Lake of the Woods
water sustainability foundation

Phosphorus Budget Studies

IN THE LAKE OF THE WOODS WATERSHED

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Satellite image of Lake of the Woods
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Acknowledgements

The content for this synthesis was based primarily on two Master of Science degree theses by:

- Kathryn Hargan—A total phosphorus budget for the Lake of the Woods—Trent University, Peterborough, Ontario, Canada, September 2010
- Joseph Hadash—Assessment of total phosphorus loading in the US portion of Lake of the Woods—St. Cloud State University, St. Cloud, Minnesota, USA, December 2010.

Supporting information was derived in part from other science initiatives in the Lake of the Woods watershed that have been presented at the Lake of the Woods Water Quality Forum which is held each year in International Falls, Minnesota. The Forum and the Lake of the Woods Water Sustainability Foundation, which facilitates the forum, were originally established to coordinate science activities to improve the understanding of factors which contribute to water quality issues in the basin.

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- **Lake of the Woods Water Sustainability Foundation**
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Pelicans and cormorants, south end of Lake of the Woods

Executive Summary

Lake of the Woods is a large and valuable resource that spans both provincial and international borders. In recent years there has been the perception that the algal blooms are increasing in both frequency and severity, although it is likely that Lake of the Woods has had algae blooms historically. Since excess nutrients are often implicated as the cause of algal blooms, there has been a great deal of effort dedicated to reducing nutrient inputs and to quantifying inputs from various sources.

In 2008, the Lake of Woods Water Sustainability Foundation assembled a consortium of researchers and agencies to conduct a "phosphorus budget study" for Lake of the Woods. The goals were to determine the sources and amounts of phosphorus entering the lake and to develop water quality models for phosphorus to begin answering some of the questions about why algal blooms might be increasing on Lake of the Woods.

This report examines two Masters theses, arising from this project, that have explored the proportion of nutrient loads (phosphorus) that originate from different sources. Further science is presented that indicates that the algal blooms are likely getting worse in response to climate change but are indeed occurring at a time when the phosphorus loads and in-lake concentrations in many areas are decreasing.

Findings of the relative contributions of nutrients from various sources indicate that the Rainy River contributes two thirds of the annual phosphorus load to the lake. On a lake-wide basis, shoreline properties contribute a small proportion of the total load of phosphorus. Importantly however, shoreline properties can contribute a relatively more important load of phosphorus in areas of the lake which are isolated from the main south to north flow of nutrients, such as Clearwater Bay and Poplar Bay. This suggests that management objectives should consider inputs on a regional basis.

Phosphorus loads to the lake from the Rainy River have decreased and may continue to decrease in the future. However, the historical phosphorus in the sediments of Big Traverse Bay that was deposited during periods of higher loads may be presently available for algal production through the process of internal loading (remobilization of phosphorus from the lake sediments). It is unclear how long it may take for the internal loads to be reduced in response to the reduction in loads from the Rainy River in recent years. There may be a significant "lag time" effect. Further research is required to shed additional light on these mechanisms.

Nutrient inputs to Lake of the Woods and the problems that they cause both in the lake itself and potentially further downstream will have consequences that must be considered and addressed by multiple jurisdictions. With the combined effects of warming trends and high nutrients in many regions of the lake, controlling algae blooms in the long term may require addressing the causes of climatic change. Nevertheless, it is apparent that it is now important to ensure that nutrient concentrations do not rise to further increase the severity of algae blooms under conditions of warmer and longer ice-free seasons.

About Lake of the Woods

Nutrient inputs to Lake of the Woods and the problems that they cause . . . will have consequences that must be considered and addressed by multiple jurisdictions.

Lake of the Woods is an international water body that spans the borders of Ontario and Manitoba in Canada, and Minnesota in the USA. It is a vast and convoluted lake covering 3,850 km^2 with a huge drainage basin of 69,750 km^2 that stretches southward into the USA and reaches almost to Lake Superior to the southeast. It is the sixth largest binational lake in North America and the second largest inland lake in Ontario after Lake Nipigon. There are less than a dozen larger lakes in Canada.

The northern portions of the lake lie on the Canadian Shield and although we intuitively expect the flow of water to be from the northern Shield areas southward to an outflow, Lake of the Woods has approximately 75% of its water supply enter the lake through the Rainy River at the south. In essence, this water forms a large internal river whereby the water flows northward through the centre of the lake to the Winnipeg River outflow at the north end of the lake. Due to the nutrient rich nature of the Rainy River, many of the southern portions of the lake including areas connected to Big Traverse Bay are very productive. In these areas, the high nutrient concentrations help to support an excellent warm-water sport fishery but also support nuisance algal blooms. Other areas of the lake which are more isolated from the south to north flow of water, such as Whitefish Bay, Shoal Lake and Clearwater Bay have lower nutrients, clearer water and are more typical of lakes on the Canadian Shield. Clearwater Bay, in fact, supports a trophy lake trout population.


Lake of the Woods
Kenora, Ontario
CANADA
U.S.A.
City/ Town
Major Highway
River
Waterbody
1:600,000
Ontario
95°18'0"W
94°36'0"W
93°54'0"W
50°0'0"N
49°18'0"N
Minaki
Winnipeg River
Kenora
Rat Portage Bay
Clearwater Bay
Northern Peninsula
Echo Bay
Indian Bay
Ontario
Shoal Lake
Western Peninsula
Lake of the Woods
Eastern Peninsula
Manitoba
Northwest Angle Inlet
Aulneau Peninsula
Sioux Narrows
Whitefish Bay
Minnesota (U.S.A.)
The Little Traverse
Big Island
Sabaskong Bay
Nestor Falls
Buffalo Bay
Big Traverse Bay
Bigsby Island
Morson
Muskeg Bay
Warroad
Sable Islands
Zippel Bay
Four Mile Bay
Rainy River
Rainy River
Baudette
17
71
11

What were our original questions?

Mats of blue green algae scum on shoreline, September 4, 2006

Before the science programs described here were begun, there were three main questions.

1. Are the algal blooms in Lake of the Woods getting worse?

There are recent concerns that the algal blooms which occur mainly in the central and southern portions of the lake are getting worse, which is to say that they are increasing in both frequency and severity. Residents who have a history of involvement with the lake were among the first to express concerns about increasing blooms. The nature of this observation, however, was anecdotal because there was no easy way to measure or compare the severity of algal blooms between years. Some help with the monitoring and tracking of algal blooms through time was required to demonstrate whether or not these observations could be validated. This would require help from scientists together with a increased focus on water quality issues in Lake of the Woods.

2. Are the algal blooms caused by shoreline development?

Shoreline owners are key stakeholders who share an interest in Lake of the Woods and its water quality. The most active lake stewards on any given lake are most often the property owners. They have a passion for the water body and a vested interest in its well being. It follows naturally that if water quality deteriorates as a direct result of their activities then there is a strong desire to describe and correct the problem. In this case there were concerns that shoreline property development could be responsible for the increase in the algal bloom frequency and severity. This was not a groundless concern considering that the development of the shoreline is continuing in many areas throughout the Lake of the Woods watershed. It was therefore important to answer this question with a degree of certainty.

3. Is there anything we can do to reduce algal blooms?

Stewardship values require that if the water quality has indeed been degraded—and if this is the result of human activity—then there should be every possible effort made to correct the problem. The response to this question, of course, would be informed by the answers to the first two questions. Would there, for example, be direct action required with respect to shoreline development or are there other human activities associated with these algal blooms?

Algal blooms in Lake of the Woods

We cannot prove that there have always been algal blooms in Lake of the Woods. We can only suspect that this is the case through the examination of several written observations that were made by historic visitors to the lake…

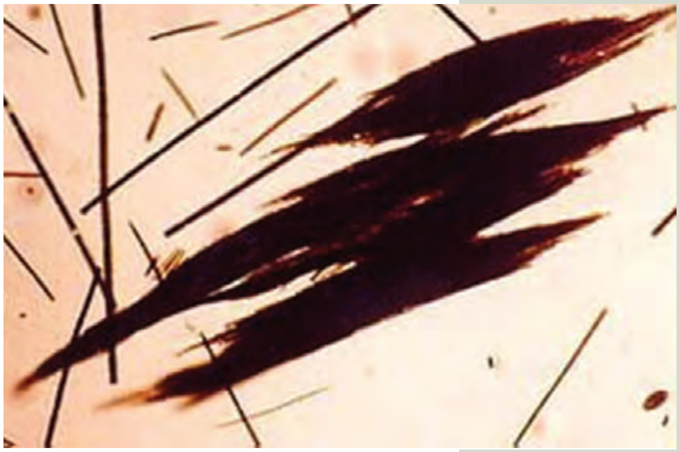
The islands were numerous and crowded, the water shoal and foul, frequently with a green scum of vegetable matter – Major Joseph Delafield, July 30, 1823.

…*the water became tinged with green, derived from a minute vegetable growth* – S.J. Dawson, summer 1857

The important question is whether or not the blooms have increased in frequency or severity in the recent past. There is concrete evidence published in the last few years that indicates that blue green blooms are becoming more frequent in northern climates, including Ontario and in some cases the research is specific to Lake of the Woods. Together with new Lake of the Woods findings that will be soon published, this leaves little doubt that algal blooms including cyanobacteria (blue green algae) blooms are more frequent and more severe in recent years than in the past. Algal blooms are fundamentally linked to both natural and human phosphorus loads and there has been sufficient P historically and today in the lake to support algal blooms. However, these recent increases in blooms are occurring at a time when the phosphorus concentrations are either the same or lower than they have been historically in many areas of the lake.

Annie, Fannie and Mike

The algal blooms in Lake of the Woods that cause the widespread floating green scums are caused by a type of plankton called cyanobacteria. These organisms share some characteristics with algae but are classed as bacteria. Although they are often referred to as blue green algae, they are technically not algae. The most severe blooms in North America are most commonly caused by the same few species of cyanobacteria, namely *Anabaena, Aphanizomenon* and *Microcystis* (Annie, Fannie and Mike) and they are watched closely because of their potential to produce toxins. In the Lake of the Woods blooms all three of these algal species are present but the most common species is *Aphanizomenon* (see photo below). Blue green algal blooms



Aphanizomenon. Roger Burks (University of California at Riverside), Mark Schneegurt (Wichita State University), and Cyanosite (www-cyaosite.bio.purdue.edu)

What causes algal blooms?

In most cases algal blooms are caused by high phosphorus (P) concentrations in the water. Many trophic indexes consider a lake to be oligotrophic with P concentrations less than 10 µg/L. These are lakes that will rarely have algal blooms. Mesotrophic or middle range lakes have 10-20µg/L of P and these lakes will occasionally have algal blooms. Lakes over 20µg/L are eutrophic and can be expected to have more severe and frequent blooms. Lake of the Woods, in south and centre areas, has enough P to support algal blooms.

are normally associated with high phosphorus concentrations because phosphorus controls algal growth in Ontario lakes. In other words, more phosphorus means more algae. Although there is not a clearly defined threshold, it is generally thought that phosphorus concentrations above 20 µg/L will support algal blooms and concentrations over 30 µg/L describe a eutrophic situation where blooms are expected to be severe. The influence of the Rainy River creates a wide range in phosphorus concentrations from south to north (high to low) and also seasonally in any given location throughout the central portions of the lake. The bottom line is that Lake of the Woods has had, through the years, phosphorus concentrations in the central portions of the lake that are high enough to support algal blooms.

Most blue green blooms, including those that occur in Lake of the Woods, are at their peak in the late summer. This is partly because the algae require more than just nutrients to proliferate. The exact environmental conditions that lead to algal blooms are not known with certainty but high water temperature and well established water column stability (low mixing of water) are commonly cited as conditions that favour blue green algae. These conditions are more typical in the late summer. So, even with the same phosphorus concentrations in two different years, it is possible to have different algal densities between the two years if one or more of these other factors are different. For example, long hot summers can lead to algal blooms that are worse than those that develop during cool summers. This is why algal bloom severity can vary between years without having the phosphorus concentrations change.

Satellite image of Lake of the Woods, October 5, 2006, showing algal blooms. NASA/GSFC, MODIS Rapid Response

Science initiatives in Lake of the Woods

Concerns about water quality and algal blooms in Lake of the Woods led to the establishment of the International Lake of the Woods Water Quality Forum, held annually since 2004, and to the formation of the Lake of the Woods Water Sustainability Foundation in 2005. The Foundation and the Forum that it facilitates, bring researchers and stakeholders together from areas throughout the international watershed to find answers to these questions about water quality and algae blooms. The Forum engages scientists and other stakeholders from both Canada and the USA to share research findings and identify gaps in our understanding of the many complex stressors that are impacting Lake of the Woods. These stressors are not limited to algal blooms and nutrient loads to the lake. They also include such things as the effects of invasive species, water level regulation, development in the watershed and climate change. A summary of the materials presented at the Forum each year is posted on the Lake of the Woods Water Sustainability Foundation website at:

http://lowwsf.com/press-a-events/water-quality-forum/proceedings.html

In 2007, the Foundation jointly funded a project with the Ontario Ministry of the Environment, the Minnesota Pollution Control Agency and Environment Canada to develop the State of the Basin Report for the Lake of the Woods and Rainy River Basin. Published in 2009, this report provides the baseline information about what is currently known, and importantly it also identifies what additional information is needed with regard to the lake and its water quality. The State of the Basin Report is posted on the Foundation's website at:

http://lowwsf.com/progress-we-are-making/docman/state-of-the-basin-report.html

Much of the science presented at the Forum and summarized in the State of the Basin Report is related to the questions surrounding algal blooms. Together, these science initiatives have advanced our understanding of many of the factors that contribute to the occurrence and severity of algal blooms in Lake of the Woods. We are now beginning to see the relationship between algal blooms and nutrients and other stress multipliers such as climate change.

One of the main pieces of information that is required to further the understanding of the link between nutrients and algal blooms is a clear idea about the sources and magnitude

We are now beginning to see the relationship between algal blooms and nutrients and other stress multipliers such as climate change.

Sampling inflows to Lake of the Woods

of nutrient inputs to the lake (a nutrient budget). Specifically, we need to know about the phosphorus inputs because this is the nutrient that controls the growth of algae in Lake of the Woods. We need to know which inputs are natural and which are the result of human activities in the watershed (anthropogenic phosphorus) so that we can identify those inputs (loads) that can be most easily controlled. First, it must be established whether or not there have been changes to the phosphorus loads to the lake that are responsible for recent increases in algal blooms. Following this we can determine if it is possible to control the blooms by controlling inputs of phosphorus to the lake. A clear understanding of these issues requires more detailed information about phosphorus loads to the lake. This can be accomplished through the construction of a detailed phosphorus budget.

In 2008, the Lake of Woods Water Sustainability Foundation launched the "phosphorus budget study" for Lake of the Woods. The Foundation assembled a consortium of researchers and agencies to jointly fund and conduct this study. Participating with the Foundation were: Trent University, Minnesota St. Cloud State University, Ontario Ministry of Environment, Minnesota Pollution Control Agency, Manitoba Water Stewardship and Environment Canada's Lake Winnipeg Basin Stewardship fund.

The goals were to determine the sources and amounts of phosphorus entering the lake and to develop water quality models for phosphorus to begin answering some of the questions about why algal blooms might be increasing on Lake of the Woods.

Phosphorus budgets

To develop a phosphorus (P) budget for the lake it is necessary to identify and quantify all of the major sources of P to the lake and all of the losses of P from the lake. So, the amount of P coming in should equal the amount of P that is lost either to the outflow of the lake or to the lake sediments (both considered losses). When the numbers match then the phosphorus budget is considered to be balanced. This is more difficult than it seems since there are many sources that are difficult to measure such as the quantity of P that:

- Falls onto the surface of the lake in the rain
- Comes to the lake through streams and from wetlands

- Enters from the watershed naturally as overland runoff
- Originates from point sources such as paper mills or wastewater treatment plants
- Originates from non point sources (diffuse sources) such as from farming or from shoreline septic systems

Identifying and quantifying the components of a P budget will allow us to assess the relative importance of the individual loads to the lake and provide some guidance as to where the loads could be reduced if necessary.

Kathryn Hargan, as part of her Master of Science Degree at Trent University, assembled the first detailed nutrient budget for Lake of the Woods. Her budget, to the greatest degree possible was based upon measured data. In other words, measured flow volumes together with measured P concentrations were used to calculate the loads from the inflows. This budget confirmed some things that we already knew or suspected. For example, we knew that the largest volume of water flowing to the lake was from the Rainy River. We suspected that the largest load of P was from the Rainy River as well. The budget also illustrated a few things that we did not know for certain. For example we now know that the contribution of P from shoreline properties relative to the whole lake budget is miniscule. However, Hargan also showed that in more enclosed or isolated bays the same contribution from shoreline properties forms a relatively larger portion of the P budget. So it becomes clear that managing phosphorus is not a straightforward process. We will have a closer look at this later.

Hargan's P budget for Lake of the Woods is shown diagrammatically in Figure 1. The most revealing aspects of this budget are that the Rainy River is the largest source of P and also that more than half of the P that comes into the lake stays in the lake and does not exit at the outflow to

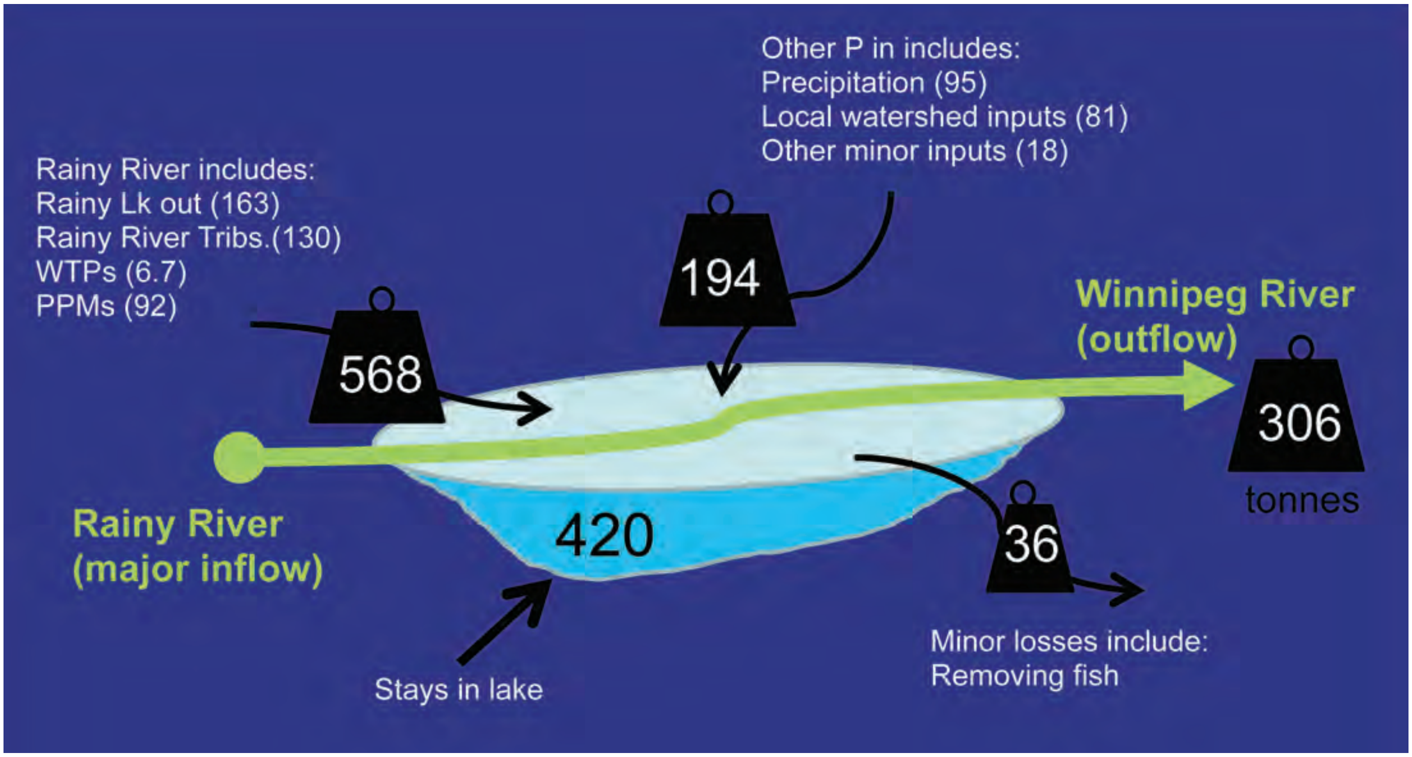


Figure 1. Phosphorus loads into and out of Lake of the Woods. WTP=waste water treatment plants, PPM=pulp and paper mills (numbers in metric tonnes; 1 t=1000 kg). Shoreline property loads are included in "other minor inputs".

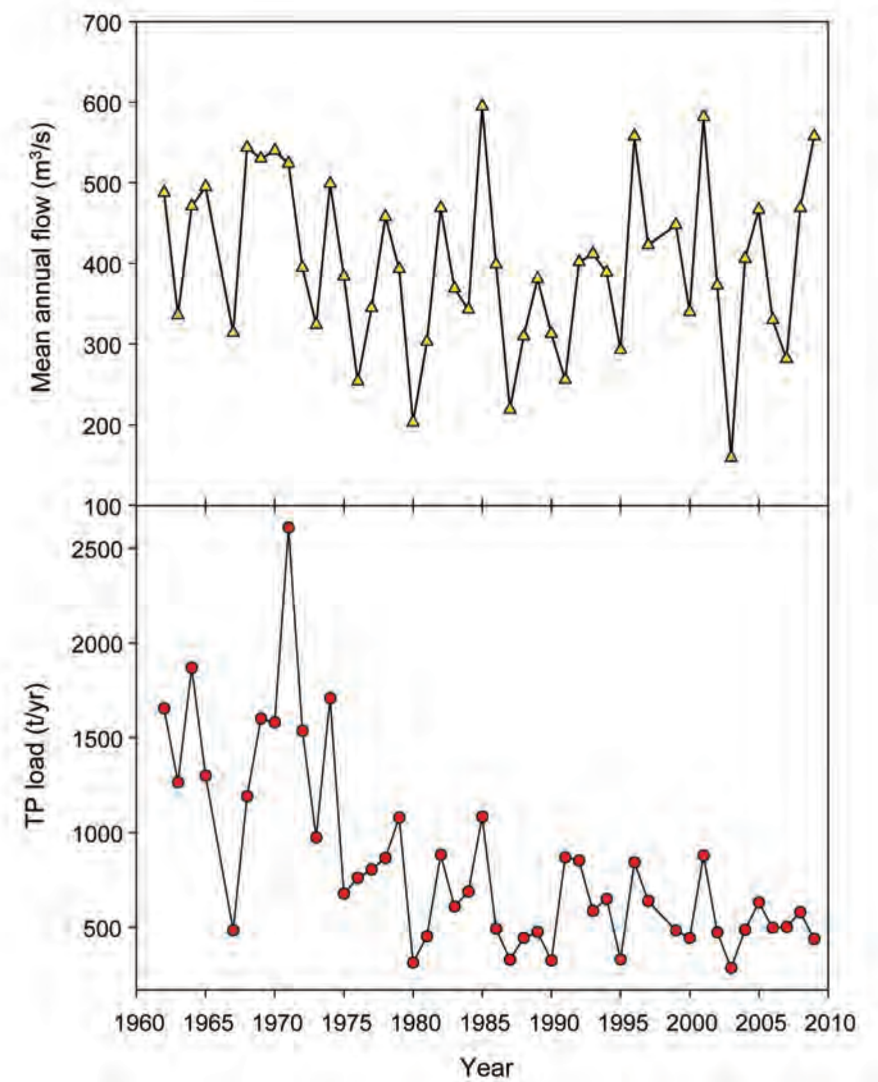


Figure 2. Flow volumes (top) and phosphorus loads (below) from the Rainy River through time.

the Winnipeg River. This P is lost to the sediments through the settling of particles such as algae and bacteria that contain P. This process happens in virtually all lakes. The degree to which this occurs (the sedimentation rate) is an important element of the models that are designed to predict P concentrations in lakes.

Hargan's phosphorus budget allows us to make several important observations.

1. First we can compare the relative contributions of P from different sources and estimate what potential exists to manage P from the various sources. For example, on a whole lake basis, it is clear that the Rainy River is contributing both the majority of the water and the majority of the P to the lake. On the other hand, shoreline properties (included in Figure 1 with other minor inputs) contribute a very small P load to the lake relative to the other sources on a whole lake basis. We will see later that the influence of shoreline properties is more important within more isolated bays.

2. We can also see that Lake of the Woods retains phosphorus. In other words the lake functions like a phosphorus "sink". We know this because each year 762 metric tonnes (t) (568 t + 194 t; Figure 1) of P comes into the lake from various sources while only 306 t exits through the outflow. Phosphorus is being lost (primarily to the sediments) between the main inflow in the south (the Rainy River) and the outflow to the north (the Winnipeg River). The end result is that there is a net loss of P and in Hargan's budget about 420 t ends up staying in the lake somewhere between the inputs and the outflow (see Figure 1). Most of the P that is lost will be tied up in the sediments but some will be bound up in other places such as in fish alive in the lake or lost through fish removal. Hargan's budget

shows that 36 t of P is lost from the lake through the removal of fish by fisherman and birds.

3. Finally the nutrient load calculations that were used to construct this budget revealed that although the Rainy River contributes 66% of the P load to Lake of the Woods (Figure 1), the P loads from the Rainy River have actually declined significantly since the 1960s and 70s (from 1500 t/yr to 500 t/yr) due to increased regulation of wastewater treatment plants and pulp mills over the past several decades (see bottom of Figure 2). We know that this reduction cannot be due to decreased volumes of water since inflow volumes show no trend (top of Figure 2). This is a significant observation since we are now faced with the fact that it is likely that algal blooms are increasing at the same time that P loads are decreasing. This is not what we commonly imagine to be true about the relationship between phosphorus and algal blooms. We would expect the blooms to be less severe in the event that P loads are decreasing. It would seem that there is more than nutrient supply influencing the blooms.

Phosphorus models

Another way to help visualize or predict the fate and impact of nutrient movements in a lake is to apply nutrient models to the data. In the case of Lake of the Woods it would be good to know what happens to the phosphorus that enters the lake from the Rainy River. We know from Hargan's work that less than half of it ends up leaving the lake through the Winnipeg River at the outflow at Kenora.

Nutrient models can use what we know about nutrient movements in other systems where these functions have been measured and apply these functions to similar lakes where these things are not known.

Joseph Hadash, as part of his Master of Science Degree at St. Cloud State University, used two such models (FLUX and BATHTUB) to examine the fate of P in Big Traverse Bay (Figure 3). He found that the models predicted quantities of P loads to the Big Traverse Bay that were similar to those measured by Hargan. In Hadash's thesis work, the BATHTUB model allowed the further estimation of

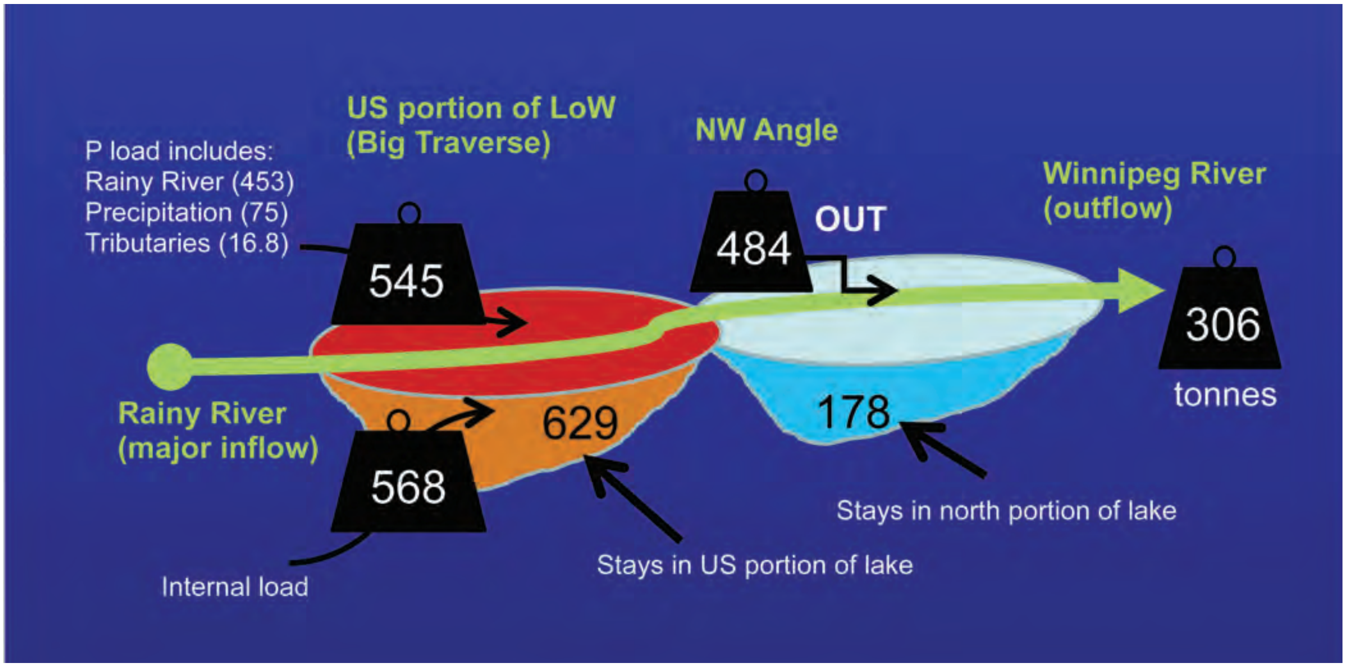


Figure 3. BATHTUB model results for the US portion of Lake of the Woods. All numbers are in metric tonnes.

two additional aspects of the nutrient budget:

1. The internal load from the sediments to the lake
2. The amount of P that leaves Big Traverse Bay to the north through the Northwest Angle

So, even though we know from Hargan's work that Lake of the Woods is acting like a P sink by transporting nutrients to the sediments (less goes out than comes in) we see from Hadash's calculations that the nutrients available for algal production in Big Traverse also includes the introduction of a rather large internal load. Phosphorus can be lost to the sediments in any lake but in some cases P can come back from the sediments into the lake. This is called an internal load and there is reason to believe that areas in the south end of Lake of the Woods have large internal loads, especially Big Traverse Bay. These internal loads contribute extra P to the lake that can be used for algal production (usually in the late summer) and at some point—usually in the late fall—these nutrients return to the sediments when the algal cells die off and sink to the bottom. Hadash's modeling results showed that if the predicted internal load of 568 t were added to the P budget there would

What is an Internal Load?

The plankton (algae and various other animals) in a lake will settle, after they die, to the bottom of the lake where they will become part of the ongoing accumulation of sediments. Each year another "layer" is added. The phosphorus (P) that is locked up in these organisms is locked into the sediments or "lost" from the lake's P budget. Under normal circumstances they are lost "almost" forever if the sediments are undisturbed. However, if the bottom waters of the lake or the sediments themselves experience a total loss of oxygen (anoxic conditions), the P can come back into the bottom waters of the lake. This is a chemical reaction that occurs when there is no oxygen. In the spring or fall, if the water is re-oxygenated, this P will return again to the sediments. It can be a bit of a revolving door but this extra P is considered to be the result of an "internal load". It can contribute to increased algal production. A consideration of the interal load can become important when we attempt to examine the seasonal nature of algal blooms.

be a total of 1113 t of P available for algal production in the US portion of the lake. The model also predicted that only 484 t of this 1113 t would leave the US portion to the north out through the Northwest Angle. This would mean that 629 t would remain in the south portion of the lake. The 484 t that move to the north are further diminished to 306 t at the outflow (Hargan's number) which means that 178 t of the original 484 t that came to the north are lost to the sediments in the northern portions of the lake (Figure 3).

Although the budget produced by Hargan and the modeling results shown by Hadash do not agree exactly they are within reasonable ranges of each other, i.e., within the bounds of error in the estimates and the variability from year to year.

The most interesting question that evolves from Hadash's work is: *if the internal load shown by Hadash's model is about equal to the amount retained by the lake (568 t vs. 629 t) then why does it matter that there is an internal load*? As long as the P leaving the south basin is a fraction of the P coming in it should have a minor influence on the northern areas of the lake. This is partly true but there are reasons why we need to consider the internal load. The budgets that Hargan and Hadash discuss are measured as annual totals, in other words the amounts that go in and out over a one year period. However, we hinted earlier about how this internal load may have a seasonal impact on algal bloom activity in the lake. This is because internal loads are usually at their maximum in the late summer when blue green algal blooms are developing in the lake. So, if there is a large internal load the lion's share of it may be entering the lake in the summer months and thereby contributing to the late summer blooms.

The internal phosphorus load may have a seasonal impact on algal blooms.

What do we know today?

OK so what does all of this tell us? What do we know that we didn't know before? We now know more about the origins of the P in the lake and the proportions of P that are contributed by different human activities. We suspected all along that the Rainy River contributes the majority of the nutrients but we now know this for certain. We also now know the magnitude of the P load and a bit more about how this load is broken down. These proportions from Hargan's budget are shown in Figure 4.

We now know the number of shoreline developments in different areas of the lake and that shoreline development has a small overall impact on the lake but could be relatively much more significant in "isolated" regions or sub basins of the lake.

We know that there may be a seasonal influence of these P loads both from the Rainy River and from internal loads from the sediments that may be impacting bloom frequency and severity in the late summer.

We know that the load from the Rainy River has decreased in recent years and at the same time algal blooms have been getting worse. This makes it difficult to determine what the results of further phosphorus reductions from the watershed would be since the reductions that have occurred to date do not seem to have helped to decrease the blooms. We also now suspect that the historical phosphorus in the sediments of Big Traverse Bay that was deposited during periods of higher loads may be presently available for algal production through the process of internal loading. As yet uncertain is whether or not the lake will eventually respond to these recent

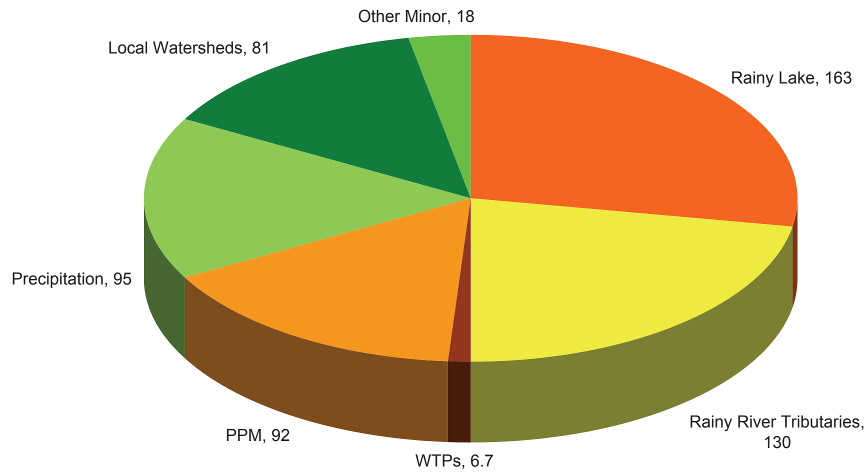


Figure 4. Proportion of P entering the lake from different sources according to Hargan's budget. Loads in orange to brown are from the Rainy River (Rainy Lake outflow 163 t, tributaries 130 t, wastewater treament plants 6.7 t and pulp and paper mills 92 t) and loads in green are loads to the lake from other sources (precipitation 95 t, local watersheds 81 t and other minor inputs including shoreline development 18 t). This diagram does not show the internal load.

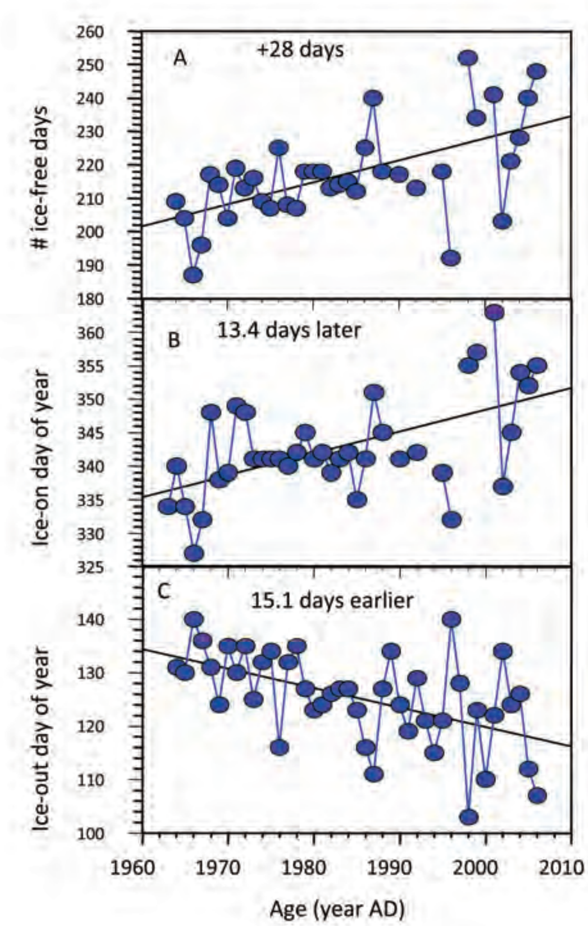
phosphorus reductions from the Rainy River and how long it will take. In addition, nutrients may not be the only factors influencing blooms. There is additional information from other science studies that can shed some light on this "multiple stressors" aspect of the blooms.

The link between algal blooms and phosphorus

Lake of the Woods supports blue green algal blooms because the phosphorus concentrations in many areas of the lake are well above 20 µg/L. In fact P concentrations are naturally high enough without human inputs to support blooms but probably to a lesser extent than we see them today. This is because there have been additional historic human inputs of phosphorus that have made the blooms worse than they would be naturally. However, recent reductions in these human loads should indicate an improved condition—So why are the blooms getting worse?

Dr. Kathleen Rhüland from Queen's University published a paper in 2010 that showed that recent changes in algal communities in northern areas of Lake of the Woods were largely due to the recent lengthening of the ice-free season. Lake of the Woods, at present, has 28 more ice free days than it had in the 1960s (Figure 5). This represents a tangible environmental change in the lake that is linked to climate warming. At the same time her work shows that there have been no appreciable changes in P concentrations over time throughout the northern parts of the lake. In fact there have been declines in P concentrations in some areas of the lake (e.g., Whitefish Bay) that are isolated from the main flow from south to north of nutrient rich water. Her research indicates that algal community changes in the northern part of the lake may be linked to climate rather than to increases in nutrients. The algae that she studied are diatoms and although these are not the same as blue green algae she showed that the types of conditions that are favoured by the more recent diatom communities are also those that are favoured by the blue green algae.

Figure 5. Length of ice cover on Lake of the Woods through time. Increased length of open water (A) is due both to later "ice-on" (B) and earlier "ice-out" (C).



Core from Lake of the Woods

The link between algal blooms and the climate

Additional paleolimnological research provides good evidence that the blue green algal blooms are worse in recent years, based on the historical deposition of algal chlorophyll pigments in the sediments. There are more pigments deposited in recent years in a way that lines up exactly with the increasing trend in the number of ice-free days over the last 20 years.

These pigments are likely the result of blue green algal growth. So it is not just the diatom communities that are changing (a type of algae used to infer historical P concentrations—see sidebar "Paleolimnologists"). If algal blooms have increased in occurrence or severity in response to climate change—then which aspects of the change are they responding to? Are the conditions which favour increased blooms related to the longer growing season or to some other factor such as increased water temperature or to some other factor like increases in the number of wet years?

Some of these changes in climate may directly influence the inputs of P through the Rainy River through the effects of drought. Less water means less supply of P from the watershed. Knowing that algal blooms are partly controlled by external factors like the climate does not mean that there are no feasible ways to reduce the frequency of blooms because climate is only one of the variables. However, we must first establish the main links between climate change and algal blooms to assess whether or not there are options for controlling the blooms. For example, we cannot do much to control blooms if the length of the growing season is the main driver. It is important to note that weather and P concentrations are both contributing to blooms. It may therefore be even more important under these circumstances to continue to reduce P inputs to the lake to ensure that this aspect of algal bloom influence is controlled as tightly as possible.

Paleolimnologists

are aquatic scientists who study the past history of lakes by examining the fossil remains of algal cells and other animals in the sediments at the bottom of the lake. They do this by retrieving a core from the bottom of the lake and then examining sections of the core that correspond to different dates in the past history of the lake. Some of the algae (diatoms) that live in the lake have water quality requirements that are unique such that different species will grow under different conditions. By recreating the species present in any given year the water quality in that year can be inferred. This, or course, is an oversimplification of a complex and robust scientific method.

What are the remaining questions?

Why are blooms worse in one year compared to the next?

We have already discussed the fact that the weather can influence blooms in many ways. Algae are influenced by the seasonal growing conditions and this very generally applies to lakes throughout North America. Most algae (including cyanobacteria) are like plants in that they produce food and energy from sunlight. Growing conditions are a regional phenomenon such that if the tomatoes in your garden are growing well, then the chances are that the algae in the lakes are also growing well, possibly in response to warmer temperatures or high levels of sunlight compared to the year before. These climate variables, however, can also change the loads of P between years from the major sources like the Rainy River. To answer these questions there are paleolimnological methods that can be used to reconstruct historical annual loads of P to the lake so that historical trends can be observed. There are also ways to look at historical trends in the algal community bloom frequencies. If these are studied together with historic weather patterns and flow data, then it may be possible to identify whether or not the blooms are more severe in hot years or in wet years.

Differences between wet and dry years, which manifest themselves as high or low water levels and through increased or decreased P supply to a lake, can have appreciable effects on the growing conditions for the algae.

Property owners in the north end of Lake of the Woods have noticed increases in algal blooms during high water years. High water means more water originating from the Rainy River and likely more erosion in the Rainy River and south basin of Lake of the Woods. This may result in a more nutrient rich environment in the north end of the lake in one year compared to another. So, there are really two things happening at the same time. There is sufficient P at any given point in time to support algal blooms throughout many areas of the lake and then there are seasonal differences that can make these blooms vary in their severity between years (the temperatures can be warmer etc.).

Will the algal blooms improve?

It is important to understand whether algal blooms will continue to grow worse, continue as they are, or return to some previous level. We have seen that the P loads to Lake of the Woods through the Rainy River have decreased in recent years. This should provide some encouragement that the blooms will also improve. Research in other lakes has shown that lake ecosystems can take many years to respond to reductions in nutrient loads. This is especially true in lakes that have large internal loads. So, it may be that Lake of the Woods will respond to the reduced loads at some point in the future. In other words there may be a lag time between the reduction of nutrient supply and the response of the lake such that we may eventually see an improvement in algal bloom intensity that is the result of our efforts to reduce inputs.

We have shown that the lengthening of the ice-free season has likely had a negative effect on the lake by causing algal blooms to become more frequent. We must consider, however, that climate change will not be a stable process. If the climate in future years is wetter or drier there may be associated changes in the algal production which may act to either increase or decrease the frequency of blooms. This of course will depend on whether or not the changes are favourable for the cyanobacteria.

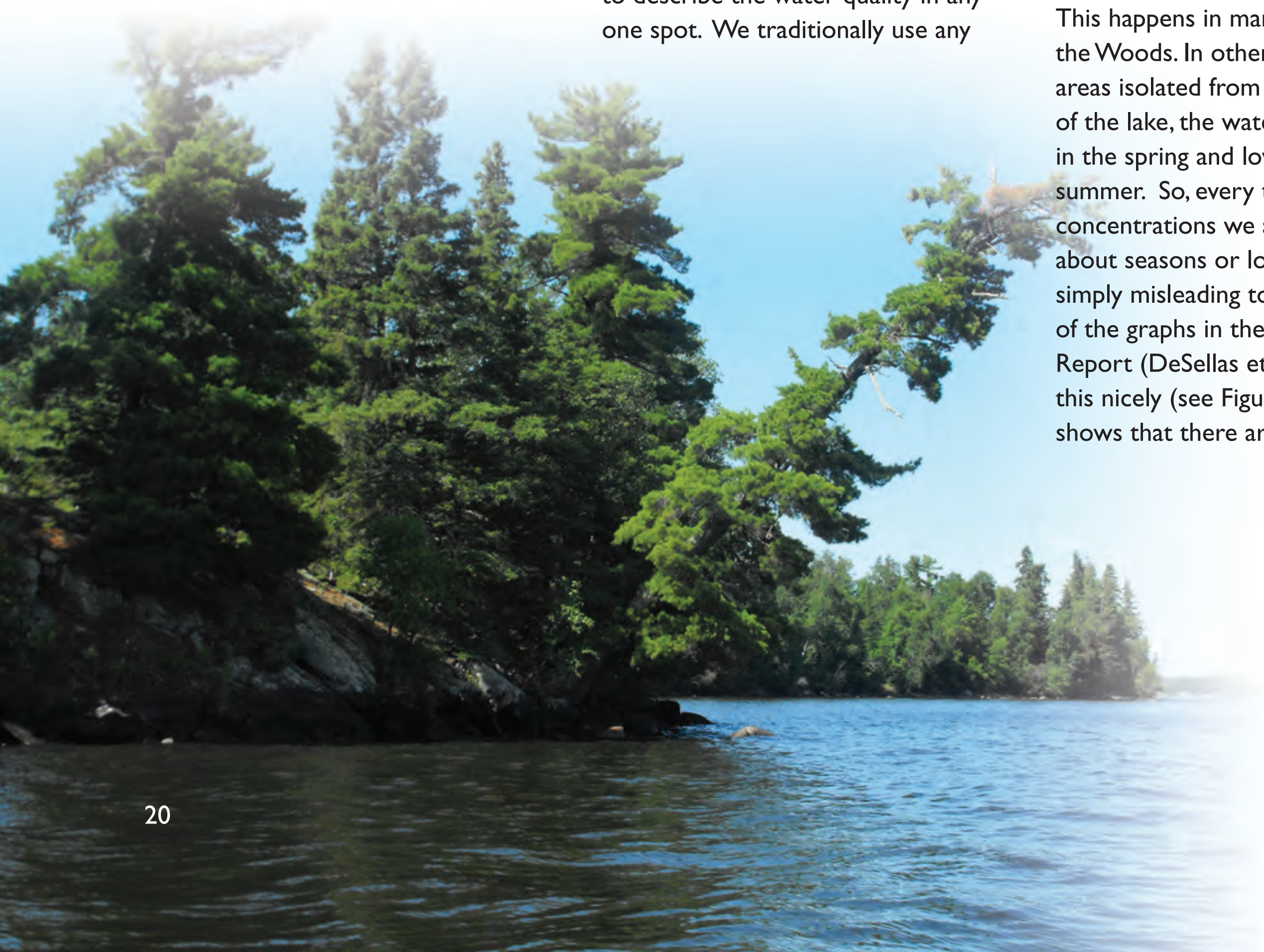
It is important to understand whether algal blooms will continue to grow worse, continue as they are, or return to some previous level.

Nutrient management objectives in Lake of the Woods

The difficulty with interpreting phosphorus concentrations

Lake of the Woods displays a wide range in phosphorus concentrations from place to place at any given time. Generally the concentrations are higher in the south, lower in the north main basin and much lower in areas that are isolated from the south to north flow of water (e.g., Clearwater Bay to the west and Whitefish Bay to the east). In addition there are strong seasonal differences between concentrations measured in any one spot (Figure 6) especially in areas that are near the northward flow of water. This creates a problem when we try to describe the water quality in any one spot. We traditionally use any one of a number of different scales to rate water quality but scientists commonly refer to water with less than 10 µg/L of P as oligotrophic. This is clear, unproductive water of the type found in lake trout Lakes. Water with 10 - 20 µg/L of P is mesotrophic—in the middle. This water can have algal blooms but there should be no serious problems. Lakes with more than 20 µg/L and especially those that are above 30 µg/L are eutrophic and these are in the zone where problems with nuisance blooms can be expected.

What if the water at the end of the dock shows a seasonal range that goes from mesotrophic in the spring to quite eutrophic in the late summer? How do we describe this? This happens in many areas of Lake of the Woods. In other areas, particularly areas isolated from the main basin of the lake, the water is higher in P in the spring and lower in the late summer. So, every time we talk about concentrations we also have to talk about seasons or locations—it is simply misleading to generalize. One of the graphs in the State of the Basin Report (DeSellas et al. 2009) illustrates this nicely (see Figure 6). The graph shows that there are large differences



between different areas with some being oligotrophic (<10 μg/L P) and others being extremely eutrophic (>30 μg/L P). It also shows that there are differences between spring and fall and these are not the same from area to area. Late summer P is higher than spring in some areas and lower in others. So, what is the P concentration at the end of my dock? A tricky question indeed! This aspect of P dynamics in Lake of the Woods makes it difficult to set nutrient guidelines or targets.

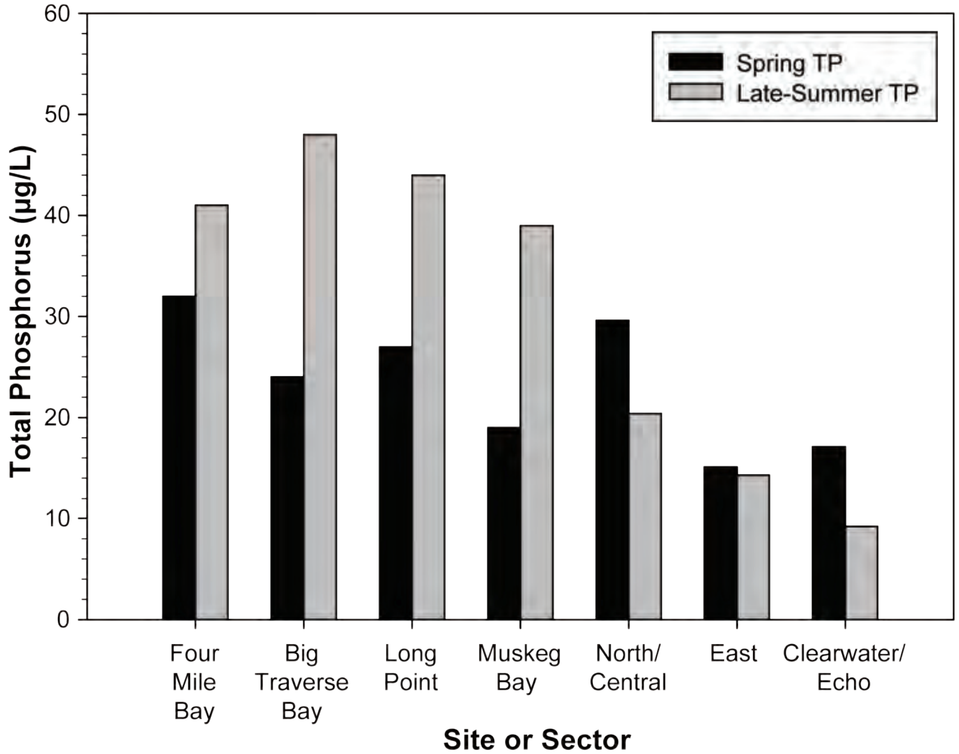


Figure 6. The difference between spring and late summer phosphorus concentrations in different areas of Lake of the Woods. Note that spring P concentrations are lower than late summer concentrations in some areas and higher in others. Note that the range in late summer concentrations is greater. East areas are in and around Whitefish Bay.

The importance of managing individual isolated bays

It is important to emphasize that the results of nutrient budgets in Hargan's thesis work presented here pertain only to those portions of the lake that are directly connected to the major south to north flow of water from the Rainy River to the outflow into the Winnipeg River. In other words, the models and budgets are designed to describe whole lake annual means which primarily represent the centre portions of the lake. When you study a map of Lake of the Woods or better yet, when you try to get from one end to the other in a boat, you quickly realize that there are hundreds of isolated bays (or "sub-basins") that, although physically connected to the rest of the lake, are not directly influenced by the south to north flow of water. These areas are more influenced by their local watersheds. Hargan's thesis includes an interesting section where she applied the Ontario Ministry of the Environment's Lakeshore Capacity Model to several isolated bays in Lake of the Woods to determine the proportional P inputs from shoreline development in these bays. Remember that the shoreline development portion of the total P loads to the whole lake is relatively small and this load is included as a part of the "minor inputs". However, when the shoreline development part of the load is considered as a percent of the total loads to the enclosed bays, the proportion is much higher. Figure 7 shows the proportional loads for several bays in the north portion of the lake, selected here to illustrate the range in proportional inputs by

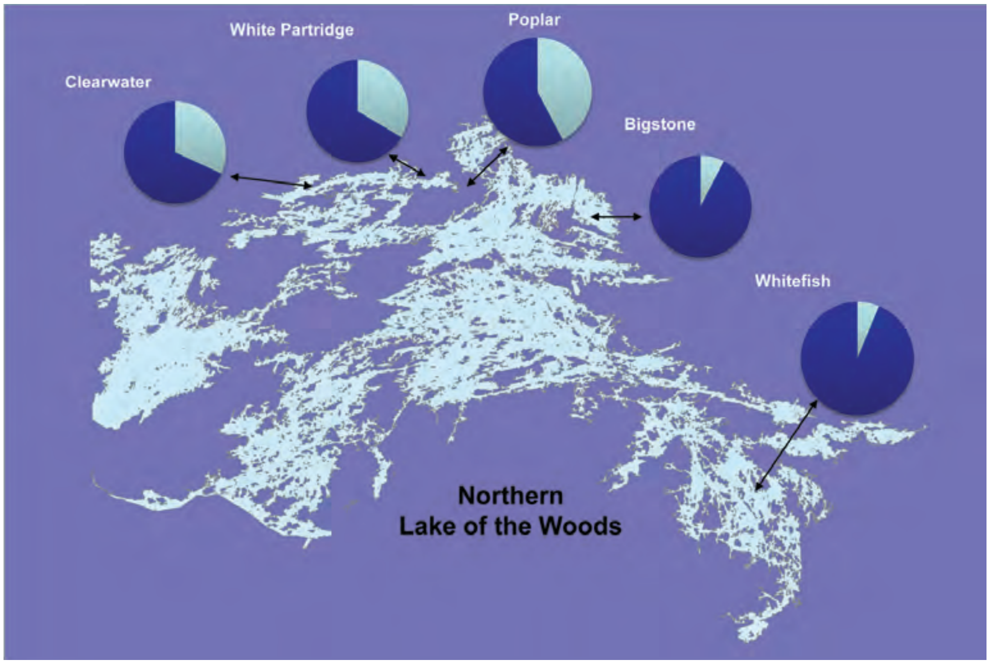


Figure 7. Proportional loads of P to several enclosed bays. Light portions of each pie diagram indicate the relative P contribution from shoreline properties relative to other inputs from runoff, precipitation etc.

shoreline properties. The percent of the total loads to each bay from shoreline properties via septic systems are: Clearwater Bay 31.8%, White Partridge Bay 33.5%, Poplar Bay 42.3%, Bigstone Bay 7.6%, and Whitefish Bay 6.2%.

It is clear that development objectives should take into consideration the localized areas that are proposed for development and attempt to assess the effects that development will have on individual basins. To illustrate how development can impact different areas of the lake to differing degrees, Hargan explored the predicted effects of:

1. Converting each existing property to a permanent residence
2. Doubling the current load, e.g., double the number of shoreline properties
3. Having the hypolimnion go anoxic[2]

Here we show Hargan's results for the whole lake and for two smaller separate areas of the lake to illustrate the potential impacts of the above three scenarios. The results are shown in Table 1 and clearly indicate the degree to which some areas could be impacted by development more than others. Future development strategies should therefore consider both the isolated and interconnected aspects of different areas of the lake.

A schematic developed by Malaher (unpubl. 2005) showing how the different areas of Lake of the Woods are linked together is shown in Figure 8. Each of these areas is in turn dissected many times into smaller bays and some of these will be quite isolated from any other part of the lake. Hargan indicated in her thesis that one of the primary difficulties with applying the Lakeshore Capacity Model for individual bays lies in the inability to assess the degree to which the water in one area of the lake exchanges between adjacent areas. More isolated areas are more likely to behave like separate lakes and therefore respond well to efforts to estimate concentrations through the use of models. These are the areas that are also more likely to require regional development strategies.

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[2] An anoxic hypolimnon refers to the condition where the bottom waters are depleted of oxygen. This is the condition that can lead to an increase in the internal load of P to the lake.

Area	Current average phosphorus concentration	1. All seasonal residences converted to permanent	2. Double the Anthropogenic load (twice the cottages)	3. Have the hypolimnion go anoxic
Lake of the Woods (whole lake)	19.2 µg/L	Increase to 19.3 µg/L – no real difference	Increase to 19.3 µg/L – no real difference	Increase to 26.6 µg/L – lake moves from mesotrophic to eutrophic
Poplar Bay	15.3 µg/L	Increase to 27.9 µg/L – bay moves from mesotrophic to very eutrophic	Increase to 20.4 µg/L – bay moves from mesotrophic to slightly eutrophic	Anoxic at present
Clearwater Bay	14.1 µg/L	Increase to 18.2 µg/L – bay is more productive but remains mesotrophic	Increase to 18.5 µg/L – bay is more productive but remains mesotrophic	Increase to 20.6µg/L – bay moves from mesotrophic to eutrophic

Table 1. Showing the increase in TP in µg/L that would occur for different bays under three different scenarios.

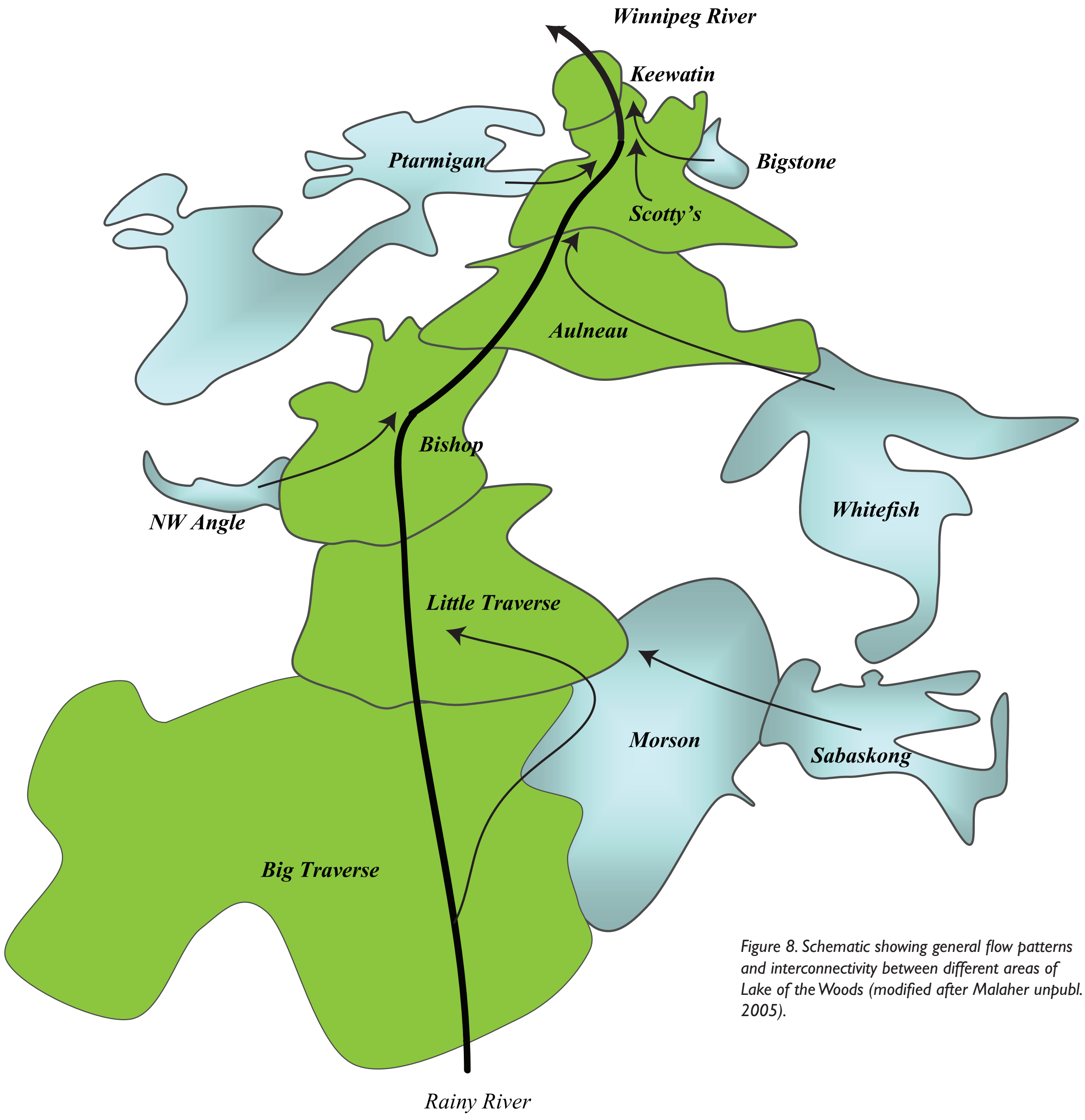

Figure 8. Schematic showing general flow patterns and interconnectivity between different areas of Lake of the Woods (modified after Malaher unpubl. 2005).

Satellite image showing Lake Manitoba (left) Lake Winnipeg (centre) and Lake of the Woods (bottom right) with severe algal blooms, August 7, 2006. NASA/GSFC, MODIS Rapid Response

Lake of the Woods on the landscape

The Lake of the Woods watershed is part of the Lake Winnipeg watershed. In the satellite image on the left you can see Lake of the Woods at the bottom right and Lake Winnipeg at the top in the centre, both with strong algal blooms. Concerns around eutrophication and the resulting widespread blue green algal blooms in Lake Winnipeg have focused attention on Lake of the Woods and its role as a partial contributor to the phosphorus budget of Lake Winnipeg. Today the Winnipeg River contributes about 15% of the P load to Lake Winnipeg. Generally the loads that the Winnipeg River (Lake of the Woods outflow) contributes to Lake Winnipeg have increased only slightly over the last 100 years. Loading from the Saskatchewan River declined over the same time but the loads from the Red River increased from being 30-40 % of the total load at the beginning of the century to 60-80% of the current loads. This is despite the fact that the Red River contributes a smaller volume of water compared to the Winnipeg River[3]. The phosphorus budgets for Lake Winnipeg, which were constructed in a similar way to the budgets that have been produced here for Lake of the Woods, allow us to calculate the relative loads to Lake Winnipeg and assess the feasibility of controlling P from the various different inputs to the lake. Lake Winnipeg, in fact, shares common attributes with Lake of the Woods.

It has:

- A history of algal blooms which may be natural
- Increased algal blooms in recent years
- A large and complex multijurisdictional watershed
- A similar landscape setting with respect to weather and climate change

These connections between Lake of the Woods and Lake Winnipeg underscore the importance of adopting an Integrated Watershed Management approach to managing these important resources.

[3] *Restoring the Health of Lake Winnipeg – Technical Annex. Terry Duguid and Norman Brandson, co-chairs.*

In Conclusion

Two recent attempts to construct phosphorus budgets for Lake of the Woods have allowed us to examine the proportional inputs of P from different sources and to explore the fate of P within the Lake. It is clear that the majority of P enters the lake through the Rainy River in the south and that more than half of this P stays in the lake. There may be additional internal loads of P from the sediments in southern parts of the lake which can contribute to algal production. However, even if these internal loads are quite large as suggested, the P budget overall shows a net loss between inputs and outputs. This loss of P is primarily to the lake sediments. In addition it is clear that the P loading trend in the Rainy River has been towards a reduction in loads over the past several decades.

Recent science initiatives have also shown that it is almost certainly true that algal blooms are worse today than in the past even in the presence of stable or possibly reduced phosphorus concentrations in the lake. In the presence of existing high phosphorus concentrations in many areas of the lake, these blooms are being stimulated by recent changes in the weather and most notably by an increase in the number of ice-free days. It will be important to ensure that nutrient concentrations do not rise to further increase the severity of algae blooms under conditions of warmer and longer ice-free seasons.

Modeling efforts have shown that although the contribution of phosphorus from shoreline properties is miniscule on a whole lake basis, these loads become relatively much more important in areas that are isolated from the main central portions of the lake. In the face of multiple stressors, such as climate change, it is especially important to manage nutrient inputs to these isolated sub-basins to ensure that there is the least possible chance that blooms will occur. Nutrient management objectives and development strategies should consider inputs on a regional (or sub-basin) basis.

Ongoing research is required to establish the link between internal loads and algal blooms and to verify the relationship between algal bloom intensity and external factors that may be linked to changes in the climate. Collaborative work that is the result of strong partnerships that have been developed throughout the watershed will help to achieve these goals.

Further Reading

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