



Guidance Document for Harmful Algal Blooms in Colorado

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Latest revision: April 20, 2015

Cover photo: Barr Lake, cyanobacteria bloom June 24, 2004, taken by Steve Lundt

1.0 Purpose

This Colorado Lake and Reservoir Management Harmful Algal Bloom (HAB) Guidance was produced to assist lake organizations, drinking water agencies, and other organizations that manage water resources in developing a safe and reliable guidance for properly handling harmful algal blooms. This guide discusses the general process, factors to consider, and suggestions and recommendations to consider when your lake or reservoir is experiencing a potentially harmful algal bloom. It also documents specific resources that can be helpful to lake management organizations for developing an appropriate response to a harmful algal bloom and includes references to other state guidelines and technical lab support.

This summary guide is a conglomerate from many different sources that have established HAB guidelines. This is not a statewide policy; this is a summary of what other states are doing. We gratefully acknowledge the United States Environmental Protection Agency (U.S. EPA) and their Office of Water website dedicated to cyanobacteria algal blooms. Other states and organizations that provided information include: Washington State Department of Health, Oregon Health Authority, World Health Organization, California Environmental Protection Agency, NALMS, Nebraska Department of Environmental Quality, the Center for Disease Control and Prevention, and PhycoTech for algal images.

We also sincerely appreciate the editorial effort of Steve Lundt and the reviewer efforts of the 2015 CLRMA board of directors. Their thoughtful comments and suggestions helped make this a better document and provided information to assist all CLRMA members.



Cyanobacteria bloom concentrated near shore

2.0 Introduction

2.1 Background

Cyanobacteria, blue-green algae, are normal components of Colorado's waterways. Their primary distinction from other algae is that they are prokaryotic (no membrane bound organelles). Cyanobacteria are more like bacteria but still create their own energy from photosynthesis like other eukaryotic algae. Cyanobacteria are credited for oxygenating the atmosphere and populating the earth for over 3.5 billion years.

Harmful algal blooms (HABs) are proliferations of microscopic algae that harm the environment by producing toxins that can impact organisms in a negative way. Impacts include human illness and mortality following direct consumption or indirect exposure in the environment, economic hardship, and dramatic fish, bird, and mammal mortalities. Equally important are the devastating impacts HABs may cause to ecosystems, leading to environmental damage that may reduce the ability of those systems to sustain species due to habitat degradation. In short, HABs lead to poisonous seafood, mortality of fish and other animals, economic impacts to shoreline communities, and long-term ecosystem changes.

Cyanobacteria can live in fresh, brackish, and marine water, on terrestrial surfaces, and in extreme cold and hot environments. All cyanobacteria are capable of producing toxins. This is just one of many survival tactics that cyanobacteria have evolved with over time. Other adaptable aspects that make cyanobacteria survive so well include abilities to live in a wide range of environments, nitrogen gas fixation, phosphorus storage, gas vesicles to change buoyancy, form large colonies, and the ability to have an adverse taste for zooplankton. Cyanobacteria also have anthropogenic modifications, including nutrient over-enrichment (eutrophication), water diversions, withdrawals, and salinization. Many cyanobacterial genera exhibit optimal growth rates and bloom potentials at relatively high water temperatures; hence global warming plays a key role in their expansion and persistence.

When dense algae populations develop, especially cyanobacteria, they turn water a greenish color referred to as a "bloom." Blooms are simply high concentrations of algal cells that give the water a "pea soup" appearance. Dense blooms near the surface may resemble a layer of green paint or spilled milk. Blooms occur in the warmer months and can be more frequent in times of drought, and as the number of algal cells increase, the chances for toxins also increase. The World Health Organization (WHO) defines their standard for problem blooms as populations of algal cells exceeding 100,000 cells/milliliter, or the equivalent of 24 million algal cells in an 8-ounce cup of water (WHO, 1999).

2.2 The Need for HAB Guidelines

As Colorado's population continues to increase, more and more pressure is being placed on the 1,500+ lakes and reservoirs across the state. Recreational and drinking water demands will only increase in the future. This requires that lake and reservoir managers continue to stay on top of the eutrophication process. The addition of nutrients that jumpstart the eutrophication process - algal growth, increase in cyanobacteria dominance, decrease in zooplankton grazing, low dissolved oxygen, and the internal release of more nutrients will only increase the chances of HABs.

Over 20 states currently have some form of a HAB program that includes monitoring, public notifications, and lake management protocols (Appendix A). Currently, there are no federal guidelines, regulations, or recommendations addressing cyanotoxins in recreational or drinking water in the United States. The U.S. EPA is working on guidelines and could be out as early as summer of 2015.

It is important to keep people, wildlife, livestock, and pets safe when they visit a lake or reservoir. There have been many cases across the United States and the world where severe illnesses and deaths have occurred. To avoid such tragedy, it is important that Colorado is proactive in managing for HABs.

2.3 Recent HAB Examples

Animals and humans have been getting sick from HABs for many years, going as far back as the early 1900's in some documented cases. Wildlife and farm animals have always been at risk of cyanotoxins. The new concern is that population growth, climate change, and increase pressures on water resources will only increase the risk of cyanotoxins causing human health issues.

Examples

Caruaru, Brazil (1996) - The only confirmed route of exposure for acute lethal human toxicity from cyanotoxins is from dialysis water used in a medical facility in Brazil in 1996. Water from a drinking water reservoir, with a history of cyanobacteria blooms (microcystis, anabaena, and cylindrospermopsis), was trucked to a dialysis clinic where it was poorly treated and used in the treatment of patients using hemodialysis. As a result, 126 patients were severely affected, 70 of them eventually dying.

Big Stone Lake, South Dakota (1925) - The first written description of an actual outbreak of HABs occurred in 1925 when a farmer lost 127 hogs and 4 cows after they drank from Big Stone Lake in South Dakota. The lake water was analyzed and the livestock deaths were attributed to algal poisoning.

Lake Erie, Toledo, Ohio (2014) – a drinking water ban occurred in August of 2014 that impacted over 400,000 people. Because of a cyanobacteria bloom of *Microcystis* occurring at the Toledo water intake in Lake Erie, the City banned all use of the water, including bathing, cooking, and drinking. Under the right conditions (winds, waves, and currents), the summer-time cyanobacteria bloom concentrated near the intake. Microcystin levels were three times higher than the allowable 1.0 µg/L after the treatment of the lake water. What was concerning was that this summer bloom was not a large one.

As a result, stores sold out of bottled water, local restaurants, universities, and libraries closed, the National Guard was brought in to help distribute water, and American Red Cross manned water distribution centers to help deliver needed water during the middle of the hot summer.

The economic impact was large. City of Toledo spent \$200,000 per month for extra carbon treatment. In addition in 2013, a year before the drinking ban, the City of Toledo spent \$3 million in plant upgrades to protect the City's water supply from HABs. According to a NOAA report, the United States seafood and tourism industries suffer an estimated annual loss of \$82 million because of HABs (Hoagland P. and Scatasta S. 2006).



Toledo, OH water intake 2.5 miles from shore on Lake Erie (2014)

3.0 Cyanobacteria

The most commonly occurring groups of freshwater algae are diatoms, green algae, and blue-green algae. Diatoms are depended on silica and prefer cooler water. Green algae are a beneficial, primary producer and zooplankton do a great job of keeping them in balance. Cyanobacteria prefer warmer water and are bloom-forming.

Cyanobacteria are often confused with filamentous green algae because both can produce dense mats that can impede activities like swimming and fishing and may cause odor problems and oxygen depletion; however, unlike cyanobacteria, filamentous algae are not generally thought to produce toxins. Freshwater cyanobacterial blooms that produce highly potent cyanotoxins are known as cyanobacterial HABs. There are some toxins produced by other marine algal besides cyanobacteria but for the purpose of this guide, harmful algal blooms will refer to fresh water, cyanobacterial algae that are capable of forming toxins.

3.1 Toxin-forming

Cyanotoxins can be produced by a wide variety of planktonic (i.e., free living in the water column) cyanobacteria. Some of the most commonly occurring genera are *Microcystis*, *Anabaena*, *Aphanizomenon*, *Gloeotrichia*, *Cylindrospermopsis*, and *Planktothrix* (a.k.a., *Oscillatoria*). These species can produce toxins but not all of the time. Just because there is a cyanobacteria bloom, doesn't mean that toxins are present, and cyanotoxins can be present when there is no bloom. It is important to know your species of algae and to identify what kind of species is blooming.

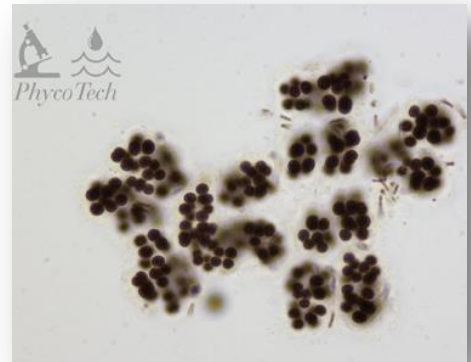
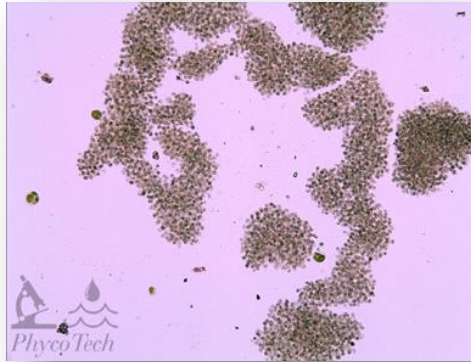
Guideline: When to test for toxins?



Just because you have an algal bloom doesn't mean that there are toxins. It is good to identify what species of algae are causing the bloom. *Anabaena*, *Aphanizomenon*, and *Microcystis* ("Annie, Fanny, and Mike") are the most common toxin-producing cyanobacteria. If you have a floating scum of one of these, take it seriously and test for toxins.

3.1.1 *Microcystis*

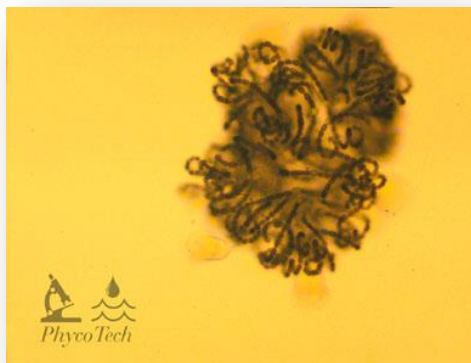
Microcystis is the most common bloom-forming genus and is almost always toxic. *Microcystis* blooms resemble a greenish, thick, paint-like (sometimes granular) material that accumulates along shores. Scums that dry on shore may contain high concentrations of microcystin for several months, allowing toxins to dissolve in the water even when the cells are no longer alive. The two genuses that are most common are *M. aeruginosa* and *M. viridis*.



If the water looks grainy or there are large floating clumps, then it is most likely *Microcystis*.

3.1.2 *Anabaena*

Species of the filamentous genus *Anabaena* form slimy, summer blooms on the surface of eutrophic lakes and reservoirs. *Anabaena* blooms may develop quickly and also resemble green paint. In less eutrophic waters, some species also form colonies, which are seen as large dark dots in water samples and on filters after filtration. The two genuses that are most common are *A. flos-aquae* and *A. subcylindrica*.



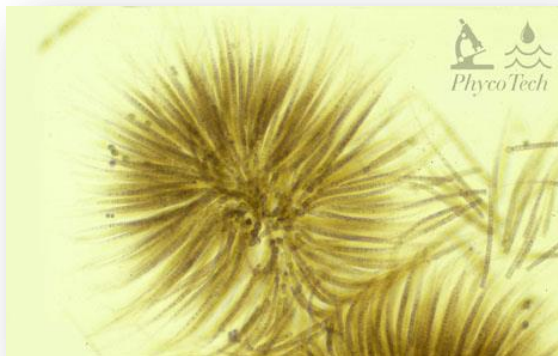
3.1.3 *Aphanizomenon*

Aphanizomenon is another common, fast-growing cyanobacteria that can survive in low-nitrogen environments. When nitrogen is not available, *Aphanizomenon* generate heterocysts that fix aqueous nitrogen gas into biologically available nitrogen. Large blooms make the water look “hairy” with large colonies of filaments. *Aphanizomenon* is very small compared to the other filamentous cyanobacteria. The two genuses that are most common are *A. flos-aquae* and *A. ovalisporum*.



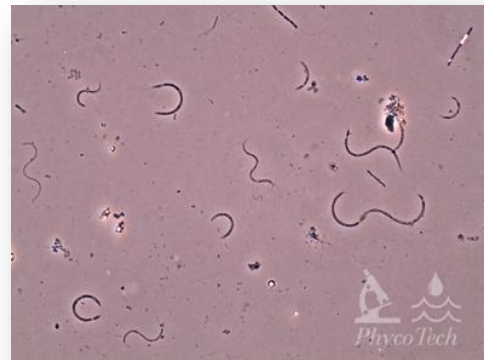
3.1.4 *Gloeotrichia*

Gloeotrichia is a nitrogen-fixing, colonial cyanobacteria that is large in size and can form filamentous blooms. The filaments form colonies in the shape of spheres. The water can look either grainy or hairy and more yellowish in color. *Gloeotrichia* is capable of dominating the algae community in a wide range of eutrophic waters. It is known to bloom even in oligotrophic and mesotrophic lakes and reservoirs. The most common genus is *G. echinulata*.



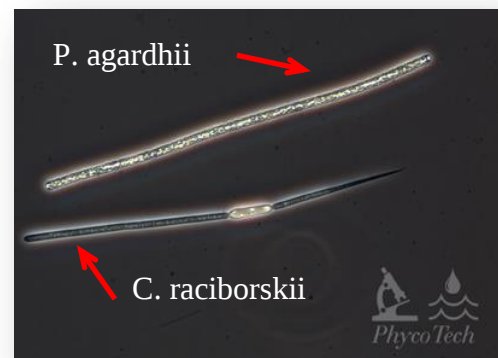
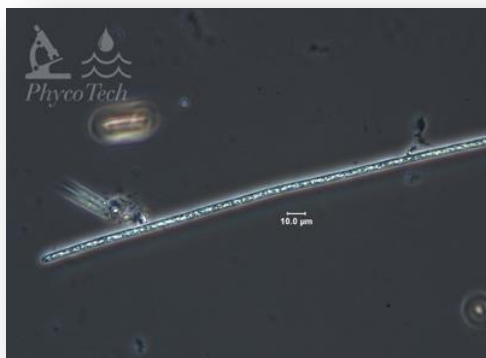
3.1.5 *Cylindrospermopsis*

Cylindrospermopsis is another filamentous cyanobacteria that is one of the most successful bloom-forming organisms in shallow lakes. This species of algae has an aggressive ability to expand to a wide range of lake conditions. Because of this invasive behavior and that it can produce two kinds of toxins, this cyanobacteria is being closely watched in the U.S. *Cylindrospermopsis* is tolerant of continuous mixing, can fix nitrogen, has high phosphorus storage capacity, and is shade tolerant. The most common genus is *C. raciborskii*.



3.1.6 *Planktothrix* (a.k.a., *Oscillatoria*)

Planktothrix (previously named *Oscillatoria*) forms long, slender, straight filaments that usually remain separate but form dense surface scums. Its presence may be revealed by a strong earthy odor and the filaments are easily detected visually in a water sample. *Planktothrix* has very similar characteristics as *Cylindrospermopsis*, except it does not have a heterocyst so it cannot fix nitrogen. This type of cyanobacteria is a resilient, shade-tolerant species and is one of the most common bloom-forming species in temperate lakes. The most common genus is *P. agardhii*.



3.1.7 Others

There are other cyanobacteria that are known to produce toxins. They are less common but still need to be closely watched. If a bloom occurs, it is good to identify the dominate cyanobacteria. Here is a brief list of other bloom-forming cyanobacteria that may produce toxins:

Nostoc (microcystins), Lyngbya (lyngbyatoxin a), Anabaenopsis (microcystins), Nodularia (nodularin), *Phormidium* (anatoxin), *Schizothrix* (aplysiatoxins), *Umezakia* (cylindrospermopsin), and Hapalosiphon (microcystins).

Guideline: When to identify algae?



Cyanobacteria have the capability to change their buoyancy because of gas vacuoles. These structures can hold gas during the day to float the cells closer to the sunlight and then release the gases at night to sink. If there is a bloom that surfaces during the day, then it is most likely a blooming-forming cyanobacteria and a sample should be collected for identification.

Summary of Cyanobacteria of Concern

<i>Name</i>	<i>Color</i>	<i>N-fixing</i>	<i>Colonies, Filaments</i>	<i>Toxins</i>
Microcystis	Blue-green, grayish, yellowish	No	Colonies	Microcystins
Anabaena	Blue-green to yellow-green	Yes	Filaments	Saxitoxins, anatoxins, microcystins, cylindrospermopsins
Aphanizomenon	Pale blue-green, blue-green	Yes	Filaments	Saxitoxins, cylindrospermopsins, anatoxin-a
Gloeotrichia	Olive green, yellow-green, brown, blue-black	Yes	Colonies	Microcystins
Cylindrospermopsis	Pale blue-green, olive green	Yes	Filaments	Cylindrospermopsin, saxitoxin
Planktothrix	Blue-green, brownish, pinkish	No	Filaments	Anatoxin, aplysiatoxins, microcystins, saxitoxins, lyngbyatoxin-a

4.0 Toxins and Symptoms

Cyanobacterial blooms may be dominated by a single species or composed of a variety of toxic and non-toxic strains (i.e., a specific genetic subgroup within a particular species). Cyanotoxins are produced and contained within the actively growing cyanobacterial cells (intracellular toxins). The release of these toxins in an algal bloom into the surrounding water as dissolved (extracellular) toxins occurs mostly during cell death and lysis (cell rupture) as opposed to the continuous excretion from the cells.

4.1 Toxins

There are three major toxin types that can have an effect on humans and other animals. Cyanotoxins can affect the liver (hepatotoxic), the nervous system (neurotoxic), and the skin (acutely dermatotoxic). Hepatotoxic freshwater blooms of cyanobacteria are more commonly found than neurotoxic blooms. There are some that cause stomach aches (gastrointestinal) and harm multiple organs (cytotoxins) but these are not common.

Neurotoxic poisoning (nervous system) - Neurotoxic poisoning, which account for most poisoning cases, can occur very quickly; signs can appear within 15 - 20 minutes after ingestion.

Humans – signs may include numbness of the lips, tingling in fingers and toes, stumbling, seizures, paralysis, disorientation, headaches, inactivity, elevated heart rate, dizziness, and respiratory failure.

Other Animals – signs may include weakness, staggering, difficulty breathing, convulsions, muscle twitching, cyanosis (tongue and mouth lining appear bluish for anatoxin-a(s)), and death.

Hepatotoxic poisoning (liver) - Hepatotoxic poisoning can have serious acute signs and also have slower chronic symptoms. Symptoms can occur hours or days after being exposed to the cyanotoxin.

Humans – signs may include abdominal pain, loss of appetite, jaundice, dark or reduced urine, diarrhea, vomiting, liver damage, and hemorrhages.

Other Animals – the signs are the same as in humans.

Dermatotoxic poisoning (skin) - Dermatotoxic poisoning is topical. Symptoms can occur quickly if the skin is not rinsed after contact with cyanotoxins.

Humans – signs may include rashes, hives, swelling, itching, and excessive drooling and seizures.

Other Animals – The signs are the same as humans and can be harder to detect because of their coat. Animal may ingest when they lick their coat.

4.1.1 Anatoxin (neurotoxin)

Anatoxins are a group of neurotoxic alkaloids produced by a number of cyanobacterial genera including *Anabaena*, *Aphanizomenon*, and *Planktothrix*. The toxicity of these compounds (LD₅₀) varies from 20 µg/kg (by weight) for anatoxin-a(s) to 200-250 µg/kg for anatoxin-a and homoanatoxin-a, making them more toxic than many microcystins.

Anatoxins bind to neuronal receptors affecting the central nervous system. There are multiple kinds, including anatoxin-a, homoanatoxin-a, and anatoxin-a(s).

Anatoxin-a was discovered in the early 1960's after several herds of cattle died in Canada from drinking from a lake with a HAB. Symptoms of this toxin can happen quickly causing loss of coordination, convulsions, muscle twitching, and death by respiratory paralysis.

4.1.2 Microcystin (hepatotoxin)

Microcystins are a group of at least 80 toxin variants which share a cyclic heptapeptide structure and primarily affect the liver. They are produced by a number of cyanobacterial genera, the most notable of which is the widespread *Microcystis* from which the toxins take their name. Microcystins are the most widespread cyanobacterial toxins and can bioaccumulate in the liver of fish, mussels, and zooplankton.

Microcystins are produced by *Microcystis*, *Anabaena*, *Planktothrix*, *Nostoc*, *Hapalosiphon*, *Anabaenopsis*, and *Snowella lacustris*. The toxin does have a short half-life (10 minutes) and can be hard to detect.

Microcystins consist of a seven-membered peptide ring which is made up of five non-protein amino acids and two protein amino acids. It is these two protein amino acids that distinguish microcystins from one another, while the

other amino acids are more or less constant between variant microcystins. Using amino acid single letter code nomenclature, each microcystin is designated a name depending on the variable amino acids which complete their structure. The most common and potentially toxic microcystin-LR contains the amino acids Leucine (L) and Arginine (R) in these variable positions.

Microcystin-LR is considered the most toxic compound of the microcystin family. This toxin has been known for about 1,000 years causing death and serious illnesses from drinking tainted lake and river water. Liver damage can occur if ingested. There are both short and long term liver effects.

Guideline: What is a toxin, how much, what kind?

WHO: http://www.who.int/water_sanitation_health/en/

CDC: http://www.cdc.gov/nceh/hsb/cwh/water_response.htm

Cyanosite: <http://www-cyanosite.bio.purdue.edu/>

4.1.3 Saxitoxin (neurotoxin)

Like anatoxins, the saxitoxins are neurotoxic alkaloids which are also known as PSP's (paralytic shellfish poisons) due to their occurrence and association with seafood. They block sodium channels in nerve cells, thus causing their neurotoxic effects. There are more than 30 different saxitoxins, and they are divided into groups based on their structure or organism of origin. The single sulphated saxitoxins are known as gonyautoxins (GTX) and the doubly sulphated saxitoxins are known as C-toxins. Saxitoxins are among the most potent natural toxins known with LD₅₀'s as low as 10 µg/kg in mice.

Saxitoxins are produced by various cyanobacteria species but are more commonly produced by dinoflagellates in marine waters causing PSP. Exposure to saxitoxin typically comes from eating shellfish contaminated by "red tides". Detection of high concentrations of saxitoxin in shellfish such as mussels, clams, and scallops frequently leads to closures of commercial and recreational shellfish harvesting. These toxins have been reported also in freshwater cyanobacteria including *Aphanizomenon flos-aquae*, *Anabaena circinalis*, *Lyngbya wollei*, and *Planktothrix* spp. In freshwater, saxitoxins accumulate in zooplankton.

Because of the lethality, The U.S. military isolated the toxin and provided the toxin in a syringe to certain pilots to be used for suicide in the event escape was not possible.

4.1.4 *Cylindrospermopsin (hepatotoxin and cytotoxin)*

Although originally described from *Cylindrospermopsis raciborskii*, cylindrospermopsin can be found also in *Aphanizomenon ovalisporum*, *Anabaena bergii*, *Umezakia natans*, and *Raphidiopsis curvata*. The toxin is a cyclic alkaloid and, like microcystins, primarily affects the liver, although causes considerable damage to other major organs (kidney, lung, spleen, thymus, and heart). Cylindrospermopsin exhibits a completely different mechanism of toxicity than the liver toxin microcystin. Damage to cells is caused by blocking key protein and enzyme functions thereby inhibiting protein synthesis. Its LD₅₀ of 200 µg/kg ranks it as a relatively potent cyanobacterial toxin.

Cylindrospermopsin was first discovered after an outbreak of a mystery disease in Australia. The outbreak was traced back to a HAB of *C. raciborskii*. *C. raciborskii*, which has an optimal growth temperature of 25⁰ C and is more common in tropical climates but is becoming more common in temperate regions. One of the more alarming characteristics about Cylindrospermopsis is that some species do not form scums making them harder to detect and have highest cell concentrations below the water surface. The half-life of cylindrospermopsin is much longer at 18 hours.

Summary of Cyanotoxin Types and Symptoms

Toxin Types	Examples	Symptoms
Neurotoxins	Anatoxin-a, Anatoxin-a(s), Saxitoxin, Neosaxitoxin	Affects central nervous system, causes seizures, paralysis, respiratory failure, and death
Hepatotoxins	Microcystins, Nodularins, Cylindrospermopsin	Affects liver, causes hemorrhaging, tissue damage, tumors, liver cancer, and death
Dermatotoxins and Gastrointestinal toxins	Aplysiatoxins, Lyngbyatoxin-a, lipopolysaccharide endotoxins	Affects skin and mucous membranes, causes rashes, respiratory illness, headache, and stomach upset
Cytotoxins	Cylindrospermopsin	Affects liver and other organs, causes chromosome loss, DNA strand breakage, and organ damage

Guideline: Don't confuse cyanotoxins with Swimmer's Itch

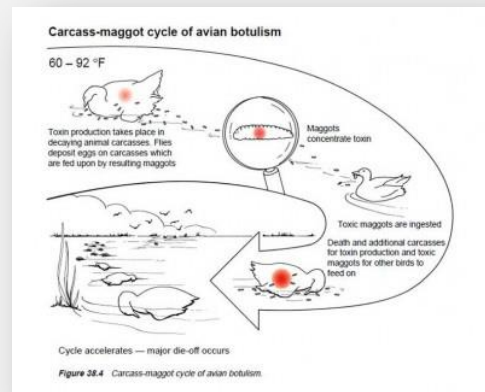
A common recreational complaint is when a lake user complains of a rash that itches after being exposed to a lake. Swimmer's Itch is not caused by cyanotoxin exposure. Swimmer's Itch is caused by a microscopic parasite that burrows under the skin.



www.cdc.gov/parasites/swimmersitch/faqs.html

Guideline: Don't confuse cyanotoxins with Avian Botulism

Among waterfowl, a serious health threat is avian botulism. This is not caused by HABs. Instead of cyanobacteria, it is a bacteria strain of botulism which a neurotoxin that causes a paralytic disease mainly among piscivorous birds. The avian botulism is not contagious. The cycle involves maggots that are infested with the bacteria that feed on infected organic material. Outbreaks occur in large numbers and signs include drooping necks.



www.nwhc.usgs.gov/disease_information/avian_botulism/

5.0 Exposure Pathways

The most likely exposure pathways to cyanotoxins for people are through recreational contact and contaminated drinking water. Pets, wildlife, and other animals have similar exposure pathways, swimming and direct drinking. Animals tend to have a lower standard for drinking water and can be more exposed to ingestion while people tend to value aquatic recreation and can have more skin exposure.

5.1 Recreational Exposure

Recreational exposures include activities such as swimming, wind surfing, jet skiing, and water skiing. Basically, it is any kind of recreation on, in, or near a water body.



There are three potential routes of exposure to cyanotoxins: 1) direct contact with exposed parts of the body, including sensitive areas such as the ears, eyes, mouth, and throat, 2) accidental swallowing, and 3) inhalation of water. Swallowing and inhalation are two important routes of exposure to cyanotoxins during water-contact sports that involve intensive submersion of the head (diving, swimming, and skiing). The nasal and throat have sensitive, mucous membranes that provide a direct route for the toxins to absorb into the body.

In particular, the risk of ingestion is high for children playing in shallow, near-shore water where scums tend to accumulate. Children (7 to 10 years old) are at a higher risk than adults because they have the highest exposure per body weight.

A HAB can also produce aerosols that can be inhaled when recreating on or near the water. Water droplets from mist, waves, and throwing of water can cause respiratory problems such as coughing, wheezing, throat irritation, nasal congestion, eye irritation, and wheezing. This type of exposure can occur to people that don't get wet and are just near shore or on a boat.

5.2 Drinking Water Exposure

Many municipal drinking water sources throughout Colorado include some kind of reservoir, even when groundwater or river water is the main drinking water source. Diverted water can be stored in holding ponds before treatment where cyanotoxins can grow. HABs that occur in a storage pond or drinking water reservoir can pose a potential pathway for toxins to be ingested by people. Conventional drinking water treatment plants are not designed to treat specifically for cyanotoxins, but they do remove algal cells and reduce toxins.

Effectiveness of the water treatment process will vary depending on the type of treatment and algae. To reduce exposure in drinking water:

- *Minimize pre-oxidation* – Pre-oxidation with chlorine and ozone can cause algae cells to rupture, thus releasing toxins. (In some cases, pre-oxidation will be necessary to meet *Giardia* and virus inactivation requirements, so pre-oxidation can only be reduced and not eliminated.)
- *Adjust coagulation, sedimentation, and filtration* – Careful monitoring and adjustment of coagulation and filtration processes may improve algae removal. Intact cells removed by these processes will significantly reduce the possibility that toxins will be present in the finished water.
- *Don't recycle backwash water* – Backwash water can contain high concentrations of algae that may rupture and release toxins.
- *Adjust post-filtration disinfection* – Once the algae cells are removed from the water, soluble toxins can be destroyed by chlorine and ozone, which are strong oxidants. Effectiveness varies depending upon the dose and the algal toxin. Microcystins can be destroyed by free chlorine at a dose of 0.5 mg/L for 30 minutes and a pH of less than 8.0. Post-clarification ozone can destroy microcystins, nodularin, and anatoxin-a when the dose is at 2.0 mg/L. Activated carbon has also proven to remove many soluble toxins very well at a dose of 25 mg/L with a contact time of 30 minutes.

Some other algal toxins are more resistant to oxidation, so longer contact times and higher doses are required before significant destruction will occur.

Guideline: When in doubt, stay out

The best thing to do is avoid contact when there is a surface scum of algae concentrated near shore. Avoid all contact and keep all pets and animals away from the water, including dried algal scum on the ground. Contact your the lake/reservoir/park manager for more information.



6.0 Monitoring and Analysis for HABs

A regular lake monitoring plan in place is the best way to detect when a HAB is about to occur. Cyanobacteria do best in warm water but can bloom under ice cover. During the summer growing season for Colorado lakes and reservoirs (about June through October for most lakes), it is good to collect water samples for algae identification and cell concentrations on a weekly basis. This includes top samples as well as bottom samples because many cyanobacteria stay dormant in the sediments and then work their way quickly to the photic zone. Regular monitoring should also include temperature and dissolved oxygen profiles and nutrient concentrations. Chlorophyll-a is the measurement of how green the water is and can help track how the algal community is doing in a lake.

It is important to analyze both for cyanobacteria and for cyanotoxins, and this can be done before, during, and after HABs. Another important consideration is to collect other water quality data when samples are collected. Field measurements include dissolved oxygen, water temperature, pH, alkalinity, and conductivity. Field conditions are also important to document. These include wind direction, water current, recent weather conditions, time of day, and any other field observations noticed during sampling such as unusual wildlife behavior or dead animals.

6.1 Cyanobacteria Monitoring

Phytoplankton samples should be collected on a regular basis. To collect a representative sample, it must be taken out in the central part of the lake and be a composite sample of the photic zone (depth of water that is exposed to sunlight). One way to estimate the depth of the photic zone (where photosynthesis occurs) is with a Secchi disk. The photic zone is roughly 1.5x the Secchi depth.

Example – if the Secchi depth is 3 meters, then the photic zone is about 4.5 meters deep. You would then take a composite sample of the top 4.5 meters of water to collect an algal sample.

To collect a bottom sample, simply lower a discrete depth water sampler (Kemmerer or Van Dorn) and collect a sample one meter from the sediments. Another method to find where the algal bloom might be in the water column is to record a dissolved oxygen profile. A lens of super saturated oxygen (called a plus heterograde profile) can indicate a layer of water that has a large concentration of algae working its way to the surface.

The phytoplankton samples need to be preserved (Lugol's solution) and stored properly. Identification and cell count is important data to collect from these samples.

6.2 Cyanotoxin Monitoring

When a HAB has been identified and there is a concern of cyanotoxins, then samples need to be properly collected. To determine the risk of HABs, it is important to collect samples that reflect the actual site conditions and are handled properly to ensure reliable results. It is important to follow detailed procedures. Among the most important sample handling considerations are the following: proper collection method, correct sample bottles, labeling, and keeping the sample chilled.

Cyanobacteria Sampling

1. Use a clean glass container (dark color if possible) that is at least 250 milliliters big and has a secure lid.
2. Select a good site in the water body to collect the algal sample. Algae accumulate downwind, along shorelines, and often in sheltered coves. If possible, sample the actual scum.
3. Collect the sample by dipping the bottle into the water 1-2 inches below the water's surface. Try to collect the surface scum (if present). Leave about an inch of space between the sample water and the top of the bottle.
4. Replace the cap on the bottle and wipe the bottle dry.
5. Using a permanent marker, fill out the following information: the date, time, your name, water body name, and sampling location.
6. Mail the sample to a laboratory as soon as possible. If there is a delay, keep the sample in the refrigerator (no more than a day or two).
7. When collecting the sample, be sure to fill out any data sheet and send it along with your sample to the laboratory.
8. It is a good idea to assemble a HAB sampling kit before a bloom occurs.

HAB sampling kit includes

- a. Brown glass bottle with an enclosed sampling label
- b. Bubble wrap
- c. Ice pack
- d. Well-padded box or cooler with proper shipping labels for the laboratory

Cyanobacteria blooms can last for several weeks and one HAB can transition into another so it is a good idea to continue weekly, follow-up monitoring until the bloom is over. Cyanotoxins are hard to predict and find. Toxins may exist when there are low cyanobacteria cell concentrations.

6.3 Laboratories

It is important to have clear communication with laboratories. Each laboratory is different. It is important to find out how they analyze, what are their sampling requirements (e.g., sample volume and bottle type), what is the turnaround time, what are their analysis methods for the various toxins, how do they report the data, what are the costs for the various tests, and do they have specific delivery requirements (e.g., what day to mail samples).

U.S. EPA provides a list of laboratories across the country that conducts cyanobacteria identification/enumeration and cyanotoxin analysis. Website is:

www2.epa.gov/nutrient-policy-data/state-resources

Algae Identification and Counting - With a microscope and some identification keys, the major cyanobacteria species can be identified in a short amount of time. To get concentrations, samples need to be sent to trained phycologists. It is recommended to send samples to the same laboratory to have consistency with the data. Lakes and reservoirs tend to have annual cycles of algal species. Monthly or bi-monthly sampling can establish the seasonal algal patterns to help with lake and reservoir management and HAB preparedness.

Non-comprehensive list of Identification/Counting Laboratories

PhycoTech (www.phycotech.com)

Water Environmental Services Inc. (water@bainbridge.net)

EcoAnalysts, Inc. (www.ecoanalysts.com)

SePRO Research and Technology Campus (www.sepro.com)

Midwest Laboratories, Inc. (www.midwestlabs.com)

Cyanotoxins Analysis - The analysis for cyanotoxins is not a common practice so there are a limited number of laboratories in the U.S. It is recommended to contact a laboratory beforehand to understand how the samples should be collected and delivered. It can take up to 48 hours to get results so it will help reduce confusion and time spent on getting results if you set up an account and have a laboratory ready.

Some test methods (field kits and laboratory) can produce false positive and false negative results. It is good to understand the pros and cons to the different cyanotoxin detection methods and how each laboratory conducts their tests.

Non-comprehensive list of Cyanotoxin Laboratories

Beagle Bioproducts Inc. (www.beaglebioproducts.com)
CH2M Hill Applied Science Laboratory (www.ch2m.com)
EcoAnalysts, Inc. (www.ecoanalysts.com)
Green Water Laboratories (CyanoLab) (www.greenwaterlab.com)
Midwest Laboratories, Inc. (www.midwestlabs.com)
SePRO Research and Technology Campus (www.sepro.com)
Abraxis Test kits (www.abraxiskits.com)
Water Management Laboratories (253-531-3121)

6.4 Interpret the Data

There is a diverse range of rapid screen tests and laboratory methods used to detect and identify cyanobacteria cells and cyanotoxins. These methods can vary greatly in their degree of sophistication and the information they provide. It is important to understand not only the sampling protocols but also how to interpret the data results.

Often, more than one toxin may be present in a sample; therefore, a single method will not suffice for the identification and accurate quantification of many cyanotoxins. The laboratory analysis can be expensive and time consuming. It is a good idea to know what toxins you want to test for so you can compare the data.

Analysis of microcystin is most commonly carried out using reversed-phase high performance liquid chromatographic methods (HPLC) combined with ultra-violet (UV) detection. Analytical methods such as enzyme-linked immunosorbent assays (ELISA) already exist to analyze cyanobacterial hepatotoxins and saxitoxins, and the protein phosphatase inhibition assay (PPIA) can be used for microcystins. These two methods are sensitive, rapid, and suitable for large-scale screening but are predisposed to false positives and unable to differentiate between toxin variants. The liquid chromatography/mass spectrometry (LC/MS) method can be fast in identifying the toxicants in the samples. Conventional polymerase chain reaction (PCR), quantitative real-time PCR (qPCR) and microarrays/DNA chips can be used to detect microcystin/nodularin and saxitoxin producers.

Many of these tests try to balance accuracy and efficiency. While a test might have a fast turnaround time, the sensitivity may produce high detection limits and vice versa. Most all results will be report in $\mu\text{g/L}$, and this number can be compared to the recommended guideline values. Communicate with the laboratory so there is a clear understanding on what the results will look like and if it will be the right information to help with making lake management decisions.



aquatic analysis ... research ... consultation

Microcystin Report

Project:

Sample Identification

Collection Date

CPL

8/8/14

DKL

8/8/14

Toxins – Microcystin (MC)

Sample Prep – The samples were ultra-sonicated to lyse all cells and release toxins. The samples required dilution in order for the concentration to fall within the standard curve range.

Analytical Methodology – A microcystins enzyme linked immunosorbent assay (ELISA) was utilized for the quantitative and sensitive congener-independent detection of MCs. The current assay is sensitive down to a LOD/LOQ of 0.15 µg/L for total MCs.

Summary of Results

Sample

MC levels (µg/L)

-CPL

23.9

-DKL

5.7

LOD/LOQ = 0.15 µg/L MC

ND = not detected above the LOD/LOQ

Submitted by:

Mark T. Aubel, Ph.D.

Date:

8/17/14

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7.0 Risk Levels and Guideline Values

7.1 Federal Regulatory Status

The Safe Drinking Water Act requires the U.S. EPA to publish a list of unregulated contaminants that are known to occur in public water systems, occur frequently, cause public health concerns, and where there is an opportunity for health risk reduction. This list is known as the Contaminant Candidate List (CCL). Maximum Contaminant Levels (MCLs) are the values that are listed. The U.S. EPA's Office of Water has listed cyanobacteria and cyanotoxins on the drinking water CCL (<http://www.epa.gov/safewater/mcl.html>). Based on toxicological, epidemiology, and occurrence studies, the U.S. EPA Office of Ground Water and Drinking Water has focused on 3 of the over 80 variants of cyanotoxins reported, recommending microcystin congeners LR, YR, RR, and LA, anatoxin-a, and cylindrospermopsin for further research activities.

The U.S. EPA uses the Unregulated Contaminant Monitoring Rule (UCMR) program to collect data for contaminants suspected to be present in drinking water that do not have health-based standards. The absence of standardized analytical methods for individual toxins has prevented the U.S. EPA from including cyanobacterial toxins in the UCMR. The U.S. EPA has not made regulatory determinations or established any guidelines for cyanobacteria and their toxins in drinking water to date. Currently, U.S. EPA is working on establishing guidelines for both drinking water and recreation.

7.2 Drinking Water Guideline Values

In 1998, The WHO released a provisional drinking water guideline for microcystin-LR, excluding other known cyanotoxins since there was insufficient data to derive guideline values for those toxins. The WHO guidance value for drinking water is 1.0 µg/L. This value is based on a lifetime consumption of microcystin-LR from drinking water. The actual calculation was (WHO, 1999):

$$\text{Drinking Water Guideline Value} = \frac{\text{TDI} \times \text{bw} \times \text{P}}{\text{L}}$$

Definitions:

TDI (Tolerable Daily Intake) is the amount of a potentially harmful substance that can be consumed daily over a lifetime with negligible risk of adverse health effects.

bw (body weight) is the weight of given person or an average for a population

P (proportion) is the proportion of total daily intake of the contaminant which is ingested from the drinking water (not from food or inhalation)

L (liter) is the amount of daily water intake by a person

For the WHO guideline value, they assumed the average body weight of a person to be 60 kg, an average adult daily water intake to be 2 liters per day, the TDI was 0.04 µg/kg body weight per day, and the proportion (P) was 0.8. The result was 0.96 µg/L, which was rounded up to 1.0 µg/L.

Several states have developed their own studies to determine their own guideline values for drinking water (Appendix B). These types of guideline values for drinking water are developed with built-in conservative factors. They are usually developed based on information from studies that look at short term impacts, subchronic effects, and chronic durations.

One example is Ohio's action levels. They are:

microcystin (1 µg/L),
anatoxin-a (20 µg/L),
cylindrospermopsin (1 µg/L), and
saxitoxin (0.2 µg/L).

As a general statement, acute lethal toxicosis in humans from cyanotoxins, in treated water supplies, should not occur because normal filtration, coagulation, and other typical treatment processes in municipal water supplies is designed to remove algal cells and released toxins to levels below that necessary to cause acute, lethal effects.

However, in cases of heavy cyanobacteria blooms and where the normal water treatment process is inadequate (lake cabins with direct use from the lake) or not properly operated, toxic algal cells and free toxins have been present in finished drinking water supplies. There are reports, for the U.S. and Australia, that cyanotoxins have been implicated in human illness (i.e., acute, non-lethal, or chronic toxicity) from municipal water supplies, especially after the bloom has been treated with copper sulfate.

7.3 Recreation Guideline Values

For recreational waters, the WHO concludes that a single guideline value for cyanobacteria or cyanotoxins is not appropriate. Due to the variety of possible exposures through recreational activities (contact, ingestion and inhalation), it is necessary to differentiate between the symptoms caused by unknown cyanobacterial substances and the more severe health effects due to exposure to high concentrations of known cyanotoxins, particularly microcystins. The WHO guideline values are based on the relative probability of acute health effects during recreational exposure to cyanobacteria and microcystins.

WHO Guideline Values for Recreation

Relative Probability of Acute Health Effects	Cyanobacteria (cells/mL)	Microcystin-LR (µg/L)	Chlorophyll-a (µg/L)
Low	< 20,000	<10	<10
Moderate	20,000-100,000	10-20	10-50
High	100,000-10,000,000	20-2,000	50-5,000
Very High	> 10,000,000	>2,000	>5,000

Many states have implemented HAB guidelines in the event of a significant bloom in recreational waterways. These include specific criteria for analyzing the severity of a bloom and the actions, public advisories, posted warnings, waterway or beach closures that correspond to a bloom that meets a certain threshold (Appendix B).

Some states use the WHO values to establish tiered approaches to the different levels. If cyanotoxin data is not possible, then the cyanobacteria cell counts and chlorophyll-a concentrations can also be used to advise the public of the health risks associated with HABs.

Some states have also evaluated their own cyanotoxin data to formulate specific guideline values for specific toxins by using a different set of assumptions. For example, Washington State used the same drinking water guideline value formula and applied different assumptions to the various components.

Washington State assumed that a typical swimmer or lake user ingests 0.05 liters of water per hour and are exposed for two hours per day per year. The proportion (P) was combined with TDI and called subchronic oral reference dose (RfD) (0.03 µg/kg per day). This is the chronic exposure to the cyanotoxin from daily swimming. Using this approach, Washington State established four recreational guideline values, and they are (Washington State Department of Health, 2011):

microcystins (1 µg/L),
anatoxin-a (1 µg/L),
cylindrospermopsin (4.5 µg/L), and
saxitoxin (75 µg/L).

Then Washington State developed a three tiered notification approach (Caution, Warning, and Danger) based on these values and algal bloom observations.

These examples of guideline values are based on chronic data and assumptions. The same approach can use acute toxicity data as well to develop guideline values.

7.3.1 *Pets and Farm Animals*

Dogs are more likely to be exposed than humans because they are more likely to drink, swim, or dive into waters with a HAB and are, therefore, more vulnerable to poisoning. The best approach for animals is to avoid any contact if there is a visual surface scum of algae. Some states have provided guideline values for animals. California has done similar toxicology calculations for humans as well as for dogs and cattle by using the WHO drinking water guideline value formula. They are (California Environmental Protection Agency, 2012):

Microcystins (2 µg/L for dog drinking and 0.9 µg/L for cattle drinking),
Anatoxin-a (100 µg/L for dog drinking and 40 µg/L for cattle drinking),
Cylindrospermopsin (10 µg/L for dog drinking and 5 µg/L for cattle drinking), and
Saxitoxin (values not available).

If a dog is exposed, owners should remove the animal from the water as quickly as possible and thoroughly hose down and wash their coat. For cattle, especially lactating dairy cows, and other farm animals, the best approach is to fence off water that has issues with algal blooms and to avoid using that water to water animals.

7.3.2 *Fish*

There is even less data and information about bioaccumulation or biomagnification when it comes to cyanotoxins and fish consumption. There have been some studies that show that fish can have liver damage from some cyanotoxins (Xie L., 2005). The risk level to cyanotoxins from eating predatory fish is relatively low compared to recreation and drinking water exposures. Some states recommend cleaning the fish and removing all organs and as much fat tissue as possible. Typically, fish consumption is not the major concern when it comes to HAB and cyanotoxin exposures.

Guideline: Example; of Different Toxicology Formula;

WHO Drinking Water Guideline Value

$$\text{Drinking Water Guideline Value} = \frac{TDI \times bw \times P}{L}$$

TDI = Tolerable Daily Intake

bw = body weight

P = proportion factor

L = daily intake

Recreational Guideline Value

$$\text{Recreation Guideline Value} = \frac{RfD \times bw}{IR}$$

RfD = Oral Reference Dose

bw = body weight

IR = Water Intake Rate

Domestic Animal Guideline Value

$$\text{Domestic Animal Guideline Value} = \frac{RfD \times bw}{IR \times UF}$$

RfD = Oral Reference Dose

bw = body weight

IR = Water Intake Rate

UF = Uncertainty Factor (3x higher than what is estimated)

Fish Consumption Guideline Value

$$\text{Fish Consumption Guideline Value} = \frac{Cf \times CR}{bw}$$

Cf = Concentration in Fish

bw = body weight

CR = Consumptive Rate (1 meal/week, 8 oz fish)

Set guideline value equal to RfD and solve for Cf

$$Cf = \frac{RfD \times bw}{CR}$$

RfD = Oral Reference Dose

bw = body weight

CR = Consumptive Rate (1 meal/week, 8 oz fish)

8.0 Approaches to Manage Lakes with HAB

Some physical factors that contribute to the creation of HABs include the availability of light, meteorological conditions, alteration of water flow, vertical mixing, and temperature. Chemical factors include pH changes, nutrient loading (principally in various forms of nitrogen and phosphorus), and trace metals.

As a result of the interplay of these factors, there may be large temporal fluctuations in the levels of cyanobacteria and their toxins that occur largely on seasonal time scales. The ratio of nitrogen to phosphorus, organic matter availability, temperature, and light attenuation likely play an interactive role in determining corresponding HAB composition and toxin production. Fresh waters that are high in phosphorus but low in nitrogen are typically dominated by toxic nitrogen fixing genera (e.g., *Anabaena*, *Aphanizomenon*, *Nodularia*, and *Cylindrospermopsis*). Such “biological nitrogen fixation” results in the production of ammonia, an important process in the global nitrogen cycle. Surface waters that are high in nitrogen are dominated by toxic blooms of non-nitrogen fixing genera (*Microcystis*, *Lyngbya*, and *Planktothrix*).

There is widespread agreement within the scientific community that the incidence of HABs is increasing both in the U.S. and worldwide. This recent increase in the occurrence of HABs has been attributed to increasing anthropogenic activities and their interaction with the factors that are known to contribute to the growth of cyanobacterial blooms. Historically, HABs have been strongly correlated with excessive levels of nutrients in water bodies with low turbidity. Point sources (which may include discharges from wastewater treatment plants and confined animal feeding operations) and non-point sources (which may include diffuse runoff from agricultural fields, roads, and storm water), may be high in nitrogen and phosphorus and can cause excessive fertilization (eutrophication) of lakes and reservoirs.

Anthropogenic climate change has recently been identified as a contributing factor to cyanobacterial blooms. Climate change will alter many environmental conditions that have the ability to affect the natural properties of fresh waters both in the U.S. and worldwide. Recent research suggests that, in addition to nutrient contamination from anthropogenic sources, the impacts of climate change may promote the growth and dominance of HABs through a variety of mechanisms including, but not limited to (U.S. EPA, 2013):

- Warmer water temperatures
- Changes in salinity
- Increases in atmospheric carbon dioxide concentrations
- Changes in rainfall patterns

8.1 Prevention

Preventative measures are the preferred approach to managing the occurrence of cyanobacterial blooms. The most effective preventative measures are those that seek to control the anthropogenic influences that promote blooms. Management practices for nutrients, specifically nitrogen and phosphorus, should have the goal of reducing loadings from both point and nonpoint sources, including water treatment discharges, agricultural runoff, internal loading, and storm water runoff.

There is a handful of lake management techniques used to treat for excessive nutrient loading. Aerations, circulation, and mixing all help with keeping water moving. Cyanobacteria favor calm, non-flowing water. Simple movement of water and drawing surface water into the darker bottom depths will help deter cyanobacteria growth. Phosphorus inactivation is another common approach that chemically removes phosphorus from the water. Aluminum, calcium, and iron salts are great at binding to phosphorus. Dredging of nutrient-rich lake sediments is expensive but can also help significantly with internal loading. Flushing or hypolimnetic withdrawal can help with removing high phosphorus water from a lake/reservoir. Application of algaecides can even help if applied at the appropriate time, ideally before the bloom occurs.

Additional, preemptive management measures are applicable on the watershed level. Various measures target nutrient input from point sources and non-point sources. Drawbacks to this watershed approach are that it does not consider internal nutrient loads that can support HABs, it is difficult to implement over large areas, and it may take many years to see nutrient and HAB reductions in a lake.

8.2 Mitigation

Once a cyanobacteria bloom has occurred, there are few management options to remove the actual bloom. The key is to not cause or increase cell lysis. Lysis is when the algal cells are ruptured allowing for the cyanotoxins to be released all at once.

The best remedial measure is physical removal of surface scums (surface skimming) if they are concentrated in an area. For example, some have used oil containment booms to corral surface scum near shore where a vacuum truck can then remove the material.

Algaecides do a great job killing algae but they typically lead to cell breaking and lysis. Algaecides should be applied only when cell numbers are low to avoid excessive toxin contamination. An example is copper sulfate. Treatment of algal

blooms with copper sulfate leads to cell breaking and release of cyanotoxins into the water and can greatly increase the risk of toxin contamination and treatment costs (Zhou *et al.*, 2013). Copper may also be toxic to other aquatic wildlife in the lake.

Biological mitigation or biomanipulation is another method. This concept looks at the entire aquatic food web. Natural zooplankton grazers help keep algae in check. By maintaining a healthy population of large-body zooplankton (daphnia), cyanobacteria blooms may be reduced. Besides grazing, competition for nutrients by other plants can also help control cyanobacteria. Aquatic macrophytes, bacteria, and other algae species can compete for nutrients and help control cyanobacteria. The one advantage is that cyanobacteria can store phosphorus and fix nitrogen unlike other algae.

8.2.1 Drinking Water Treatment

Cyanobacteria and cyanotoxins in drinking water supplies may also be mitigated during the treatment process (Appendix C). Conventional water treatment (flocculation, coagulation, sedimentation, and filtration) is effective in removing algal cells but not intracellular cyanotoxins. Drinking water treatment facilities that use micro-strainers or fine screens to remove debris from the water intake are useful in removing larger algae. Oxidants are often added at the intake to reduce taste and odor problems and to discourage biological growth (zebra mussels, biofilm, and algae) on the intake pipe; however, pretreatment oxidation is not recommended because it may rupture cyanobacteria cells releasing the cyanotoxin to the water column. This may also cause the formation of chlorinated disinfection by-products.

During a bloom, a substantial proportion of toxins are released to the water column. Furthermore, the application of algaecides in drinking water reservoirs may exacerbate this issue since the use of these substances leads to the further release of toxins through the lysing of cyanobacteria. Conventional water treatment is usually not effective in removing extracellular cyanotoxins (soluble toxins). Neither aeration nor air stripping are effective treatments for removing soluble toxins or cyanobacterial cells. Advanced treatment processes, such as powdered and granular activated carbon adsorption, must be implemented to remove extracellular toxins as well as intact cells.

Different cyanotoxins react differently to chlorination. While chlorination is an effective treatment for destroying microcystins and cylindrospermopsin, effectiveness is dependent on the pH. Anatoxin-a is not degraded by chlorination. Other chlorine disinfectants such as chloramines and chlorine dioxide that are frequently used to minimize the formation of regulated

disinfection by-products, have little impact on microcystin, cylindrospermopsin, anatoxin-a, and saxitoxins. Those treatment utilities that use disinfectants other than chlorine in order to reduce the formation of disinfection by-products may not have an oxidant treatment barrier for cyanotoxin inactivation.

Other disinfection techniques like ozone and ultraviolet (UV) light have been shown to be effective in inactivating cyanotoxins. Ozone is a good oxidant of microcystins, anatoxin-a, and cylindrospermopsin. Saxitoxins, however, appear to have low to moderate susceptibility to ozone oxidation. UV is an effective treatment in destroying microcystin, anatoxin-a, and cylindrospermopsin cells; however, it requires high dosages, making it a non-viable treatment barrier for cyanotoxins.

Generally, mitigation and treatment techniques that are applied once a bloom has formed can be important management tools but can also increase the problem with cell lysing. Prevention has many options and yields better results over long term. There is a wide range of technologies for preventing nutrients from getting into a water body and for treatment of toxins in drinking water. All of these technologies have specific trade-offs that must be carefully considered before implementation. Choosing the most efficient, safest, and cost-effective approach should be done on case-by-case basis.

Cyanobacteria can produce a number of low molecular weight, earthy-, musty-smelling compounds including geosmin, and 2-methylisoborneol (MIB). These do not present health hazards but can affect the quality of raw and treated drinking water.

Resource: **Managing Lakes and Reservoirs**. Prepared by NALMS, the Terrene Institute, in cooperation with the U.S. EPA

Resource: **The Lake Pocket Book**. Produced by the Terrene Institute in cooperation with the U.S. Environmental Protection Agency Region 5



9.0 Public Communications

The goal of public communication is to keep the public safe and informed. To avoid panic, rumors, and misunderstandings, communication about HABs should be early and often before a cyanobacteria bloom even starts. Every HAB management plan should include accurate public education/information before a bloom occurs and clear public notification when a bloom does occur.

9.1 Information/Education

Public education about lake and reservoir management, water quality, and watershed impacts can help with controlling the inputs of nutrients and is a great proactive approach to informing the public about how lakes work in general.

Newsletters, lake awareness events, utility inserts, press releases, and other mass public communications can help with establishing a higher lake/reservoir IQ. Then when an actual HAB appears, the public will be informed with accurate information and will know how to react.

Nebraska has a great HAB guideline that includes websites and hotlines where the public can access reliable information. An example is their fact sheet that covers precautions and facts about toxic algae. A good Q&A includes questions like:

(<http://www.deq.state.ne.us/Press.nsf/pages/ENV042607>)

What is a toxic algae (blue-green)?

What is a toxic algae health alert and what are the different risk levels?

What should I look for to avoid toxic algae, what does a bloom look like?

What are the risks and symptoms?

Where can I find out more information about lake sampling for toxic algae?

If I think a public lake has a toxic algae bloom, who do I call?

If I am experiencing health problems, who do I call?

Short, concise answers are important in order to provide information that the public can remember and use. The right questions need to be asked and the right answers need to be provided.

9.2 Notification

When a HAB does occur during the summer growing season, most of the work has been done if the public information/education was done correctly. Public notification is important for the safety of the people that are potentially exposed to the HAB.

To be prepared, it is good to have a list of organizations and key people to contact before, during, and after a HAB. Watershed groups, health agencies, community groups, lake/neighborhood associations, newspapers, and other local news media can help send out the right information. The goal would be to have a well-informed community that knows the basic information about HABs and knows who to contact when there is a bloom. The news that gets distributed can then be accurate, helpful, and not cause panic.

For drinking water utilities, water supply managers should develop a contingency plan including monitoring efforts but also communication efforts. A Communication Plan would include identifying the required communication steps such as working with internal department (distribution and public relations), other agencies that might be impacted (mayor's office, city agencies, or state health department), and with potential consumers.

Notification about recreational restrictions should include clearly marked signs by the major access points to a lake or reservoir - boat ramps, swim beaches, parks, and restrooms. Signs should summarize the water quality condition, concerns, and clear directions for people to follow.

Notifications are less permanent and will change on a much shorter time frame than public information/education. Make sure notifications are quick to get to the public and can be updated or changed readily. Quarterly newsletters, utility inserts, etc... will provide the information too late and will be quickly outdated. If a website is used, make sure the site is updated frequently to reflect the changing conditions on the lake or reservoir.

One example of an efficient public notification system is Washington State's three tiered approach. They combine good public education, access to monitoring protocols, training and instructions on what to do when a bloom is noticed, and a clear procedure to follow when guideline values are detected.

Tier I Trigger (*Caution*) - There is a cyanobacteria bloom or scum visible. Local health officials post “*Caution*” signs. Samples of the scum are collected and sent for cell concentration and toxicity testing. Weekly sampling until bloom dissipates. This may take a couple of days to several weeks.



Tier II Trigger (*Warning*) - If the bloom does not dissipate and the lab results come back higher than the calculated recreational guideline value, then “*Warning*” signs are posted. When values are reached, “*Caution*” signs are reposted until bloom dissipates.



Tier III Trigger (*Danger*) - If the water body has a history of high toxicity or there are reports of illnesses or pet death, “*Danger*” signs are posted. Return to Tier II or Tier I when lab results are below guideline values.



Guideline: Keep it Simple Examples

Public Education

What? Blue-Green algae are common and produce toxins.

When? Typically July through October

Where? Algae float and can be blown to shore

Why? Phosphorus is the main nutrient that the algae like, keep it out

Public Notification

What? Blue-Green algae blooms of Microcystis is occurring

When? Lake is closed until testing results show it is safe

What to do? No contact, no pets, no swimming

What to look for? Skin rashes, headaches, stomach pains

Who to contact? Call xyz

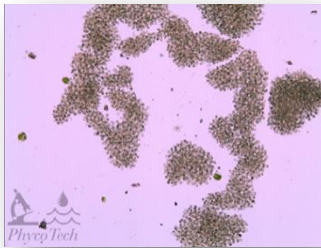


10.0 Go-2 Fact Sheets

Following are some quick, summary sheets that summarize this HAB guideline document.

10.1 Cyanobacteria

Cyanotoxins can be produced by a wide variety of planktonic (i.e., free living in the water column) cyanobacteria. Some of the most commonly occurring genera are *Microcystis*, *Anabaena*, *Aphanizomenon*, *Gloeotrichia*, *Cylindrospermopsis*, and *Planktothrix*. These species can produce toxins but not all of the time. Just because there is a cyanobacteria bloom, doesn't mean that toxins are present and cyanotoxins can be present when there is no bloom.



Microcystis



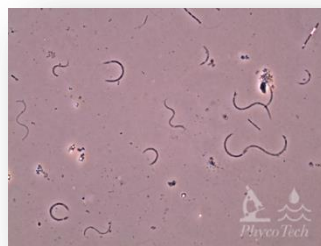
Anabaena



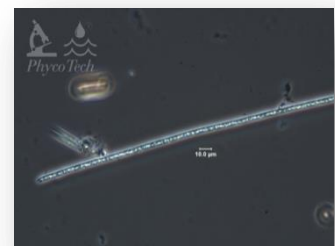
Aphanizomenon



Gloeotrichia



Cylindrospermopsis



Planktothrix

10.2 Cyanotoxins and Symptoms

There are three major toxin types that can have an effect on humans and other animals.

Neurotoxins (nervous system) - Neurotoxin poisoning, which account for most poisoning cases, can occur very quickly; signs can appear within 15 -20 minutes after ingestion. Signs include numbness of the lips, tingling in fingers and toes, stumbling, seizures, paralysis, disorientation, headaches, inactivity, elevated heart rate, dizziness, and respiratory failure.

Hepatotoxins (liver) - Hepatotoxin poisoning can have serious acute signs and also have slower chronic symptoms. Symptoms can occur hours or days after being exposed to the cyanotoxin. Signs include abdominal pain, loss of appetite, jaundice, dark or reduced urine, diarrhea, vomiting, liver damage, and hemorrhages.

Dermatotoxins (skin) - Dermatotoxin poisoning is topical. Symptoms can occur quickly if the skin is not rinsed after contact with cyanotoxins. Signs include rashes, hives, swelling, itching, and excessive drooling and seizures.

Specific cyanotoxins

Anatoxin (neurotoxin) are a group of neurotoxic alkaloids produced by a number of cyanobacterial genera including *Anabaena*, *Aphanizomenon*, and *Planktothrix*.

Microcystin (hepatotoxin) are a group of at least 80 toxin variants, microcystin-LR is the most toxic. They are produced by *Microcystis*, *Anabaena*, *Planktothrix*, *Nostoc*, *Hapalosiphon*, *Anabaenopsis*, and *Snowella lacustris*. The toxin does have a short half-life (10 minutes) and can be hard to detect.

Saxitoxin (neurotoxic) are also known as PSP's (paralytic shellfish poisons) due to their occurrence and association with seafood. There are more than 30 different saxitoxins. Saxitoxins are produced by various cyanobacteria species but are more commonly produced by dinoflagellates in marine waters.

Cylindrospermopsin (hepatotoxin) can be found in *Cylindrospermopsis*, *Aphanizomenon*, *Anabaena*, *Umezakia*, and *Raphidiopsis*. The toxin can also damage other major organs (kidney, lung, spleen, thymus, and heart).

10.3 Monitoring

It is important to monitor for both cyanobacteria and for cyanotoxins.

Phytoplankton samples should be collected on a regular basis. To collect a representative sample, it must be taken out in the central part of the lake and be a composite sample of the photic zone (depth of water that is exposed to sunlight). The photic zone is roughly 1.5x the Secchi depth.

Cyanotoxin samples need to be collected when a HAB has been identified and there is a concern of cyanotoxins due to a large surface bloom. It is important to collect samples that reflect the lake/reservoir conditions. Among the most important sample handling considerations are the following: proper collection method, using the correct sample bottle, labeling, and keeping the sample chilled.

Cyanobacteria Sampling

1. Use the correct kind of sampling bottle and lid.
2. Select a representative site to sample the algal scum.
3. Collect the sample by dipping the bottle into the water 1-2 inches below the water's surface.
4. Collect the appropriate amount of sample.
5. Properly label the sample bottle.
6. Mail the sample to a laboratory as soon as possible. If there is a delay, keep the sample in the refrigerator (no more than a day or two).
7. When collecting the sample, be sure to fill out any data sheet and send it along with your sample to the laboratory.
8. It is a good idea to assemble a HAB sampling kit before a bloom occurs.

Be prepared, have good communications with the lab about what they need and what they will analyze for. Have a sampling kit ready well before the summer season.

HAB sampling kit includes

- a. Brown glass bottle with an enclosed sampling label
- b. Bubble wrap
- c. Ice pack
- d. Well-padded box or cooler with proper shipping labels for the laboratory

10.4 Labs

It is important to have clear communication with laboratories. Each laboratory is different. It is important to find out how they analyze, what are their sampling requirements (e.g., sample volume and bottle type), what is the turnaround time, what are their analysis methods for the various toxins, how do they report the data, what are the costs for the various tests, and do they have specific delivery requirements (e.g., what day to mail samples).

U.S. EPA has a great list of laboratories identification/enumeration and cyanotoxin analysis - www2.epa.gov/nutrient-policy-data/state-resources

Algae Identification and Counting - With a microscope and some identification keys, the major cyanobacteria species can be identified in a short amount of time. To get concentrations, samples need to be sent to trained phycologists. Monthly or bi-monthly sampling is a good frequency.

Cyanotoxins Analysis - The analysis for cyanotoxins is not a common practice so there are a limited number of laboratories in the U.S. It is recommended to contact a laboratory beforehand to understand how the samples should be collected and delivered. It can take up to 48 hours to get results so it will help reduce confusion and time spent on getting results if you set up an account and have a laboratory ready.

10.5 Guideline Values

WHO Guideline Value for Drinking Water – 1.0 µg/L of microcystin-LR

Based on toxicology formula:

$$\text{Guideline Value} = \frac{\text{TDI} \times bw \times P}{L}$$

Definitions,

TDI = Tolerable Daily Intake

P = proportion factor

bw = body weight

L = daily intake

WHO Guideline Values for Recreation

Relative Probability of Acute Health Effects	Cyanobacteria (cells/mL)	Microcystin-LR (µg/L)	Chlorophyll-a (µg/L)
Low	< 20,000	<10	<10
Moderate	20,000-100,000	10-20	10-50
High	100,000-10,000,000	20-2,000	50-5,000
Very High	> 10,000,000	>2,000	>5,000

10.6 Helpful Resources

Center for Disease Control and Prevention

www.cdc.gov/nceh/hsb/cwh/water_response.htm

Foundation for Water Research

www.fwr.org/cyanotox.pdf

U.S. EPA CyanoHABs

www2.epa.gov/nutrient-policy-data/cyanohabs

GLEON HAB Research List

<http://blooms.uwcfl.org/research/>

USGS Paper on State Programs (NALMS Lakeline Article)

ks.water.usgs.gov/static_pages/studies/water_quality/cyanobacteria/LLsummer-graham2.pdf

Washington State DOE Algae Control Program

www.ecy.wa.gov/programs/wq/plants/algae/index.html

Washington State HAB Guidance

www.doh.wa.gov/Portals/1/Documents/4400/332-118-CylindroSax%20Report.pdf

Review of Current Knowledge of Cyanobacterial Toxins in Water

www.fwr.org/cyanotox.pdf

Human Health Effects from HABs

www.ijc.org/files/publications/Attachment%202%20Human%20Health%20Effects%20from%20Harmful%20Algal%20Blooms.pdf

Purdue Cyanosite

www-cyanosite.bio.purdue.edu

Veterinary Overview of Cyanotoxins Effects to Pets

www.merckvetmanual.com/mvm/toxicology/algae_poisoning/overview_of_algal_poisoning.html

Algal Images

www.phycotech.com

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California Environmental Protection Agency, 2012. Developing Cyanotoxin Action Levels for Humans and Domestic Animals. Presentation by Regina Linville for Office of Environmental Health Hazard Assessments.

Xie L., Xie P., Guo L., Li L., Miyabara Y., Park H. Organ distribution and bioaccumulation of microcystins in freshwater fish at different trophic levels from the eutrophic Lake Chaohu, China. *Environ. Toxicol.* 2005;20:293–300.

U.S. EPA, 2013. Impacts of Climate Change on the Occurrence of Harmful Algal Blooms. Office of Water, EPA 820-S-13-001, May 2013.

Hoagland P, Scatista S. 2006. The economic effects of harmful algal blooms. In E Graneli and J Turner, eds., *Ecology of Harmful Algae*. Ecology Studies Series. Dordrecht, The Netherlands: Springer-Verlag, Chap. 29

Appendix A – State HAB Websites

California – www.waterboards.ca.gov/water_issues/programs/bluegreen_algae/

Delaware – www.dnrec.delaware.gov/wr/INFORMATION/OTHERINFO/Pages/Blue-GreenAlgae.aspx

Florida – www.dep.state.fl.us/labs/biology/hab/index.htm

Illinois – www.epa.illinois.gov/topics/water-quality/surface-water/algal-bloom/index

Indiana – www.in.gov/idem/algae/

Iowa – www.idph.state.ia.us/eh/algal_blooms.asp

Kansas – www.kdheks.gov/algae-illness/index.htm

Maine – www.maine.gov/dep/water/lakes/cynobacteria.htm

Maryland – www.dnr.state.md.us/bay/hab/

Minnesota – www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/blue-green-algae-and-harmful-algal-blooms.html#research-and-reports

Nebraska – deq.ne.gov/NDEQProg.nsf/Beaches2014.xsp

New Hampshire - www2.des.state.nh.us/WaterShed_BeachMaps/WaterShed_BeachMaps.aspx

New York – www.dec.ny.gov/chemical/83310.html

North Carolina – epi.publichealth.nc.gov/oe/a_z/algae.html

Ohio – epa.ohio.gov/habalgae.aspx

Oklahoma – www.checkmyoklake.com

Oregon – public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/index.aspx

Rhode Island – www.health.ri.gov/healthrisks/harmfulalgaeblooms/

Texas – tpwd.texas.gov/landwater/water/enviroconcerns/hab/

Vermont – healthvermont.gov/enviro/bg_algae/bgalgae.aspx

Virginia – www.vdh.state.va.us/epidemiology/DEE/habs/cyanobacteria/index.htm

Washington – www.nwtoxicalgae.org/Program.aspx

Wisconsin – dnr.wi.gov/lakes/bluegreenalgae/

Appendix B – State Guideline Values

State	Recreational Water Guidance/Action Level	Recommended Action
California	Microcystin: 0.8 µg/L Anatoxin-a: 90 µg/L Cylindrospermopsin: 4 µg/L	Advisory
Connecticut	-Visual Rank Category 1: Visible Material is not likely cyanobacteria or water is generally clear. -Visual Rank Category 2: Cyanobacteria present in low numbers. There are visible small accumulations but water is generally clear. -Visual Rank Category 3: Cyanobacteria present in high numbers. Scums may or may not be present. Water is discolored throughout. Large areas affected. Color assists to rule out sediment and other algae.	-Visual Rank Category 3, or blue-green algae cells > 100k/ml: POSTED BEACH CLOSURE (If public has beach access, alert water users that a blue-green algae bloom is present), POSTED ADVISORY (At other impacted access points)
Illinois	Microcystin-LR concentration results approach or exceed 10 µg/L	Reporter of HAB event and the local lake management entity will be informed immediately.
Indiana	Level 1: very low/no risk < 4 µg/L microcystin-LR Level 2: low to moderate risk 4 to 20 µg/L microcystin-LR Level 3: serious risk > 20 µg/L microcystin-LR Warning Level: Cylindrospermopsin: 5 ppb	Level 1: use common sense practices Level 2: reduce recreational contact with water Level 3: consider avoiding contact with water until levels of toxin decrease
Iowa	Microcystin ≥ 20 µg/L	Caution - bloom present no toxin data available Warning - when toxin levels exceed 20 µg/L
Kansas	PHA: >4 µg/L to <20 µg/L for microcystin or > 20,000 cell/mL to <100,000 cell/mL cyanobacteria cell counts PHW: > 20 µg/L or > 100,000 cell/mL cyanobacterial cell counts and visible scum present	Public Health Advisory (PHA): avoid contact Public Health Warning (PHW): all contact with water is restricted
Kentucky (Louisville District)	Advisory: >20,000 cells/mL of cyanobacteria cell counts Caution: > 100,000 cells/mL of cyanobacteria cell counts	Advisory: contact discourage, water may be unsafe Caution: Closure, contact prohibited
Massachusetts	14 µg/L for microcystin-LR and ≥ 70,000 cells/mL for cyanobacteria cell counts	Advisory - Avoid contact with water
Nebraska	Microcystin ≥ 20 µg/L	Health Alert

State	Recreational Water Guidance/Action Level	Recommended Action
New Hampshire	>50% of cell counts from toxigenic cyanobacteria	Public Health Advisory
North Carolina	Visible discoloration of the water or a surface scum may be considered for microcystin testing	Advisory/Closure
Ohio	Microcystin-LR: PHA: 6 µg/L; NCA: 20 µg/L Anatoxin-a: PHA: 80 µg/L; NCA: 300 µg/L Saxitoxin: PHA: 0.8 µg/L; NCA: 3 µg/L Cylindrospermopsin: PHA: 5 µg/L; NCA: 20 µg/L	Public Health Advisory (PHA) - swimming and wading are not recommended, water should not be swallowed and surface scum should be avoided. No Contact Advisory (NCA) -recommend the public avoid all contact with the water
Oklahoma	100,000 cell/mL of cyanobacteria cell counts and > 20µg/L for microcystin	Blue-Green Algae Awareness Level Advisory
Oregon	Option 1: Visible scum and cell count or toxicity Option 2: Toxigenic species >100,000 cells/mL Option 3: Microcystis or Planktothrix > 40,000 cells/mL Option 4: Toxin Testing Microcystin: 10µg/L Anatoxin-a: 20 µg/L Cylindrospermopsin: 6µg/L Saxitoxin: 100 µg/L	Public Health Advisory
Rhode Island	Visible cyanobacteria scum or mat and/or cyanobacteria cell count > 70,000 cells/mL and/or ≥14 µg/L of microcystin-LR	Health Advisories
Texas	>100,000 cell/mL of cyanobacteria cell counts and >20µg/L microcystin	Blue-Green Algae Awareness Level Advisory
Vermont	4,000 cells/mL cyanobacteria cell counts or ≥ 6µg/L microcystin-LR and the visible presence of cyanobacterial scum Anatoxin-a ≥ 10 µg/L	Beach Closure
Virginia	5,000 to <20,000 Microcystis cells/mL 20,000 to 100,000 Microcystis cells/mL > 100,000 Microcystis cells /mL, or > 6 µg/L microcystin concentration, or Blue-green algal “scum” or “mats” on water surface	Local agency notification; initiate bi-weekly water sampling Public notification indicating a harmful algal bloom is present in recreational water; initiate weekly sampling Immediate public notification to avoid all recreational water contact where bloom is present; continue weekly sampling
Washington	Microcystin-LR: 6 µg/L Anatoxin-a: 1 µg/L Cylindrospermopsin: 4.5 µg/L Saxitoxin: 75 µg/L	Tier 1. Caution: when a bloom is forming or a bloom scum is visible (toxic algae may be present) Tier 2. Warning: Toxic algae present Tier 3. Danger: Lake closed
Wisconsin	> 100,000 cells/mL or scum layer	Advisory/Closure

Appendix B – State Guideline Values

State	Drinking Water Guidance/Action Level
Minnesota	Microcystin-LR: 0.04 µg/L
Ohio	Microcystin: 1 µg/L Anatoxin-a: 20 µg/L Cylindrospermopsin: 1 µg/L Saxitoxin: 0.2 µg/L
Oregon	Microcystin-LR: 1 µg/L Anatoxin-a: 3 µg/L Cylindrospermopsin: 1 µg/L Saxitoxin: 3 µg/L

Appendix C – Drinking Water Treatment

Treatment Process	Relative Effectiveness
Intracellular Cyanotoxins Removal (Intact Cells)	
Pretreatment oxidation	Avoid pre-oxidation because often lyses cyanobacteria cells releasing the cyanotoxin to the water column. If oxidation is required to meet other treatment objectives, consider using lower doses of an oxidant less likely to lyse cells (potassium permanganate). If oxidation at higher doses must be used, sufficiently high doses should be used to not only lyse cells but also destroy total toxins present (see extracellular cyanotoxin removal).
Coagulation/ Sedimentation/Filtration	Effective for the removal of intracellular toxins when cells accumulated in sludge are isolated from the plant and the sludge is not returned to the supply after separation.
Membranes	Study data is scarce; it is assumed that membranes would be effective for removal of intracellular cyanotoxins.
Flotation	Flotation processes, such as Dissolved Air Flotation (DAF), are effective for removal of intracellular cyanotoxins since many of the toxin-forming cyanobacteria are buoyant.
Oxidation	Avoid because often lyses cyanobacteria cells releasing the cyanotoxin to the supply.
Extracellular Cyanotoxins Removal	
Membranes	Depends on the material, membrane pore size, and water quality. Nanofiltration and ultrafiltration are likely effective in removing extracellular microcystin. Reverse osmosis filtration would likely only be applicable for the removal of some extracellular cyanotoxins like cylindrospermopsin. Cell lysis is highly likely. Further research is required to characterize performance.
Potassium Permanganate	Effective for oxidizing microcystins and anatoxins.
Ozone	Very effective for oxidizing extracellular microcystin, anatoxin-a, and cylindrospermopsin.
Chloramines	Not effective.
Chlorine Dioxide	Not effective with doses used in drinking water treatment.
Chlorination	Effective for oxidizing extracellular cyanotoxins as long as the pH is below 8; ineffective for anatoxin-a.
UV Radiation	Effective for degrading microcystin and cylindrospermopsin but at impractically high doses.
Activated Carbon	PAC: Most types are generally effective for removal of microcystin, anatoxin-a, and cylindrospermopsin, especially wood-based activated carbon. GAC: Effective for microcystin but less effective for anatoxin-a, and cylindrospermopsins.

Appendix D – NALMS Position Statement

Toxic Cyanobacteria Blooms

Toxin-producing cyanobacteria (commonly referred to as blue-green algae) are an emerging issue for lake managers throughout the world. Cyanotoxins have caused the death of domestic and wild animals and have been implicated in illness and even death in humans. They also have negative impacts on fish and other aquatic biota, and can have economic impacts on water uses and property values. Thus there is a critical need for objective scientific information regarding bloom occurrence and impacts, so that responsible agencies can set guidelines and limits where necessary to protect humans, livestock, pets and natural resources.

The environmental factors responsible for the formation of cyanobacterial blooms and toxicity are diverse, and bloom dynamics are complicated. Cyanobacterial blooms can be episodic or persist year-round, and often, but not always, occur in highly productive (eutrophic or hypereutrophic) waters. The eutrophication (over fertilization) of North America's surface waters has led to the increasing frequency, duration and magnitude of toxic cyanobacterial blooms. Toxic blooms are difficult to treat safely due to the risk of liberating the toxins into the water.

Which cyanobacteria produce toxins and what types of toxins are produced?

Approximately 50 species of cyanobacteria have been shown to produce toxins that are harmful to vertebrates. Common bloom-forming species include members of the genera *Microcystis*, *Anabaena*, *Planktothrix* (*Oscillatoria*), *Cylindrospermopsis*, *Aphanizomenon*, *Plectonema* (*Lyngbya*) and *Nodularia*. All cyanobacterial toxins can affect humans. Cyanotoxins fall broadly into three groups: neurotoxins, hepatotoxins and dermatotoxins. Neurotoxins include anatoxin-a, anatoxin-a(s), saxitoxin and neosaxitoxin and primarily cause neurological symptoms, including paralysis and respiratory failure. β -N-methylamino-L-alanine (BMAA) is a unique amino acid widely produced by cyanobacteria. It has been linked to neurological disorders in humans, but occurrence or risk data are limited. Hepatotoxins include microcystin (80+ variants), nodularin and cylindrospermopsin acting primarily on the liver and kidneys (as well as other organs). The most common dermatotoxin is lyngbyatoxin produced by *Plectonema* (*Lyngbya*) *wollei*, primarily causing skin irritation, rashes and gastrointestinal upset. Some data also suggest that microcystins and cylindrospermopsin can be carcinogenic (causing cancer) and teratogenic (causing birth defects). Although each of the toxins acts somewhat uniquely, initial, low-level exposure may include skin irritation and gastrointestinal upset, regardless of the specific toxin involved.

Particular problems arise from these cyanobacteria in drinking water supplies. Microcystins and cylindrospermopsin are highly heat stable (boiling may not destroy them), and they are not easily removed by conventional drinking water treatment methods such as sand filtration, if they are free (dissolved) in the water, although they are destroyed by strong

oxidants like chlorine. Of these cyanotoxins, microcystin (- LR, -RR, -YR, -LA variants), cylindrospermopsin, and anatoxin-a are on the US EPA Contaminant Candidate List (CCL2) and are currently being evaluated for risk in treated drinking water. Canada and several other countries have already established drinking water guidelines for microcystin-LR.

History and Threats Posed by Cyanotoxins

Toxic cyanobacterial blooms are not a new phenomenon. They have been documented for over two thousand years dating back to ancient Rome. Initial increases in cyanobacterial blooms in North America coincided with European colonization of the continent, resulting in continued growth and development of population centers and substantial land use changes in watersheds and associated increases in nutrient export over the last 200-300 years. More recently, it appears that milder winter temperatures, reduced ice cover, and warmer summers are increasing the occurrence of blooms across the United States and Canada. Additionally, resting stages (akinetes) produced by some toxin-producing cyanobacteria can remain viable for hundreds of years in the sediments, remaining as a 'seed bank' to initiate cyanobacterial blooms.

Cyanobacterial blooms occur in all freshwater systems, from man-made dugouts and natural ponds to rivers, lakes, and reservoirs. Though they tend to occur at the height of summer and early fall, some can persist well into late fall or winter. Some cyanobacteria cause blooms under ice which can result in the build-up of toxins, and blooms may persist through spring ice-out. Cyanobacteria may bloom all year long in tropical to sub-tropical regions, creating a persistent threat.

Most bloom-forming cyanobacteria (*Microcystis*, *Anabaena* and *Aphanizomenon*) accumulate in characteristic scums that initially look like blue-green paint chips or slicks on the water surface, and can develop into bubbly masses up to a meter thick. Their color can range from yellows and browns to bright blue. Wind often concentrates these scums near boat docks or shores. However, not all toxin-producing cyanobacteria form scums. *Cylindrospermopsis* does not concentrate at the surface, remaining more evenly distributed in the subsurface waters. Some species of *Planktothrix* concentrate at depths where light intensities are much reduced. As in under-ice blooms, these metalimnetic blooms (blooms at depth) can contain very high concentrations of microcystin.

Exposure routes to cyanobacterial toxins include ineffectively treated drinking water and casual recreational water contact from swimming, fishing, and water skiing. Recreational exposure includes skin contact, ingestion or inhalation. Children appear to be at greater risk, as a function of lower body mass and the way they play in the water, often ingesting water or playing with scums. Family pets (especially dogs) experience elevated risk, as they often consume the water intentionally. Human exposure can also occur via popular food supplements containing *Aphanizomenon flos-aquae* and *Spirulina* collected from lakes, which in some cases have been found to contain cyanotoxins. Animals exposed to potent toxic cyanobacterial blooms can die within minutes following ingestion. Effects on humans can be acute or chronic; deaths related to cyanobacterial toxins have occurred, and a number of chronic effects have been implicated but not yet adequately studied.

Most US states and Canadian provinces have documented toxic cyanobacterial blooms. Toxic cyanobacteria alerts are now routinely issued in those states (e.g., Minnesota, Nebraska, Iowa, and Oregon) and provinces (e.g., Alberta and Manitoba) that have monitoring programs. Unfortunately, there is no standard program or approach for monitoring toxic cyanobacterial blooms, and most go undocumented.

Issues and Concerns Relating to Cyanotoxins

1. There is no US or Mexican policies and practices to deal with freshwater cyanobacterial blooms or toxins in drinking water supplies. In Canada, a federal drinking water guideline for microcystin-LR has been adopted by the provinces and territories.
2. North American countries have no federal recreational policies or practices regarding toxic blooms.
3. Prevention, monitoring and control must be coordinated at the local, state, provincial, and national levels. Protection and mitigation efforts are poorly supported in most cases.
4. Adequate monitoring programs do not exist in most systems, and there is little infrastructure in place to notify populations at risk from developing or fully developed cyanobacterial blooms.
5. New toxins are being discovered, while known toxins still need to be fully characterized.
6. The public remains mostly ignorant of potential exposure routes for toxins present in cyanobacterial blooms.
7. Children, dogs and livestock appear to be at greatest risk among terrestrial vertebrates. Chronic impacts seem more likely for adult humans, with a risk of carcinogenic and teratogenic effects, but deaths have occurred.
8. Almost all laboratory exposure data are based on mice and rats, with limited replication of complete studies, and few other appropriate mammalian models, restricting our knowledge of human impacts.
9. The human health, ecological and economic impacts of toxic cyanobacterial blooms can be very high.

NALMS Positions on Cyanotoxins

1. NALMS supports international, national, provincial and state efforts to monitor, control and mitigate freshwater cyanobacterial blooms.
2. NALMS supports more research towards understanding the factors that control blooms and quantifying the effects of cyanotoxins on humans.
3. NALMS encourages and supports local efforts to protect lakes, and thereby limit cyanobacterial blooms. This includes public education, monitoring and mitigation programs.
4. NALMS supports the development of scientifically supported and appropriately protective limits on the primary toxins in drinking and recreational waters (microcystins, anatoxin-a, cylindrospermopsin) at the national level.