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FOCUS ON

Cyanobacterial Toxins in Drinking Water

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Introduction

Cyanobacteria (also referred to as blue-green algae) are a group of bacteria that naturally occur in all types of surface water environments. Many different genera of cyanobacteria can produce toxins referred to as cyanotoxins.[1] In general, there is a potential for concentrations of cyanotoxins to increase when cyanobacteria proliferate and form a bloom.

The growth and development of blooms is influenced by a variety of chemical, physical, and biological factors. Blooms can occur under a wide range of environmental conditions including:[1–4]

- high nutrient availability (such as phosphorous and nitrogen from sewage, agricultural and industrial inputs),
- slow-moving or still waters,
- elevated temperatures (such as in late summer and early fall),

- low carbon dioxide availability,
- high light intensity, and
- elevated pH can encourage the formation of blooms and subsequent production of cyanotoxins.

These conditions can encourage the formation of blooms and subsequent production of cyanotoxins. Toxins can be released at the end of a bloom event and can remain in waters even after a bloom has dissipated and is no longer visible, although the length of time cyanotoxins can persist is dependent on numerous factors such as dilution rate, the type of toxin, rate of degradation.[5] Exposure to these toxins have the potential to harm human health.

The objective of this Focus On is to provide information on the following questions:

1. What acute and chronic human health effects have resulted from exposure to cyanobacterial toxins in drinking water? Specifically, are there any documented cases of human illnesses as a result of consuming drinking water contaminated with cyanobacterial toxins?

2. What are the current guidelines for cyanobacteria in drinking water?

3. What actions have been taken to reduce exposure to cyanobacterial toxins in drinking water?

This document addresses exposures via drinking water. Evidence related to human health risks following cyanobacteria exposure in recreational freshwaters are discussed in Public Health Ontario's Focus On: Cyanobacterial Toxins in Recreational Freshwater.

Key Findings

- Cyanobacteria, commonly known as blue-green algae, are naturally occurring photosynthetic bacteria that can form dense blooms in water, affecting water quality and potentially producing toxins harmful to human health. The most commonly studied cyanotoxin is Microcystin-LR, which is considered the most important freshwater cyanotoxin and can persist in waters even after a bloom has dissipated.
- Epidemiological data on human health impacts from cyanotoxins in drinking water are limited and often occur alongside recreational water exposures. Case reports suggest an association with a variety of acute health effects such as gastroenteritis, sore throat, dry cough, blistering of the mouth, headache, fever, anorexia, pallor, laboured breathing, muscle weakness, hepatoenteritis and elevated liver enzyme levels in humans. Chronic exposures to microcystins may increase the risk for development of liver and colon cancers, but more research is required to better determine their carcinogenicity.
- The Ontario Drinking Water Quality Standard is 1.5 µg/L for microcystin-LR and Health Canada's maximum acceptable concentration for total microcystins in drinking water is 1.5 µg/L with separate reference value of 0.4 µg/L for formula-fed infants. Ontario does not provide a separate value for infants, but advises households not serviced by municipal water supply to use an alternate water source when reconstituting infant formula during a bloom event.
- Many cyanotoxins are stable in the environment and resistant to degradation, and can withstand several hours in boiling water. Residential-scale water treatment is available that can remove intact cyanobacterial cells and dissolved microcystins in drinking water. Devices certified by an accredited body as meeting NSF International (NSF) or American National Standards Institute (ANSI) drinking water treatment standards are recommended and should be maintained and/or replaced regularly as per manufacturer's recommendations.

Methods

A scoping literature search was conducted in Medline, Embase, Scopus, and Environment Complete in November 2022. The search strategy was developed by PHO Library Services and included a combination of search terms including: microcystin, cyanotoxin, cyanobacteria, harmful algal bloom, water quality, drinking water, health, disease, illness, exposure, and toxicity. The search returned 2,535 records; titles and abstracts were screened for relevance to human health effects and cyanobacteria in drinking water. Additional articles were identified from reference lists in articles that passed screening, and through an informal grey literature search. A grey literature search was completed in November 2022 using the same combination of search terms entered into custom search engines (targeting public health resources) and Google. Information and references identified in the grey literature search were reviewed for relevance. The full search strategy for both the literature and grey literature search and accompanying results are made available upon request.

Main Findings

Cyanotoxins of Concern

Cyanobacterial blooms have been observed in surface water based drinking water sources all over Canada, with the exception of the territories, and Prince Edward Island (PEI) where drinking water is sourced exclusively from groundwater.[1] Over 20 different genera of cyanobacteria have been identified as capable of producing toxins, some of which may present a hazard to human health.[1] When present, cyanotoxin concentrations are likely at their highest while the bloom is present, but due to their stability in the environment they may persist for a short time (e.g., days to weeks) after the bloom has visually disappeared.[1,3] The concentration of cyanotoxins in a water source is influenced by dilution, adsorption (onto sediment or organic matter), photolytic degradation (degradation by exposure to sunlight) and biodegradation by aquatic organisms.[1,2]

There are many types of cyanotoxins including microcystins, nodularins, anatoxins, cylindrospermopsin, and dermatotoxins.[3] Among the cyanotoxins encountered in freshwater environments, microcystins are considered to be the greatest concern to public health due to their frequency of occurrence and their stability in the environment.[1,6] Microcystins are resistant to chemical hydrolysis and oxidation, and they can withstand several hours in boiling water.[1–3] There are more than 85 different variants of microcystins, and microcystin-LR is often reported as the most commonly encountered variant globally.[1,3,7,8]

Microcystin-LR is the most commonly studied cyanotoxin and is considered by Health Canada to be the most important freshwater cyanotoxin.[1] In Ontario, *Microcystis* was one of the most frequently reported taxon of cyanobacteria between 1994 and 2009.[9] Microcystin is also the basis for the Canadian and Ontario drinking water guidelines. Therefore, most of the material reviewed for this Focus On is related to microcystin-LR or other microcystins.

Potential Human Health Risks

Limited epidemiological data are available for human health impacts related to cyanotoxins exposure in drinking water.[3] According to case reports and epidemiological studies published in the scientific literature cited by Health Canada, the United States Environmental Protection Agency (US EPA), and the World Health Organization (WHO), symptoms related to ingesting cyanotoxins are varied and may include nausea, vomiting, diarrhea, sore throat, dry cough, blistering of the mouth, stomach cramps, stomach pains, headache, fever, anorexia, pallor, laboured breathing, muscle weakness and elevated liver enzyme levels in humans.[1,2,7,10–12] Although cyanobacterial toxins can be encountered alongside other common environmental hazards in freshwater (e.g., microbial pathogens and chemical contaminants), more research is required to better understand the health effects of combined exposures.[13]

Acute Human Health Effects

Ingesting drinking water is considered to be the dominant route of exposure to microcystin-LR.[1,2] Exposure to cyanobacteria and their toxins can also occur through dermal contact and inhalation of aerosolized particles during showering. Health Canada notes that inhalation of contaminated drinking water is not a significant source of exposure, but having baths instead of showers can be an option to reduce exposures during a bloom event.[1,14] Other possible sources of exposure include food ingestion (e.g., consuming algal dietary supplements or fish/seafood caught in waters with a high abundance of cyanobacteria) and recreational water ingestion (e.g., inadvertent ingestion during swimming and other watersports).[2]

Wood conducted an international review of cyanobacteria exposure incidents and suspected human illnesses.[15] No Canadian drinking water case reports were identified but five Canadian case reports of acute morbidity were attributed to recreational freshwater exposure to cyanobacterial toxins. A variety of symptoms were reported in these recreational water case reports including headache, nausea, gastrointestinal upset, diarrhea, vomiting, stomach cramps, abdominal pain, fever, muscle aches, weakness, wooziness, thirst, general malaise, and loose stools. All cases occurred in Saskatchewan between 1959 to 1961 and were linked to swimming.[15]

A prospective cohort study from Quebec followed over 250 families for 8 weeks in summer 2009, looking at human health effects from exposure to both drinking water and recreational freshwater exposures. Researchers had participants record a daily journal of symptoms. The researchers also collected daily water samples for cyanobacterial cell counts and measurements of dissolved microcystin. Participants who were supplied with drinking water from a treatment plant whose source had a high concentration of cyanobacteria (Lake Champlain's Missisquoi Bay) noted an increase in muscle pain, gastrointestinal, skin, and ear symptoms.[16] Attribution of symptoms solely to drinking water exposure was not possible as gastrointestinal symptoms were also associated with recreational contact with water that contained high cyanobacterial cell counts. Symptoms were likely mild as none of the study participants sought medical care for their illness.

While Canadian reports are scarce, case reports of acute human illnesses resulting from exposure to cyanobacterial toxins in drinking water have been reported in other countries, including the United States, Zimbabwe, Australia, and Brazil.[15,17] Cases of gastroenteritis were reported in populations living along the Ohio River in 1930-31.[18,19] Bacteriological tests were performed by measuring coliform bacteria in treated effluent from water purification plants, and the water was deemed to have met US Treasury bacterial standards at the time. However, microscopic tests revealed an abundance of blue-green algae. As bacteriological assessments were negative and the cases of gastroenteritis could not be attributed to other infectious agents at the time, the presence of cyanobacterial blooms in the source water during the outbreak and abundance of blue-green algae were proposed as a possible cause of illness.[18,19] Other potential sources such as biological hazards (e.g., viruses, parasites) or chemicals (e.g., non-cyanobacterial toxins) were not evaluated and cannot be ruled out as a potential cause of the reported gastroenteritis.

In the 1960s, seasonal peaks in gastroenteritis in children living in Harare, Zimbabwe could not be attributed to bacterial or viral cultures. A local pediatrician suggested that the illnesses might be related to algal growth and decay and subsequent release of toxins in the Lake McIlwaine reservoir, although neither the algal species nor the toxins were identified.[20]

Nearly 150 cases of hepatoenteritis (a hepatitis-like illness associated with dehydration and bloody diarrhea), largely in children (age range 2 to 16 years) who required hospitalization, occurred among individuals obtaining their drinking water from the Solomon Dam, Australia.[21,22] A causative agent was not determined but the reservoir water was noted to have algal blooms and in subsequent years, high cylindrospermopsin levels were noted in the Solomon Dam reservoir and thought to be implicated as the cause of this epidemic. However, the Solomon Dam reservoir was treated with copper sulfate at the time of the outbreak. Copper can accumulate in the liver and suddenly be released from hepatocytes, which can result in acute hepatitis and intestinal hemorrhage. As the details of the water treatment of the dam are not known, the addition of copper sulfate cannot be ruled out as the causative agent for the cases of hepatoenteritis.[23]

In 1988, contaminated drinking water from Itaparica Dam in Brazil resulted in over 2,000 cases of gastroenteritis and 88 deaths over a 42-day period. The timing of the outbreak coincided with cyanobacterial blooms, and *Microcystis* cell counts above WHO guidelines for drinking water prior to treatment were noted.[24] *Salmonella, Shigella,* rotavirus, adenovirus, heavy metals, or agricultural chemical contaminants (pesticides) were not found in the water supply based on laboratory testing. Outbreak investigators could not rule out other causes of gastroenteritis (such as *Vibrio, Yersinia, Campylobacter* and viral agents) but the boil water advisory was not effective at reducing cases of gastroenteritis and therefore a bacterial or viral agent was considered unlikely to be the cause. A reduction in the number of cases of gastroenteritis coincided with treatment of the water with copper sulfate, which reduced cyanobacteria (*Anabaena* and *Microcystis*) concentrations in the reservoir.[24]

More recently, in August 2, 2014, a water use advisory was posted for residents in Toledo, Ohio in response to levels of microcystins in treated drinking water that exceeded Ohio's drinking water advisory threshold (1 ppb, or 1 µg/L).[22] The advisory was lifted 2 days later on August 4, 2014 after multiple water samples detected microcystin levels less than the local advisory threshold levels. The Ohio Department of Health and the Toledo-Lucas County Health Department conducted a survey amongst residents of Lucas County where 84% of those who obtained their water from the affected water treatment plant resided.[25] In 16.2% of households, at least one person reported physical symptoms attributed to the water advisory; cases of gastrointestinal illness (diarrhea, nausea and vomiting) were most common with other reported symptoms including skin irritation, headache, eye irritation or pain, and respiratory illness or cough. Of the households reporting physical symptoms, most (89.1%) did not seek medical care and no fatalities were reported.[8,25]

Chronic Human Health Effects

Studies have suggested that chronic exposure to microcystins may increase the risk for development of liver and colon cancers, but more research is required to determine their carcinogencity.[1–3,7,10–12,22,26–28] The International Agency for Research on Cancer (IARC) classified microcystin-LR as a group 2B carcinogen (possibly carcinogenic to humans) based on inadequate evidence of carcinogenicity in humans and experimental animals but strong evidence supporting a plausible tumour promotion mechanism in the liver of rats, and in the liver and colon of mice.[29] The US EPA determined that there is inadequate information to assess the carcinogenic potential for microcystins.[12]

Non-cancer chronic health effects are seen in animal studies with exposure to microcystin. A 13-week study with mice showed gross and microscopic liver pathology and changes in blood chemistry.[30] A 28-day study with rats showed an increase in liver weight, elevation of serum liver enzymes, and evidence of liver damage on histopathology.[31] Data in humans are limited, but acute liver failure was seen in individuals exposed to microcystins from contaminated dialysis fluid.[15]

Guidelines for Microcystins in Drinking Water

Limited epidemiological data are available for human health impacts from cyanotoxins. In addition, illnesses caused by cyanobacterial toxins are not reportable (with the exception of paralytic shellfish poisoning, or PSP, caused by exposures to saxitoxins, typically via ingestion of contaminated seafood).[32] The following section summarizes relevant guidelines and advisories that have been established to address drinking water quality when a bloom is reported. A more detailed description of these guidelines and how they were derived is presented in the Appendix.

Health Canada Drinking Water Guideline

The Health Canada drinking water guideline for cyanotoxins is based on total microcystins; guidelines are not provided for other cyanotoxins (such as anatoxins and cylindrospermopsin) due to limited health data.[1] The Health Canada maximum acceptable concentration (MAC) for total microcystins in drinking water is 1.5 µg/L. On a bodyweight basis, infants can consume up to five times more drinking water than an adult. Therefore, a precautionary reference value of 0.4 µg/L was established for infants based on their high drinking water intake. When this concentration is exceeded, Health Canada advises that an alternate source of drinking water be used to reconstitute infant formula.[1]

Ontario Drinking Water Quality Standard

Ontario's Drinking Water Quality Standard (ODWQS) is 1.5 µg/L for microcystin-LR.[33] While there is no separate reference value for infants, the Ontario Ministry of the Environment, Conservation and Parks (MECP) suggests that when there is a harmful algal bloom, private systems relying on surface water should use an alternate source for infants (i.e. bottled water), rather than relying on a private treatment system (given the uncertainty on whether these private systems are properly operated and maintained).

United States Environmental Protection Agency Health Advisories

Cyanotoxins are not subject to national drinking water regulations in the United States, but the US EPA has developed Health Advisories (HAs) for these compounds. The HAs serve as informal technical guidance to assist federal, state, and local officials, as well as managers of public or community water systems to protect public health.[34]

The ten-day drinking water HA value for total microcystins is 1.6 µg/L for school-age children (i.e., children 6 years of age and above) and adults. A separate, lower ten-day HA value of 0.3 µg/L is set for formula-fed infants and pre-school children (i.e., children less than 6 years of age) based on higher drinking water intake rates (exposure of infants is assumed to be five times higher relative to adults on a body weight basis).[35]

The ten-day drinking water HA value for cylindrospermopsin is 3.0 µg/L for school-age children and adults, and a lower ten-day HA value of 0.7 µg/L is set for formula-fed infants and pre-school children.[36] The US EPA has also reviewed relevant toxicological information on anatoxin-a, which is summarized in a Health Effects Support Document. The available data on anatoxin-a was considered inadequate to derive a health-based value for anatoxin-a and therefore a drinking water HA value was not established.[37]

World Health Organization Guidelines for Drinking Water Quality

The WHO has derived drinking water guidelines for microcystins, cylindrospermopsins, anatoxin-a (and their analogues) and saxitoxins.[38]

The WHO provisional guideline values for microcystins is based on studies of microcystin-LR, but since microcystins generally occur as mixtures, the WHO assumes that comparison of guideline values to total microcystins concentrations is likely to be protective of public health.[2] The WHO has set a provisional guideline value of 1 µg/L for lifetime exposure to microcystins in drinking water.[2] A separate provisional guideline value of 12 µg/L has been established for short-term exposures to drinking water; the short-term guideline value indicates the extent to which the lifetime value can be exceeded for periods of up to 2 weeks until water treatment can reduce microcystin concentrations to below guideline values and is not intended to allow for repeated exceedances of the lifetime value.[2] As a precautionary measure, the

WHO also recommends that formula-fed infants and small children use an alternative water source if total microcystin concentrations are greater than 3 µg/L.[2]

The WHO's provisional guideline values for cylindrospermopsin are 0.7 µg/L and 3 µg/L for lifetime and short-term exposures, respectively.[39] The WHO also recommends that formula-fed infants and small children use an alternative water source if cylindrospermopsin concentrations are greater than 0.7 µg/L.[39]

The WHO considers the toxicological information on anatoxin-a and its analogues inadequate to support derivation of a formal guideline value. Therefore, a provisional health-based reference value of 30 µg/L for acute or short-term (up to 28 days) is provided as a risk assessment value where adverse effects in exposed adults are not expected.[40] A reference value for chronic exposures was not calculated due to the lack of studies of chronic anatoxin exposure. Use of an alternative water source is recommended for formula-fed infants and small children if anatoxin concentrations exceed 6 µg/L.[40]

The guideline value for saxitoxins is 3 µg/L in drinking water.[41] The guideline value is applicable to acute exposures and should not be exceeded even for a short time. As there is no indication of chronic toxicity from follow-up of human cases of PSP, a lifetime guideline value was not derived.[41] The WHO derived the saxitoxin guideline value based on formula-fed infants as the most sensitive subgroup. Therefore, recommendations for using an alternative water source to reconstitute formula are not necessary.

Reducing Exposures to Cyanobacterial Toxins

An approach incorporating multiple intervention methods is required to reduce exposures to cyanobacterial toxins via drinking water and prevent potential health risks. These interventions can include drinking water source protection, monitoring, disease surveillance and water treatment. Given that microcystins are heat stable and boiling is ineffective in reducing concentrations in water, it may be more effective to focus efforts on upstream interventions such as reducing the source of microcystins via source protection (preventing bloom formation) or preventing cyanobacteria and their toxins from entering the drinking water supply via monitoring.

The MECP has provided information on recognizing and managing cyanobacterial blooms. The Ontario government and its partners are working to manage blooms by reducing nutrients, drinking water source protection, legislation and regulatory tools, bloom/toxin monitoring and providing research, financial and laboratory analysis support to partners.[33]

Source Protection

Nutrient management such as reducing inputs of phosphorous and nitrogen into surface waters can reduce growth of cyanobacteria.[6,7,42] Artificial mixing of water bodies (via air bubbling or mixing devices) can reduce lake stratification and prevent the formation of surface blooms in still waters.[7,42]

Although a full discussion of bloom prevention is beyond the scope of this Focus On, additional detail on control measures in watersheds and reservoirs are found in the *Guidelines for Canadian Drinking Water Quality* technical document on cyanobacterial toxins.[1]

In Ontario, drinking water sources are protected via the Drinking Water Source Protection Program established under the *Clean Water Act*.[43,44] Regional source protection plans outline policies and actions to protect drinking water sources, including addressing the threat of cyanobacterial blooms through management of water inputs. These plans are implemented through a collaborative effort between municipalities, source protection authorities, local health boards, the provincial government and others; the full list of source protection plans enacted locally is available via Conservation Ontario.[43]

Monitoring for Blooms and Sampling for Cyanotoxins

Microcystins can be present in drinking water sources whenever there is a bloom. Blooms have been observed in surface water sources across Canada, with the exception of the territories and PEI.[1]

Standard practices for monitoring and assessment of cyanobacterial blooms have not been developed, and the management of cyanobacterial blooms and toxins vary across jurisdications.[8,45] In Ontario, algal blooms should be reported to the MECP Spills Action Centre which members of the public can submit online.[33,46]

Un-published data from 2009 – 2012 detected cyanobacterial blooms at 24 – 29 sites in Ontario from as early as May to as late as November, with detectable levels of microcystins in 20 – 73% of those sites sampled in any given year.[1] A 2011 study of Ontario bloom data from 1994 to 2009 found a statistically significant increase in the number of algal blooms reported each year, with over 40 algal blooms reported in Ontario during the last year of available data in 2009.[9] A more recent study demonstrated that this upward trend of algal bloom reports has persisted, with more than 65 confirmed cyanobacterial blooms reported in 2019.[47] In 2021 and 2022, there were 90 and 54 confirmed blue-green algae blooms reported in Ontario, respectively.[48,49]

The increasing trend in bloom reports may be attributed to an increase in cyanobacterial bloom incidences in Ontario as well as increased public reporting due to heightened awareness of cyanobacteria as a potential hazard.[47] Increased reporting by municipal drinking water system owners may also be a contributing factor. Municipal systems that obtain water from one or more surface water sources are now required to develop and implement a Harmful Algal Bloom Monitoring, Reporting and Sampling Plan as part of their licensing conditions.[50] At minimum, these plans require system operators/owners to perform visual observations of the water source, report observed or suspected harmful algal blooms (HAB), conduct sampling whenever a HAB is suspected or occurring and at regular intervals during a bloom, and to submit samples to a licensed laboratory for testing.[50] The MECP has also previously provided advice to municipal drinking water system operators/owners on monitoring for and addressing HABs prior to the requirements for implantation of Harmful Algal Bloom Monitoring, Reporting and Sampling Plans. This advice may also be useful to operators of small drinking water systems. Per their recommendations, all observed blooms can be regarded as *potentially toxic*. Other general recommendations are summarized as follows:[51]

- Monitoring on a weekly basis is recommended during bloom season (beginning of June to the end of October). Monitoring includes direct observation of source water approaching and standing at system intakes for algal blooms. Regular collection of water samples for microcystin testing can be conducted, with samples including both raw and finished water.
- If analytical testing determines that concentrations of total microcystin meets or exceeds 1.5 µg/L in finished water, it should be treated as a provisional adverse water quality incident and the licensed laboratory is required to report the incident to the MECP, the drinking water system owner/operator and the local Medical Officer of Health (MOH).

Note that not all of the MECP recommendations may apply to owners/operators of small drinking water systems. However, some of the general measures can be adopted to address bloom formation in water sources.

Health Outcome Surveillance

As previously mentioned, illnesses caused by cyanobacterial toxins are currently not reportable in Ontario (with the exception of PSP cases). The wide range of different symptoms that a person can experience following exposure to cyanotoxins also poses challenges for health outcome surveillance.

In some other jurisdictions, these outcomes are captured by surveillance systems which can provide useful information on trends and the extent to which blooms are resulting in adverse effects on health. For example, the US Centers for Disease Control and Prevention established the One Health Harmful Algal Bloom System (OHHABS). The OHHABS is a voluntary reporting system accessible by state and territorial health and environment departments that collect data on human and animal cases of illness from HAB exposures and the associated environmental data necessary to describe the blooms.[54] By integrating health and environmental data, the goal of OHHABS is to further the understanding of HABs and associated illnesses so that future occurrences can be prevented. Surveillance for blooms can help determine patterns of occurrence to inform which water supplies require protection, and to alert the public to potential problems caused by blooms.

Residential-Scale Water Treatment

Individual households that obtain their drinking water from a surface water source where cyanobacterial blooms may occur can reduce their exposure to microcystins by switching to an alternate water supply and moving the location of the drinking water supply pipe (by changing its distance and depth).[1] For example, the drinking water supply pipe or intake can be moved away from the bloom or to a location greater than 4 metres in depth, although note that some cyanobacteria can move vertically in the water column and water levels can fluctuate.[14,55]

Households can also consider installing a residential-scale drinking water treatment system.[1] Residential-scale water treatment systems processes should be capable of removing intact cyanobacterial cells from drinking water, followed by removal of dissolved microcystins that may have been released into the water. This can be done by using a combination of filtration systems installed at the point of entry (POE) upstream of any disinfection in a home treatment system, along with a filtration system installed at the point of use (POU) such as at the kitchen faucet.[1] POE systems consist of a prefilter to remove large particles (such as sand and sediment), followed by a filter with a smaller pore size (1 µm or less) effective at removing cyanobacteria. POU systems can include an activated carbon filter followed by a reverse osmosis filter. Time and usage will reduce the removal capacity of activated carbon and reverse osmosis filters. Therefore, it is important that these systems are maintained and/or replaced regularly as per manufacturer’s recommendations.

Health Canada recommends consumers use devices certified by an accredited body as meeting NSF International (NSF) or American National Standards Institute (ANSI) drinking water treatment standards.[1] Specifically, NSF certification should include certification of water filters for removal of microcystins. The *NSF Protocol P477: Drinking Water Treatment Units Microcystin* certifies that a water filter is able to reduce microcystin levels from 4 µg/L to 0.3 µg/L or below.[56,57] These targets correspond to the highest consistent levels detected in finished drinking water in North America and the US EPA recommended health advisory for children less than six years old, respectively.[57] Water treatment performing to NSF standards would also be capable of reducing microcystins to levels below the Health Canada’s reference value of 0.4 µg/L for infants. Note that products meeting the NSF standard must be retested periodically and re-certified each year to ensure their performance is adequate.

Residential-scale water treatment can also provide other benefits such as reducing exposures to other biological and chemical hazards (e.g., bacteria and metals).

Municipal-Scale Water Treatment

Water treatment plants are not typically designed to specifically reduce cyanotoxins. However, municipal drinking water treatment plants have the necessary technology to remove many other organic compounds having molecular weights similar to cyanotoxins and therefore are capable of effectively removing microcystin-LR. The occurrence of high levels of cyanotoxins at the location of intakes of municipal treatment plants have not reached levels that pose challenges to meeting Ontario standards (i.e., 1.5 µg/L for microcystin-LR in finished water) or reaching concentrations that would be expected to affect human health. As such, residential-scale treatment devices for cyanotoxins are generally not necessary for households that obtain their drinking water from a municipal supply.[1]

In the event that microcystins are detected in treated water at levels exceeding drinking water guidelines, operators have options to adjust processes to improve microcystin removal efficiency.[1,10,56,57]

Conclusions

Documented cases of human illness from drinking water exposure to cyanotoxins in Ontario and Canada are not available, although limited case reports from recreational water exposures exist. A 2009 Quebec study (the only Canadian study to examine health effects from both drinking water and recreational water exposure) found that participants reported muscle pain, gastrointestinal, skin, and ear symptoms from exposure to drinking water contaminated by cyanobacteria from Lake Champlain's Missisquoi Bay. Gastrointestinal symptoms were also associated with recreational contact with the contaminated water.[16] There is some limited evidence regarding chronic health effects (e.g. increased risk of developing liver and colon cancers) from chronic exposure to microcystins, however, more research is needed.[1–3,7,10–12,22,26–28] Health Canada's drinking water guideline value for total microcystins is 1.5 µg/L (with a separate reference value of 0.4 µg/L for infants on formula), while Ontario's drinking water guideline value is 1.5 µg/L microcystin-LR.[1,33]

The most common route of exposure to cyanotoxins is through ingestion of drinking water, although exposure is also possible through food consumption and recreational activities such as swimming and during other watersports.[1,2,12] Multiple approaches can be taken to reduce exposures to cyanobacterial toxins including source protection, monitoring for bloom events, and water treatment. Prevention of cyanobacterial growth is the most effective long-term strategy for reducing harmful cyanobacterial blooms and minimizing cyanobacterial-related health risks. Measures that can be taken by residents in the event of a bloom can include switching to an alternate water supply, moving the water supply pipe, or installation and use of drinking water treatment systems that are designed and certified for removal of microcystins.

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Appendix A – Drinking Water Guideline Values

Table 1: Guideline values for cyanobacteria and their toxins in drinking water.

Jurisdiction	Guideline Value	Derivation Assumptions
Canada[1]	**1.5** µg/L total microcystins Reference value of **0.4** µg/L total microcystins – seek alternate water source for infant formula	• Microcystin-LR LOAEL of 50 µg/kg body weight per day, based on increased liver weight and slight to moderate liver lesions with hemorrhages in rats[31] • Uncertainty factor of 900 • Assumed weight of exposed person is 70 kg (average weight of Canadian adult) • Estimated consumption of 1.5 L/day of water • Allocation factor of 0.8 (80% of a person's exposure to microcystins are attributed to ingestion of drinking water) • Although the resulting health-based value is 2.0 µg/L, the seasonal MAC of 1.5 µg/L was adopted as drinking water authorities were already achieving this concentration • Reference value of 0.4 µg/L based on infants ingesting 5x more water than an adult
Ontario[33]	**1.5** µg/L microcystin-LR	• Adopted from Health Canada guideline
United States EPA[35]	**1.6** µg/L total microcystins for school-age children & adults **0.3** µg/L total microcystins for bottle-fed infants & pre-school children	• Microcystin-LR LOAEL of 50 µg/kg body weight per day, based on increased liver weight and slight to moderate liver lesions with hemorrhages in rats[31] • Uncertainty factor of 1000 • Assumed weight of exposed person is 80 kg (mean weight for adults ages >21) • Estimated consumption of 2.5 L/day of water • A normalized ratio of drinking water ingestion to body weight (0.15 L/kg/day) was calculated using data for infants (birth to <12 months)
United States EPA[36]	**3** µg/L cylindrospermopsin for school-age children & adults **0.7** µg/L cylindrospermopsin for bottle-fed infants & pre-school children	• Cylindrospermopsin NOAL of 30 µg/kg body weight per day, based on kidney toxicity • Uncertainty factor of 300

Jurisdiction	Guideline Value	Derivation Assumptions
World Health Organization[2]	**1** µg/L total microcystin-LR	• Microcystin-LR NOAEL of 40 µg/kg body weight per day, based on liver pathology in mice[30] • Uncertainty factor of 1000 • Assumed weight of exposed person is 60 kg (average weight of an adult) • Estimated consumption of 2.0 L/day of water • Allocation factor of 0.8
World Health Organization[38]	**0.7** µg/L total cylindrospermopsins	• Cylindrospermopsin NOAEL of 30 µg/kg body weight per day, based on renal pathology in mice • Uncertainty factor of 1000 • Assumed weight of exposed person is 60 kg (average weight of an adult) • Estimated consumption of 2.0 L/day of water

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