Preliminary Assessment of Human Exposure Risk to the Algal Toxin, Microcystin, in Lake of the Woods and the Winnipeg River

A Report to the Lake of the Woods District Property Owners Association

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Acknowledgements

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Summary

A research study was undertaken in 2009 to determine the risks to human health (and that of family pets that may drink lake water) of exposure to the algal toxin, microcystin, during periods of algal blooms on Lake of the Woods and the Winnipeg River system in Ontario. Microcystins, if accidentally ingested by humans (through accidentally swallowing water during water-based activities – e.g., swimming, or in drinking water) or pets (through drinking untreated lake water) can result in severe damage to the liver or death. The risk is generally highest when algal blooms are present and accumulate along shorelines or beaches where human contact or contact with pets or other wildlife can occur.

The objectives of the study were:

- To monitor shoreline concentrations of microcystin during algal blooms in Lake of the Woods and the Winnipeg River in order to assess the potential risk from recreational contact, and risk to family pets that are allowed to drink water during such blooms
- To monitor microcystin concentrations in water intake pipes and concentrations in kitchen tap water in cottages and camps, during periods of algal blooms in order assess the potential risk to human health of using lake/river water for domestic use (e.g., drinking, washing, showering)
- To determine the effectiveness of various water treatment systems in use by cottages and camps for removing microcystin
- To identify species or groups of species of algae (phytoplankton) that may be responsible for the production of microcystin in Lake of the Woods and the Winnipeg River, and
- To provide recommendations to cottagers and governments, to reduce exposure of the public to microcystin

Water samples were collected in August and September 2009 by a group of 18 volunteers who own cottages/camps on Lake of the Woods and the Winnipeg River in Ontario. Water sampling occurred at:

- Moth Lake
- Gun Lake (Winnipeg River system)
- Shoal Lake
- Echo Bay (LOW)
- Clearwater Bay (LOW)
- Town Island (LOW)
- Channel Island (LOW)
- Sunbath Island (LOW)
- Pine Portage Bay (LOW)
- Bigstone Bay (LOW)
- Lobstick Bay (LOW)
- Nestor Falls (LOW)
- Frenchman's Rock Road (LOW)

A total of 63 shoreline samples were collected. Shoreline samples from some lakes or lake areas (e.g., Moth Lake, Shoal Lake, Clearwater Bay, Lobstick Bay, Town Island, Channel Island) did not contain detectable concentrations of microcystin (less than 0.10 ug/L – micrograms per litre) or contained low concentrations (less than 5.4 ug/L) of microcystin. According to the World Health Organization, concentrations of less than 10 ug/L represent a low risk to human health for recreational contact (e.g., swimming). In contrast, much higher shoreline concentrations were measured at Frenchman's Rock Road (maximum concentration of 45.6 ug/L), Pine Portage Bay (maximum of 59.7 ug/L), Sunbath Island (maximum of 105.5 ug/L), Nestor Falls (maximum of 146.6 ug/L), Gun Lake (maximum of 238.0 ug/L) and Bigstone Bay (maximum of 545.7 ug/L). With respect to the World Health Organization guidelines for microcystin, recreational contact with water containing more than 20 ug/L of microcystin represents a high risk to human health. It is clear that on Lake of the Woods and the Winnipeg River, algal blooms can at times represent a serious health risk to people through recreational contact and to pets that may drink algae-laden (very green) lake water. Indeed, during the 2 months of this project, a border collie dog died within 1 hour of drinking green lake water along a shoreline at Caliper Lake (south of Nestor Falls, ON). In this case, death was caused by ingestion of a neurotoxin produced by the algae.

In order to determine which species of algae were responsible for producing microcystin in Lake of the Woods and the Winnipeg River, algal species composition and abundance were determined from shoreline samples. The data indicated that there are likely several species of *Anabaena* and *Microcystis* that produce microcystin. This conclusion is consistent with other lakes in Canada, including Lake Winnipeg.

Despite (at times) very high concentrations of microcystin in the water along shorelines during blooms, microcystin concentrations in water intake lines were very low. The maximum concentration of microcystin in water intake lines was 0.20 ug/L. To put this into context, the Canadian drinking water guideline value for microcystin is 1.5 ug/L. Even if this intake water were to be consumed untreated, the very low microcystin concentrations present would not be expected to have any effect on human health. The reason for the low concentration of microcystin in water intake lines despite much higher concentrations at the source (e.g., along shorelines) like reflects the fact that most intake lines are not located near the surface of the water, where the algae tend to accumulate. Even if a toxin-producing algal bloom dies off and releases its microcystin directly into the water, the dilution effect of the lake water would also dramatically reduce the concentration of microcystin able to be taken into a water intake line.

Microcystin concentrations were also measured in water from kitchen taps in the cottages/camps. Microcystin concentrations in the majority (85%) of samples were generally below the detection limit (< 0.10 ug/L). Microcystin was detected in tap water from two cottages/camps, but the concentrations (maximum of 0.21 ug/L) were well below the Canadian drinking water guideline of 1.5 ug/L.

The study results suggest that the greatest risk to humans involve exposure to microcystin through recreational contact activities such as swimming. During periods of algal blooms, when green slicks of algae accumulate along shorelines, swimming should be avoided. It is impossible to visually determine if an algal bloom is producing microcystin. Laboratory analysis is required to detect the toxin. To complicate matters, not all algal species produce microcystin, and even when toxin-producing species are present, toxin concentrations can vary greatly. Therefore, the best rule of thumb is to avoid contact with water when the water is very green. The same principle applies to family pets (e.g., dogs), which may drink lake water directly from a shoreline. Significant health risks to pets exist when they drink algae-laden water.

The first line of defense to minimizing exposure to microcystin when lake water is used in a cottage/camp is to ensure that your water intake line is located at an appropriate water depth. The intake should not be located at or near the water's surface, especially in areas where algal blooms tend to accumulate. Also important is to locate the water line in an area where there is a good exchange with other lake water, if possible. In very calm bays that are not exposed to the wind or to exchange of water from other parts of the lake, a die-off of a microcystin-producing algal bloom can release the toxin into the water and can cause high concentrations of the toxin in immediate surrounding the water.

Water treatment systems that would typically be used at cottages/camps would not likely be efficient at removing microcystin from the water. In fact, filters that become clogged with algae have been shown to damage the algal cells, releasing microcystin directly into the water line, causing the concentration of toxin to be higher after water treatment. Generally, only sophisticated water treatment processes (that are typically used by water utilities) that include flocculation, coagulation, activated carbon filtration and ozonation or reverse osmosis are effective at removing or destroying microcystin. Our study demonstrated that microcystin concentrations were generally low in water intake lines (or even below detection limits). Since microcystin is not absorbed through the skin, the low concentrations that could be present in water used for washing dishes and showering would not be expected to have any impact on human health. Finally, because the concentration of microcystin in water intake lines (before any water treatment) was below detection limits in cottages with water treatment systems, we were not able to assess the ability of individual water treatment systems for removing microcystin.

Ultimately, the best way of minimizing risk of exposure to microcystin is through public education. It is recommended that a public education campaign (using information/fact sheets, presentations, etc.) be developed for cottage/camp owners, commercial tourism establishments (e.g., fishing camps), campgrounds and health care practitioners (nurses, doctors and veterinarians) in the Lake of the Woods region.

This is the first preliminary study to examine the exposure risk to microcystin in the Lake of the Woods region. The linkage between exposure and human health needs to be explored further.

Introduction

Algal Blooms and Algal Toxins

Many lakes experience periodic "blooms" of blue-green algae (also known as cyanobacteria), which can result in green or blue-green, paint-like slicks along shorelines. While algal blooms occur naturally in most lakes, many lakes worldwide are experiencing more frequent and more intense blooms due to increased nutrient loading. Algal blooms commonly occur in parts of Lake of the Woods and the Winnipeg River, particularly during the summer and fall months. Algal blooms have also been documented in deeper lakes in the Lake of the Woods region. In some cases, the algal blooms may form in deeper water of the lake in winter, rising towards the surface in late winter or early spring and coloring the remaining lake ice or snow a purple or pink color. At times, this type of algal bloom can produce significant concentrations of toxins (Kling, unpublished data). Some believe that algal blooms in Lake of the Woods are getting worse over time. Research is being carried out to determine if this is true, but it is also known that such blooms are not a recent phenomenon. Indeed, in 1870, Colonel Garnet Wolseley and his troops paddled through Lake of the Woods on his way to Upper Fort Gary (now Winnipeg). In his journal, Wolseley notes that the water "is, except at very few places, of a dark green colour, and almost opaque from a profuseness of confervoid growth [algae]" (as quoted in Robertson and McCracken, 2003). His detailed description of the algae being "minute, needle-shaped organisms" likely describes a type of algae called *Aphanizomenon* or "grass clipping algae" (as the algae resemble tiny clippings of grass from a lawn), which is common in the south basin of Lake of the Woods today (Chen et al., 2009) and also in the northern part of the lake in late fall. He also describes the water as having a "green pea soup" appearance, a familiar description used by cottagers around the lake to describe the color of the water during algal blooms.

Many consider such algal blooms a nuisance (e.g., thick green slicks of algae make beaches unattractive for swimming and release a foul odor when they decompose on the shoreline), but there is growing evidence that such blooms can also represent a significant health risk. In particular, several species of blue-green algae are known to produce a group of more than 70 liver toxins termed microcystins (Kotak et al., 1995, 2000). Blue-green algae also produce other toxic compounds, including neurotoxins (which affect the nervous system and cause respiratory arrest) and dermatotoxins (contact irritants which cause skin rashes). All three main classes of toxins can also cause vomiting and diarrhea from accidental ingestion. This study on Lake of the Woods and the Winnipeg River focused on the liver toxins, microcystins.

Accidental ingestion of water containing microcystins has resulted in the illness and deaths of wildlife, livestock, family pets and humans worldwide (e.g., Jochimsen et al., 1998). More recent research has also now shown that long-term exposure of humans to microcystins, through inadequately treated drinking water, can lead to cancer (Uneo et al., 1996; Zhou et al., 2002). Microcystins appear to be quite common in lakes of the Canadian prairies (Kotak and Zurawell, 2007) including Lake Winnipeg (Kotak et al., 2011), but their occurrence in Canadian Shield lakes and rivers (such as Lake of the Woods and the Winnipeg River) is just starting to be studied.

Exposure to Microcystins Through Recreational Activity

Microcystins are generally present within the algal cells themselves, but can also be released from the cells into the surrounding water. Microcystins are not absorbed through the skin, but exposure can occur through accidental ingestion of the toxin, either dissolved in the water or in the algal cells themselves. Swimming in areas where intense algal blooms are present increases the risk of exposure significantly. In particular, children are more at risk than adults, as children are more likely to accidentally swallow water while playing in the water than an adult. The small weight of children compared to adults also means the toxins can have a more severe impact in children. Accidental ingestion can also occur when a person loses control (i.e., a "wipe out") during water sports such as water skiing, knee boarding and wake boarding. Although not studied to date, the scientific literature speculates that water skiing through very green water may also create an aerosol of algal cells and water, which can be accidentally inhaled. Historically, recreational exposure to microcystins has been poorly studied, but is now currently receiving considerable attention.

The World Health Organization (WHO, 2003) has developed guidelines for recreational exposure to microcystins. According to the WHO, recreational exposure to microcystin concentrations of **less than 10 ug/L** (micrograms per litre) represent a **low** risk to humans, exposure to concentrations of **10 – 20 ug/L** represents a **moderate risk**, and recreational exposure to microcystin concentrations **greater than 20 ug/L** represent a **high health risk** to humans. Any contact with water containing more than 20 ug/L of microcystin should be avoided.

Exposure to Microcystin in Drinking Water

Exposure to microcystins can also occur through drinking water that is contaminated with the toxin. When algae are actively growing in a water body (i.e., when thick blooms are not present), only a small amount of microcystin is found dissolved in the water. The majority of the toxin is found in the algal cells. However, when an algal bloom that is producing microcystin suddenly dies (or is treated with chemicals to kill the bloom or if the cells are broken apart by pressure through water filtration), the microcystin present in the algal cells may be released quickly and in significant concentrations to the water. Under such circumstances, proper water treatment is required to remove microcystin from drinking water. Only sophisticated drinking water treatment, including coagulation, flocculation and the use of activated carbon filtration and ozone or reverse osmosis are effective at removing microcystins from water or destroying the toxin. Most cottagers do not utilize such sophisticated treatment systems in their cottages, cabins and camps. The simple treatment systems commonly being used may be ineffective at removing microcystins, although this has not been studied to date. A common misconception is that boiling lake or river water containing algae will destroy microcystins. While this may work for some algal neurotoxins, microcystins are stable compounds, and are able to withstand heating or boiling.

Drinking water guidelines have been developed in several countries, including Canada, which specify concentrations of microcystin in drinking water that are deemed to be safe. Health Canada has established a **drinking water guideline of 1.5 ug/L** for microcystin. Consumption of water containing less than this amount is not anticipated to have adverse effects on human health. While for the most part, humans will likely never be exposed to concentrations in excess of 1.5 ug/L through drinking water, it is important to note that family pets (e.g., dogs) can be exposed to microcystin (or other algal toxins) far in excess of this value, by drinking directly from water bodies during periods of intense algal blooms. For example, in July 2009, a border collie dog died within 1 hour of drinking water from the shoreline at Caliper Lake (located near Lake of the Woods, south of Nestor Falls, Ontario). The symptoms displayed by the dog prior to death were consistent with poisoning by an algal neurotoxin. A water sample collected by provincial park staff was analyzed and found to contain a high concentration (140 ug/L) of anatoxin-a, a very potent and fast acting algal neurotoxin. Anatoxin-a is an algal toxin for which monitoring is rarely conducted. Only sophisticated instruments can detect anatoxin-a, and the cost of analysis is prohibitively expensive for routine monitoring purposes. It is important to realize therefore, that a water test result that is negative for microcystin may still be unsafe, due to the presence of other algal toxins that are not monitored for.

Microcystins in Lake of the Woods and the Winnipeg River – Previous Studies

Few studies have been undertaken to assess the occurrence of microcystins in the Lake of the Woods or the Winnipeg River. A very high concentration (> 1200 ug/L) of microcystin was measured in an algal bloom sample from Lily Pad Bay in 1999 (Kling and Hebert, unpublished data). More recently, Chen et al. (2009) detected low concentrations (< 0.69 ug/L) of microcystin in water from several locations in Lake of the Woods in 2006 and 2007. In August and September 2006, Kotak (unpublished data) monitored microcystin concentrations along shorelines and beaches as well as off-shore sites in the south basin of Lake of the Woods, near Frenchman's Rock Road (south of Morson, ON). Concentrations of microcystin were generally low (<1 ug/L) in off-shore sites (i.e., sampling sites away from shorelines), except during an intense algal bloom when microcystin concentrations exceeded 50 ug/L. Both Environment Canada and the Minnesota Pollution Control Agency currently monitor microcystin at off-shore sites periodically as part of routine water quality monitoring. All of these investigations have shown that, except during periods of significant algal blooms, the concentrations of microcystin in off-shore areas are generally low or below detection limits.

Microcystin concentrations along shorelines and beaches however, can be much higher, as these areas are where algal blooms tend to accumulate. For example, in 2006, Kotak found that almost one-third of the 55 shoreline/beach samples collected in the Frenchman's Rock Road area, contained microcystin in excess of 20 ug/L (the concentration considered as high risk for recreational activity). The highest concentration recorded was 608 ug/L. Therefore, it appears that there are occasions in Lake of the Woods when microcystin concentrations, particularly along shorelines and beaches, may make the water unsafe for recreational activities. This also holds true for allowing pets to drink such water. It is important to note that there is no routine beach monitoring program for microcystin (or other algal toxins) on Lake of the Woods, and without collecting and testing samples, it is not possible to determine whether an algal bloom is producing toxins or not.

Not all species of algae are capable of producing toxins, and even within a certain species, there are strains or environmental conditions (e.g., deficiency in a certain nutrient) that triggers the algae or strain to produce toxins. Some species appear not to produce toxins, although recent research is demonstrating that many more are capable of producing toxins than previously thought. It is not possible to determine if an algal bloom is producing toxins by visually looking at the bloom, or even by examining the bloom material with the aid of a microscope. For this reason (and given that no routine toxin monitoring occurs on beaches on Lake of the Woods) the best rule of thumb to reduce recreational exposure to microcystin is to avoid swimming in areas when algal blooms are present. Likewise, the risk of exposure to high concentrations of microcystin when swimming in water that is only slightly green (i.e., only a small amount of algae, not an algal bloom) is likely low. This same logic holds for allowing pets to swim in or drink lake water from shorelines. When the water is only slightly green, the risk of toxicity to a pet is likely low. The risk increases dramatically however, when a slick of algae is present along the shore (as was the case for the border collie which died at Caliper Lake, ON in 2009).

Microcystin is not monitored routinely on the Winnipeg River. Algal blooms do periodically occur along the Winnipeg River system (especially in bay areas) and the potential for elevated levels of microcystin does exist. For example, in August 2006 the microcystin concentration measured in a bloom at the boat launch in St. Georges (located between Lac du Bonnet and Pine Falls, MB) was 398 ug/L (Kotak, unpublished data). In addition, Kling (unpublished data) detected microcystin in algae (*Nostoc* sp.) found on rocks in the Winnipeg River in the Pine Falls region. No other data on microcystin for the Winnipeg River system exists.

It is evident that intense algal blooms in Lake of the Woods have the potential to create a significant health risk to humans through recreational exposure, and to family pets that are allowed to drink water from shorelines during such blooms. Two recent reports describing Lake of the Woods (State of the Basin Report for the Lake of the Woods and Rainy River Basin [DeSellas et al., 2009] and Water and Health in Lake of the Woods and Rainy River: For Health Professionals Task Force – International Joint Commission [Oblak, 2009]) stress the need for research and studies to better understand the risks associated with algal toxins. Unfortunately, the risk to human health from exposure in drinking water is relatively unknown for the Lake of the Woods basin. This study, funded by the Lake of the Woods District Property Owners Association (LOWDPOA), will help to address some of these unknowns.

Objectives of the LOWDPOA Study

The objectives of this study were:

- To monitor shoreline concentrations of microcystin during algal blooms in Lake of the Woods and the Winnipeg River in order to assess the potential risk from recreational contact, and risk to family pets that are allowed to drink water during such blooms
- To monitor concentrations in water intake pipes and concentrations of microcystin in kitchen tap water in cottages and camps, during periods of algal blooms in order assess the potential risk to human health of using lake/river water for domestic use (e.g., drinking, washing, showering)
- To determine the effectiveness of various water treatment systems in use by cottages and camps for removing microcystin
- To identify species or groups of species of algae (phytoplankton) that may be responsible for the production of microcystin in Lake of the Woods and the Winnipeg River, and
- To provide recommendations to cottagers and governments, to reduce exposure of the public to microcystin

This study was funded by the Lake of the Woods District Property Owners Association. All samples were collected by cottagers and camp owners, who volunteered their time.

Study Methods

Participants and Study Sites

A total of 28 cottage/camp owners from the Lake of the Woods region expressed interest in participating in the study as a result of information published in Lake of the Woods District Property Owners Association (LOWDPOA) Area News magazine in the spring of 2009, and through attending the Toxic Algae information presentations at the LOWDPOA Annual General Meeting on May 4, 2009 in Winnipeg, MB. Follow up telephone calls and emails resulted in 18 people confirming their willingness to participate in the study. Sample coolers, complete with background information on the study, all the necessary sampling equipment, money for return postage and a short survey form to fill out was sent to the interested individuals. The short survey included questions about where their water intake line is located (e.g., at the surface, 5 feet below the surface, etc.), whether they use lake water for domestic purposes (drinking, showering, washing dishes), type of water treatment, and their perspectives on whether they think that the water quality in their area has changed over the years.

The participants in the study were located in several areas around the Lake of the Woods, on the Winnipeg River system, as well as some lakes near Lake of the Woods. Water samples were collected from:

- Frenchman’s Rock Road (south of Morson), LOW
- Nestor Falls, LOW
- Lobstick Bay, east of Souix Narrows, LOW
- Bigstone Bay, LOW
- Pine Portage Bay, LOW
- Kenora area, LOW
- Clearwater Bay, LOW
- Echo Bay, LOW
- Shoal Lake
- Moth Lake
- Gunn Lake, near Minaki

Figure 1 provides a map of the locations of where samples were collected by the volunteers.

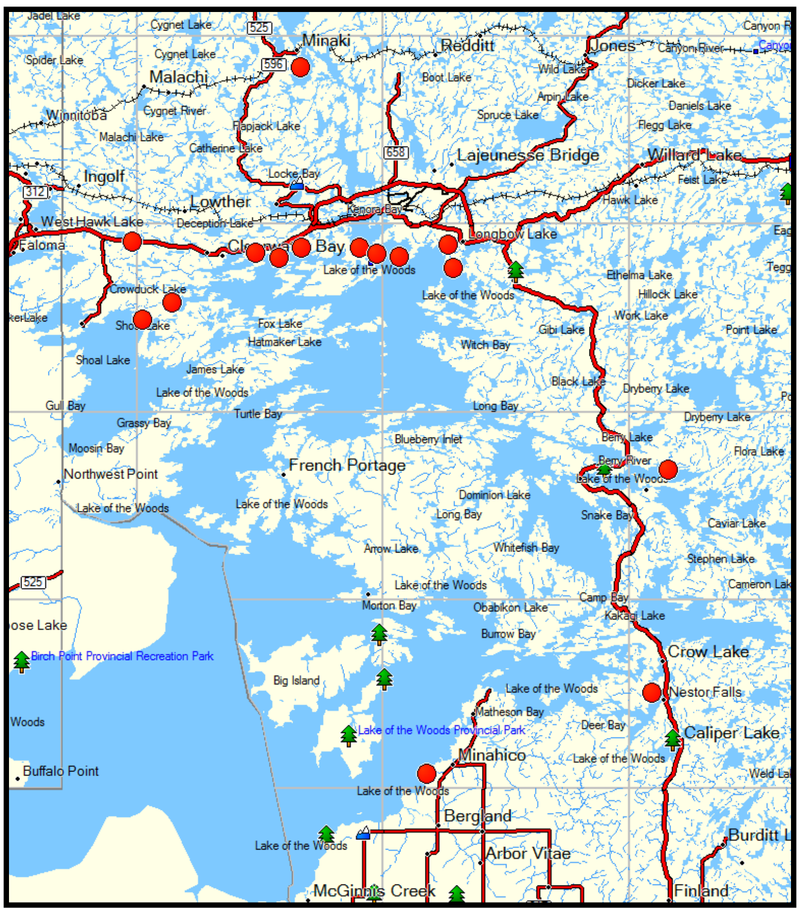


Figure 1. Locations (red circles) of sample collection in the Lake of the Woods region in 2009.

Sample Collection and Analyses

The weather during the summer of 2009 was not very conducive to producing algal blooms. The cool temperatures in June and July inhibited algal blooms from forming on the lake (or at least near the participant's cottages/camps). However, warmer weather in August, and especially in September, resulted in some algal blooms. Therefore, all of the samples were collected in these latter 2 months.

The participants collected water samples from their shoreline or dock area when algae was present, as well as water samples from their water intake line (before water treatment, if the cottage used water treatment) and kitchen tap. The shoreline, water line and tap samples were collected within minutes of each other on each sampling day. In this way, the study could be able to assess the concentration of microcystin in the lake water near the shoreline (i.e., the source water concentration) as well as the concentration of microcystin coming into the cottage (before and after treatment). In addition, a subset of the water samples collected from the shoreline/dock area, were analyzed to determine which species of algae were present in the lake water. For shoreline samples, participants were asked to collect water from the surface of the lake where the algal bloom was the thickest. This would give an indication of a "worst-case" scenario for exposure to microcystin. Samples for microcystin analysis were frozen until analysis. Part of the shoreline sample was also diluted and preserved with Lugol's iodine for later determination of algal species composition, abundance and biomass. Prior to collecting samples from their water line (before any treatment system) and kitchen tap (after water treatment, if present in the cottage/camp), participants ran their water system for 5 minutes to ensure that the water collected from the intake line and tap reflected water in the lake at the time when the shoreline sample was collected. All samples (shoreline and water line/tap) were collected between 10 AM and 6 PM.

In total, 63 shoreline samples were collected by the participants, as well as 38 samples from participant's water lines (before water treatment) and 48 samples from their kitchen taps. Not all participants had water treatment systems at their cottage/camp. The above samples were analyzed for microcystin. In addition, the shoreline samples were analyzed to determine which algae species were present in the lake water.

Water samples analyzed for microcystin (i.e., shoreline, water intake line, tap water) were thawed and any algal cells present were disrupted using an ultrasonicator. This released microcystin from the cells. The samples were then filtered through 0.45 um nitrocellulose filters to remove the cellular debris. Total microcystin was quantified using Enzyme-Linked Immunosorbent Assay (ELISA) (Abraxis, Pennsylvania). Samples were analyzed in duplicate, with triplicate positive controls (microcystin standards). The detection limit of the assay was approximately 0.10 ug/L. Samples were analyzed by AlgalTox International in Pine Falls, MB.

A subset of the shoreline samples were analyzed for phytoplankton (algal) species composition, abundance and biomass by Algal Taxonomy and Ecology Inc using phase-contrast microscopy under a number of magnifications. Phytoplankton were identified to species when possible and abundance expressed as cells/mL. Biomass (biovolume, mg/m^3) was estimated for each species by first measuring the dimensions of a subset of the cells for each species and using a volume formula that most closely matched geometric shape for each species. The volume was then converted to biomass using a standard volume-mass formula.

Results

Survey/Questionnaire Responses

The results of the survey/questionnaire are given in Table 1 below. Fifteen of the 18 participants completed and returned the survey. From the survey, it was clear that few participants used the lake or river water as a source of drinking water. Most participants likely brought drinking water from their homes to their cottages/camps, or purchased bottled water. However, a majority of participants used the lake or river water for showering or washing dishes. Nine of the 15 participants indicated that they use some form of water treatment prior to using the water in their cottage/camp. Water treatment ranged from simply adding bleach to the water (one cottage/camp), the use of either single or multiple filters, or the use of ultraviolet disinfection (one cottage/camp). Four participants indicated that their water treatment systems included carbon filters. These types of filters could assist in reducing microcystin concentrations, if present in the intake water. Activated carbon filtration has been shown to be effective at removing microcystin, but usually as part of a large-scale, municipal water treatment system. The ability of in-home carbon filter systems to remove microcystin has not been studied to our knowledge. Bleach can also be effective at destroying microcystin, but the high concentration required would make the water unpalatable for any sort of use.

Table 1. Results of the Toxic Algae Participant Survey

Survey Question	Response
Do you use the lake/river water for drinking water?	3 of the 15 participants use the water for drinking
Do you use the lake/river water for showering?	13 of the 15 participants use the water for showering
Do you use the lake/river water for washing dishes?	14 of the 15 participants use the water for washing dishes

Survey Question	Response
Do you treat the water prior to using it in your cottage/camp?	9 of the 15 participants treat their water in some way: ▪ Simply adding bleach to the water (no filtration) ▪ Single coarse filter ▪ Multiple filters: coarse filter followed by either an activated carbon filter or ceramic filter ▪ Ultraviolet (UV) disinfection
Approximately how deep in the water is your intake line?	Anywhere from 5 to 30 feet deep. The majority of lines were in 10-15 feet of water
Are algal blooms common in your area? In your opinion, have algal blooms been getting more frequent or worse (more intense) over the years?	Most participants indicated that blooms occur mostly in the summer and fall. Some participants indicated that algal blooms are getting worse, possibly due to changes in the watershed (e.g., a road was built, more cottage development, etc.). Some participants indicated that water quality is improving in their area, possibly due to better environmental regulations (e.g., better septic fields)
Do you know of any persons, family pets or wildlife that have been sick from drinking water or after playing in the water in your area?	14 of the 15 participants indicated that they were not aware of any health problems. One participant indicated a possible link between green water and a sick golden retriever dog.

Microcystin Along Shorelines

A total of 63 water samples were collected from shoreline and dock areas. Some of these samples were clearly collected during algal blooms (judging by the thick, green appearance of the sample), while other samples contained only a small amount of algae (indicative of the presence of algae, but not an algal bloom). Figure 2 shows the maximum concentration of microcystin measured in the shoreline/dock samples.

Several areas of Lake of the Woods contained only low microcystin concentrations. For example, maximum concentrations in Clearwater Bay and Lobstick Bay were less than 0.50 ug/L. Microcystin was not detected in Moth Lake. Maximum concentrations in Shoal Lake and at Town Island and Channel Island in Lake of the Woods were also low (maximum of 5.36 ug/L near Channel Island). These microcystin values are below the threshold for what the World Health Organization would consider a risk for recreational contact. In contrast, several other areas of Lake of the Woods and the Winnipeg River system had much higher shoreline concentrations of microcystin. In increasing order, maximum shoreline concentrations were observed near Frenchman's Rock Road (45.6 ug/L), Pine Portage Bay (59.7 ug/L), Sunbath Island (105.6 ug/L), Nestor Falls (146.6 ug/L), Gun Lake-Winnipeg River (238.0 ug/L) and Bigstone Bay (545.7 ug/L). According to the World Health Organization criteria, all of these concentrations would be considered as high risk for recreational contact and recreational contact at these concentrations should be avoided.

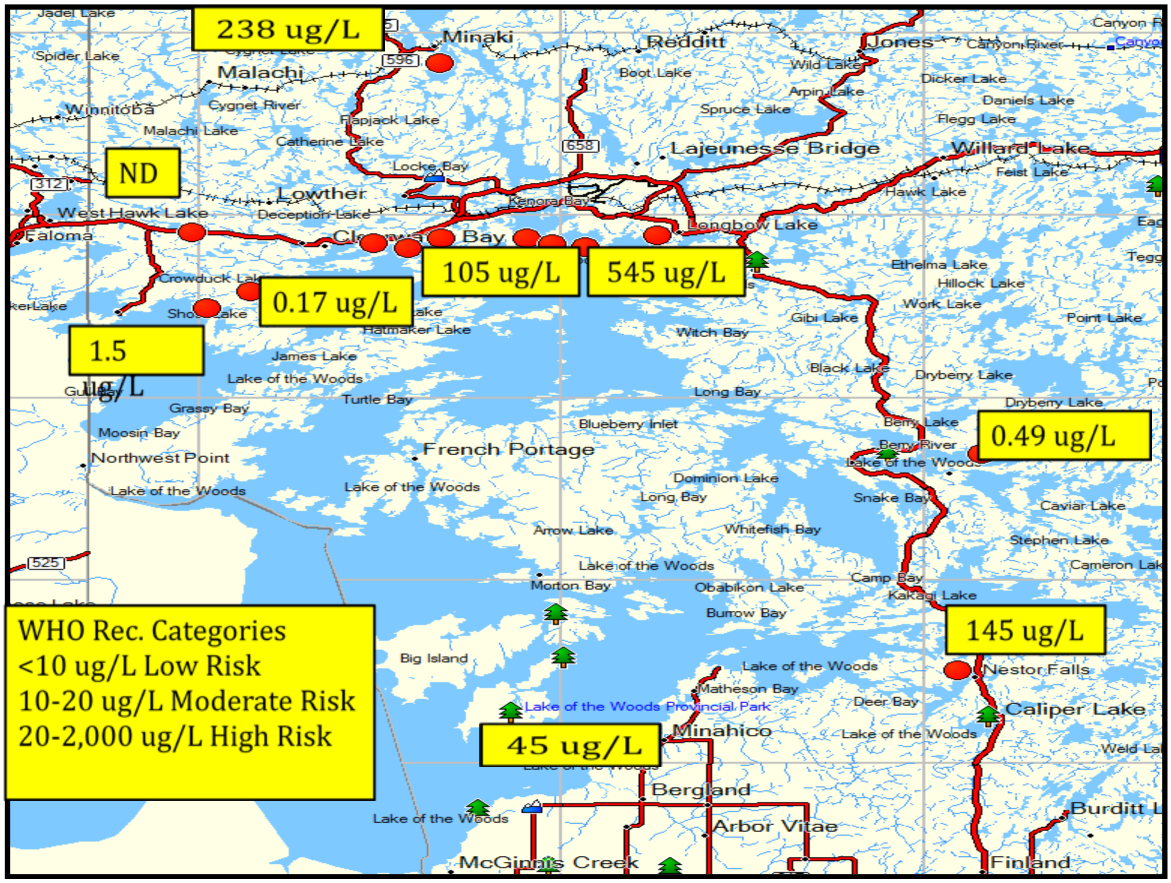


Figure 2. Maximum microcystin concentration (ug/L) at study locations in Lake of the Woods and Winnipeg River in 2009. ND = not detected (< 0.10 ug/L). Also shown are the World Health Organization Recreational Contact Risk Categories for Microcystin.

It is important to note that these concentrations are maximums based on a limited number of samples, and do not imply that high concentrations are always found in these areas of Lake of the Woods or the Winnipeg River. As can be observed in Table 2, there were some sites that, while having a high maximum concentration, also had samples that contained much lower microcystin concentrations (as indicated by low concentrations in the "range" column or by a low mean or median value). However, there were some sites that consistently had high microcystin concentrations, as shown by their high mean or median concentrations. Bigstone Bay in particular, had consistently high microcystin concentrations. In the case of Bigstone Bay, the high concentrations occurred in early September.

Table 2. Mean, median and range of microcystin concentrations in Lake of the Woods and Winnipeg River in 2009. Concentrations are reported as ug/L.

Location	# samples	Mean	Median	Range
Moth Lake	2	< 0.10	< 0.10	< 0.10
Clearwater Bay	9	< 0.10	< 0.10	< 0.10 to 0.17
Lobstick Bay	4	0.16	< 0.10	< 0.10 to 0.49
Shoal Lake	4	0.52	0.24	< 0.10 to 1.55
Town Island	4	2.20	2.50	< 0.10 to 3.73
Channel Island	2	4.26	4.26	3.16 to 5.36
Frenchman's Rock Road	4	9.05	5.96	0.87 to 45.57
Pine Portage Bay	4	17.31	4.69	0.16 to 59.69
Sunbath Island	4	47.32	39.03	5.73 to 105.37
Nestor Falls	4	40.35	7.31	0.21 to 146.55
Gun Lake	3	86.00	17.50	2.50 to 238.02
Bigstone Bay	4	264.33	231.58	48.42 to 545.71

The concentration of microcystin can vary seasonally (over the summer and fall months for example, as seen for some of the sites in this study), from year to year in a lake or even on an hourly basis. Previous studies in western Canada have observed high concentrations of microcystin in lakes in one year, and low or no microcystin in other years (Kotak et al., 1995, 2000). Changes in microcystin concentration may reflect changes in the species present, the amount of algae, or changes in the production of the toxin over time (from hour to hour, day to day, month to month or year to year). Not only can microcystin concentrations change over time, but the concentration can also vary widely over relatively short distances. This is not unexpected, as algal blooms along shorelines can be very patchy (e.g., the water may be very green in one area of a beach, and only metres away, the water is clear). As part of this LOWDPOA study, 14 samples were collected along the shoreline of one of the study participants to examine the variability of microcystin concentration over a relatively short distance. The samples collection sites were spaced 5m apart. As indicated in Figure 3, microcystin concentrations ranged from 3 to over 170 ug/L. The most extreme difference was between to sites located next to each other where the microcystin concentration at Site 2 was 7.4 ug/L and was 173.8 ug/L at Site 3, located only 5 metres away. Based on this data, and considering the World Health Organization recreational contact guidelines, swimming at certain areas along this beach on this particular day could pose a moderate or high health risk, or no health risk at all. As mentioned previously, the best rule of thumb to reducing risk is to avoid swimming in areas where algal blooms are present.

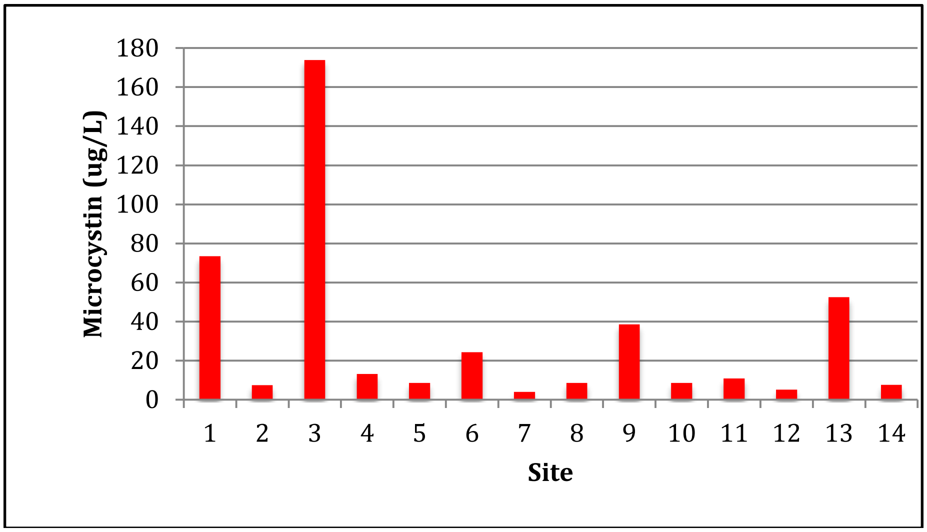


Figure 3. Concentration of microcystin along a shoreline near Frenchman's Rock Road. Sampling sites were located 5 m apart from each other. World Health Organization recreational risk categories: < 10 ug/L – **Low** risk, 10 - 20 ug/L – **Moderate** Risk, > 20 ug/L – **High** risk.

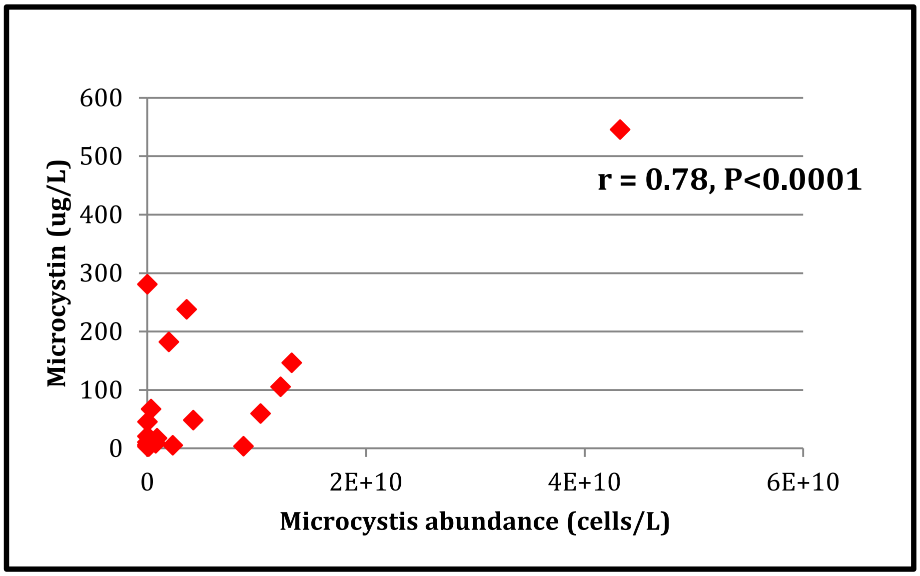
Algal Species Potentially Producing Microcystin in Lake of the Woods and Winnipeg River

In order to determine which species of algae could potentially be producing microcystin in Lake of the Woods and the Winnipeg River, two types of analyses were performed. Firstly, correlation analysis was performed on shoreline data using the algal species composition data and microcystin data. From this analysis, microcystin concentration was positively correlated to the abundance (cells/mL) and biomass (mg/m^3) of several species. In particular, microcystin concentration was positively correlated to the abundance of *Microcystis ichthyoblabe*, *Anabaena flos-aquae* and *Anabaena circinalis* in shoreline samples (Table 3). When all species of either *Microcystis* or *Anabaena* were combined (for *Microcystis*, there were a total of 8 species, for *Anabaena* there were a total of 8 species), there was also a relationship with microcystin concentration in shoreline samples (Table 3, Figure 4).

All of these species have been shown to produce microcystin in other studies (Zurawell et al., 2005). In addition, a weaker correlation (r = 0.47, P = 0.02) was observed between microcystin concentration and the abundance of *Lyngbya* sp. This species has also been known to produce microcystin. There was also a statistically significant correlation (r = 0.76, P < 0.001) between microcystin concentration and *Aphanizomenon* sp. Generally, this genus has not been thought to produce microcystin, although this is still being researched. *Pseudanabaena* sp., which is commonly found in close association with blooms of *Aphanizomenon* sp., is known to produce microcystin in Lake of the Woods (Kling et al., submitted for publication), and the correlation between microcystin and *Aphanizomenon* sp. may be partly due to the presence of *Pseudanabaena* sp.

Table 3. Correlation Analysis Between Algal Species Abundance and Microcystin Concentration in Shoreline Samples

Species	**Correlation Coefficient (*r*)**	***P* value**
Microcystis ichthyoblabe	0.69	< 0.001
Microcystis (all species combined)	0.78	< 0.001
Anabaena flos-aquae	0.88	< 0.001
Anabaena circinalis	0.61	0.001
Anabaena (all species combined)	0.87	< 0.001



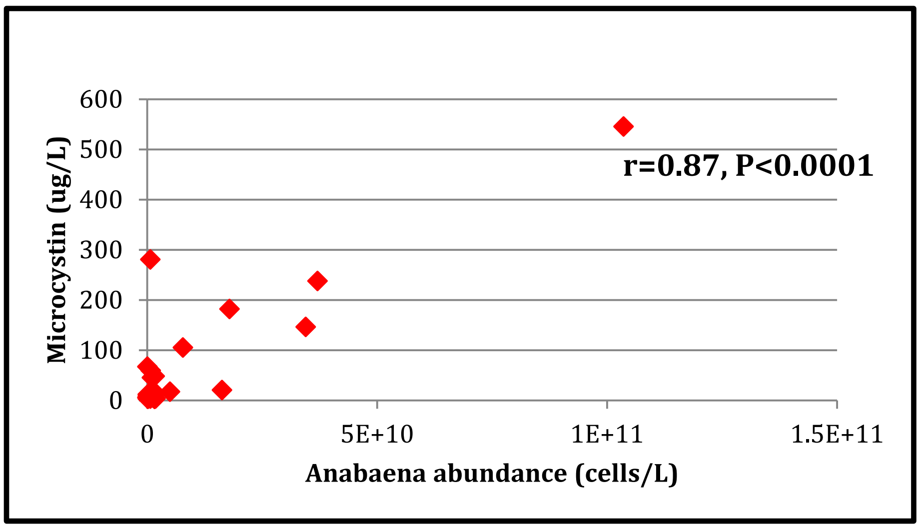


Figure 4. Relationship between the abundance of *Microcystis* sp. abundance and microcystin concentration in shoreline samples (top graph) and *Anabaena* sp. abundance and microcystin concentration in shoreline samples (bottom graph).

Another method of determining which species could be producing microcystin in Lake of the Woods and the Winnipeg River is to examine only the shoreline samples which were related to the most significant recreational contact risk (i.e., shoreline samples with > 20 ug/L of microcystin). Table 4 shows the algal species, which were either dominant or co-dominant in shoreline samples when microcystin concentration exceeded 20 ug/L. It is evident from Table 4 that a number of species were either dominant or co-dominant in the phytoplankton when microcystin concentrations were high. In particular, several species of *Microcystis* and *Anabaena* are likely responsible for the production of microcystin in Lake of the Woods and the Winnipeg River. Chen et al. (2009) also concluded in their study of Lake of the Woods that microcystin is likely being produced by species of *Anabaena* and other species of *Microcystis* and *Lyngbya*. It is also interesting to note that species of *Anabaena*, *Microcystis* and *Pseudanabaena* are thought to be the main microcystin producers in Lake Winnipeg (Kotak et al., 2011). Other species such as *Pseudanabaena* are known to produce microcystin, and was either dominant or co-dominant in 9% of the shoreline samples containing > 20 ug/L of microcystin in the present study. In contrast, even though *Aphanizomenon* was also either dominant or co-dominant in a large percentage of samples with > 20 ug/L microcystin, the contribution of *Aphanizomenon* towards producing microcystin is unknown, but is being studied by others.

Table 4. Percent of shoreline samples with microcystin concentration in excess of 20 ug/L in which algal species are either dominant or co-dominant.

Species	% of samples where species is either dominant or co-dominant
***Microcystis* (all species combined)**	**72**
Microcystis ichthyoblabe	45
Microcystis sp.	36
Microcystis aeruginosa	27
Microcystis flos-aquae	18
Microcystis smithii	9
***Anabaena* (all species combined)**	**81**
Anabaena flos-aquae	72
Anabaena mendotae	63
Anabaena lemmermannii	36
Anabaena crassa	18
Anabaena planktonica	9
Anabaena circinalis	9
Pseudanabaena sp.	9
Woronichina sp.	9
Aphanizomenon (all species combined)	72
Aphanizomenon flos-aquae complex	55

Microcystin in Water Intake Lines – Prior to Treatment

Despite the very high concentrations of microcystin along shorelines at some sites, microcystin concentrations in water intake lines (before any water treatment) were consistently low, and generally below the detection limit of 0.10 ug/L. Figure 4 demonstrates two important points with respect to microcystin along shorelines and in water intake lines. Firstly, there was no relationship between microcystin concentration in lake/river water along shorelines and the concentration in water intake lines. Even when microcystin concentration may be very high in an algal bloom along a shoreline, the concentration in a water intake line can be low. It is likely that even if a heavy shoreline algal bloom died off and released microcystin into the surrounding water, the microcystin concentration in a water intake line would not likely increase because of the massive dilution effect as the toxin in the algal cells is diluted into the surrounding lake water. In addition, most intake lines were not located near the surface of the water (where blooms tend to accumulate). However, high concentrations of microcystin in water could theoretically occur if a microcystin-producing algal bloom in a shallow bay releases the toxin in a part of the bay where exchange of water between the bay and the rest of the lake is minimal. In this case, the dilution effect would be minimal, causing elevated toxin concentrations in the water. The second point with respect to Figure 4 is that concentrations of microcystin in water intake lines were substantially below the Canadian Drinking Water Guideline for microcystin of 1.5 ug/L. The highest microcystin concentration observed in water intake lines was 0.20 ug/L.

When comparing the data of the concentration of microcystin in algal blooms along shorelines with the concentration in water in intake lines, an important recommendation can be made to help cottages/camps to minimize the risk of microcystin being present in water that is drawn into a dwelling. Since algal blooms are most severe at the surface of the water, water intake lines should be located at an appropriate depth (5 to 10 feet below the surface for example). This would provide better dilution of the toxin should an algal bloom die off and release microcystin. The actual depth and the location of a water intake line would obviously need to consider the local circumstances. For example, the water in front of some cottages/camps may be very shallow (3 to 5 feet for example) and the option of reaching deeper water may involve a very long water line. Boat and other watercraft traffic may limit your options as well. In addition, deeper water may not always be a good option either. In some parts of the Lake of the Woods, deep water (30 feet or more, for example) may contain little or no dissolved oxygen. This water may contain high sulfide concentrations or high concentrations of other elements, which make it less palatable for cottage use (either for drinking or other uses). The depth of your waterline will therefore depend on a number of factors, but a water line should never be placed right along the surface of the water, especially where algal blooms can accumulate.

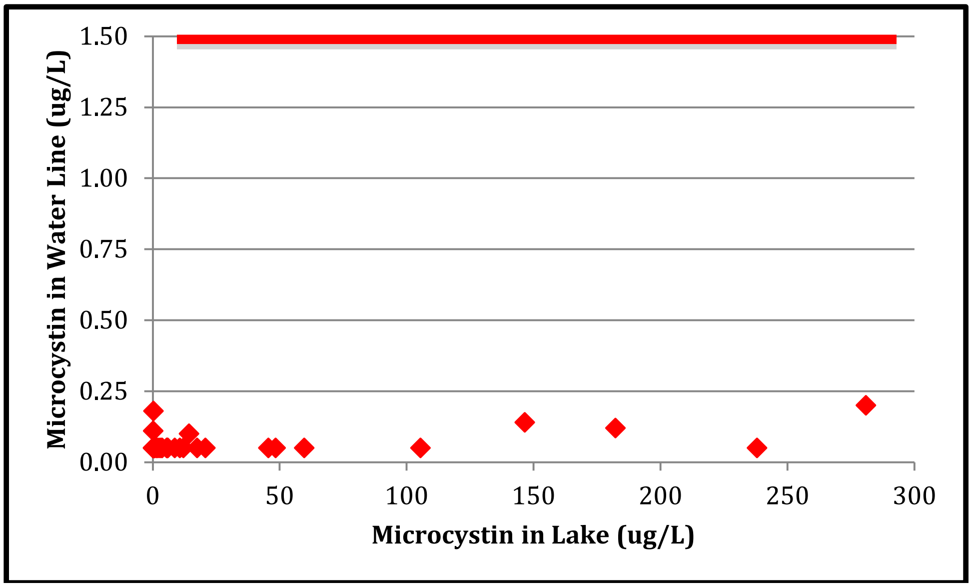


Figure 3. Relationship between microcystin along shorelines (bottom axis) and microcystin concentration measured in water intake lines (vertical axis). Red bar indicates the Canadian Drinking Water Guideline for microcystin.

Microcystin in Tap Water

A total of 48 samples were collected from kitchen taps. Forty-one samples (85%) did not contain detectable concentrations of microcystin. Of the 7 tap samples that did contain detectable concentrations of microcystin, the average concentration detected was 0.16 ug/L and the maximum concentration was 0.21 ug/L, values that are well below the Canadian drinking water guideline of 1.5 ug/L. The highest concentrations detected in tap water were from 2 cottages/camps, and neither dwelling treated their water, nor did they use lake water for drinking. The data from the study indicate that the use of lake water (whether treated or not) in a cottage/camp on Lake of the Woods or the Winnipeg River generally does not represent an unacceptable risk to human health with respect to exposure to microcystin.

From the present study, it was not possible to evaluate the effectiveness of the various water systems for removing microcystin from water. For the cottages/camps that used water treatment systems prior to water use in their dwelling, none had detectable concentrations of microcystin in their water intake lines (i.e., prior to the water treatment step). Therefore, it was impossible to determine if their water treatment systems aided in removing microcystin before water was used in the cottage/camp. As mentioned previously, small-scale water treatment systems such as those used in cottages/camps, including the use of carbon filters, may not afford any protection against microcystin in a cottage/camp setting. Ultraviolet disinfection would also not reduce microcystin concentrations (although it would provide benefits of killing bacteria).

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