a research program on Lake Winnipeg. The Freshwater Institute situated in Winnipeg was operated by the Fisheries Research Board of Canada, a crown agency in 1969 to 1970 when a group of federal scientists undertook an intensive study of Lake Winnipeg (see Section 5). In 1972, the Freshwater Institute was established as a federal government agency and shortly thereafter became the Headquarters for the DFO Central and Arctic Region. Later, in the mid 1990s, scientists from the Geological Survey of Canada conducted geophysical and paleolimnological studies of Lake Winnipeg with minor involvement of DFO scientists. In 1999, a group of DFO and other researchers that would form the Lake Winnipeg Research Consortium undertook active and comprehensive research on the lake with the cooperation of the Coast Guard. Thus, Lake Winnipeg research has not been a DFO program to date.

Like DOE, DFO is reviewing policy and practices to bring them more in line with the current complex operating environment. DFO is proposing a renewed *Fisheries Act*, to modernize the current one promulgated in 1857, and better reflect and respond to the evolving needs of fisheries resources and citizens' expectations. Essentially, resource users and citizens wish to see[432]:

- stable management framework
- allocation stability
- participatory decision-making – greater role of provinces and territories, commercial fleets, Aboriginal groups, recreational fishers and others in planning, policy-making and operations
- co-management
- more effective enforcement and administrative sanctioning.

In 2004, DFO has initiated an Environmental Process Modernization Plan (EPMP) to improve Habitat Management Program, including permitting, focused on five elements[433]:

- risk management framework – to allow DFO to focus on projects that pose the highest risk to fish habitat
- streamlining regulatory reviews
- coherent and predictable decision-making – more national consistency in decisions
- new management model for major projects and environmental assessments
- enhanced partnering.

Recently, in a highly significant contribution to research on Lake Winnipeg, DFO's Coast Guard transferred ownership of the former Class 900 Buoy tender, now the MV Namao to the Lake Winnipeg Research Consortium.

Agriculture and Agri-Food Canada (AAFC)

Three years ago, federal and provincial governments and the agriculture and agri-food industry launched the Agricultural Policy Framework (APF), a national plan to drive the Canadian agriculture and agri-food industry to the number one position as the preferred supplier in the international marketplace. The policy has key elements:

- Food Safety and Food Quality
- Environment
- Science and Innovation
- Renewal
- Business Risk Management [434]

Under the Environment element are the goals of:

- Reducing risks and providing benefits to health of
  - water, with priority on nutrients, pathogens, pesticides and water conservation
  - soils, with priority on soil organic matter and erosion
  - air and the atmosphere, with priority on particulate matter, odours, and greenhouse gas emissions
- Ensuring compatibility between biodiversity and agriculture
  - with priority on habitat availability, species at risk, and economic damage to agriculture from wildlife.

By way of implementation, the Government of Canada developed the Environmental Farm Planning Initiative to help Canada's agricultural producers develop and implement environmental farm plans (EFPs). These are to help the agricultural sector better identify its impacts on the environment and promote the growth of stewardship activities within the agricultural industry such as by implementing beneficial management practices (BMPs) and to continuously evaluate the environmental performance of their farming operations.

More recently, AAFC is proposing the development of a National Strategy for Agriculture Science and Innovation. While focusing most attention on farm commodity prices, the Strategy is also concerned with the relationship between agriculture and the environment. The shift towards larger, more intensive farms is raised as the possible cause of agriculture's increasing negative impact on the environment.

Health Canada – Water Quality and Health Bureau

The Water Quality and Health Bureau handles aspects of drinking water, such as assessment of exposure and impact on human health of selected contaminants in tap and groundwater, assesses drinking water treatment processes, promotes public awareness. Moreover, Health Canada works in partnership with First Nations to ensure that drinking water quality monitoring programs are in place[435].

Indian and Northern Affairs Canada (INAC)

INAC has primary, but not exclusive, responsibility for meeting the federal government's constitutional, treaty, political, and legal responsibilities to First Nations, Inuit and Northerners. INAC's primary role is to support First Nations and Inuit in developing healthy, sustainable communities and in achieving economic and social aspirations. Responsibility for drinking water and wastewater treatment is shared between First Nation Band Councils and the federal government.

NATIONAL ORGANIZATIONS

National Round Table on the Environment and Economy (NRTEE)

The NRTEE was established in 1994 as an independent advisory body reporting to governments and the Canadian public. Appointed by the Prime Minister, members represent business and labour, universities, environmental organizations, Aboriginal communities and municipalities.

The NRTEE sees climate change adaptation as integral to economic and social development in the boreal. As one of seven broad-based recommendations on sustainable development in the boreal, NRTEE recommends[436]:

- Federal, provincial, territorial, Aboriginal and community-level governments, industry, and civil society organizations should cooperate to:
  - improve understanding of how climate change may affect the boreal and its residents
  - help build awareness among their constituencies of the challenges posed by climate change and of the need to put in place adaptation strategies to reduce the environmental, social and economic impacts of climate change
  - support the development and implementation of adaptation strategies at the sectoral and community levels to reduce the potential social and economic impacts of climate change in the boreal.

GOVERNMENT OF MANITOBA

Manitoba Water Stewardship

Manitoba Water Stewardship was created in November, 2004. Manitoba was the first jurisdiction in Canada to create a stand-alone department dedicated to water management. Manitoba Water Stewardship is comprised of 15 components[437]. The Ecological Services Division is responsible for planning and co-ordination, transboundary issues, water science and management, fisheries and drinking water. The Infrastructure and Operations Division is responsible for water licensing, water control infrastructure and regional operations. Since the department's formation, the *Water Protection Act* has been tabled in the legislature[438]. This important legislation will govern water in Manitoba into the future, allowing for stricter water-quality standards, regulation of water-quality management zones for nutrients and control of invasive species through regulation. The act recognizes that watershed planning is an effective means to address risks to water resources and aquatic ecosystems and it will provide a comprehensive framework for integrated watershed management.

A long-term vision and goal for the protection and restoration of Lake Winnipeg was announced by Manitoba Water Stewardship on February 18, 2003 with the release of the *Lake Winnipeg Action Plan*[439]. The Action Plan is a commitment to reduce nitrogen and phosphorus loads to Lake Winnipeg to pre-1970s levels. *Lake Winnipeg Action Plan* was developed in part from scientific research conducted through the Nutrient Management Strategy[440] and will be updated as studies continue. *Lake Winnipeg Action Plan* recognizes that nutrients are contributed by most activities occurring within the drainage basin and that reductions will need to occur across all sectors.

Action under the six-point plan includes:

- establishment of a Lake Winnipeg Stewardship Board to help Manitobans identify further actions necessary to reduce nitrogen and phosphorus to pre-1970 levels in the lake by 13 percent or more, subject to further findings of the Nutrient Management Strategy
- introduction of new measures to help protect natural growth along the Red and Assiniboine rivers to prevent erosion and reduce nutrient run-off into the rivers to complement the Riparian Areas Tax Credit introduced in 2001
- provision of a program to expand soil testing to ensure appropriate fertilizer application in both rural and urban settings
- introduction of a new sewage and septic field regulation that will outline clear standards for the placement of systems

- development of a shoreline protection project in partnership with Manitoba Hydro to help address erosion concerns
- commencement of cross-border nutrient management discussions.

Lake Winnipeg Stewardship Board

The role of the Lake Winnipeg Stewardship Board[441] (LWSB) is to assist the government of Manitoba to achieve the main commitments in the *Lake Winnipeg Action Plan* of reducing phosphorus and nitrogen in the lake to pre-1970 levels. Board members represent a variety of interests, including fishing, agriculture, urban land use, First Nations, federal, provincial and municipal government, and non-governmental organizations. The Board reports through the Chair to the Minister of Water Stewardship.

In January 2005, the LWSB released its first interim report[442] with recommendations under 32 topics. The results from public consultation on the interim report have recently been released[443]. Selected recommendations are:

- Transboundary and inter-jurisdictional issues
  - Work towards reducing the loadings of nitrogen and phosphorus from the U.S. Saskatchewan and Alberta, and strengthen relationships with First Nations on water quality issues
- Livestock
  - Pursue a variety of activities to reduce impact of livestock production on water and riparian areas
- Watershed nutrient practices
  - Encourage matching of nutrient inputs with crop requirements
- Integrated Watershed Management Planning and Management
  - Base Watershed Management Districts on natural watershed boundaries, consider the impacts of all types of drainage
- Restriction on cosmetic use of phosphorus-based fertilizers
- Water usage, sewage treatment, and related financing
  - Ensure all Manitobans are served by effective wastewater treatments facilities or practices
  - Establish mechanisms for Manitobans to pay the true cost of water and wastewater services; encourage water use efficiency
- Science needs for the long-term protection of Lake Winnipeg
  - Implement a collaborative, long-term science plan for Lake Winnipeg
- Public and formal education on water quality protection and watershed citizenship

Livestock Stewardship Initiative

In March 2000, the Government of Manitoba announced the Livestock Stewardship Initiative (LSI) with the goal of ensuring the sustainable development of Manitoba's livestock industry. The LSI sought views of Manitobans on the expansion of the livestock industry in Manitoba, particularly around common ground between the livestock industry and Manitoba's environment and rural landscape. Views expressed included the concern that the regulation of (hog) manure spreading according to nitrogen content rather than phosphorus content leads to over-application of phosphorus and the potential for eutrophication, including that of Lake Winnipeg. The report acknowledges that phosphorus is the critical nutrient influencing the primary productivity and development of algal blooms in freshwater ecosystems.

The formal recommendations with most relevance to watershed processes and other environmental concerns are[444]:

- Government focus substantially increased resources on the intensive livestock industry in Manitoba to provide analysis, guidance, inspection, monitoring, enforcement and technological assistance that can accommodate the present scale of the industry and anticipate its expansion. Capability to undertake comprehensive analysis of the potential impact of new or expanded ILOs (intensive livestock operations) upon both local and larger area environments should be enhanced immediately in order to lead to strong critical decisions.

- Government of Manitoba should accumulate all relevant data concerning livestock operations in a central openly available information system in a geographic information (GIS) format to provide Manitobans with a realistic assessment of the sustainability of current operations and their effect on both the local and provincial environments.
- For large scale livestock operations, monitor and enforce environmental and health regulations with a view to enabling these farms to be competitive in export markets while ensuring environmental stewardship.
- New and expanding ILOs should require formal approval by both the host municipality for compliance with land use by-laws, and the province for environmental impact before construction is allowed to begin.

A supporting recommendation included:

- The province should move toward regulating manure application according to phosphorus content of soil and manure, and future ILOs should be located in order to provide sufficient acres for manure application according to phosphorus content.

Manitoba Livestock Manure Management Initiative Inc.

The Manitoba Livestock Manure Management Initiative Inc.[445] (MLMMI) was set up in 1998 to bring a livestock industry-driven approach to address concerns over manure odour and management in Manitoba's growing livestock industry. The Initiative is directed by a volunteer board of industry and related professionals.

> Among other objectives, MLMMI fosters and supports technical and commercial initiatives that enhance the sustainability and acceptability of livestock operations from the perspective of:
> - odour
> - manure management
> - environmental impacts
> - public information and opinion

Particularly relevant to Lake Winnipeg is the MLMMI support of projects on the role and fate of phosphorus in livestock and crop production systems with reference to Manitoba. This is in response to concerns about increasing concentrations of phosphorus in Manitoba's surface waters.

INTERPROVINCIAL ORGANIZATIONS

Prairie Provinces Water Board

The Prairie Provinces Water Board (PPWB)[446] was formed in 1948 by Saskatchewan, Alberta, Manitoba and Canada to recommend the best use of interprovincial water and recommend water allocations between the provinces. This worked well until the 1960s, when the provinces began requesting large allocations of water. The approach used by the Board was no longer adequate to allow long-term water planning by the provinces and a new system for sharing this limited resource was developed. In 1969, the parties to the original agreement signed the Master Agreement on Apportionment, that is still in effect today. It embodies the principle of equal sharing of available water in the prairies by stating that Alberta and Saskatchewan may each take up to one half of the natural flow of water originating within its boundaries and one half of the flow entering the province. The remainder is left to flow into Manitoba.

Natural flow is defined as the volume of flow that would occur in a particular river if that river had never been affected by human activity. Calculating this amount can be difficult but the result is that all three provinces, even in drought periods, end up with approximately equal shares of the total water flow. It is up to each province to decide how to use their share of water. Environment Canada monitors the conditions described under the Master Agreement and provides information from 75 long term water quantity monitoring stations, 16 meteorological stations and12 water quality monitoring sites. Other agencies provide information from an additional 13 water quantity monitoring stations. Five of the water quantity stations are also used for international apportionment calculations. The information collected at these stations is used to calculate natural flows and the levels of water quality parameters.

The values calculated for 14 water quantity and 12 water quality monitoring sites along the Alberta-Saskatchewan and Saskatchewan-Manitoba borders are used to inform the PPWB whether requirements of the Agreement are being met.
Groundwater is a critically-important source of water for people on the prairies where 33 per cent of the population depends on groundwater to some extent. Aquifers that extend across one of the common borders of the prairie provinces fall under the mandate of the PPWB. The board deals with interprovincial groundwater concerns through its Committee on Groundwater (COG) - a permanent committee of the PPWB. The COG's main area of responsibility is to advise and make recommendations on the management of interprovincial groundwater.

FIRST NATIONS

Southern Chiefs' Organization Inc. (SCO)

The Southern Chiefs' Organization Inc. adopted their constitution on 25 July, 2000. The mission of the organization is to establish an independent political forum to protect, preserve, promote, and enhance First Nations peoples' inherent rights, languages, customs, and traditions through the application and implementation of the spirit and intent of the Treaty-making process[447]. The SCO played a role in educating the public about water issues, Lake Winnipeg, and First Nations perspectives through their Water for Life 2005 Conference in Winnipeg on 19-20 October, 2005[448]. High profile scientist, Dr. David Suzuki, Chair of the David Suzuki Foundation was a featured speaker. The SOC also distributes South Wind, an official newspage that serves to communicate and inform.

Centre for Indigenous Environmental Resources (CIER)

The Centre for Indigenous Environmental Resources is a national First Nation-directed environmental non-profit organization founded in 1995[449]. The organization offers research, technical services and education and training services to Indigenous communities, governments and private companies in four inter-related topic areas: forests, climate change, water, and sustainability.

Water, fundamental to the existence of all life, holds special significance in Indigenous communities. CIER's projects focus on the water rights of Indigenous communities and how to protect these rights. Assessing the impacts on Indigenous communities of water policy and water management strategies is a focus.

A particular emphasis of CIER is education and training. Most Aboriginal communities require training in technical and scientific skills to identify, record, interpret, monitor, problem-solve and engage in an ongoing process of environmental protection of their lands. In a needs assessment carried out by CIER in 1993-1994, First Nations were unanimous in their identification of the lack of qualified First Nation personnel to begin to deal with these issues. One training stream, Environmental Education & Training Program (EETP) provides theoretical and technical environmental training to Aboriginal youth. In all of the courses offered in the EETP both an Indigenous and western perspective are taught and discussed by a teaching team of Aboriginal and western instructors. As a result, the EETP environmental courses are unique, culturally-based, and emphasize the importance of including Aboriginal knowledge of the environment.

The integration of Aboriginal traditional ecology knowledge (TEK) with western science approaches is a particular on-going strength of CIER in Manitoba. This program is in partnership with the University of Manitoba so that credits from EETP can be used towards a university degree.

Manitoba Commercial Inland Fishers Federation

The Manitoba Commercial Inland Fisheries Conference (MCIFC) organized by the Assembly of First Nations (MB) in April, 2005 resolved to establish the Manitoba Commercial Inland Fishers Federation. The Federation is a province-wide representative body of the Manitoba Commercial Inland Fishers set up in response to a variety of challenges that threaten the commercial fishing livelihood and the future of communities, including environmental challenges. Other resolutions urged full enforcement of all legislation and regulations related to the protection of fish and fish habitat and improved measures to enhance and clean up natural spawning areas and the issuance of commercial licences to harvest rough fish as the market demands.

SCIENTIFIC COMMUNITY

Lake Winnipeg Science Workshop (LWSW)

A science workshop was held in November, 2004 through collaboration by Manitoba Water Stewardship, Fisheries and Oceans Canada, and Environment Canada. It provided the following specific advice to the departments[450]:

- The Departments should develop an integrated science program proposal for funding within each Department, based on the research proposals described in this workshop.
- The Departments should develop an overarching administrative framework, similar to the Lakewide Management Plans developed under the Great Lakes Water Quality Agreement, for their joint management responsibilities for the Lake Winnipeg aquatic ecosystem.
- The Departments should support ongoing governance mechanisms and initiate new mechanisms to ensure coordination of scientific activities on the Lake and its watershed to ensure that those activities address stated management needs.
- The Departments should initiate triennial State of Lake Winnipeg Conferences to inform the public and the scientific community of the health of the system. As a first step to the establishment of regular conferences, the Departments should immediately begin the preparation of a State of the Lake report for Lake Winnipeg to provide a baseline for future progress to measure achievement of goals to improve the condition of the Lake.
- The Departments should develop a comprehensive program of integrated monitoring of the biological, chemical and physical components of the Lake Winnipeg ecosystem and its watershed based on management objectives and science-based ecosystem indicators.

ACADEMIA

University of Manitoba

Science Departments

With the DFO Freshwater Institute situated on the University of Manitoba campus there has collaboration on aquatic issues, including Lake Winnipeg, for decades. Professors and students from several University of Manitoba departments are presently integrally involved with the Lake Winnipeg studies of the FWI and the LWRC. These include the Department of Zoology[451], the Faculty of Science[452], and the Clayton H. Riddell Faculty of Environment, Earth, and Resources' Centre for Earth Observation Science[453] (CEOS). CEOS provides satellite photos of Lake Winnipeg on a current basis and retrospectively back to 1985 to track trends in eutrophication. Several theses on Lake Winnipeg have been completed by students of the Natural Resources Institute.

Department of Agribusiness and Agricultural Economics

Recommendations on regulating phosphorus originating from agriculture in Manitoba came from a study funded by the Manitoba Livestock Manure Management Inititative[454]:

- Given that about 60 per cent of phosphorus loadings in the Red River originate from U.S. sources, efforts need to be expended by the Government of Manitoba to work with U.S. jurisdictions to reduce phosphorus loadings before they enter Manitoba.

- There is a need for a more collaborative approach among government departments and agencies in the development of a phosphorus management strategy for Manitoba, especially among Manitoba Agriculture, Food and Rural Initiatives, Manitoba Conservation, Environment Canada's National Water Research Centre, and Fisheries and Oceans Canada's Freshwater Institute.
- Develop a comprehensive approach to nutrient management, with manure and phosphorus as components.
- Invest in research to reduce phosphorus in manure (e.g. phytase management and other feed additives), before regulating phosphorus.
- Monitor and regulate on a watershed basis rather than an individual farm basis, focusing first on regions with high nutrient loads.
- Implement soil phosphorus regulations that include a voluntary education program on best management practices within a regulatory framework.
- Planning of initial siting of intensive livestock operations (ILOs) should be a high priority.
- Evaluate regulatory tools to ensure the choice is scientifically sound, targeted to ameliorate environmental concerns while minimizing unnecessary constraints on agricultural activities.
- Government has to commit sufficient resources for monitoring and enforcing theregulations for regulations to be effective.
- Legislation and regulation regarding phosphorus management should be introduced cautiously to ensure environmental protection without undue hardship to the agricultural industry.

Some cautions are added:

- Tighter environmental regulations will impact small-scale farm operators more negatively than large-scale farm operators. Larger farm operations are in a better position to have the financial resources, technical knowledge, and human resources to know and follow increasingly complex regulations.
- Regulations add to the costs of production and decrease the competitiveness of the agricultural sector. The Province of Manitoba should not get too far out in front with its regulation of the livestock industry relative to competing jurisdictions in Canada and the U.S.

Research Chair

The Vice-President (Research), University of Manitoba[455] proposed the establishment of a Research Chair in Watershed Management. The activities of this Chair will:

- develop bridges between terrestrial and aquatic sciences, adding essential expertise at the soil-water interface, where the process of water contamination is initiated.
- play an important role in efforts to understand the processes and development of the management practices that will improve the quality of our streams, rivers and lakes in Manitoba.
- have broad applicability as a model system for other watersheds in Canada and internationally, giving high profile to this provincial initiative, enriching the educational and training experience of the undergraduate and graduate students, providing exciting opportunities for their involvement in this endeavour.

University of Winnipeg

Full professor, Dr. Eva Pip at the University of Winnipeg has focused attention on Lake Winnipeg and the Nelson River with her long-term research and teaching interests in heavy metal cycling in freshwater aquatic ecosystems, aquatic mollusc biogeography, aquatic macrophyte ecology and biochemistry, and water quality and public health[456].

NON-GOVERNMENTAL ORGANIZATIONS

Manitoba Eco-Network Water Caucus (MBEN-WC)

The Manitoba Eco-Network is an umbrella for environmental non-government organizations (ENGOs) throughout the province. It is a registered charitable organization , and a regional affiliate of the Canadian Environmental Network, based in Ottawa[457]. One of the project areas of MBEN is the Water Caucus (WC). The WC brings together a core of 30 environmental, labour, consumers, and citizens groups around water issues to share information and resources, prioritize issues, and support positive actions for improved water stewardship. It has met since November, 2004 and includes water-related member groups of MBEN as its core, and actively seeks out and interacts with other water interest groups around the province. A key function of the Caucus is to encourage and facilitate broader ENGO and citizen involvement in water stewardship activities[458]. The WC offered advice to the Lake Winnipeg Stewardship Board on issues pertaining to the nutrient problems and solutions for Lake Winnipeg[459]:

- Embrace a holistic approach in developing solutions to the nutrient problem of Lake Winnipeg, and including other pollutants within the scope of the review.
- Monitor a number of issues that may impact the integrity of the Lake Winnipeg ecosystem:
  - hydro development and the regulation of Lake Winnipeg as a reservoir
  - the reduced flows of the Saskatchewan River
  - East Side of Lake Winnipeg planning process and potential impacts resultant from increased development
  - climate change and related impacts to water quantity and quality
  - North Dakota's Red River Valley Water Supply Assessment
  - Non-nutrient contaminants relating to waste water and runoff, including pesticides, pharmaceuticals, endocrine disrupters, household and industrial cleaners
- Resolve with the federal and provincial governments which nutrients are required to control eutrophication.
- Request that both the federal and provincial governments substantially increase investment for the protection of our water resources, such as for watershed planning, improving our baseline data, implementing the Lake Winnipeg remediation plan, and hiring staff for monitoring, enforcement, research, education and public outreach.
- Estimate costs of any incentive and/or instrument recommended, whether voluntary, regulatory or financial. Consideration should also be given to ease of implementation and expected results.
- Consider potential side effects when making recommendations; improvements on one side of the equation may have severe impacts of the other side. Seek at-source solutions that are superior, environmentally and economically, to end-of-pipe solutions.
- Support more regulatory action and accountability and less voluntary compliance.
- Include stronger federal perspectives on the LWSB.

Water Caucus participants perceived that major governmental departments and agencies responsible for environmental (and water) protection lack the resources, capacity and sometimes the will to ensure that Manitoba's environment is safeguarded and that human health impacts are addressed. They identify the priority issues in governance as[460]:

- Stable leadership at the ministerial and deputy minister levels of provincial departments responsible for water resources; cooperation among all department and ministries involved with water resources; suggestion that the Premier demonstrate a strong commitment to protecting Manitoba's water resource by ensuring that stability and co-operation.
- Substantially increase financial resources to Water Stewardship for staffing in a large number of program areas, including enforcement; explore socially-acceptable economic instruments to generate new revenue.
- Ensure succession of ability and expertise in Departments of Conservation and Water Stewardship prior to staff retirements; training opportunities for staff; and an adequate range of policy and other advisors.

- Ensure timely release to the public of data on water resources monitoring, use, emerging developments and issues.
- Support and improve citizenship consultation processes, including those with First Nations, for developing laws, regulations, policies and programs, observing OECD guiding principles of commitment, rights, clarity, time, objectivity, resources, coordination, accountability, evaluation and active citizenship[461].
- Include a number of these principles in watershed planning authorities.
- Build citizen capacity and trust by empowering communities through volunteer water monitoring programs[462].

Manitoba Wildlands (MW)

Manitoba Wildlands is a non-profit environmental organization in Manitoba, that continues the protected areas work of World Wildlife Fund (WWF) Canada and Nature Canada in Manitoba[463]. Working with Manitoba communities, industry sectors, and environmental organizations, MW supports establishment of protected areas in Manitoba, with a special focus on Manitoba's boreal forest. To this end, the organization also provides information about and participates in public processes that affect Manitoba lands and waters, decisions for use of crown (public) lands and water. ManitobaWildlands.org, the website of Manitoba Wildlands, includes a significant amount of technical information about lands decisions and processes. The site makes a wealth of information about Lake Winnipeg accessible to the public, including information on the Lake Winnipeg Stewardship Board, the Lake Winnipeg Research Consortium, Manitoba Conservation Districts, the Devil's Lake Outlet project, and the East Side of Lake Winnipeg Land Use Planning project.

Manitoba Wildlands provides advice on Land Use Planning for East Lake Winnipeg Development. The organization supports the view of COSDI (Consultation On Sustainable Development Implementation) that Manitoba must change from a system where 'development drives planning' to a system where large area land use planning, based on sound social, environmental and economic principles, drives development decisions. Considerable infrastructure and industrial development is proposed for the East Side[464].

Manitoba Wildlands provided input to the Lake Winnipeg Stewardship Board (LWSB) in November 2004[465] January 2005[466] and April 2005[467]. These submissions are available electronically. Highlights are given here. MW agrees there is an immediate need to address the excessive level of nutrient loading in the Lake Winnipeg and Red River basins. The organization also advises:

- Use existing documents and reports in making LWSB recommendations and monitor the uptake of recommendations relevant to LWSB's mandate.
- Co-ordinate, communicate and partner with various inter-jurisdictional bodies with responsibilities for these waters.
- Recognize the value of the independent Lake Winnipeg Research Consortium; support funding for its activities; urge timely public release of research results.
- Encourage a public awareness campaign to encourage citizen and householder responsibility and empowerment.
- Adopt a set of Lake Winnipeg principles, including the precautionary principle.
- Restrict, reduce and regulate septic fields; precautionary siting of Intensive Livestock Operations; encourage the completion of Manitoba's Nutrient Management Plan in order to better manage waste water and protect ground water.
- Improve cumulative impact assessments (through increased transparency and resources for independent review and analysis) as one way of addressing Manitoba's environmental deficit.
- Invest in traditional ecological knowledge and local knowledge and meaningfully consider this knowledge in decision processes.
- Encourage the development of soil nutrient inventories and guidelines for the application of fertilizers in Manitoba and the U.S.
- Examine the linkages between hydro water power licences, regulation of Lake Winnipeg and nutrient loading in Lake Winnipeg; offer advice to the Manitoba government about mitigation.
- Audit landfills to identify risks; GIS map all nutrient sources and landfills as a planning tool.

Lake Winnipeg Shoreline Erosion Advisory Group

Property owners, First Nations, Metis, and municipalities are very concerned about erosion on Lake Winnipeg that is resulting in a significant loss of both private property and beaches. There is general frustration that there is no regulatory or other body that represents the interest of First Nations, property owners, commercial interests and environmental interests. Moreover, there is felt to be a lack of advice available concerning design and construction of appropriate shoreline protection measures. Consequently, there has been the construction of a wide range of shoreline protection measures on private and public land and impediments to access and use of beaches and shorelines.

In an effort to learn more about the lake and support efforts to protect shorelines, the Manitoba Ministers responsible for the Manitoba Hydro Act and for Natural Resources established the Lake Winnipeg Shoreline Erosion Advisory Group[468]. This independent public advisory group was made up of 15 representatives from various stakeholders around Lake Winnipeg including First Nations, Metis, municipalities, local residents, cottage owners, realtors, academics, and engineers. The advisory group was charged with assessing the accuracy and integrity of Manitoba Hydro's reporting of Lake Winnipeg water level data and methodology as well as looking for practical options for addressing the erosion problems. The group received support from Manitoba Hydro.

The Group delivered the following recommendations[469]:

- An Advisory Board be established to
  - review and consider management issues relative to erosion and environmental issues
  - prepare and implement an overall shoreline management plan, including design and construction standards for docks, boathouses; standards for shoreline protection; a system for approval of design and construction; development standards for shoreline development including building setbacks, elevations, sewage management and disposal
  - participate in a semi-annual review of lake levels; more frequently during unusual hydrological events
  - monitor erosion
  - monitor shoreline protection demonstration projects
  - hold public meetings
  - coordinate development of technical support
- Advisory Board members would include technical experts as well as stakeholders
- Regulation and/or legislation should be enacted to control the design and placement of structures on the Lake Winnipeg shoreline
- Three demonstration projects be constructed to demonstrate proper techniques and to evaluate designs and monitored over at least ten years.
- Adoption of the Lake Winnipeg Shoreline Protection Handbook as the reference standard for design and construction of shoreline structures.
- Long-term commitment to provision of advisory services to municipalities and cottage owners such as through a professional advisory service for a period of five years. This recognizes that erosion issues are site-specific.
- Actual water levels should be reported on a daily basis throughout the open water season and forecasts given of expected events. Manitoba Hydro act to maintain water levels within the target range. An internet website should be developed to report instantaneous water levels at various locations throughout the South Basin.
- Wherever practical, non-structural solutions to erosion should be adopted. If required, structural solutions should replicate natural processes and work with natural processes. Solutions that oppose natural forces should be used carefully and only is specific situations.

Citizens for the Responsible Application of Phosphorus

Recognizing that the supply of phosphorus to surface waters in Manitoba, including Lake Winnipeg is the source of eutrophication, this citizens' group urges peer-reviewed, scientific research be undertaken soon to determine a safe upper limit for phosphorus in soil. Once this level is determined, they urge that immediate adjustments to manure application practices to this limit be made.

FOUNDATIONS

Lake Winnipeg Foundation

The Lake Winnipeg Foundation was established in 2005 with a mandate to actively promote the health of Lake Winnipeg. The Foundation supports:[470]

- scientific research
- public education through the sharing of the results of research
- advocacy to encourage governments to promote ecological health through legisltation, policy and programs
- implementation of appropriate watershed management plans
- co-ordination of people working on issues that affect the lake.

The Foundation is a membership-based organization.

NEW OR EMERGING MULTISTAKEHOLDER ORGANIZATIONS

Lake Winnipeg Research Consortium (LWRC)

The LWRC is a unique research and educational organization focused on Lake Winnipeg that came about fortuitously and has played a significant role in bringing national attention to the deterioration of Lake Winnipeg. It is a self-reporting coordinating group with no formal reporting mechanism to any agency or formal management responsibility for Lake Winnipeg.

> **Awareness is the first step in solving a problem.**
> **- Al Kristofferson, Coordinator, LWRC**

The LWRC is based around the ownership and operation of the research vessel, the MV Namao, a Class 900 Buoy tender, built in 1975, that was operated by Coast Guard to set navigational buoys on Lake Winnipeg. In 1998, buoy tending was privatized and the ship was scheduled to be decommissioned. A group of forward-thinking researchers and environmentalists recognized the value of this vessel to science on Lake Winnipeg.

Fig. 40. The MV Namao proudly displaying her new colours[471] .

The vessel was known to researchers since it had been used for cruises on Lake Winnipeg in 1994 by the Geological Survey of Canada. It was found to be eminently suitable for research in terms of size, stability, and space for deploying scientific sampling equipment.

The LWRC was founded in 1998 and incorporated as a not-for-profit in 2001. It is comprised of a Board of Directors of six members and an 24 additional members-at-large who together represent commercial and recreational fishing organizations, the Universities of Manitoba and Winnipeg, aboriginal groups, a variety of NGOs, and federal and provincial agencies, and other organizations[472]. Although this membership is diverse, there is a common goal to better understand the biological, chemical and physical processes that are critical to the well being of Lake Winnipeg, and to provide information key to managing and sustaining its positive values.

The LWRC was initially formed to seek funding for, and to coordinate scientific cruises of, the MV Namao, under a Memorandum of Understanding with the Canadian Coast Guard. The LWRC now owns the MV Namao (Fig. 40), a vessel with a replacement cost of about $10 million. Based on this valuable asset, the LWRC has the capability to provide ship time to provincial, federal, and university researchers, to offer educational opportunities for high school and university students and the public, to provide objective results on the health of Lake Winnipeg in a timely way. Moreover, it can attract researchers from outside Manitoba and Canada and provide a climate for synergistic collaboration and cooperation. The LWRC hosts an annual research forum to report results to the scientific community, managers, lake residents, and the public.

The organization is a diverse, independent, and flexible organization equipped to undertake not only long-term research studies but also to quickly respond to emerging issues. Its formal objectives are to:

- Facilitate scientific research on Lake Winnipeg to gain a better understanding of the biological, chemical and physical processes that are critical to its well-being.
- Create educational opportunities and increase public awareness of the ecology of Lake Winnipeg and environmental issues facing the Lake.
- Expedite information exchange and foster co-operation among all stakeholders.
- Provide a research platform, the MV Namao, for research and education on Lake Winnipeg[473].

Lake Winnipeg Watershed Action Council (LWWAC)

A group of interested stakeholders have come together as the LWWAC Interim Board to recommend that the Government of Canada form a Lake Winnipeg Watershed Action Council with a mandate to examine the watershed as a whole, and to seek the best ways to ensure the future viability of this valuable resource, through consultation with interested parties, organizations, Federal, Provincial and State governments. Further, they recommend that the Federal government take a leadership role in implementing recommendations from the Lake Winnipeg Watershed Action Council[474]. The organizational structure of the LWWAC, the roles it will play, and its terms of reference are being determined. It is envisioned as a body that is non-partisan, inter-provincial and international. Possible roles for the organization include watchdog, advocacy, educational, advisory to government, lobbying, and provider of awards for excellent watershed activities.

6. Conclusion

Overall, except for signs of extreme eutrophication, Lake Winnipeg appears to relatively free of hazardous and toxic chemicals, supports a productive fishery, and generally provides safe living environments and recreational opportunities. Yet, there is a fragility and sense of unpredictability associated with our lack of sound knowledge about the basic ecology of the lake, the impacts of eutrophication, the sustainability of the fisheries, and the implications of a changing climate.

The reduction of nutrient loading to the lake is a clear requirement for reversing eutrophication in Lake Winnipeg. This is a complex issue involving reducing a number of point and non-point sources in Canada and the U.S. As well, there are confounding factors that add further complexity to the determination of appropriate action in order to restore and maintain the ecological, economic, social, and spiritual values of Lake Winnipeg. These factors include the fact that the lake is now a reservoir. The natural hydrology is being significantly altered. The ecosystem has been altered by the invasion of non-indigenous species. But most challenging is climate change that profoundly changes water flows, natural and anthropogenic inputs of nutrients, temperature, ice, permafrost, and the ranges of organisms. It will not be possible to turn back the clock. Rather, a plan for action will need to focus on better managing the human activities under our control while adapting to natural events that are beyond our direct influence.

Two of the problems facing Lake Winnipeg, nutrient over-enrichment and climate change, are of global significance. Released in July 2005, the Millennium Ecosystem Assessment, a four-year, U.S. $24 million report by 1,400 experts from 95 countries, has as one of its key messages[475]: "Among the outstanding problems identified by this assessment are the dire state of many of the world's fish stocks; the intense vulnerability of the two billion people living in dry regions in the loss of ecosystem services, including water supply; and the growing threat to ecosystems from climate change and nutrient pollution".

Changes to the ways human activities are managed in the Lake Winnipeg sub-basin are required. Clearly, many organizations and individuals from various walks of life are concerned about the present state of Lake Winnipeg, are proposing and taking action, and are willing to work together to restore the health of Lake Winnipeg. A healthy Lake Winnipeg is not only an ecological and scientific imperative, it is also an economic and social one. As noted by the World of Business council for Sustainable Development[476], "Business cannot function if ecosystems and services they deliver - like water, biodiversity, fiber, food, and climate - are degraded or out of balance". The time for action is now.

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Glossary

Anatoxin also known as Very Fast Death Factor - a potent alkaloid toxin derived from a species of cyanobacteria called *Anabaena flos-aquae*; a severe neurotoxin, affecting the functioning of the nervous system, and often causing death due to paralysis of the respiratory muscles.

Anthropogenic - Caused by human activity; human-induced

Boreal - referring to a far northern region; boreal forests are dominated by cone-bearing trees and typically found between the temperate deciduous forests to the south and the treeless tundra to the north.

Cyanophytes or Cyanophyceae, also referred to as 'blue-green algae' – actually are a large and varied group of bacteria, the cyanobacteria, without a true nucleus, but because they contain chlorophyll and undergo photosynthesis they are often referred to as algae.

Drainage basin[1] – the area of land drained into a river than ends in the sea, e.g., Nelson River Drainage Basin that ends in Hudson Bay.

Ecozone - a broad-scale ecological unit that is based on patterns that include climate, geography and ecological diversity.

Endocrine disruptors - substances that interfere with the endocrine system by mimicking, blocking or otherwise disrupting the function of hormones. Thereby affecting development, growth, or reproduction in people and animals.

Eutrophication - over-enrichment of a water body with phosphorus or the response of the biological community to phosphorus over-enrichment, resulting in excessive growth of organisms, such as algal blooms, and depletion of oxygen concentration.

Exotic species, also referred to an non-indigenous species - a species that did not originally occur in the areas in which it is now found, but that arrived as a direct or indirect result of human activity.

Glacial rebound - vertical raising of a portion of the earth's crust following the removal of an ice mass also referred to as deglaciation.

Glaciation - the condition of being covered with glaciers or masses of ice; a period during which the polar ice-caps extend towards the equator, covering large areas of the Earth and altering the land surface.

Greenhouse gas – A gas, such as water vapour, carbon dioxide, methane, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), that absorbs and re-emits infrared radiation, warming the earth's surface and contributing to climate change.

Indicators - are pieces of evidence that tell us about the condition of something of interest, such as the state of the environment, the impacts from human activity, or the actions that are being taken for environmental protection and improvement.

Indigenous species, also referred to as endemic species - A species that is native or naturally occurring in a specific area; plants and animals that live in a place without human influence.

Microcystins – a class of peptides (components of protein) produced by some cyanobacteria; can be very toxic plants and animals including humans; they may be accumulated by organisms and cause damage to or cancer of the liver.

Nutrient – substances that provide nourishment and promote growth of micro-organisms and vegetation; include nitrogen, phosphorus, carbon, hydrogen, oxygen, potassium, sulfur, magnesium and calcium, as well as minor elements such as iron, zinc, copper, manganese, boron, molybdenum and chloride.

Nutrient loading – the quantities of the principal nutrients, nitrogen and phosphorus entering a river, stream, lake or other body of water per unit time; occurs naturally with seasonal variation at levels characteristic of the ecozone; can be modified considerably by human activity.

Paleozoic – one of four geological eras, extending from about 570 to 225 million years ago, from the end of the Precambrian to the beginning of the Mesozoic.

Precambrian – the first of four geological eras extending from the formation of the earth to the beginning of the Paleozoic about 600 million years ago; equivalent to 90 per cent of geologic time.

Sub-basin[1] – major portion of a drainage basin, upstream of the river that flows into the sea; e.g., Lake Winnipeg Sub-basin that ends at the outflow of the lake into the Nelson River.

Taxonomy - the scientific discipline of naming organisms; the classification of organisms in an ordered system that indicates natural relationships; the theory and practice of classifying, i.e., identifying the species of, organisms

Tributary - a river or stream that feeds into a larger stream, river, or lake; does not reach the sea.

Watershed[1] - the specific land area that drains water into a river system or other body of water, e.g., Red River watershed, used here to mean a portion of the sub-basin.

Zooplankton - the animal component of plankton that passively drift or weakly swim within the water column; all major animal phyla are represented in zooplankton as adults, larvae, or eggs.

[1] These terms are given as they are used in this report. Definitions may vary depending on the source.

Acronyms and Abbreviations

AAFC – Agriculture and Agri-Food Canada
CIER – Centre for Indigenous Environmental Resources
COSEWIC – Committee on the Status of Endangered Wildlife in Canada
DDT – Dichloro-Diphenyl-Trichloroethane
DFO – Department of Fisheries and Oceans; Fisheries and Ocean Canada
DOE – Department of Environment; Environment Canada
ELA – Experimental Lake Area
GHG – Greenhouse gases
HCH – Hexachlorocyclohexane
IISD – International Institute for Sustainable Development
IJC – International Joint Commission
INAC – Indian and Northern Affairs Canada
IRRB – International Red River Board
LWSB – Lake Winnipeg Stewardship Board
LWRC – Lake Winnipeg Research Consortium
LWSW – Lake Winnipeg Science Workshop
LWWAC – Lake Winnipeg Watershed Action Committee
MLMMI – Manitoba Livestock Manure Management Initiative
NRTEE – National Round Table on Environment and the Economy
PCB – Polychlorinated Biphenyl
POP – persistent organic pollutant
PPCP – Pharmaceuticals and Personal Care Products
RRBC – Red River Basin Commission
SARA – Species at Risk Act
USEPA – United States Environmental Protection Agency
WINGRO – City of Winnipeg program of applying dewatered biosolids from waste water treatment on agricultural land

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