Managing Cyanotoxins in Drinking Water: A Technical Guidance Manual for Drinking Water Professionals

September 2016

American Water Works Association

Dedicated to the World's Most Important Resource®

Water Research Foundation®

advancing the science of water

Managing Cyanotoxins in Drinking Water

A Technical Guidance Manual for Drinking Water Professionals

September 2016

The American Water Works Association is the largest nonprofit, scientific and educational association dedicated to managing and treating water, the world's most important resource. With approximately 50,000 members, AWWA provides solutions to improve public health, protect the environment, strengthen the economy and enhance our quality of life. The Water Industry Technical Action Fund is managed by the Water Utility Council to support projects, studies, analyses, reports and presentations in support of AWWA's legislative and regulatory agenda. WITAF is funded by a portion of every organizational member's dues.

The Water Research Foundation is an international, 501(c)3 nonprofit organization that sponsors research that helps water utilities, public health agencies and other professionals provide safe, reliable and affordable water to the public. Its research provides practical solutions to today's most complex challenges facing the water community.

Cover cyanobacteria photos are courtesy of Dr. Barry Rosen, United States Geological Survey

American Water Works Association
6666 West Quincy Avenue
Denver, CO 80235-3098
303.794.7711
www.awwa.org

Water Research Foundation
6666 West Quincy Avenue
Denver, CO 80235-3098
303.347.6100
www.waterrf.org

Primary Authors
Karen Sklenar, The Cadmus Group
Judy Westrick, Wayne State University
David Szlag, Oakland University

Steering Committee
Keith Cartnick, Suez
Ric De Leon, Metropolitan Water District of Southern California
Joe Natress, CH2M

Technical Review
Benjamin Stanford, Hazen and Sawyer

Staff Project Managers
Adam Carpenter, American Water Works Association
Djanette Khiari, Water Research Foundation

Additional Project Support
Steve Via, AWWA
Mary Parmelee, AWWA

Contents

List of Tables

List of Figures

Executive Summary

Toxin-producing cyanobacteria blooms are a growing concern for water utilities that use surface water supplies across the country. To make informed decisions about how to limit exposure to cyanotoxins, water utilities need to understand:

- How, when, and why cyanotoxins occur,
- How to determine if they are present in a given water source,
- What management strategies are available to reduce cyanotoxin production in source waters? and
- What treatment can prevent cyanotoxins from reaching customers?

This guide was created in a partnership between the American Water Works Association (AWWA) and the Water Research Foundation (WRF). In early 2015, a short guide was published to help water utility managers consider whether cyanotoxins may be an issue for their water systems. It provides a brief overview of cyanobacteria, cyanotoxins, their health risks, and how cyanobacteria blooms and cyanotoxins can be effectively prevented or treated. A short self-assessment near the end of the guide allows utility managers to evaluate whether their water systems may be at risk and, if so, where they can go for additional information and guidance.

This second, more technical guidance manual gathers and summarizes the most recent information about cyanotoxin occurrence, measurement, and management. Like the first guide, it is also intended to benefit water utility managers, operators and consultants. More specifically, though, it is intended for users working for or with water utilities that have already been determined to be at risk of having cyanobacteria and possibly cyanotoxin issues. While this second guidance contains more detailed information than the first guide, it is organized to help readers navigate the issues and make informed decisions about appropriate mitigation measures and how to be prepared in case of a toxic cyanobacteria bloom.

The information provided in this guide is presented in four steps:

Step One: Understanding the Issue
The first step helps readers understand the issues associated with cyanotoxins in drinking water. Background information is provided on cyanobacteria, as well as cyanotoxin characteristics, occurrence, health effects, and regulations. Additional information is provided about measurement techniques for cyanobacteria, cyanotoxins, and their indicators.

Step Two: Managing and Treating the Issue
Successful approaches to managing and treating water containing cyanotoxins are discussed in detail. Source water management and water treatment are both addressed. Careful consideration is given to which techniques are effective for addressing cyanotoxins present within intact cyanobacteria cells (intracellular), and which techniques are effective for removing cyanotoxins that are dissolved in the water (extracellular).

Step Three: The Balancing Act
Challenges related to full-scale treatment for cyanotoxins are discussed in this section. Additional discussion is provided about unintended consequences that may be encountered when managing and treating a water source for cyanotoxins. Specific focus is provided regarding balancing simultaneous compliance objectives.

Step Four: Using Your Knowledge to Plan Ahead
The material provided in this section helps water utilities prepare for a toxic cyanobacteria event, should they have to contend with such a situation. Information is provided on how to develop a communication plan and consumer notifications. Additional discussion addresses how water utilities can prepare for toxic cyanobacteria events by developing an action plan for their utility and its community. Examples of existing guidance are provided to help with that planning effort.

I. Step One: Understanding the Issue

1. Background on Cyanobacteria and Cyanotoxins

Cyanobacteria, also known as blue-green algae, are photosynthetic bacteria that can live in many types of waters. They are an important primary producer in aquatic ecosystems and help form the base of the food chain. While critical to water and soil resources, excessive cyanobacteria growth can pose significant ecological and public health concerns. Rapid, excessive cyanobacteria growth is referred to as a "bloom," and is often grouped in the general category of "harmful algal blooms" or HABs. Other types of HABs may include "red tide" events in marine environments and algal blooms that result in fish kills in fresh water, among many others, as well. Cyanobacteria blooms can result in inches-thick layers of cells, especially those located near the shorelines of lakes and reservoirs, and occur most often during warm weather, but can also be less pronounced. They sometimes appear foamy or accumulate as mats or scum covering the surface of a water body. They can also be elusive, because some cyanobacteria sink and rise through the water column, depending on the time of day.

Aside from being visually unpleasant, cyanobacteria can cause several issues for water utilities including

- Taste and Odor (T&O) issues,
- Increased raw water turbidity,
- Increased disinfection byproduct precursors, and
- Cyanotoxins.

Cyanotoxins make up a large and diverse group of chemical compounds that differ in their molecular structure and toxicological properties. They are generally grouped into major classes according to their toxicological targets: liver, nervous system, skin, and gastrointestinal system. Some of these substances are among the most powerful natural toxins at high concentrations, of which no known antidotes exist (CDC n.d.). A single bloom may contain different types of cyanotoxins because a bloom may have more than one toxin-producing genus and/or potentially one genus may produce more than one toxin (Chorus and Bartram 1999).

a. Characteristics of Cyanobacteria

Table 1 summarizes some of the basic physical (morphological) and other characteristics of cyanobacteria that have the potential to produce cyanotoxins. The table is classified by genera, but there may be variability among individual species that makes it difficult to universally apply the morphological descriptions.

> **Morphology:** The form and structure of cyanobacteria cells, such as their size, shape, number of cells in a colony or filament.

Some of the same types of cyanobacteria can produce both cyanotoxins and T&O compounds such as geosmin and 2-methylisoborneol (MIB). However, a T&O episode does *not* necessarily mean cyanotoxins are also present. In addition, some cyanobacteria that produce cyanotoxins do not produce these musty and earthy compounds. Cyanotoxin production and T&O production should not be assumed to occur together.

> While T&O can indicate the presence of cyanotoxins, a T&O episode does not necessarily mean cyanotoxins are also present. Likewise, the absence of T&O compounds does not mean cyanotoxins are also absent.

Table 1. Morphology description for most prevalent toxic-producing cyanobacteria

Cyanobacteria Genus	Shape	Individual Cell	Cyanotoxins Produced	MIB or Geosmin Producer
Microcystis	Unicellular and/or colonies surrounded by mucilage	Spherical 2–5 µm	Microcystin	No[1]
Anabeana	Unbranched filament (beaded chain)	Spherical to oblong—4–14 µm in diameter, 6-12 µm long	Anatoxin-a and microcystin	Geosmin
Aphanizomenon	Unbranched filament, solitary or mat forming	Cylindrical–5–6 µm diameter, 8–12 µm long	Microcystin, anatoxin-a, and cylindrospermopsin[1]	Geosmin
Planktothrix	Unbranched filament	Cylindrical 3.5–10 µm wide and length <4 µm	Microcystin	Geosmin
Psuedoanabeana	Unbranched filament, solitary or agglomerated in very fine, mucilaginous mats	Cylindrical cells 0.8–3 µm	Microcystin and anatoxin-a	MIB and geosmin
Cylindrospermopsis	Unbranched filament, straight and coiled	Cylindrical 1.7–3.0 µm in width and 3-10 µm cell length	Cylindrospermopsin	Anecdotal—MIB

[1] Hurlburt et al. 2011

b. Characteristics of Cyanotoxins

Detecting a cyanobacteria bloom does not always mean there is a cyanotoxin issue. Multiple strains of cyanobacteria can exist in a single bloom, and not all are toxic. Even ones that can produce toxins do not always produce the toxins and cause health risks. Sometimes strains of

cyanobacteria will not produce toxins at all, since they have the ability to turn on or off certain genes depending on environmental conditions. The conditions that trigger or inhibit production of cyanotoxins remain poorly understood. Laboratory analysis is usually needed to determine if the cyanobacteria are actually producing toxins.

Chemical and physical properties of the cyanotoxins affect how effectively extracellular cyanotoxins (i.e., toxins dissolved in the water outside of the cyanobacteria cells) can be treated, as well as how they are measured. For example, activated carbon adsorption and membrane filtration efficiency can be affected by both the molecular size and the charge on the functional groups of the cyanotoxin. Table 2 lists the molecular weights (often used as a surrogate for molecular size) and descriptions of different cyanotoxins. The general rule of thumb is that there is a direct relationship between molecular weight and molecule size; therefore, as the molecular weight increases, the molecular size generally increases. Several cyanotoxins that are generally thought of as high-priority, from most hydrophilic to most hydrophobic, are microcystin variants MC-LR, MC-RR, MC-LA and MC-YR; anatoxin-a; and cylindrospermopsin.

> When considering cyanotoxins and how they should be measured or treated, it is important to distinguish between cyanotoxins located inside intact cyanobacteria cells and extracellular cyanotoxins that are dissolved in the water. When cells remain intact, the intracellular toxins are removed along with the cells. However, once those cells break apart (lyse) the toxins are released into the water to become extracellular substances. Physical removal of in-tact cells before the cyanotoxins (and other T&O compounds) are released is the first barrier to minimizing the cyanotoxin concentration in drinking water.

Table 2. Important characteristics of selected cyanotoxins for drinking water[1]

Cyanotoxin	Molecular Weight— *amu*	Descriptive Stability and Biodegradation
Microcystin LR	994	Microcystin is a very stable molecule and resistant to physical degradation at environmental pH and temperature. Several bacteria have, however, been reported to degrade microcystin in water. There is evidence that *Sphingomonadaceae* have specific genes required to degrade microcystin. Most of the degradation work has been performed on microcystin LR.
Microcystin RR	1037	
Microcystin LA	909	
Microcystin YR	1044	
Anatoxin-a	165	Anatoxin-a is sensitive to light and high pH.[2] Although there have been reports of biodegradation of anatoxin-a, only *Pseudomonas* has been shown to degrade anatoxin-a.
Cylindrospermopsin	415	Biodegradation occurs in natural waters. No isolates have been reported.

[1] Ho et al. 2012
[2] Yang and Boyer 2005

Microcystins

The most prevalent group of cyanotoxins is the microcystins. Microcystins are hepatotoxins and are produced by several freshwater genera of cyanobacteria: *Microcystis; Anabaena; Oscillatoria; Planktothrix; Nostoc; Psuedoanabeana*; and *Anabaenopsis*. The microcystins are water-soluble and do not break down on their own, even during boiling. With at least 160 reported variants of microcystin, successful treatment barriers will capitalize on similarities between the various molecular structures.

Cylindrospermopsin

Most reports of the presence of cylindrospermopsin have come from the southern states. This cyanobacterial metabolite has three known variants with molecular weights around 415 Da. In the typical pH range of natural waters, cylindrospermopsin is water-soluble. Cylindrospermopsin originates from several genera of cyanobacteria, including: *Cylindrospermopsis, Anabaena, Umezakia*, and *Aphanizomenon*. The structure of the molecules promotes hepatotoxicity, cytotoxicity, and genotoxicity. Of the three major functional groups of cylindrospermopsin, only one (uracil) is susceptible to oxidation.

Anatoxin-a

Anatoxin-a is a potent neurotoxin. Anatoxin-a has only one additional reported variant, homoanatoxin-a. Both variants are the smallest of the cyanotoxins, with molecular weights of 165 Da (anatoxin-a) and 179 Da (homoanatoxin-a). Anatoxin-a is typically found in its cationic form in natural waters, though changes in pH during drinking water treatment will impact the speed at which the compound is oxidized (Koskinen & Rapoport 1985). Anatoxin-a is produced by five genera of cyanobacteria: *Anabaena; Phormidium; Planktothrix; Oscillatoria*, and *Aphanizomenon*. Anatoxin-a has two functional groups that are susceptible to oxidation, the amine and the unsaturated ketone.

c. Health Effects of Cyanotoxins

Human exposure to cyanotoxins can occur in several ways:

- Ingesting contaminated food (fish or shellfish);
- Making skin (dermal) contact with water containing cyanotoxins;
- Inhaling or ingesting aerosolized toxins when swimming or otherwise recreating in waters when cyanotoxins are present; and
- Consuming drinking water impacted by a toxic cyanobacteria bloom.

While confirmed occurrences of adverse health effects in humans are rare, some incidents have been documented worldwide (AWWA 2010). In 1931, approximately 8,000 people fell ill when
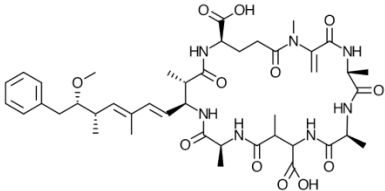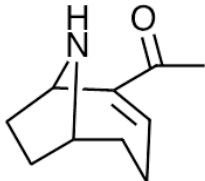
drinking water that originated from tributaries of the Ohio River was contaminated by a massive cyanobacteria bloom (Lopez et al. 2008). In 1975, approximately 62% of the population of Sewickley, Penn., reported gastrointestinal illness, which the Centers for Disease Control and Prevention (CDC) attributed to cyanotoxins released into open finished-water storage reservoirs (Lippy and Erb 1976).
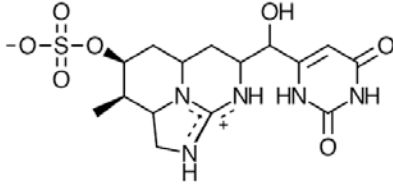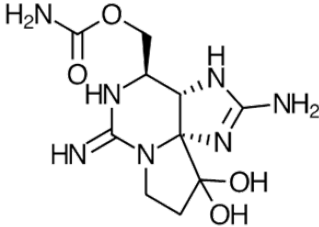
Health effects of cyanotoxins can be acute or chronic and have been observed in the liver, nervous system, and gastrointestinal system. Liver cyanotoxins (i.e., microcystins) seem to be the most commonly found in cyanobacteria blooms and the most frequently studied. At least 160 microcystins variants are known. In laboratory animal studies, researchers have observed both acute and chronic effects from microcystins. In studies, microcystins have rapidly concentrated in the livers of test animals, and at high doses, have resulted in organ damage, heart failure, and death. Long-term animal studies revealed chronic effects, including liver injury, renal damage, and an increased number of tumors (Humpage et al. 2000).

The impacts of chronic or acute exposure to cyanotoxins in humans, especially at the lower levels more common in drinking water, remain elusive. Studies in China have reported a correlation between liver or colorectal cancer and the consumption of water contaminated with microcystin-producing cyanobacteria blooms (Zhou et al. 2002). More research is needed to understand how cyanotoxins promote tumor growth and cancer.

Anatoxin-a targets the nervous system and at very high levels of exposure can induce paralysis and death by respiratory failure. Other nonlethal cyanotoxins can trigger fevers, headaches, muscle and joint pain, diarrhea, vomiting, or allergic skin reactions. Table 3 briefly summarizes the toxicological effects of different cyanotoxins and the genera of cyanobacteria known to produce the toxins.

Table 3. Cyanotoxin structures, toxicological effects, and known producers

Toxin	Structure	Organ(s) Effected	Genera
Microcystin		Liver (possible carcinogen)	*Microcystis Anabaena Planktothrix Anabaenopsis*
Anatoxin-a		Neurotoxin (nerve synapse)	*Anabaena Planktothrix Aphanizomenon Cylindrospermopsis*

Cylindrospermopsin		Liver and possibly kidney (genotoxic and carcinogen)	*Cylindrospermopsis* *Aphanizomenon*
Saxitoxin[1]		Neurotoxin (sodium channel blocker)	*Anabaena* *Aphanizomenon* *Cylindrospermopsis* *Lyngbya* *Planktothrix*

[1] Since it is not on the third Contaminant Candidate List, this guide does not address saxitoxin to the same extent it addresses microcystin, cylindrospermopsin, and anatoxin-a.

d. Drinking Water Regulations Related to Cyanotoxins

Currently, there are no federal regulations for cyanobacteria or their toxins in drinking water. However, the US Environmental Protection Agency (USEPA) developed 10-day health advisory levels (HALs) for two cyanotoxins of concern, microcystins and cylindrospermopsin. These Health Advisories are non-regulatory guidance for unregulated drinking water contaminants to assist federal, state and local officials, and public water systems in protecting public health. Ten-day Health Advisory recommended concentrations for total microcystins are 0.3 micrograms per liter (µg/L) for children younger than school age (<6 years old) and 1.6 µg/L for all other age groups, and for cylindrospermopsin are 0.7 µg/L for children younger than school age and 3.0 µg/L for all other age groups. The Health Advisories have been accompanied with USEPA guidance (USEPA 2015), providing some information on management of algae and monitoring and treatment of cyanotoxins. In addition, the document provides suggested guidance on communicating possible cyanotoxin detections in finished water, suggesting "Use of alternative [drinking water] sources for bottle-fed infants and young children of pre-school age" in the event of *finished water* microcystin levels of greater than 0.3 µg/L, and issuance of "Do Not Drink/ Do Not Boil Water" advisories for microcystin concentrations greater than 1.6 µg/L in the finished water.

The Safe Drinking Water Act (SDWA) requires USEPA to publish a list of unregulated contaminants that are present or are expected to be detected in public water systems. This list is called the Contaminant Candidate List (CCL). The USEPA uses it to prioritize research efforts to help determine whether a contaminant has sufficient data to meet regulatory determination criteria specified in the SDWA. As of 2012, three cyanotoxins are listed on the Third Contaminant Candidate List (CCL3): one targets the nervous system (anatoxin-a), another causes liver failure (microcystin-LR), and the last one is toxic to liver and kidney tissue (cylindrospermopsin). For microcystin-LR, the WHO has developed a drinking water guideline of 1 µg/L, and the USEPA has been reviewing this work published by the WHO (USEPA 2014, USEPA 2012). A summary of state, federal, and other country's advisory levels is provided in

Table 4). However, these levels are not all directly comparable because they were designed for different time periods of exposure. However, they nevertheless demonstrate the range of levels of concern from different organizations.

Table 4. Specific drinking water advisory levels for microcystin and other cyanotoxins as of January 2016

Agency, state, or province	Advisory Level Microcystins (µg/L)	Advisory Level Anatoxin-A (µg/L)	Advisory Level Cylindrospermopsin (µg/L)	Advisory Level Saxitoxin (µg/L)
USEPA (2015) Children (five and younger)	0.3	None	0.7	None
USEPA (2015) All Other age groups	1.6	None	3.0	None
Ohio[1]	0.3	20	0.7	0.2
Ohio[2]	1.6	20	3	0.2
Oregon Children (five and younger)	0.3	0.7	0.7	0.3
Oregon adults	1.6	3	3	1.6
Minnesota	0.1[3]	None	None	None
Quebec (LR only)	1.5 (LR only)	3.7	None	None
Health Canada (LR only)	1.5 (LR only)	None	None	None
WHO (LR only)	1 (LR only)	None	None	None

[1]Do Not Drink Advisory for: bottle-fed infants and children younger than school age; pregnant women; nursing mothers; individuals with pre-existing liver conditions; individuals receiving dialysis treatment.
[2]Do Not Drink Advisory for: all people of all ages; pets; livestock.
[3] Minnesota previously had a level for microcystin-LR only of 0.04 µg/l to be protective of a short-term exposure for bottle-fed infants.

2. Identifying and Measuring Cyanobacteria and Cyanotoxins

Background information is provided here on measurement techniques for cyanobacteria, cyanotoxins, and their indicators.

a. Identifying and Counting Cyanobacteria

Cyanobacteria are a diverse group of organisms ranging from unicellular (one cell) to filamentous forms, containing some 2,000 species in 150 genera (Vincent 2010). The classification of cyanobacteria has traditionally relied on observed morphological characteristics, which can vary depending on different environmental or growth conditions (Weiqun et al. 2006). While this method has limitations that have prompted researchers to re-evaluate cyanobacteria taxonomy, the prevailing classification system can still provide the information that is needed to make a preliminary assessment of the potential for cyanotoxicity (Weiqun et al. 2006, Chorus and Bartram 1999).

Cyanobacteria taxonomy differentiates by genus and species, but identifying the genus of the cyanobacteria is often enough when assessing its potential toxicity. Table 5 lists common genera of cyanobacteria that contain toxin-producing species. Differentiating down to the level of species can be an uncertain process because some morphological characteristics change under different environmental or stress conditions. In addition, cyanobacteria that belong to the same species may also show substantial differences with respect to cyanotoxin production. As a result, toxin levels are difficult to predict and should be measured.

Table 5. Common genera of cyanobacteria that contain toxin-producing species

Genera	Dermatoxins (Skin)			Hepatotoxins (Liver)			Neurotoxins (Nervous System)			
	LYN	APL	LPS	CYL	MC	NOD	ATX	SAX	BMAA	NEO
Anabaena			X	X	X		X	X	X	X
Anabaenopsis			X		X					
Aphanizomenon			X	X			X	X	X	X
Cylindrospermopsis			X	X				X	X	
Microcystis			X		X				X	
Nodularia			X			X			X	
Planktothrix (Oscillatoria)	X	X	X		X		X	X	X	
Raphidiopsis			X	X			X			

Source: Graham et al. 2008

LYN—lyngbyatoxin-a, APL—aplysiatoxins, LPS—lipopolysaccharides, CYL—cylindrospermopsins, MC—microcystins, NOD—nodularins, ANA—anatoxins, SAX, saxitoxins, BMAA—β-N-methylamino-L-alanine, NEO—neosaxitoxins

Table is not exhaustive.

Morphological Characteristics Used for Identification

Identifying cyanobacteria in source waters is usually based on morphological characteristics observed under a microscope. Cell shape and appearance of cell contents are the main features that are used to distinguish between genera among the unicellular cyanobacteria and identification is usually conducted by a trained technician (AWWA 2010).

Counting Cyanobacteria

Microscopic counts can directly assess the presence of cyanobacteria and require little equipment in addition to a microscope. Cell counting is a widely available and cost-effective method for detecting water quality issues, but does require training to perform this method with accuracy and reliability. Counting cyanobacteria can be performed in several ways. Most methods count only a defined part of the sample and then back-calculate to the volume of the entire sample. The most common methods are:

     • Total surface counting which counts all cells within the chamber,

• Counting only cells within transects spanning one edge of the chamber to the other, and

• Counting cyanobacteria occurring in randomly selected fields.

Selecting the counting method suitable to the sample is important in order to get an accurate count, since the density of different species in one sample can vary substantially. However, accurate quantification using microscopic methods requires careful quality control, as described by Chorus and Bartram (1999).

b. Other Ways to Quantify Cyanobacteria

A surrogate method for quantifying cyanobacteria abundance is to measure chlorophyll *a*, the predominant photosynthetic pigment used in oxygenic photosynthesis. Chlorophyll *a* is relatively easy to measure, but the validity of analytical results is complicated by the large presence of other pigments and their degradation products (Carlson & Simpson 1996). Some of these pigments cannot be readily separate from chlorophyll *a*, which can lead to chlorophyll *a* values that are falsely high (Carlson & Simpson 1996)*.* In addition, measuring chlorophyll *a* alone will not distinguish cyanobacteria from other algae in the water sample collected. To be useful, long-term monitoring of chlorophyll *a* could be used in combination with data regarding cyanobacteria presence to develop alert triggers for a given utility.

In the past few years, dynamic imaging particle analysis technologies have been applied to an automated platform that separates cyanobacteria from algae. This platform is based on identifying cyanobacteria by the presences of their unique phycocyanin fluorescence. The addition of this technology provides the detection and verification of cyanobacteria, including biovolume and cell density calculations without identifying the individual genera of cyanobacteria. However, the system can still be trained to identify photographs of individual cells and colonies for genera identification and enumeration. The data from this platform can be used to monitor source water and evaluate treatment efficiency. The major drawback from this platform is the cost.

In a treatment setting, the performance of treatment unit processes to remove intact cyanobacteria cells is usually tracked and optimized with particle counters or surrogate monitoring parameters such as turbidity and streaming current meters. Cyanobacteria cell removal efficiency can be tracked and optimized using several different methodologies including: particle counts; streaming current measurements; cell identification and enumeration; and chlorophyll *a* or pigment by visible or fluorescence spectrophotometry. Table 6 summarizes the advantages and disadvantages to each of these monitoring methods.

Table 6. Monitoring methodologies for intact cells during treatment studies

Methodology	Type	Advantages	Disadvantages
Turbidity	Surrogate for all particles that scatter light	Already being used, continuous monitoring	May not reflect the amount of cyanobacteria cells present or being removed
Streaming current	Surrogate for charged particles (cyanobacteria have a negative charge)	Continuous monitoring, provides information for determining types of coagulant and coagulant aids	- Does not specifically show cell removal - Results may not provide an accurate surrogate for cyanobacterial cells
Chlorophyll *a*	Surrogate for algae	Specific to algae and cyanobacteria, indicates extent of an algal bloom, probes for continuous monitoring are available	Does not distinguish between cyanobacteria and other algae
Phycocyanin	Surrogate for cyanobacteria	Specific to cyanobacteria, probes for continuous monitoring are available	Does not distinguish between different cyanobacteria.
Identification and enumeration	Specific for algae and cyanobacteria	Can track removal of each type of cyanobacteria	Time consuming, training needed, microscope needed

c. Measuring Cyanotoxins

Over the past thirty years, several analytical methods have been developed to either screen for or quantify cyanotoxins. Each method has advantages and disadvantages that should be considered when deciding how the method will be used. In order to determine how best to use the analytical tools available, the first step is to understand the roles that selectivity and sensitivity play. **Selectivity** is the degree of confidence one has that the specific compound or compounds of concern have been identified. **Sensitivity** refers to the amount (concentration) needed to determine the presences of the compound. Figure 1 illustrates where the most common methods used to detect cyanotoxins fall in terms of selectivity and sensitivity. Instrumental assays such as liquid chromatography with mass spectrometer (LC-MS) and bioassays such as enzyme-linked immunosorbent assays (ELISA) and protein phosphatase inhibition assays (PPIA) can detect picogram (pg) quantities of cyanotoxins, however LC-MS can distinguish between cyanotoxins better than the bioassay techniques can. Neither selectivity nor sensitivity directly refers to the dependability of an analytical method. The dependability of a method refers to its robustness, reproducibility, and reliability.

In order to use the right tool for a particular task, the drinking water practitioner must understand the strengths and weaknesses of the different analytical methods and how they will impact the decision-making process that will follow once the results have been obtained. Cyanotoxin screening assays such as ELISA can be used as a semi-quantitative analysis to:

monitor source waters, evaluate through treatment removal efficacies, and quantify toxins for bench or pilot studies. The advantage of these assays over the analytical methods is that samples do not have to be concentrated and results can be finalized within hours. Although numerous organic and inorganic compounds commonly found in water samples have been tested and do not interfere with the cyanotoxin ELISA assays and biochemical assays, variability in sample water quality may lead to unreliable results. There is some controversy surrounding the use of ELISA methods, with some (such as USEPA) suggesting that ELISA alone is appropriate for decision-making and others recommending that the more standardized LC-MS methods are more appropriate for this purpose. Positive test results from these assays can be confirmed by an analytical method such as liquid chromatography with mass spectrometry (LC-MS). Table 7 summarizes the advantages and disadvantages of using different analytical methods when monitoring for cyanotoxins during treatment studies.
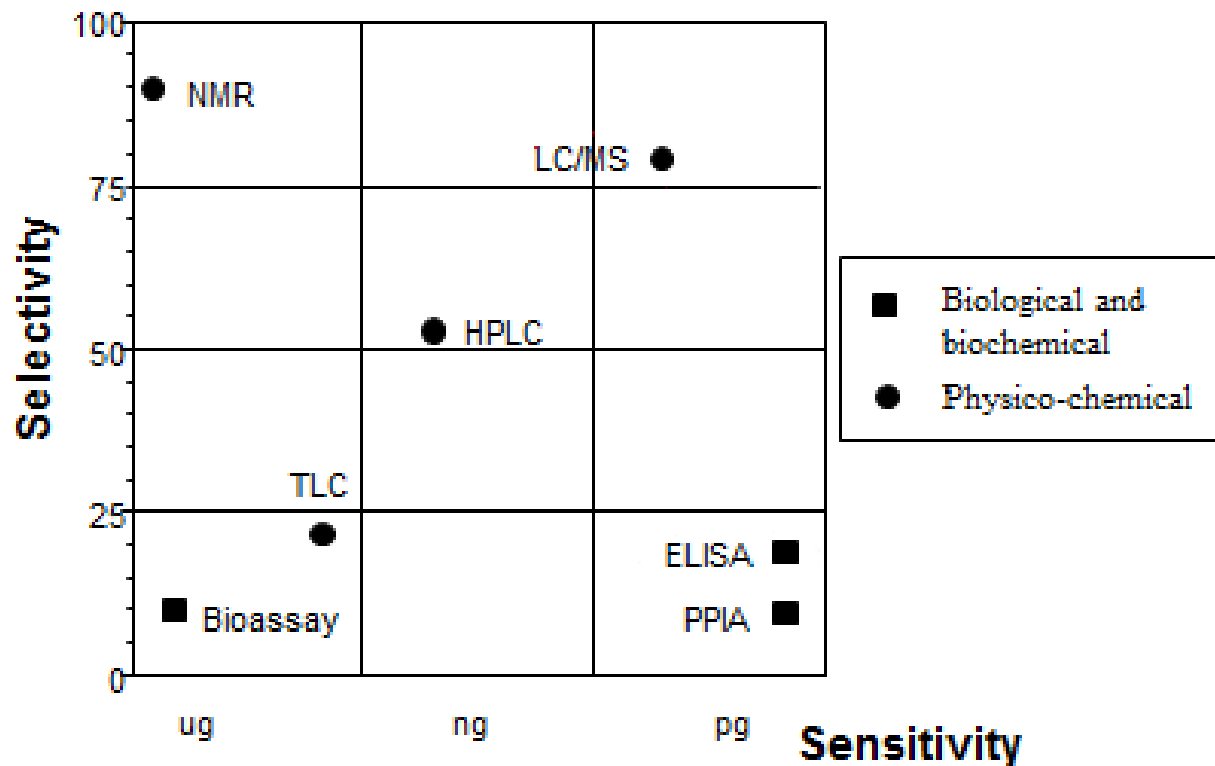
Figure 1: Selectivity and sensitivity of instrumental or separation techniques, including nuclear magnetic resonance (NMR), high-pressure liquid chromatography with a photodiode array (HPLC/PDA), liquid chromatography with mass spectrometry (LC-MS), thin layer chromatography (TLC), and bioassay techniques such as enzyme-linked immunosorbent assays (ELISA) and protein phosphatase inhibition assays (PPIA). *Figure courtesy of Andy Eaton, Eurofin International*

Table 7. Monitoring methodologies for cyanotoxins during treatment studies

Methodology	Cyanotoxin Type	Advantages	Disadvantages
ELISA	Microcystin—Plate reader, dipsticks (e.g., test strips), test tubes Cylindrospermopsin Anatoxin-a	Minimal sample preparation, minimal overhead, 4–5 hours analyses time, dipstick and test tubes can be done in the field, detects known and unknown congeners	False positives and negatives, does not provide individual congener concentration, nonlinear response, dipstick can be difficult to read
Multiplexing qPCR	Microcystin Cylidrospermopsin Saxitoxin Cyanobacteria	4–5-hour analyses	Identifies the gene not the amount of toxin, gene and toxin do NOT always correlate
LC-PDA	Microcystin Cylindrospermopsin Anatoxin-a	Determine individual congener concentration, one chromatographic analysis for three classes	Concentration needed, medium overhead, medium training
LC-MS/MS	Microcystin Cylindrospermopsin Anatoxin-a	Minimal sample preparation, determine individual congener concentration, one chromatographic analysis for three classes	Costly overhead, extensive training, detects only known/specific congeners

II. Step Two: Managing and Treating the Issue

1. Source Water Management

Managing cyanobacteria blooms effectively requires an understanding of the limnology of the lake or reservoir supplying the water. Some blooms are likely to grow when the water reaches a warm enough temperature. Others tend to grow when the thermocline begins to destratify in late summer or early fall (i.e., when turnover begins). Blooms may take place after a substantial rain event or they may occur after a series of sunny days. By understanding the limnological conditions of their particular source water, utility managers have a better chance of understanding what conditions precede the development of a bloom.

An active source water management program can play an important part in preventing and avoiding cyanobacteria blooms in a water supply. For example, combining a reservoir monitoring program with multiple intake depths in the reservoir can allow a water utility to draw the best quality water from the reservoir and avoid poorer water quality during a bloom. Algaecide applications may not necessarily be the most effective approach to reducing cyanotoxins, since the algaecide lyses (breaks open) cyanobacteria cells and can result in the release of higher concentrations of cyanotoxins; however, algaecide applications are often used in certain circumstances.

This section considers different source water management and treatment techniques that can be used individually or in combination to control cyanobacteria and related cyanotoxin production before reaching the water treatment facility, including:

- Source water monitoring and management;
- Source water treatment; and
- Selection of alternate source or alternate withdrawal point.

a. Using Source Water Monitoring as a Management Tool

Effective monitoring of a drinking water source can serve as an early warning system for potential cyanobacteria blooms that are developing. Samples should be collected that represent the water body as a whole but, more importantly, samples should represent the part of the water body that is being used for the water supply. While there is value to visually observing the water body on a daily basis, a bloom may be present but not visually obvious. This has been found to occur with cyanotoxin-producing *Planktothrix rubescens* blooms that are located deeper in the water column and not visible at the water surface. Also, some cyanobacteria blooms look like turbid brown water (e.g. *Cylindrospermopsis*) and may appear more like suspended sediments than algae.

Water utilities can benefit from observations that experienced water operators have made related to past cyanobacteria blooms in their water sources (e.g., occurrence after a significant

summer rainstorm, when the water temperature reaches a certain point, if it is sunny for several days in a row, once the thermocline starts to weaken in late summer before turnover). These observations are usually specific to the drinking water source, its conditions, and its climate. A water operator can contribute to that historical information about his or her water source by keeping written notes in addition to any measurements that are made. Notes about cloud cover and weather over the previous week can be helpful. For some water utilities, a problematic cyanobacteria bloom may take place after another algae bloom has grown and is dying off; knowing about such a pattern can help the operator catch the cyanobacteria bloom early.

Sampling schedules are determined by factors that may vary depending on the drinking water utility, including the cost of monitoring. During the warm summer months, sampling frequency might need to be increased, especially for scum-forming cyanobacteria that can change their concentration and distribution in the water within a matter of hours to a day or two. Sampling during and immediately following wet weather events can also provide helpful information, especially if the source is impacted by nutrient loading from runoff. In addition to monitoring intervals, the time of day when samples are collected is important for accurate estimates of cyanobacteria abundance, for example, buoyant cyanobacteria accumulate near or at the water surface at night, therefore sampling later in the day and maintaining consistent sampling times for each sampling location is preferred.

Cyanobacteria tend to be unevenly distributed both vertically and horizontally, primarily due to water column stratification and prevailing winds. As a result, depth-integrated sampling in open water is generally the most representative way to measure average cyanobacteria abundance, and is the preferred method for monitoring drinking water supplies (Newcombe et al. 2010). If open water sampling is not feasible, another option is to collect samples from the intake structure or, if necessary, the reservoir shoreline.

A combination of environmental factors (e.g., water temperature, pH, turbidity, nutrient concentrations, and dissolved oxygen) controls and indicates the formation of cyanobacteria blooms. Monitoring these parameters can provide early warning signs of an oncoming cyanobacteria bloom that may or may not be toxic.

Water temperature, pH, turbidity, and dissolved oxygen can be measured using probes or simple techniques such as Secchi disks that can be lowered into the water or attached to a buoy in the water. When this is done, depth profiles should be made whenever monitoring is carried out; depth profiles can be developed by taking measurements at several depths in the water body and graphing out the values with depth. Doing this frequently will allow one to determine trends and characteristics of the water body, including

- **The strength and location of the thermocline in the water column, if the water body is thermally stratified.** A cyanobacteria bloom may occur in the water body when the thermocline is either strengthening or weakening (i.e., when turnover is beginning to take place).

- **Changes in pH associated with algae growth.** The pH of water generally increases with increasing algae growth. However, it may be difficult to attribute any pH change to algae given the many other factors that change pH.
- **Changes in turbidity associated with algae growth.** While there are other sources of turbidity in a water supply, especially during and after wet weather, some utilities have found turbidity to be an effective indicator of algae growth. Daily Secchi disk measurements during months of high algae growth can be a helpful, easy part of a source water monitoring and management program.

Chlorophyll *a* is another common parameter that can be measured and used to indicate the presence of algae. It measures algal biomass fairly accurately and can be analyzed using probes or relatively simple laboratory equipment. One possible shortcoming of chlorophyll *a* as an indicator of cyanobacteria growth is that it is found in all algae, not just cyanobacteria.

> Understanding and managing your source water is like understanding and managing your treatment plant; operators who pay attention develop intuition about water quality conditions. Information about conditions that result in harmful algal blooms can be used to develop early warnings and triggers for more intensive monitoring.

Buoy monitors are becoming an increasingly popular way to collect real-time water quality data. Sensors are available that measure phycocyanin, a pigment unique to cyanobacteria, and chlorophyll *a* as described previously. Real-time chlorophyll *a* and phycocyanin measurements are probably most helpful if the water utility considers them in terms of relative changes, rather than considers them as stand-alone measurements.

Satellite photographs of water bodies and visible algae blooms are being used as an early warning tool in some regions in the United States. Ohio Environmental Protection Agency (OEPA) routinely reviews satellite data to see if any drinking water sources seem to be having algae blooms. If the agency determines a bloom may be present, the water utility is contacted and asked to provide information, including how close the bloom is to the intake. Based on that information, OEPA decides if cyanobacteria counts and cyanotoxin screening should take place.

Developing a Source Water Monitoring Program

Predicting cyanobacteria blooms is challenging. Well-designed monitoring programs can provide effective early warning systems to let water utilities know that toxic cyanobacteria blooms are occurring or, better yet, beginning to occur. Keep in mind that a cyanobacteria bloom does not necessarily mean cyanotoxins are present; additional steps are needed to understand actual cyanotoxin levels.

Developing a monitoring program requires striking a balance between monitoring frequency and how sophisticated and expensive the parameters are that are being measured. A recommended approach is to set up a tiered monitoring program, using the easiest, least expensive measurements more often and establishing trigger levels for more labor-intensive,

expensive sampling. Table 8 provides an overview of a range of different monitoring approaches. At the most basic level, monitoring for visual indicators of cyanobacteria requires some staff training but will not require new, specialized facilities. Monitoring of chemical and physical variables (e.g., nutrient concentrations, physical conditions, and transparency) can help identify in a timely way that a bloom is beginning to take place.

Table 8. Different types of monitoring, parameters, and personnel or equipment required

Monitoring Type	Parameters/Variables	Demands on Equipment and Personnel	Who
Basic		Minimal	
Site inspection for indicators of cyanobacteria in water body	Transparency, discoloration, scum formation, detached mat accumulation	Secchi disk, regular site inspection by trained staff, basic skill required, training easily provided	Operators, practitioners
Surrogates		Low to moderate	
Potential for cyanotoxin issues in water body	Total phosphorus, nitrate and ammonia, flow regime, thermal stratification, transparency, phycocyanin, pH, chlorophyll *a*	Boat, depth sampler, Secchi disk, submersible temperature/oxygen probe, fluorimeter, spectrophotometer, buoys, basic skills requiring specific training and supervision	Limnologist
Cyanobacteria		Low to moderate	
In water body and drinking water	Dominant taxa (quantity); determination to genus level is often sufficient; quantify only as precisely as needed for management	Microscope, photometer, specific training and supervision required (skills required can be readily mastered)	Phycologist or a technician trained by a phycologist
Cyanotoxins		Moderate to high	
In water body and drinking water	Microcystin, anatoxin-a, cylindrospermopsin	Enzyme-linked immune assay (ELISA) kits—moderate); liquid chromatography photo-diode array (LC/PDA)—moderately high; liquid chromatography mass spectrometry (LC/MS, high)—specific training and supervision required, but skills can be readily mastered	Chemist

An important part of developing a tiered monitoring program is deciding on the conditions that trigger each tier of monitoring. This can be very site-specific. For example, some operators use daily Secchi disk depths as a first measurement; when the Secchi disk depth drops to less than a certain value, a water sample is collected for chlorophyll *a* analysis or algae identification and counts. If enough cyanobacteria are counted in the algae sample, or cyanotoxin-producing genera are found, then cyanotoxins may be measured. A tiered monitoring program should be tailored to the specific water body and its environment, and tiers should be reconsidered and modified with experience over the years.

b. Treatment Techniques for Source Waters

Two very different fundamental theories are used to guide source water management of cyanobacteria blooms; proactive and active treatment. Proactive treatment uses techniques that focus on discouraging cyanobacteria growth, whereas active treatment treats the actual cyanobacteria bloom. An example of proactive treatment for a small waterbody is to decrease the cyanobacteria population with aeration or sonication. Other proactive treatment techniques may involve the use of riparian buffers, wetlands to attenuate nutrient transport to lakes/reservoirs, or even the use of shade covers (e.g., floating mats, shade balls, floating vegetation islands) to block sunlight. The main challenges to proactive treatment are the investment and labor costs. The advantage to proactive treatment is that it is generally more environmentally friendly and minimizes the risk of cyanotoxin exposure and subsequent need for response and possible notification. Active treatment, such as the use of algaecides, does not guarantee that some cyanotoxins will not be present in the water—the approach is more about controlling the issue rather than preventing it. This section briefly describes different proactive and active approaches to treating and managing source water for cyanotoxin control. Readers are encouraged to also refer to the WRF report titled *Alternative and Innovative Methods for Source Water Management of Algae and Cyanobacteria* (Hobson et al. 2012) for more detailed descriptions and evaluations of these techniques.

Algaecides

Water managers should consider several important issues when controlling cyanobacteria with algaecides. Algaecides rupture cyanobacteria cells and can pose risks if not applied appropriately. Due to the ruptured cells, the effectiveness of cyanotoxin removal through conventional filtration methods may become less effective, and alternative treatments such as activated carbon or oxidation may need to be used. The USEPA does not recommend use of copper sulfate for algal toxin control due to the risk of cell lysis (USEPA 2014), though a multi-barrier approach could incorporate its use with other appropriate means of removing dissolved cyanotoxins during subsequent drinking water treatment.

The best time to apply algaecides is during a bloom's early stages of development, since the low cell density minimizes the potential release of intracellular toxins and odor metabolites. Performance can be optimized if applied under calm weather conditions and early in the day if the reservoir is stratified. Cyanotoxin monitoring after treatment with algaecides is

recommended since degradation of all toxins can range from days to months, depending on the cyanotoxin and other conditions (Newcombe et al. 2010).

Traditionally, the most widely used algaecide has been copper sulfate because it is relatively inexpensive, easy to apply, and relatively safe. Water utilities should check with their states about restrictions and permitting requirements that the state may have related to copper use. Some states, for example, require that anyone applying copper sulfate must have a pesticide application license.

The dose rate and effectiveness of copper sulfate depends on the pH, alkalinity, and dissolved organic carbon levels. It is recommended that water managers measure these three parameters prior to application. The water body should also be analyzed for copper residuals for several days after treatment. Despite the advantages of copper sulfate, its use has been diminishing as a result of increased concerns regarding copper accumulation in lake sediments and its indiscriminate toxicity to other aquatic organisms. Copper sulfate loses effectiveness in hard alkaline water, and chelated copper algaecides have been developed to overcome this issue. Chelated copper algaecides are also widely used but pose the same environmental risks as copper sulfate (Fan 2013, Newcombe et al. 2010, Deas et al. 2009).

Peroxide-based algaecides are being developed, and are in use in some areas, to provide an alternative to copper algaecides. These relatively recent products are promoted as an "environmentally friendly" oxidant that causes oxidative damage to cell membranes before dissociating to water and oxygen. Several manufacturers have added these formulations to USEPA's list of registered pesticides as algaecides for use in drinking water reservoirs (Newcombe et al. 2010, Deas et al. 2009,).

Artificial Mixing

Some cyanobacteria can regulate their buoyancy so that they gather at a depth that optimizes light conditions. Interrupting this vertical migration of the cyanobacteria through artificially mixing the lake or reservoir can prevent the mass development of scum-forming species. Artificial mixing can also reduce the growth rate of cyanobacteria because they cannot migrate towards optimum light conditions; this may ultimately shift the algae species composition away from predominantly cyanobacteria to other less harmful algae (Oberholster et al. 2006).

Artificial mixing can be conducted using mechanical, solar, or wind mixers. A common approach uses aerators placed on the bottom of the deeper regions of a water body to release compressed air into the water column. In order for artificial mixing to be successful, water managers must ensure three general conditions are satisfied: 1) at least 80% of the water volume should be mixed; 2) the mixing rate should be greater than the vertical movement of the cyanobacteria; and 3) a large part of the water body must be sufficiently deep (Chorus and Bartram 1999). Shallow areas have a low circulation rate that can negatively impact artificial mixing, although the needed depth is site-specific. Furthermore, in a shallow area or water

body, mixing cannot overcome the availability of light enough to prevent cyanobacterial growth.

Aeration/Oxygenation

Cyanobacteria growth can be controlled by reducing nutrient concentrations, particularly phosphorus. Water managers can control the phosphorus levels released from sediments within the reservoir (also referred to as internal nutrient load) by hypolimnetic aeration. Hypolimnetic aeration involves the injection of air or pure oxygen into the deep, often nutrient-enriched, low oxygen hypolimnion. The goal of hypolimnetic aeration is to oxygenate the water lying above the sediment to limit the release of phosphorus. Three popular devices that are used are the airlift aerator, Speece Cone, and bubble-plume diffuser (Singleton and Little 2006). A properly designed aeration/oxygenation system will introduce dissolved oxygen at the appropriate depths but still preserve thermal stratification of the water body (Welch & Gibbons 2010). In this way, this approach is different from the strategy of using aeration to mix a water body.

The capital and annual operating costs of hypolimnetic aeration can be high. A large portion of that expense can come from energy costs alone (Welch & Gibbons 2010). As a result, the suitability of hypolimnetic aeration/oxygenation for an individual reservoir must be critically considered before application. Pretreatment studies can answer questions related to the sources of internal nutrients and the mechanism of their release (Newcombe et al. 2010). A careful nutrient budget should also be developed for the water body and its watershed to make sure that internal phosphorus loading is a decisive portion of the overall phosphorus load that provides the nutrients for the cyanobacteria. Given the potentially substantial costs, the processes that determine water quality should be well understood and quantified before this technique is selected.

Dredging

Similar to hypolimnetic aeration, dredging aims to reduce the release of phosphorus from the sediments in the lake or reservoir but through sediment removal. Specialized heavy equipment can remove accumulated sediments to increase depth and water body volume, as well as to eliminate nutrient-rich sediments. Dredging is a costly method that can have drawbacks, including the potential for resuspension of sediments and damage to wildlife habitats. Although small water bodies may benefit from dredging to increase water depth and storage volume, this method's requirement for heavy equipment usage, its permitting issues, and disposal challenges can limit is use.

Sonication

There has been growing interest in the use of ultrasound in reservoirs to control algae growth. Sonication is the process of sending ultrasonic radiation through the water to control cyanobacteria blooms. This technique has been shown to adversely impact the function and

structure of cyanobacteria (Rajasekhar et al. 2012). Likewise, Schneider (2015) found the use of a tunable sonication device was highly effective at controlling algae and preventing T&O events in a eutrophic lake in New Jersey. It is an attractive reservoir management technique in that it could be used as an alternative to addition of potentially harmful algaecides and can be operated by solar power alone. However, the effectiveness of sonication for controlling cyanobacteria in lakes and reservoirs has not been sufficiently documented to determine its universal applicability as a control mechanism.

Phosphorus Sequestration

Alum treatment is an established technology that aims to control internal phosphorus loads by using aluminum salts (aluminum sulfate) to keep phosphorus from being available for cyanobacteria to use as a nutrient. The alum floc removes phosphorus from the water by binding with sedimentary phosphorus to form an aluminum phosphorus compound. This immobilizes the phosphorus, ultimately reducing algae levels. In addition, as the floc gradually settles, it also collects suspended particles and carries them down to the bottom, which can noticeably improve water clarity (Kasper et al. 2005).

The success of alum treatment is generally evaluated based on changes in phosphorus concentration, primary production (e.g., algae levels), and Secchi disk depth (Egemose et al. 2011). Phosphorus sequestration effectiveness depends on the amount of alum and the depth of the water body. As with water treatment using alum as a coagulant, effective alum dosage in a lake or reservoir is often based on the alkalinity of the water (Kasper et al. 2005). Guidelines recommend alum application to maintain pH within the range of 5.5–9.0 (Wisconsin DNR 2003). This determination ensures maximum phosphorus immobilization and minimization of potential aluminum toxicity to aquatic life. In some areas of the United States, alum treatment has been documented to be effective for more than eight years, and has been particularly long lasting in stratified water bodies (Wisconsin DNR 2003). Phosphorus inactivation in shallow water bodies may not be nearly as effective. However, when the phosphorus source is largely from external sources (e.g., runoff), alum treatment was found to be ineffective (Wisconsin DNR 2003).

The cost of alum treatment depends primarily on the type of alum, dosage rate, area to treat, and equipment. Water utilities may also be restricted from using alum in the water body because of state or local regulations.

Table 9. Summary of possible source water control options

Control Option	Impact	Advantages	Disadvantages
Algaecides	Kills cyanobacteria and prevents growth	Can prevent bloom formation and growth, inexpensive, easy to apply	Can rupture cells and release cyanotoxins, may require permits, may impact other algal species
Artificial Mixing	Disrupts vertical migration of cyanobacteria, disrupts thermal stratification	Limits cyanobacteria ability to obtain optimal light and nutrient conditions, can be solar powered	Energy intensive, may be less effective in clear or shallow lakes, may stir up sediments
Aeration/Oxygenation	Limits the release of phosphorus from sediments	Preserves thermal stratification, controls phosphorus release along with iron and manganese, can be solar powered	May not manage external phosphorus loading, can be energy-intensive, may require multiple aeration systems to impact large lakes
Dredging	Removal of phosphorus-producing sediments	Removes source of phosphorus from within the lake, can return lake to design depth	Expensive, does not control external phosphorus inputs, can damage wildlife habitat, disrupts sediments
Sonication	Disrupts buoyancy control in cyanobacteria, prevents proliferation	Can be solar powered, avoids disruption of sediments, redox conditions, and stratification	Limited demonstration sites in United States, may require multiple units for large area control
Phosphorus Sequestration	Precipitation of phosphorus with salts such as alum	Can provide long-lasting sequestration, may help control both internal and external phosphorus sources	Effectiveness depends on water quality and reservoir depth, may require permit to apply or may be prohibited

c. Selecting the Best Quality Water Available

Flow modification strategies generally include selecting alternate sources of water and taking advantage of the availability of different water intake depths. While the simplest approach to minimizing exposure is to switch sources, few utilities have multiple sources that can meet 100% of their water demand (Westrick et al. 2010). Selecting among intake depths requires a good understanding of the water quality throughout the water column and knowing the type of cyanobacteria bloom that is taking place.

As mentioned earlier, the cyanobacteria distribution can vary throughout a water body. Some cyanobacteria species have aerotopes, or gas vesicles, that regulate their buoyancy throughout the day in search of optimal light and photosynthetic conditions (AWWA 2010). Therefore, the choice of intake depth must consider the range of depths through which the cyanobacteria are moving. Varying the time and depth of intake during the day can minimize withdrawal of water concentrated with cyanobacteria (Westrick et al. 2010).

2. Effective Water Treatment

In order to select the appropriate treatment process, a drinking water manager will need to consider the type(s) of cyanotoxin (microcystin, anatoxin-a, and cylindrospermopsin) and whether it is contained within the cyanobacteria cells (intracellular) or dissolved in the water (extracellular). Intracellular toxins can be eliminated through removal of the cyanobacteria cells. Extracellular toxins are generally more difficult to remove and require either physical removal via adsorption, exclusion, or chemical transformation.

> *Intracellular* toxins can be eliminated by removing the cyanobacteria cells. *Extracellular* toxins are dissolved in the water and are generally more challenging to remove.

The key objective is to facilitate the design of contingent operational plans utilizing each plant's specific treatment barriers to minimize the risk from cyanotoxins, while meeting their other goals under the DPB rules, microbial regulations, and the Lead and Copper Rule. The narrative that follows reviews and organizes the published peer-reviewed literature in a manner that will help drinking water utilities develop and operate a multi-barrier treatment train to remove/inactivate cyanotoxins.

Identifying which cyanobacteria and cyanotoxins are present in their water helps utilities know they are using the appropriate treatment processes. Table 10 provides a summary of the effectiveness of different water treatment practices for removing cyanotoxins (USEPA 2014, Westrick et al. 2010, Lopez at al. 2008). Some processes are effective at removing cyanotoxins by removing the intracellular cyanotoxins contained within intact cyanobacteria, while other processes are effective at removing extracellular cyanotoxins that have been dissolved into the water. In addition, research is currently being carried out to investigate how conventional treatment methods can be used to effectively remove cyanobacteria cells and their intracellular toxins.

Table 10. Common cyanotoxin treatment practices and their relative effectiveness

Treatment Process	Relative Effectiveness
Intracellular Cyanotoxins Removal (Intact Cells)	
Conventional coagulation, sedimentation, filtration	Effective for the removal of intracellular/particulate toxins by removing intact cells. Generally, more cost effective than chemical inactivation/degradation, removes a higher fraction of intracellular taste and odor compounds, and easier to monitor.

Flotation (e.g., dissolved air flotation)	Effective for removal of intracellular cyanotoxins because many toxin-forming cyanobacteria are buoyant.
Pretreatment oxidation (oxidant addition prior to rapid mix)	Overall, can either assist or make treatment more difficult, depending on the situation. Pre-oxidation processes may lyse (cause dissolution or destruction of) cells, causing the cyanotoxins contained within to be released. Ozone may be an exception (see "Ozone" row) because it both lyses cells and oxidizes the cyanotoxins.
Membranes (microfiltration or ultrafiltration)	Effective at removing intracellular/particulate toxins. Typically, membranes require pretreatment.
Extracellular Cyanotoxins Removal	
Chlorination	Effective for oxidizing extracellular cyanotoxins (other than anatoxin-a) when the pH is below 8.
Chloramines	Not effective.
Permanganate	Effective for oxidizing microcystins and anatoxins. Not effective for cylindrospermopsin.
Chlorine dioxide	Not effective with doses typically used for drinking water treatment.
Ozone	Very effective for oxidizing extracellular microcystin, anatoxin-a, and cylindrospermopsin.
Activated carbon (powdered activated carbon and granular activated carbon)	Most types generally effective for removal of microcystin, anatoxin-a, and cylindrospermopsin. Because adsorption varies by carbon type and source water chemistry, each application is unique; activated carbons must be tested to determine effectiveness.
UV radiation	Degrades toxins when used at high doses, but not adequate to destroy cyanotoxins at doses used for disinfection.
Membranes (reverse osmosis [RO] or nanofiltration [NF])	RO effectively removes extracellular cyanotoxins. Typically, NF has a molecular weight cut off of 200 to 2,000 Daltons, which is larger than some cyanotoxins. Individual membranes must be piloted to verify toxin removal.

a. Physical Removal of Intact Cyanobacteria Cells

Although many drinking water utilities have successfully avoided or removed intact algae and cyanobacteria for years, the primary motivation for this was centered on aesthetics, disinfection byproduct rules, and preventing filter clogging rather than health risks related to cells containing toxins. Several treatment processes should be considered when optimizing the removal of intact cyanobacteria cells. The primary treatment options include: intake

> If possible, optimize your treatment process to remove fragile cyanobacteria as intact cells, since up to 95% of anatoxin-a, cylindrospermopsin, and microcystin variants are found <u>inside</u> intact cyanobacteria cells during bloom formation.

management; coagulation/flocculation and sedimentation; dissolved air flotation (DAF); and filtration.

A key thought to keep in mind is to optimize the treatment process to remove fragile cyanobacteria as intact cells, since up to 95% of anatoxin-a, cylindrospermopsin, and the microcystin variants are found to be intracellular during a healthy bloom (Chorus and Bartram 1999). When cell growth slows and the population begins to die off, a larger proportion of intracellular toxin is released into the water. The opposite treatment option is to use enough oxidant to lyse the cells and chemically inactivate the cyanotoxin. Both of these processes will be discussed.

At the Intake

As discussed previously, knowing and understanding buoyancy and buoyancy patterns of the dominant cyanobacteria provides practitioners with two options to avoid drawing contaminated water into the treatment plant, 1) draw water from different depths, and 2) draw water at specific times. If avoidance is not possible, other techniques are sometimes applied at the intake for cyanobacterial control.

Oxidants are often added at the intake to address one or several concerns: 1) reduce T&O compounds; 2) discourage bio fouling (zebra mussels, biofilm, and algae) of the intake pipe; 3) reduce the production of disinfection byproducts; 4) assist with coagulation; and 5) remove dissolved metals, such as iron and manganese. However, the addition of an oxidant at the intake poses issues with respect to cyanotoxin removal. The first concern is to prevent lysing of the cells (making them "leaky"). The general consensus is that it is best to remove the maximum amount of cyanotoxins through intact cell and particulate removal prior to release of the toxins (Falconer 2005, Hurdey et al. 1999, Yoo et al. 1995). However, it will be described later in the full-scale treatment section, that several utilities have added enough oxidant to successfully lyse and chemically inactivate the cyanotoxin. An overview of pre-treatment strategies (i.e., at the intake or in the reservoir) versus oxidation strategies is provided in Table 11.

Table 11. Intake treatment versus cell integrity

Intake Treatment	Cell Integrity	Advantages	Disadvantages	Effective Cyanobacteria
Chlorine	Intact cells <1 min at 2 mg/L (some genera are more resistant to oxidation)	Rapid oxidation of cyanotoxins	Disinfection byproduct formation, pH dependent, dose varies by genus, release of cyanotoxins and taste and odor compounds	*Aphanizomenon, Anabaena, Cylindrospermopsis, Microcystis*
Copper	Intact cells 1.5 mg/L up to 24 hours	No total trihalomethane (TTHM) formation, algistatic potential	Blue—overfeed, no residual oxidative capability	*Microcystis*
Perman-	Intact cells 0-	No TTHM formation	MNO_2, Pink—overfeed	*Microcystis*

| ganate | 5 mg/L up 2 hours | | | |
| Ozone | Intact cells 5 min at 2 mg/L | No TTHM formation | No residual oxidative capability | *Microcystis* |

Source or intake treatment can be risky business. The treatment processes must be optimized to remove intact cyanobacterial cells when possible or else there is a high risk of producing high levels of extracellular cyanotoxins. However, intake treatment can produce a variety of effects on cyanobacterial cells and there are reports that pre-oxidation can improve the removal of cyanobacteria in the flocculation/sedimentation process. The factors controlling cell lysis are never completely known, however, and the consensus is that the risk is high and intake/raw water treatment with oxidants or copper compounds should only be used in certain circumstances.

Pre-Filtration Treatment Processes

During a cyanobacterial bloom, coagulation treatment processes can be managed as auxiliary barriers to effectively remove intracellular cyanotoxins. Coagulation treatment processes include conventional treatment, enhanced coagulation, dissolved air flotation, and ballasted flocculation. Additional consideration could be given to the physical control of presedimentation basins as water treatment plants. Presedimentation basins that are designed for microbial removal credit provide advantages such as reduced influent fluctuations in particle loading, flow, and other parameters. This barrier gives operators flexibility to handle rapid changes in water quality. However, an uncovered presedimentation basin with low flow can act as an incubator for cyanobacteria.

Because each organism has unique cell morphology, each genus may respond differently to physical removal in the remaining conventional treatment processes. Therefore, the guidance below provides the treatment information that can be applied to generic cyanobacteria blooms.

Conventional Treatment (Coagulation and Sedimentation)

The standard conventional treatment train is coagulation, flocculation, and sedimentation, followed by filtration. A well-optimized coagulation and sedimentation step is critical to cyanobacterial cell removal during treatment but because of the variability between each bloom, specific coagulation guidelines cannot be provided. Jar test, pilot plant, and full plant studies suggest that both alum and ferric chloride coagulation is effective at removing intact *Microcystis* and *Anabaena* cells in addition to other algal and cyanobacterial cells (Knappe et al. 2004, Chow et al. 1999, Chow et al. 1998). Enhanced coagulation can also be optimized to remove *Microcystis* and *Anabaena* cells (Freese et al. 2001). Because conventional coagulation, flocculation, and sedimentation will be the key line of defense for most utilities, jar testing for site-specific conditions to optimize coagulant dose, pH, and settling time are critical to setting full-scale operational parameters.

<u>Dissolved Air Flotation</u>

Dissolved air flotation (DAF) is a clarification process that can provide particle removal before membrane or conventional filtrations. DAF is one of the best available technologies for removal of intact cells and can be more effective than coagulation/sedimentation, especially for the removal of cyanobacteria with gas vacuoles that exhibit diurnal buoyancy patterns. Removal of *Microcystis* via DAF can range as high as 92–98%, while sedimentation may remove only 70–90% (Teixeira and Rosa 2006, Falconer 2005, Knappe et al. 2004, Hrudey et al. 1999).

<u>Ballasted Flocculation</u>

Several drinking water utilities have implemented microsand ballasted coagulation/flocculation with lamella settling plate. This process has a very small footprint with typical residence times from chemical addition to top of filter running of about 30 minutes. The in efficiency comes as a result of the microsand providing a large contact area and acting as ballast to settle floating cyanobacteria scum. Studies have shown that the ballasted flocculation treatment process can remove algae and cyanobacteria as intact cells, hence removing the intercellular cyanotoxins and T&O (Robinson and Fowler 2007).

<u>Lime Soda Softening</u>

There is very little information available about lime precipitation and cyanobacteria removal efficiency. Two treatment studies by Kenefick et al. (1993) and Lam et al. (1995) evaluated drinking water treatment trains using lime showed removal of cyanobacteria without lysing the cells. Jar testing to evaluate individual systems is recommended.

Filtration

Drinking water filtration is used to remove particles (sediment and pathogens) from the water to improve the aesthetics and safety of drinking water. However, none of the physical filtration processes are well-suited for removal of extracellular cyanotoxins. The following sections describe various filtration options.

<u>Conventional Media Filter Beds</u>

Although direction media filtration without coagulation and sedimentation has only limited efficacy for removing cyanobacteria, properly managed coagulation/flocculation/ sedimentation followed by filtration is very effective. Standard sand, anthracite, and multi-media filters that meet state standards are effective for removing cyanobacteria cells when used in combination with upstream coagulants (Zamyadi et al. 2013, Westrick et al. 2010).

<u>Microfiltration and Ultra Filtration</u>

Advances over the last three decades in membrane technology have allowed membrane filtration to become a viable drinking water treatment process. Four types of membrane filtration are used in the drinking water industry: 1) microfiltration, 2) ultrafiltration, 3) nanofiltration, and 4) reverse osmosis filtration. Microfiltration and ultrafiltration, commonly used to remove particulate contaminants, can be suitable for the removal of cyanobacteria,

while nanofiltration and reverse osmosis can potentially remove a significant fraction of cyanotoxins in addition to any particulates. Because of the size exclusion-based nature of membrane-based filtration, membranes will almost always perform better than conventional media filtration in terms of removal of algal cells, even without upstream coagulation (Gijsbertsen-Abrahamse et al. 2006, Zhou & Smith 2002, Chow et al. 1997). However, studies and a review by Huang et al. (2009) have shown that pretreatment such as coagulation can lessen membrane fouling (Heng et al. 2008, Lee 2006, Qin et al. 2006, Kwon et al. 2005).

b. Physical Removal of Cyanotoxins

Activated Carbon

Adsorption by activated carbon (AC), either as granular activated carbon (GAC) or powdered activated carbon (PAC), is well established as an effective method for dissolved cyanotoxin removal, which is complimentary to and can be combined with other unit processes. Although new sorbents such as modified clays and carbon nanotubes have been shown to remove cyanotoxins at the bench-scale, AC-based technologies offer a proven and flexible solution. The most common materials for large-scale production of AC used in the water industry are coal, wood, and coconut shell. The main criteria for AC selection is ability to remove the contaminants of concern for a given water utility (e.g., synthetic organics, volatile organics, natural organic matter [NOM], cyanotoxins) and ability to stand up to backwash cycles. The different precursors and activation processes can be varied, resulting in a range of adsorptive properties that can be optimized for specific classes of contaminant compounds. As such, a GAC or PAC that is selected for control of typical water contaminants for a utility may not be the optimal carbon for cyanotoxin control. Thus, proper jar testing and evaluation for each utility and contaminant concentration is recommended. Additionally, the pH of the water and the presence of competing substances in the water such as natural organic matter all affect the adsorption process.

Selecting an Activated Carbon Technology

Two basic types of AC-based unit operations are typically used in the drinking water industry: pre-filtration addition of powdered activated carbon (PAC) and flow-through beds or pressure vessels loaded with granular activated carbon (GAC). PAC and GAC can be differentiated according to mesh size. PAC contains smaller particles that will pass through a US 80-mesh sieve (0.177 mm). GAC is larger in size with the most popular sizes for water treatment being the 12 x 40 and the 8 x 30 meshes, which provide a good balance of hydraulic properties and surface area.

PAC is widely used as a temporary treatment for transient contaminants like cyanotoxins and T&O compounds and is fed at the front of the treatment process at a point that will provide sufficient contact time before the particle removal processes. GAC is used in flow-through beds to reduce natural organic matter, T&O compounds, or synthetic organic compounds (SOCs). Depending on the source water and plant configuration, GAC may serve strictly as an adsorber

(typically in a pressure vessel) or as a filter/adsorber (typically in an open filter bed or, less effectively, as a filter cap).

As stated previously, many factors influence the adsorption of the cyanotoxins including the effective size of the target molecule, pH, and the presence of NOM that directly competes with the target molecule for sites on the AC. The best way to evaluate the performance of an AC is through onsite jar testing for PAC or a GAC pilot that directly models the plant. The selection of AC technology for drinking water treatment is complicated by the multiple and sometimes competing functions that the AC must perform, including

- Removal of NOM to minimize the formation of DBPs;
- Removal of industrial synthetic organic compounds and pesticides;
- Removal of color;
- Removal of T&O; and
- Removal of cyanotoxins.

Activated carbon technologies may also be combined with biological or membrane technologies to create hybrid technologies. In the drinking water industry, GAC filters can be operated and designed to develop a biofilm that can perform the functions of filter, adsorber, and biodegradation. These biological filter processes are collectively known as biological activated carbon (BAC). PAC can be combined with membrane filtration to create PAC-UF, though possible warranty issues should be carefully evaluated as PAC may abrade the MF or UF surface.

Most of the research on AC adsorption of cyanotoxins has been focused on microcystins. Several general trends emerge in these studies:

- Laboratory, pilot, and full-scale applications have demonstrated that both PAC and GAC are effective at removing cyanotoxins from water.
  The amount and nature of NOM in the water greatly influences the adsorption and capacity of AC for cyanotoxins. NOM is often present at thousands of times the concentration of cyanotoxins and competes for active sites on the AC.
  The AC must be tested with water from the source or plant. NOM and other variables make performance difficult to predict.

Powdered Activated Carbon (PAC)

Both the microcystins and cylindrospermopsin can be absorbed by activated carbon with high mesopore capacity (i.e., pores between 2 and 50 nm) (Newcombe 2008). However, the microcystin variants may have different adsorption efficiencies; the order for four variants from most to less adsorbent was reported to be MC-RR, MC-YR, MC-LR, and MC-LA. Many blooms produce multiple congeners and MC-LA will not be effectively removed while less toxic variants may be removed completely.

What dose of PAC to use? The answer to that question is complicated, but in general 20-30 mg/L is a reasonable starting point. Because multiple factors play into removal efficiency with PAC, it is recommended that jar testing be conducted to determine optimal dose and PAC type and to determine likely removal efficiency. AWWA has published guidance and protocols for the testing of PAC as well as a spreadsheet tool that can be used to evaluate results and decide upon which type and dose of PAC may be best suited for use at a given facility (AWWA 2015a).
<u>Granular Activated Carbon (GAC)</u>

Granular activated carbon (GAC) can be used either as filter media or as an adsorber. GAC filters are designed to remove particulates, provide limited adsorption of chemicals, and can be used to biodegrade some organic contaminants (if designed as BAC). When used as a filter, GAC media is replaced after several years of service and may not effectively control cyanotoxins. In contrast, GAC adsorbers are used to remove organic contaminants by adsorption after filtration and GAC adsorber media is replaced or regenerated when total organic carbon (TOC) breakthrough (or other contaminants of concern) reaches pre-defined set points, usually around 50 to 60% of the influent concentration. When used as a post-filter adsorber, GAC can be a highly effective barrier for microcystin but must be replaced or regenerated with sufficient frequency to minimize breakthrough. Rapid small-scale column tests can be used to evaluate cyanotoxin breakthrough and expected carbon life for a given source water and GAC combination.

Nanofiltration and Reverse Osmosis

Several nanofiltration and reverse osmosis filtration studies report from 82% to complete microcystin removal (Neumann and Weckesser 1998, Vuori et al. 1997, Muntisov et al. 1996, Fawell et al. 1993). Both nanofiltration and reverse osmosis membranes can provide a good removal mechanism for most cyanotoxins, though this is highly dependent upon the membrane type and the chemical properties of the membrane surface (Gijsbertsen-Abrahamse et al. 2006, Teixeira and Rosa 2006). However, because of the short-term duration of cyanotoxin events, it is not recommended that RO and NF membranes be selected solely on their cyanotoxin rejection characteristics. Most utilities that employ RO and NF membranes for desalting or softening applications will likely observe greater than 80% cyanotoxin rejection, at a minimum, for the water that is treated through those unit processes.

c. Inactivation of Cyanotoxins

Chlorine, ozone, ultraviolet (UV)-advanced oxidation (to produce hydroxyl radicals), potassium permanganate, chloramines, and chlorine dioxide are used as primary and secondary oxidants in the drinking water industry. These oxidants are commonly used pre-coagulant (intake), pre-filter (filter aid or to reduce biological activity in filter), or post-filter (disinfectants). In recent years, more stringent DBP regulations have been implemented in order to decrease the DBPs formed during chlorination, chlorite, and chlorate formed from chlorine dioxide, and bromate formed from ozone. In response, drinking water utilities have changed the addition points of chemical feeds, altered their water chemistry parameters, and added new chemical treatment

processes. Each of these changes may also impact the inactivation or oxidation of cyanotoxins present in the water. For example, chloramines and chlorine dioxide may be used as supplementary disinfectants in order to reduce formation of halogenated compounds; however, they will not degrade cyanotoxins. Other strategies to decrease halogenated compound formation include ozone addition pre- and post-coagulation, before chlorine disinfection, and adjusting the pH of the treatment water to 9 or greater. AWWA recently published the Hazen-Adams CyanoTOX Model that allows utilities to examine the impact of various oxidants, pH conditions, and reaction times on cyanotoxin concentrations (AWWA 2015b). Table 12 summarizes relative reaction rates (qualitatively listed at pH 7 and 20 °C as fast (<10 min to reach 90% oxidation), medium (<100 min to reach 90% oxidation), and slow (<100 min to reach 90% oxidation), though actual removal will depend on oxidant dose, contact time, temperature, and pH.

Table 12. Summary of cyanotoxin inactivation by oxidants at 20 °C and pH 7

	Microcystin	**Anatoxin-a**	**Cylindrospermopsin**
Chlorine	Medium[1]	Slow[2]	Fast [2, 3, 4,]
Ozone	Fast [5, 6]	Fast [7]	Fast [3, 7, 8]
Chloramine	Slow [9]	Slow [2]	Slow [3, 10]
Chlorine dioxide	Slow [11]	Slow [12]	Slow [3, 10, 12]
Advanced oxidation processes (hydroxyl radical)	Fast [7]	Fast [7]	Fast [7]
Permanganate	Medium [13, 14]	Fast [2, 15]	Slow [2, 3]

[1]Acero et al. 2005, Ho et al. 2006, Nicholson et al. 1994, Xagoraraki et al. 2006; [2]Rodriguez et al. 2007; [3]Cheng et al. 2009, [4]Senogles et al. 2000, [5]Fawell et al. 1993, [6]Rositano et al. 2001, [7]Onstad et al. 2007, [8]Newcombe and Brenton 2004, [9]Nicholson et al. 1994, [10]Banker et al. 2001, [11]Kull et al. 2006, [12]Rodriguez et al. 2007, [13]Chen and Yeh 2005, [14]Rodriguez et al. 2007, [15]Hall et al. 2000

Chlorine

For more than 100 years, chlorine has played an important role in drinking water disinfection. Chlorine has been investigated and can be used as auxiliary treatment for cyanotoxins because of its moderate-to-fast reaction rate. However, with the use of free chlorine and potentially longer contact times or higher doses needed to oxidize cyanotoxins, there will be a balancing

act between the creation of DBPs, maintaining adequate disinfection, and cyanotoxin control. It is important to fully consider how pH, temperature, and contact time will impact cyanotoxin degradation while also having an impact on disinfection efficacy and DBP formation.

Chlorine Dioxide

Chlorine dioxide reacts with tertiary amine and aromatic systems relatively slowly, depending on pH, but does not promote halogenated, organic disinfection byproducts (Hoigne and Bader 1994). While chlorine dioxide does not promote organic DBPs, it does produce chlorite that is a regulated inorganic compound. In general, the reaction rate of chlorine dioxide with cyanotoxins is sufficiently slow that only slight removal would be expected to occur during oxidation and as such it is not considered a major barrier to cyanotoxins (Rodriguez et al. 2007, Kull et al. 2004).

Chloramines

Chloramines have a low oxidation potential, but they are frequently used to provide residual disinfectants in the distribution system to minimize the formation of regulated chlorinated by-products such as trihalomethanes and haloacetic acids. Chloramine is not an effective treatment barrier for microcystin, cylindrospermopsin, or anatoxin-a. However, if ozone or free chlorine is used to achieve contact time (CT) credit prior to addition of ammonia, then sufficient oxidation of cyanotoxins may occur during those steps depending on temperature, pH, and total contact time.

Permanganate

Permanganate reacts differently with each of the cyanotoxins. The reactivity of potassium permanganate with MC-LR is not dependent on pH and occurs moderately fast (>10 min oxidation time required to reach 90% removal) (Rodriguez et al. 2007, Chen & Yeh 2005). Permanganate is not reactive with cylindrospermopsin (Rodriguez et al. 2007, Banker et al. 2001), while the reaction between permanganate and anatoxin-a is fast, though there is a pH dependence as the apparent rate constant doubles between pH 8 and 10 (Ho et al. 2009).

Ozone

Ozonolysis acts through two mechanisms of oxidation, ozone and hydroxyl radical. Both ozone oxidation and hydroxyl radical oxidation of cyanotoxins is generally quite fast, though the amount of oxidation depends on pH, temperature, and dose. In general, ozone is thought to be a very effective barrier for cyanotoxins in drinking water treatment.

UV

UV photolysis at disinfection doses is not considered a barrier to cyanotoxins. The absorbance of UV energy can break molecular bonds without chemical addition and is used to inactivate many pathogens in drinking water. Several studies (Senogles et al. 2000, Chorus and Bartram 1999, Tsuji et al. 1994) suggest that microcystin, anatoxin-a, and cylindrospermopsin can undergo photolytic destruction by UV light, but only at energies that range from 1530 and

20,000 mJ/cm^2 which are orders of magnitude higher than that needed for disinfection. As a point of comparison, disinfection doses range between 10 and 40 mJ/cm^2. Because of the high doses required, low to medium pressure lamp UV treatment is not recommended as a viable treatment barrier for cyanotoxins.

Hydroxyl Radical Advanced Oxidation Processes

To generate advanced oxidation conditions with UV light, UV reactors need to be designed to deliver approximately 10 times more energy than those used in UV disinfection systems (i.e., UV AOP requires around 400 mJ/cm^2 versus 40 mJ/cm^2 for disinfection). While UV energy alone at 400 mJ/cm^2 is not sufficient to photolyze cyanotoxins, by adding hydrogen peroxide to the water passing through the UV reactor(s), hydroxyl radicals are formed that can oxidize cyanotoxins in addition to T&O compounds. Several utilities have installed such systems specifically for seasonal T&O control with a co-benefit of providing excellent cyanotoxin control.

d. Biological Treatment

In the last thirty years, researchers have investigated converting biological activity into a dependable treatment barrier referred to as biological treatment. Although biological activity, the presence of growing bacteria, occurs throughout the drinking water processes, most investigations have focused on the biological activity in different types of filtration such as river bank, rapid, and slow filtration. Biologically active river bank, slow, and rapid filtration have been reported to remove/inactivate microcystins (Bourne et al. 2006, Grutzmacher et al. 2002, Lahti et al. 2001, Yoo et al. 1995) and cylindrospermopsin (Ho et al. 2008). However, seasonal differences in removal rates and variable performance over time may make biological treatment an unreliable control option for cyanotoxins (Klitzke et al. 2010, Christoffersen et al. 2002, Grutzmacher et al. 2002, Cousins et al. 1996, Jones and Orr 1994, Rapala et al. 1994, Bourne et al. 1996).

III.   Step 3: The Balancing Act

Once a water utility has identified a contaminant, the balancing act begins. The initial challenge is determining how to address the contaminant using the current treatment and budget immediately available to the water utility without unintended consequences impacting other water quality parameters (DBPs, corrosion control, and others). Another challenge is determining and planning for a longer-term solution. With cyanotoxins not currently being federally regulated and their occurrence being more sporadic than many other contaminants of concern, the balancing act becomes trickier. The objective of this section is to provide tools for optimizing current and future site-specific treatment of cyanotoxins. This discussion describes bench-scale pilot studies and full-scale treatment studies, as well as considers possible treatment solutions in the context of compliance challenges.

1. Evaluating Site-Specific Treatment Processes for Cyanobacteria and Cyanotoxins

AWWA and the WRF have produced several guidance documents, models, and protocols for evaluating performance of various treatment processes. These include:

- Hazen-Adams CyanoTOX Model (AWWA 2015b)
- Cyanotoxin PAC Jar Testing Procedures (AWWA 2015a)
- Cyanotoxin Oxidation Jar Testing Procedures (AWWA 2015c)
- Several WRF reports (e.g., Hobson et al. 2012)

Standard bench methodologies, such as jar testing, column studies, and simulated distribution system (SDS) studies, can be modified to evaluate the removal/inactivation cyanobacteria and cyanotoxin treatment. Table 13 presents a summary of standard bench-scale methodologies and their goals relative to cyanotoxin removal and oxidation. Similarly, pilot and full-scale treatment studies can achieve the same goals; however, there are specific considerations that need to be considered when monitoring cyanobacteria and cyanotoxins. In general, the most frequently overlooked areas in study design include 1) adding ("spiking") test waters with cyanotoxin to achieve sufficient concentrations to measure removal, 2) identification and replication of the water quality likely to be experienced during a cyanobacteria bloom, 3) sample preservation techniques, 4) sample preparation for analysis, and 5) the change in distribution of particulate to dissolved cyanotoxins that may occur because of treatment techniques and/or facility operation. It is recommended that utilities examine the resources available on AWWA's website and develop a clear set of experimental goals, plans, analytical techniques, and budget prior to conducting any evaluations of cyanotoxin treatment at their facility.

Table 13. Bench studies for cyanobacteria and cyanotoxin treatment

Cyanobacteria Removal	Process	Goals
Jar Testing[1,2]	Inline feed from intake to Pre-treatment Oxidants Coagulants PAC Algaecide	1) Efficiency of intact cell removal 2) Efficiency of cyanotoxin removal 3) Change in distribution between intracellular and dissolved
Jar Testing[2]	Coagulation/Sedimentation Sand Ballasted Flocculation Dissolved Air Flotation	
Filter Index Test[2]	Evaluate the filterability of the floc.	1)Filter clogging 2)Frequency of backwash 3)Efficiency of intact cell removal 4)Change in distribution between intracellular and dissolved
Rapid small-scale column test[3]	GAC media filter and adsorbers	Filter: 1) Efficiency of intact cell removal 2) Efficiency of dissolved cyanotoxin removal Adsorbers: 1) Efficiency of dissolved cyanotoxin removal
Bench-scale membrane[4]	Microfiltration and ultrafiltration	1) Efficiency of intact cell removal 2) Efficiency of dissolved cyanotoxin removal 3) Change in distribution between intracellular and dissolved
Rapid bench-scale membrane test[3]	Nano- and reverse osmosis filtration	1) Efficiency of dissolved cyanotoxin
Simulated Distribution System[3]	Oxidants add post-filtration and pre-clearwell, Clearwell and distribution	1) Efficiency of dissolved cyanotoxin inactivation

[1]AWWA 2015a, ASTM n.d., [2] AWWA 2011, [3] US EPA 1996, [4]Westrick 2015

2. Maintaining Simultaneous Compliance while Addressing Cyanotoxins

Effective water treatment and source water management cannot focus on only one water quality issue. Many water quality parameters are regulated and need to be addressed. This can make for a juggling act for water operators, especially when the way to treat one water quality issue may interfere with appropriate treatment for another. On some occasions, however, treatment can address more than one water quality issue if it is carried out thoughtfully. This section briefly discusses how measures taken to comply with drinking water regulations and T&O events can adversely and beneficially affect cyanotoxin control.

Surface Water Treatment Rules

The goal of the Surface Water Treatment Rules (SWTR) is to improve control of microbial contaminants in systems using surface water or ground water under the direct influence of surface water. These rules mandate that surface water systems and ground water systems under the direct influence reduce their source water concentration of *Giardia lamblia* and viruses by at least 99.9% (3 log) and 99.99% (4 log), respectively. Source water concentrations of *Cryptosporidium* are to be reduced between 99% (2.0 log removal) and 99.9995% (5.5 log removal) depending on the source water quality. Also, a detectable residual of disinfectant is to be maintained through the entire distribution system.

Enhanced performance requirements for filtration that are intended for pathogen control have also enabled utilities to remove cyanobacteria more effectively. In general, coagulation with filtration effectively removes both *Cryptosporidium* and cyanobacteria. In addition, by discouraging filter backwash recycling and encouraging filtering to waste before placing a filter online, utilities can minimize breakthrough of cyanobacteria and cyanotoxins that are released from damaged cells, as well as *Cryptosporidium*. However, the addition of cyanobacteria can make it challenging to maintain filter performance. A general rule is to have less than 100 cyanobacteria cells/mL in the filter influent. Therefore, it is imperative that operators keep SWTR at the forefront of operations while responding to HAB events.

Disinfectants and DBP Rule

The DBP rule requires utilities to comply with maximum contaminant levels (MCLs) and respond to operational evaluation level triggers for disinfection byproducts. Utilities that use activated carbon or ozone with biologically active filtration for DBP compliance can also use these treatment processes as part of their multi-barrier approach to reduce cyanotoxins. However, these barriers must be optimized to effectively provide this dual purpose (DBP rule compliance and removal of cyanotoxins). Drinking water utilities that have achieved compliance by increasing pH, using chloramines, chlorine dioxide, or UV, and minimizing free chlorine contact time may no longer have an effective oxidation barrier that can address cyanotoxins. The increased pH decreases chlorine's rate of cyanotoxin oxidation, rendering it far less effective for cyanotoxin degradation, while chloramines and chlorine dioxide are not effective at chemically degrading the cyanotoxins. Several drinking water utilities that have depended on pH control to

minimize DBP production may find themselves out of compliance with the DBP MCLs if they change pH, chlorine dose, and contact time to manage cyanotoxin events.

Lead and Copper Rule

The purpose of the Lead and Copper Rule is to protect public health by minimizing lead and copper exposure from drinking water. The key operating parameters used to comply with the Lead and Copper Rule are pH and alkalinity. High pH values that are often used to comply with the Lead and Copper Rule will lower the effectiveness of chlorine for oxidizing cyanotoxins.

Organic Contaminants (i.e., SOCs and VOCs)

Several organic contaminants (synthetic organic contaminants [SOCs] and volatile organic contaminants [VOCs]) are regulated in public water systems, including pesticides, herbicides, solvents, and manufacturing byproducts. Treatment processes recommended for removing or degrading SOCs and VOCs include activated carbon, advanced oxidation processes, nanofiltration and reverse osmosis. Each of these barriers has the potential to also be a barrier to cyanotoxins. However, since these barriers were not specifically designed to remove cyanotoxins, they should be evaluated carefully for their cyanotoxin removal efficiency. Likewise, changing barriers to manage cyanotoxins could result in lower removal rates of regulated SOCs or VOCs if not carefully evaluated before full-scale implementation.

T&O Control

Treatment designed for T&O control often provides effective treatment for cyanotoxins. T&O compounds (i.e., geosmin and MIB) and cyanotoxins are commonly found in high concentrations within the intact cyanobacteria cells; therefore, removing intact cells may be a strategy for both types of treatment. However, the adsorption efficiencies for cyanotoxins and T&O compounds can differ; one cannot assume that the presence of activated carbon will guarantee good removal of both. Several oxidants (ozone, permanganate, hydroxyl radical) are considered effective for both cyanotoxins and T&O compounds. Chlorine dioxide provides a counter-example; it can effectively treat for T&O but not cyanotoxins.

Summary

Table 14 summarizes regulatory drivers, standard practices, and their impact on treating cyanobacteria and cyanotoxins. The objective of this table is to highlight the role and importance of common drinking water practices and how they fit into treating cyanobacteria and cyanotoxins. Understanding how each process works relative to cyanotoxins and compliance with other regulations provides context for appropriate decision making.

Table 14. Summary of impacts of current rules/regulations and standard practices on cyanobacteria and cyanotoxins

Regulations/Standard Treatment Processes	Goal	Treatment Recommendation	Positive (+), Negative (-), or Variable (?) Impact on Cyanobacteria and Cyanotoxins
Surface water treatment rules	Microbial safe water	Riverbank filtration	(+) Cyanobacteria removal (+) Biofiltration
		Pre-sedimentation basin	(-) Incubator for cyanobacteria (+) Buffer for quick changes in cyanobacteria blooms
		Conventional filtration treatment	(+) Monitoring turbidity breakthrough of individual and combined filters (+) Discouraging backwash recycle (+) Filter to waste (+) Sludge awareness
		Covered finished water reservoirs	(+) No cyanobacteria regrowth
DBPR (Stage 1 and 2)	Reducing DBPs	Increase pH (>8)	(-) Several of cyanotoxins take longer to degrade
		Chloramines	(-) Does not chemically degrade cyanotoxins.
		Decrease TOC	(+) Improved cyanobacteria removal with TOC removal (+) Less oxidant competition
		Ozone and biological filtration	(+) Oxidizes cyanotoxins (?) Biofiltraiton provides variable benefit
Lead and Copper Rule	Reduce exposure to lead and copper	Increase pH	(-) Chlorine has less oxidation potential
		Alkalinity Adjustment	(?) May increase ozone demand
		Organic corrosion inhibitor	(?) Not known
Organic Contaminants	Reduce	Activated carbon	(?) Most likely but must

(SOCs and VOCs)	Exposure	Oxidation	determine if they are barriers for cyanotoxins
		Membrane filtration	
Taste and Odor (T&O)	Reduce unpleasant T&O compounds (e.g. geosmin and MIB)	Copper sulfate	(-) Lyses cells and releases toxins (-) Kills bacteria responsible for biodegradation (+) If carried out very early in a bloom, may be effective
		Oxidants (ozone, hydroxyl radical, permanganate)	(-) Lyses cells (+) Chemically degrades cyanotoxins
		Chlorine dioxide	(-) Does not degrade cyanotoxins

IV. Step Four: Using Your Knowledge to Plan Ahead

1. Preparing for Toxic Cyanobacteria Events

It is important to keep in mind that cyanobacterial blooms and even cyanotoxin events in the source water do not necessarily mean that cyanotoxins will be present in the finished water at sufficiently high levels or with sufficient duration to result in a voluntary public notification. However, it is prudent and recommended that water utilities plan and prepare for responses to potential and real finished water cyanotoxin events. Water utilities that are considering how to develop a systematic approach to addressing possible cyanotoxin events should consider the following steps:

- Complete the self-assessment in *A Water Utility Manager's Guide to Cyanotoxins* on AWWA's website to determining the level of risk from cyanotoxin contamination;
- Determine water quality conditions that would trigger monitoring for cyanotoxins or surrogates;
- Conduct jar testing or use existing AWWA resources to optimize treatment barriers, keeping in mind the need for simultaneous compliance;
- Develop fact sheets and answers to frequently asked questions ahead of time that can be ready to give to media and the public in the event of future events;
- Determine if alternate potable water sources or alternative intake points are available;
- Implement plan in the event of cyanotoxin occurrence; and
- Communicate plans and information with the public and media.

A primary goal should be establishing early warning programs to help prevent a utility from delivering water-containing cyanotoxins to its customers in the first place. One approach is to develop a decision tree that guides the water utility's practitioners through a series of questions and considerations that help characterize, prepare for and manage the situation. The decision tree could consider the following questions, among others, and follow up with related recommended procedures/actions depending on the answers to those questions.

- Do you have cyanobacteria blooms?
- Do these cyanobacteria blooms produce toxins?
- Do you test for toxins? When?
- Can you determine intracellular and dissolved cyanotoxin concentrations?
- How are you going to monitor blooms? Do you have labs ready to count and analyze your samples?
- Do you have different source water options? Different intake depths or intakes? Under what conditions do you use each of your sources? What are the limiting factors to using each source?
- What are your treatment barriers for cyanotoxins? How effective is each barrier for controlling cyanotoxins? Under what conditions?
- Do you have any additional processes and/or chemicals you can use if cyanotoxins are present in the water? When would you implement them?

- How are you going to determine cyanotoxin concentration in finished water? Where? How quickly can you get a result? Do you have an expert or expert panel ready to help you?
- If cyanotoxins are detected in finished water, what is your notification procedure? What additional monitoring will be carried out?
- Who declares the "do not drinking advisory"? How is a "do not drink advisory" removed?

Answering these questions (and others that come up during discussion) will be helpful in developing your own decision/response tree for responding to events. It is important, however, to include local regulators in determining the questions and decision points for responses to cyanotoxin events. The USEPA has a set of published recommendations for cyanotoxin event triggers and responses. Likewise, AWWA's cyanotoxin self-assessment provided in *A Water Utility Manager's Guide to Cyanotoxins* can be a useful starting point for determining your level of risk and for beginning to prepare information and response procedures. An example flow chart of triggers and response is provided from the State of Oregon that can be used as a starting place for developing your own utility-specific response procedures (Figure 2). Other resources that may be of assistance include:

- Chapter 6 (Situation Assessment, Planning and Management) from the WHO's *Toxic Cyanobacteria in Water: A Guide to their Public Health Consequences, Monitoring and Management* (Bartram and Chorus 1999), which provides helpful guidance on developing a contingency plan for cyanotoxins.
- The Incident Management Plans from *International Guidance Manual for the Management of Toxic Cyanobacteria* (Newcombe et al. 2010).
- OEPA's guidance (2014) for water utilities in that state regarding developing contingency plans for dealing with cyanotoxin events.
- Appendix A contains links and state-specific resources that may be of assistance to utility managers.
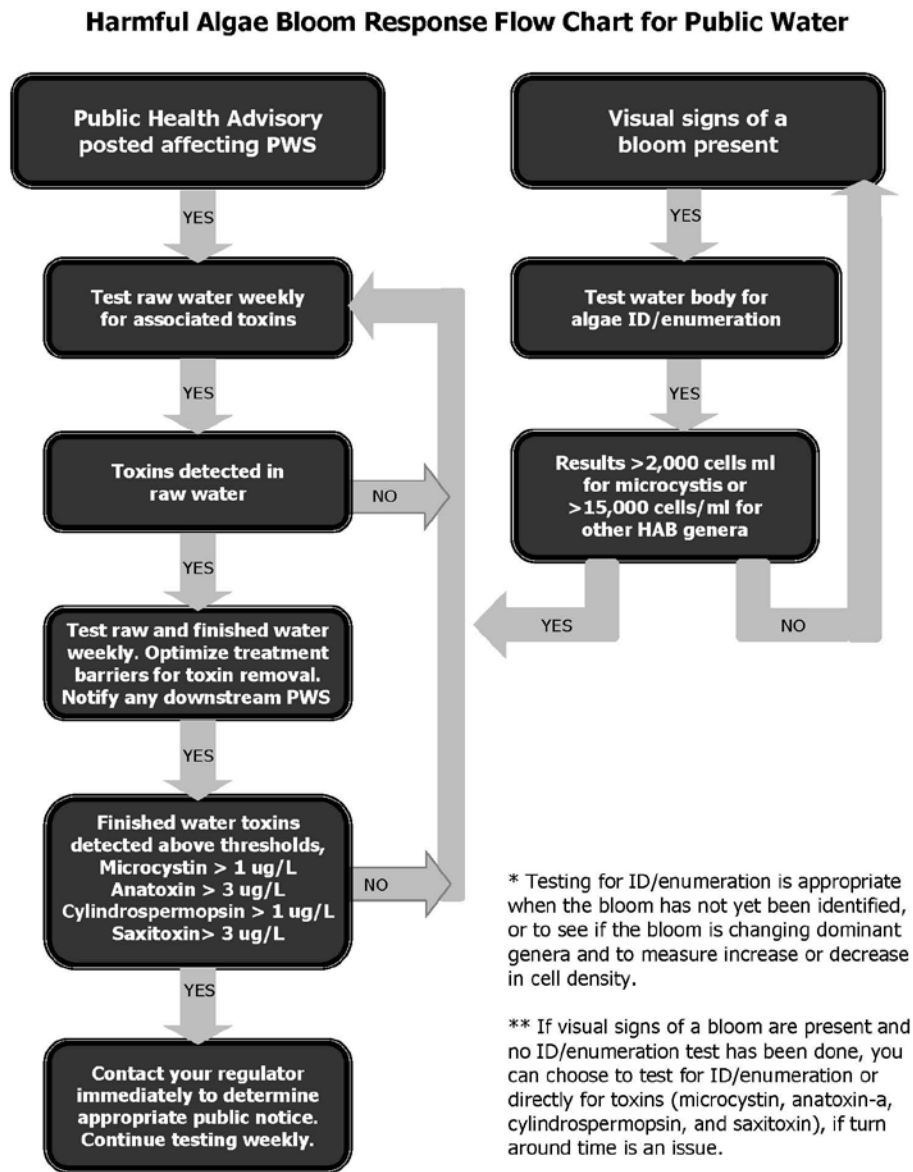
Harmful Algae Bloom Response Flow Chart for Public Water

Figure 2: Example of harmful algal bloom response flowchart for public water systems from Oregon (Oregon Health Authority n.d.)

2. Communication and Customer Notification

This section provides descriptions of materials available to support water utilities as they decide whether they have a cyanotoxin issue and if and how they should notify the public (and possibly others) as a result. Descriptions of materials available from each state are included, along with information on where the materials can be found. Additional publications and guidance related to public outreach regarding cyanotoxins (e.g. WHO, Health Canada, USEPA, Australian organizations) is also reviewed.

At-risk water utilities should consider how to prepare for three stages:

   1) Before the event (preparing an outreach strategy and advisory);
   2) During the event (implementing the strategy and issuing the advisory); and
   3) After the event (evaluating strategy and advisory effectiveness).

A water utility can prepare for and enhance its response by developing a coordinated risk communication plan. Utilities can prepare for a cyanotoxin event by preparing a plan that includes following pre-established notification methods, uses pre-determined types of information, and identifies a spokesperson who is prepared to speak on behalf of the utility.

Water utilities with a risk communication plan in place commonly include various means of notifying the public during an event. These methods can be tailored to meet the specific needs of a utility and the type of emergencies:

- Print (e.g., bill stuffers, boil water notifications, Consumer Confidence Reports)
- Community Events (e.g., community workshops)
- Media (e.g., press release, fact sheets, radio and television announcements)
- Web site/Internet communication
- Message Delivery (e.g., door-to-door delivery, direct mail, especially to high-risk populations
- General listserv notifications and other specialized contact lists for nursing care, social service agencies, and churches working with minority/non-English speaking populations (Mobley et al. 2010).
- Reverse 911 calls

Utilities with and without a formal communication plan may benefit from considering how to:

- Integrate risk communication into overall management and operational plans,
- Prepare internally for events, including training staff to provide them with the knowledge and instructions necessary to respond to specific contaminant events,
- Build working relationships with consumers and partners,
- Identify the target audiences that need information during events, especially susceptible groups,

- Educate the media on contaminant issues, and
- Achieve readiness by identifying and engaging partners that can help reach out to the affected community.

a. Communication Toolbox for Drinking Water Advisories

Drinking water advisories can be triggered by a range of events that differ in scope, scale, and severity. Effectively communicating with the public before, during, and after an event triggering issuance of a drinking water advisory is critical. The following section provides a summary of the Center for Disease Control and Prevention's (CDC) Drinking Water Advisory Communication Toolbox to enable dynamic communication between a water utility, its stakeholders, and the community during each of the three stages (CDC 2013). Figure 3 provides a flowchart illustrating the process of preparing for, issuing, and following up after a drinking water advisory.

Before an Event

Organization

Collaboration

Message development

Conducting exercises

After an Event

Reporting

Debriefing

Evaluation

Modifying protocols

Updating public outreach

During an Event

Initating an advisory

Preparing an advisory

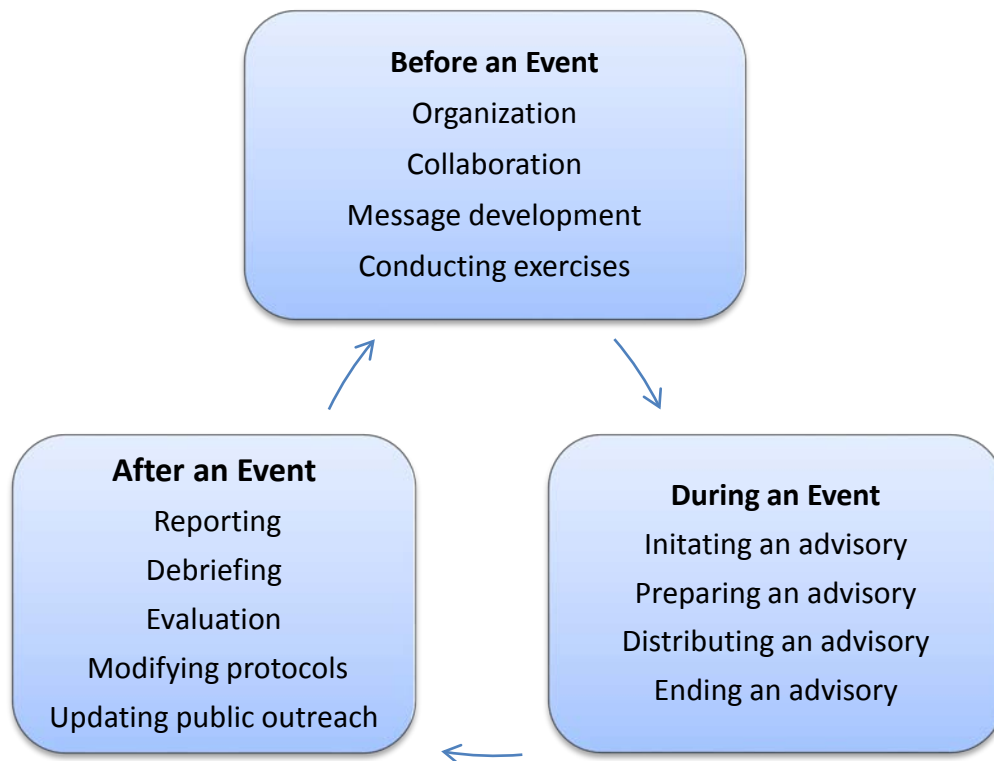Distributing an advisory

Ending an advisory

Figure 3: Centers for Disease Control and Prevention flowchart for drinking water advisory communication toolbox

1) Before an Event – Preparing for an Advisory

Pre-event planning to design advisories and processes to issue them can enhance delivery of accurate and useful information to affected customers. This stage of planning can be further divided into four sub-stages: a) organizing for drinking water advisories; b) collaborating with partners; c) developing a message, and; d) conducting exercises.

Organizing for Drinking Water Advisories

An important first step involves assessing the resources available and those that are needed for the effective exchange of information. Stakeholders include residential and commercial customers and any governing bodies. Existing communication plans can provide guidance on how to deliver necessary information to the affected community.

An effective drinking water advisory relies on various modes of communication, and the media can play a significant role in distributing the information to a large audience. The scope, scale, and severity of an event will determine the level of media involvement. Major factors to consider in this component include:

- **Timing:** A media outlet may not respond outside of business hours. This will necessitate a utility to contact the outlets to understand their staffing and hours, and to also inquire about how long it will take the media to broadcast an advisory.
- **Audience:** An advisory affecting a large area should seek a media release with multiple outlets. A utility serving a large non-English speaking population will also need to consider ethnic media outlets.
- **Channels**: A large utility may serve a region containing multiple media outlets that only broadcast to certain areas, which will then entail the system to identify precisely which outlets cover which areas. Rural communities may receive their television news from distant urban areas, and these outlets should be noted by the system. The timing of an advisory issuance can also influence the type of media outlet (i.e., television news during working hours may not be effective).
- **Messages**: Preparation of press releases and statements can follow generalized templates tailored to the types of events. These materials should also include links to primacy agencies and health departments to provide customers with additional useful information
- **Approval**: Pre-determined procedures on how media materials will be reviewed, approved, and shared. The utility should also design spokesperson(s) that understands the system's operations and is able to communicate technical language clearly.

Emergency response plans should also integrate communication strategies so that authorized personnel can make quick decisions when needed.

<u>Collaborating with Partners</u>

Developing and regularly communicating with a network of partner agencies and organizations can help water utilities deliver advisories in a timely and effective manner. Public agencies, such as local or state health departments or health care centers, can help with information delivery to a socially and ethnically diverse group of people, particularly the susceptible populations. The contact information of these partners should be recorded, regularly updated, and maintained in readily accessible places.

<u>Developing a Message</u>

A number of factsheets and templates are readily available on state/primacy agencies' websites to guide the development of advisories. Collaboration with partners can also help in develop messages targeted at specific audiences, especially when notices need to be translated for non-English speakers or the visually impaired. Local governments, especially public health departments, can offer valuable resources for translations.

<u>Conducting Exercises</u>

A communication plan for issuing advisories needs to be tested to ensure it adequately reaches the affected community. Testing exercises can be limited to the water system and its partners, and large drills involving the entire community can help identify any gaps in outreach. Debriefing after an exercise—whether large or small—will generate comments for areas of the advisory communication and protocols that require improvement. In addition, the federal National Incident Management System (NIMS) has established a systematic approach to guide all levels of governmental departments or agencies, non-governmental organizations, and the private sector (which includes drinking water utilities) on communicating effectively during potentially hazardous events.

2) During the Event – Issuing an Advisory

Events trigger drinking water advisories can occur anytime. Water utilities need to be prepared to follow standard operating procedures (SOPs) to issue an advisory one when an event is suspected or identified. This stage can be further divided into four sub-stages: a) initiating an advisory, b) preparing for an advisory, c) distributing an advisory, and d) ending an advisory.

<u>Initiating an Advisory</u>

Federal or state regulations generally require drinking water advisories to be issued under a variety of conditions, but water systems can also independently make a decision to distribute one. The types of advisory—informational, boil water, do not drink, or do not use—is determined by the situation and contaminant(s) of concern. Advisories issued in accordance with regulations will specify protocols to notify the primacy agency. In addition to the primacy

agency, internal staff and partners should also be informed according to the utility's communication plans.

Clearly delineating the affected area is a vital part of a drinking water advisory, especially when media outlets typically cover large areas beyond the impacted communities. Maps that show boundaries or reference points of the areas of concern will be useful materials for stakeholders, and can be posted on websites or distributed electronically or as printed documents.

<u>Preparing an Advisory</u>

Primacy agencies usually have specific templates available to guide the development and format of the advisory. Public notification issued in accordance with regulations will also require the inclusion of ten elements established by USEPA's Public Notification Rule. This stage of the preparation should also involve the assignment of communication liaisons to coordinate information exchange with partner agencies or organizations.

<u>Distributing an Advisory</u>

Prior to notifying the media, appropriate public officials should be briefed about the circumstances as the media will oftentimes contact them for additional comments rather than the water utility itself. Distribution methods (e.g., number of media outlets, door-to-door contact, and social media) will depend on the scale and severity of the event. As discussed in the "Organizing for an Advisory Stage," an established network of partners can offer significant assistance with information delivery to diverse populations.

After issuance of a drinking water advisory, continual communication with the media throughout the duration of the advisory is an effective strategy to appropriately inform the public. Maintaining a clear and consistent message about the implications of an advisory when contacting the media will ensure accurate information reaches the target audience. Large-scale advisories may even require press conferences. Coordination with partners is essential in planning and conducting a press conference.

<u>Ending an Advisory</u>

Generally, decisions to end an advisory are made through consultations between water utilities and primacy agencies regarding water quality data, criteria, and protocols. Sampling results are usually used to help make the decisions. The same communication methods and media outlets used to issue an advisory should also be used when one is lifted. Notifications to end an advisory should include an explanation of why an event is no longer a concern based on information such as sampling data. In order to effectively end an advisory, the utility needs to update the media, its partners, and any electronically or printed notifications posted for the affected area. A lifted advisory notice should specify the date and time.

3) After the Event—Evaluating an Advisory

Evaluating the components that worked and did not work following a drinking water advisory can facilitate future improvements. This stage can be further divided into five sub-stages:
1. Reporting requirements,
2. Debriefing an event,
3. Conducting an evaluation,
4. Modifying SOPs, and
5. Updating public outreach.

Debriefing an Event

Debriefing offers an opportunity to discuss what factors contributed to success, how to replicate them in the future, as well as areas that need improvement. The scope of the advisory will determine the size of a debriefing, but any internal personnel and external partners that were involved should participate. Participants can also agree on any follow-up actions items, as well as devise plans focused how strategies to improve factors that were ineffective. In addition, debriefings provide opportunities to update contact lists because all the participants involved in the advisory are gathered together. Debriefing notes should be recorded and kept on file for future reference.

Conducting an Evaluation

Evaluations can be conducted iteratively and over time, using information from operational reports, debriefings, or public comments, among a few. Some of these data can be collected after an advisory has been lifted. Surveys, for example, can be used to collect both qualitative and quantitative information regarding communication effectiveness during the advisory. Information can also be requested from partners or media. These data will be valuable when used for future purposes, including ways to improve public outreach and decision making.

Modifying SOPs

Results from the debriefing and evaluations can assist in developing recommendations to improve SOPs. Depending on the scale of the advisory, these recommendations can range from a simple memo to a comprehensive report. Any changes to the contact information of a partner that were gathered during the debriefings should also be incorporated into the modified SOPs.

Updating Public Outreach

Advisories may cause major disruptions to the affected community and undermine the public's confidence in the water utility. As a result, continued public outreach following the end of an advisory is important to maintain credibility with the customers and stakeholders. Some follow-up outreach actions to engage the public include: updating websites or newsletters with information on how the utility is committed to providing safe water; meeting with reporters

and editors to improve understanding of advisories; or providing additional sources of information in Consumer Confidence Reports (CCRs).

Table 15 provides descriptions of materials referenced in the drinking water advisory communication strategy along with where the resources can be found.

Table 15. Federal documents to assist in developing communication strategies

Federal Documents		
Document	**Web Link**	**Description**
Drinking Water Advisory Communication Toolbox	http://www.cdc.gov/healthywater/pdf/emergency/drinking-water-advisory-communication-toolbox.pdf	The report includes a number of web links and templates to help in implementing the three stages of a drinking water advisory communication plan.
Public Notification (PN) Rule	http://water.epa.gov/lawsregs/rulesregs/sdwa/publicnotification/index.cfm	Provides resources for drinking water utility owners and operations, as well as customers, on the PN Rule established to ensure consumers are informed of issues in their drinking water. It includes a number of drinking water advisory templates for utilities to use when their supplies do not meet the SDWA requirements.
USEPA Revised Public Notification Handbook	http://www.epa.gov/ogwdw000/publicnotification/pdfs/guide_publicnotification_pnhandbook.pdf	Contains extensive information about how to provide effective public notices. Some primacy agencies may categorize violations differently, or may have additional requirements for the wording of the notice, so utilities should check with their individual state before using any of the templates in this handbook.
Consumer Confidence Reports	http://water.epa.gov/lawsregs/rulesregs/sdwa/ccr/index.cfm	Provides key phrases translated into Spanish that utilities can use in developing messages before an event. CCRs summarize information regarding water sources in use, detected contaminants, and educational information.
Cyanotoxin Q&A's and Health Effects Language	https://www.epa.gov/nutrient-policy-data/recommendations-public-water-systems-manage-cyanotoxins-drinking-water	Appendices C and D of the document *Recommendations for Public Water Systems to Manage Cyanotoxins in Drinking Water* provide a short list of questions and answers, as well as potential language water utilities could use for cyanotoxin public notifications and social media releases (e.g., Twitter, Facebook).

Federal Documents		
Document	**Web Link**	**Description**
Cyanotoxin Guidelines and Recommendations	http://www2.epa.gov/ nutrient-policy- data/guidelines-and- recommendations	Provides an overview of Federal guidance related to cyanotoxins and cyanobacteria, including information on causes, control, treatment, and health advisory levels. Much of the information here can be used to help populate a FAQ document for a water utility.

The table in Appendix A describes materials available to support water utilities as they evaluate whether they have a cyanotoxin issue along with where resources can be found. Many of the state websites contain factsheets or FAQs that provide a general background about cyanobacteria and occurrence of blooms within the state. This simplified language can be incorporated into a water utility's messaging and outreach plans to increase public awareness and understanding of cyanobacteria. Other states provide more sophisticated information related to monitoring and treating the water, as well as evaluating the level of risk. The table is organized by the types of available information provided by the state.

References

Acero, J. L., Rodriguez, E.M., Meriluoto, J. 2005. Kinetics of reactions between chlorine and the cyanobacterial toxins microcystins. *Water research* 39 (8), 1628-38.

American Water Works Association (AWWA). 2015a. Hazen-Adams CyanoTOX Tool Supplemental Material: PAC Jar Testing Protocol for Cyanotoxin Removal in Drinking Water (Ver. 1.0) available at http://www.awwa.org/resources-tools/water-knowledge/cyanotoxins.aspx

American Water Works Association (AWWA). 2015b. Hazen-Adams CyanoTOX Oxidation Calculator available at http://www.awwa.org/resources-tools/water-knowledge/cyanotoxins.aspx

American Water Works Association (AWWA). 2015c. Hazen-Adams CyanoTOX Tool Supplemental Material: Cyanotoxin Oxidation Testing Protocol (Ver. 1.0) available at http://www.awwa.org/resources-tools/water-knowledge/cyanotoxins.aspx

American Water Works Association (AWWA). 2011. M37: Operational Control of Coagulation and Filtration Processes 3rd Edition. Denver, CO.

American Water Works Association (AWWA). 2010. M57: Algae: Source to Treatment. ISBN: 9781583217870. Denver, CO.

ASTM D2035-13, 2013. Standard Practice for Coagulation-Flocculation Jar Test of Water, ASTM International, West Conshohocken, PA, 2013, www.astm.org .

Banker, R., Carmeli, S., Werman, M., Teltsch, B., Porat, R., Sukenik, A. 2001. Uracil moiety is required for toxicity of the cyanobacterial hepatotoxin cylindrospermopsin. J. Toxicol. Environ. Health Part A 2001, 62, 281–288. http://dx.doi.org/10.1080/009841001459432.

Bourne, D. G., Blakeley, R. L., Riddles, P., Jones, G. J. 2006. Biodegradation of the cyanobacterial toxin microcystin LR in natural water and biologically active slow sand filters. *Water research 40* (6), 1294-1302.

Bourne, D. G., Jones, G. J., Blakeley, R. L., Jones, A., Negri, A. P., Riddles, P. 1996. Enzymatic pathway for the bacterial degradation of the cyanobacterial cyclic peptide toxin Microcystin LR. *Applied and environmental microbiology* 62 (11), 9.

Carlson, R. and Simpson, J. 1996. A Coordinator's Guide to Volunteer Lake Monitoring Methods. North American Lake Management Society. Retrieved on June 25, 2014 from: http://www.nalms.org/home/publications/free-nalms-publications/free-nalms-publications.cmsx.

CDC (Centers for Disease Control and Prevention), 2013. Drinking Water Advisory Communication Toolbox. Retrieved June 26, 2014 from: http://www.cdc.gov/healthywater/emergency/dwa-comm-toolbox/index.html/.

CDC, (no date). Physician Reference: Cyanobacteria blooms. When in doubt, it's best to stay out! Publication #CS258192. http://www.cdc.gov/nceh/hsb/hab/habsphysician_card.pdf

Chen, J. J., Yeh, H. H. 2005. The mechanisms of potassium permanganate on algae removal. *Water research 39* (18), 4420-4428.

Cheng, X., Shi, H., Adams, C. D., Timmons, T., Ma, Y. 2009. Effects of oxidative and physical treatments on inactivation of Cylindrospermopsis raciborskii and removal of cylindrospermopsin. *Water science and technology* 60 (3), 689-698.

Chorus, I. and Bartram, J. 1999. Toxic Cyanobacteria in Water—A Guide to Their Public Health Consequences, Monitoring and Management. Routledge, London and New York.

Chow, C. W. K., Drikas, M., House, J.; Burch, M. D. 1999. The impact of conventional water treatment processes on cells of the cyanobacterium Microcystis aeruginosa. *Water research* 33 (15), 3253.

Chow, C. W. K., House, J., Velzeboer, R. M. A., Drikas, M. 1998. The effect of ferric chloride flocculation on cyanobacterial cells. *Water research* 1998, *32* (3), 808.

Chow, C. W. K., Panglisch, S., House, J., Drikas, M., Burch, M. D., Gimbel, R. 1997. A study of membrane filtration for the removal of cyanobacterial cells. *Aqua* 1997, *46* (6), 11.

Christoffersen, K., Lyck, S., Winding, A. 2002. Microbial activity and bacterial community structure during degradation of microcystins. *Aquatic Microbial Ecology* 2002, *27*, 125-136.

Cousins, I. T., Bealing, D. J., James, H. A., Sutton, A. 1996. Biodegradation of Microcystin-LR by indigenous mixed bacterial populations. *Water research* 1996, *30* (2), 481.

Deas, M.L., Vaughn, J.C., Tanaka, S.K. 2009. Algaecide Pilot Study: Copco Reservoir 2008. PacifiCorp. Retrieved June 25, 2014 from:
http://www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Hydro/Hydro_Licensing/Klamath_River/2008AlgaecidePilotStudy.pdf.

Egemose, S., Vicente, I., Reitzel, K., Flindt, M.R., Andersen, F., Lauridsen, T.L., Søndergaard, M., Jeppesen, E., Jensen, H.S. 2011. Changed cycling of P, N, Si, and DOC in Danish Lake Nordborg after aluminum treatment. *Canadian Journal of Fisheries and Aquatic Sciences*. 68(5): 842-856.

Falconer, I. R. 2005. Cyanobacterial Toxins of Drinking Water Supplies: Cylindrospermopsins and Microcystins. CRC Press, Boca Raton, Fla.

Fan, J. 2013. Evaluating the effectiveness of various control and water treatment processes on the membrane integrity and toxin fate of cyanobacteria. Doctoral dissertation. Retrieved June 25, 2014 from: http://digital.library.adelaide.edu.au/dspace/bitstream/2440/83360/3/02whole.pdf

Fawell, J. K., Hart, J., James H, A., Parr, W. 1993. Blue-green algae and their toxins - analysis, toxicity, treatment and environmental control. *Water supply: the review journal of the International Water Supply Association* 1993, *11* (3-4), 109-122.

Freese, S., Nozaic, D., Pryor, M., Rajogopaul, R., Trollip, D., Smith, R. 2001. Enhanced coagulation: a viable option to advance treatment technologies in the South African context. *Particle Removal from Reservoirs and other Surface Waters* 2001, 1 (1), 33-41.

Gijsbertsen-Abrahamse, A. J., Schmidt, W., Chorus, I., Heijman, S. G. J. 2006. Removal of cyanotoxins by ultrafiltration and nanofiltration. *Journal of Membrane Science* 2006, *276*: 1–2:252-259.

Graham, J.L., Loftin, K.A., Ziegler, A.C., Meyer, M.T. 2008. Cyanobacteria in Lakes and Reservoirs: Toxin and Taste and Odor Sampling Guidelines (ver. 10). U.S. Geological Survey Techniques of Water-Resources Investigation, book 9, chap. A7, section 7.5. Retrieved June 24, 2013 from: http://water.usgs.gov/owq/FieldManual/Chapter7/7.5.pdf.

Grutzmacher, G., Bottcher, G., Chorus, I., Bartel, H. 2002. Removal of microcystins by slow sand filtration. *Environmental toxicology* 2002, *17* (4), 9.

Hall, T., Hart, J., Croll, B., Gregory, R. 2000. Laboratory-Scale Investigation of Algal Toxin Removal by Water Treatment. *Water and Environmental Management: Journal of the Institution of Water and Environmental Management* 2000, *14* (Part 2), 143-149.

Heng, L., Yanling, Y., Weijia, G., Xing, L., Guibai, L. 2008. Effect of pretreatment by permanganate/chlorine on algae fouling control for ultrafiltration (UF) membrane system. *Desalination* 2008, *222* (1), 7.

Ho, L., Sawade, E., Newcombe, G. 2012. Biological treatment options for cyanobacteria metabolite removal–A review. *Water research* 2012, *46* (5), 1536-1548.

Ho, L., Tanis-Plant, P., Kayal, N., Slyman, N., Newcombe, G. 2009. Optimising water treatment practices for the removal of *Anabaena circinalis* and its associated metabolites, geosmin and saxitoxins. *Journal of water and health* 2009, *7* (4), 544-56.

Ho, L., Stlman, N., Kaeding, U., Newcombe, G. 2008. Optimizing powdered activated carbon and chlorination practices for cylindrospermopsin removal. *Journal AWWA* 2008, *100*:11:88-96.

Ho, L., McDowall, B., Wijesundara, S., Shaw, G., Saint, C., Newcombe, G. 2008. *Biological Filtration Processes for the Removal OF Algal Metabolites, Research Report 64*; Cooperative Research Centre for Water Quality and Treatment, Adelaide, South Australia.

Ho, L., Onstad, G., Gunten, U. v., Rinck-Pfeiffer, S., Craig, K., Newcombe, G. 2006. Differences in the chlorine reactivity of four microcystin analogues. *Water research* 2006, *40* (6), 1200-1209.

Hobson, P., S. Dickson, M. Burch, O. Thorne, L. Tsymbal, J. House, J. Brookes, D. Chang, S. Kao, T. Lin, K. Bierlein, J. Little. 2012. Alternative and Innovative Methods for Source Water Management of Algae and Cyanobacteria. Water Research Foundation Project #4094. Denver, Colo.

Hoigne, J. and Bader, H. 1994. Kinetics of reactions of chlorine dioxide (OCIO) in water--I Rate constants for inorganic and organic compounds. *Water research* 1994, *28* (1), 45.

Hrudey, S., Burch, M., Drikas, M., Gregory, R. 1999. Remedial Measures. In *Toxic Cyanobacteria in Water: A Guide to Their Public Health Consequences, Monitoring, and Management*, Chorus, I.; Bartram, J., Eds. 1999. WHO/E & FN Spon, London, United Kingdom.

Huang, H., Schwab, K., Jacangelo, J. G. 2009. Pretreatment for Low Pressure Membranes in Water Treatment: A Review. *Environmental Science and Technology* 2009. 1;43(9):3011-9.

Humpage, A.R., S.J. Hardy, E.J. Moore, S.M. Froscio, and I.R. Falconer. 2000. Microcystins (cyanobacterial toxins) in drinking water enhance the growth of aberrant crypt foci in the mouse colon. *Journal of Toxicology and Environmental Health*, Part A: Current Issues. 61(3): 155–165.

Hurlburt, B., S. Brashear, P. Zimba. 2011. Detection of Cyanobacteria in Closed Water Systems in Southern Louisiana (USA). *Water* 3, 79 - 86, Sep 17.

Jones, G. J. and Orr, P. T. 1994. Release and degradation of microcystin following algicide treatment of a *Microcytis aeruginosa* bloom in a recreational lake, as determined by HPLC and protein phosphatase inhibition assay. *Water research* 1994, *28* (4), 871.

Kasper R., Hansen, J., Andersen, F., Hansen, K.S., Jensen, H.S. 2005. Lake restoration by dosing aluminum relative to mobile phosphorus in the sediment. *Environmental Science and Technology*. 39:11:4134-4140.

Kenefick, S.L., Hrudey, S.E., Peterson, H.G., Prepas, E.E. 1993. Toxin release from *Microcystis aeruginosa* after chemical treatment. *Water Sci. and Technol.* 27 (3-4) 433-440.

Klitzke, S., Apelt, S., Weiler, C., Fastner, J., Chorus, I. 2010. Retention and degradation of the cyanobacterial toxin cylindrospermopsin in sediments – the role of sediment preconditioning and DOM composition. *Toxicon* 2010, *55* (5), 999-1007.

Knappe, D. R. U., Belk, R. C., Briley, D. S., Gandy, S. R., Rastogi, N., Rike, A. H., Glasgow, H., Hannon, E., Frazier, W. D., Kohl, P., Pugsley, S. 2004. *Algae Detection and Removal Strategies for Drinking Water Treatment Plants*. AWWA Research Foundation. Denver, Colo.

Kull, T. P. J., Sjovall, O. T., Tammenkoski, M. K., Backlund, P. H., Meriluoto, J. A. O. 2006. Oxidation of the cyanobacterial hepatotoxin Microcystin-LR by chlorine dioxide: influence of natural organic matter. *Environmental science & technology* 2006, *40* (5), 1504-1510.

Kull, T. P. J., Backlund, P. H., Karlsson, K. M., Meriluoto, J. A. O. 2004. Oxidation of the cyanobacterial hepatotoxin Microcystin-LR by chlorine dioxide: reaction kinetics, characterization, and toxicity of reaction products. *Environmental science & technology* 2004, *38* (22), 7.

Kwon, B., Park, N., Cho, J. 2005. Effect of algae on fouling and efficiency of UF membranes. *Desalination* 2005, *179* (1), 12.

Lahti, K., Rapala, J., Kivimaki, A. L., Kukkonen, J., Niemela, M., Sivonen, K. 2001. Occurrence of microcystins in raw water sources and treated drinking water of Finnish waterworks. *Water science and technology: a journal of the International Association on Water Pollution Research* 2001, *43* (Part 12), 225-228.

Lam, A.-Y., Prepas, E., Spink, D., Hrudey, S. 1995. Chemical control of hepatotoxic phytoplankton blooms: Implications for human health. *Water research* 1995, *29* (8), 1845-1854.

Lee, J. W. H. W. 2006. Effect of Process Variables and Natural Organic Matter on Removal of Microcystin-LR by PAC-UF. *Environmental science & technology* 2006, *40* (23), 7.

Lippy, Edwin C. and James Erb. 1976. Gastrointestinal Illness at Sewickley, PA. *Journal AWWA*. 68(11):606–610.

Lopez, C.B., Jewett, E.B., Dortch, Q., Walton, B.T., and Hudnell, H.K. 2008. Scientific Assessment of Freshwater Harmful Algal Blooms. Interagency Working Group on Harmful Algal Blooms, Hypoxia and Human Health of the Joint Subcommittee on Ocean Science and Technology, Washington, DC.

Merel, S., Walker, D., Chicana, R., Synder, S., Baures, E., and Thomas, O. 2013. State of knowledge and concerns on cyanobacterial blooms and cyanotoxins. *Environment International* 59: 303-327.

Mobley, J., Reinhard, K., Speranza, E., and Burke, M. 2010. Contaminant Risk Management Communication Strategy and Tools. Water Research Foundation. Retrieved June 26, 2014 from: http://www.waterrf.org/PublicReportLibrary/4001.pdf.

Muntisov, M., and Trimboli, P. 1996. Removal of Algal Toxins Using Membrane Technology. *Water: official journal of the Australian Water and Wastewater Association* 1996, *23* (3), 34.

Neumann, U., Weckesser, J. 1998. Elimination of Microcystin Peptide Toxins from Water by Reverse Osmosis. *Environmental toxicology and water quality* 1998, *13* (2), 6.

Newcombe, G., House, J., Ho, L., Baker, P., and Burch, M. 2010. Management Strategies for Cyanobacteria (Blue-Green Algae): A Guide for Water Utilities. Water Quality Research Australia, Adelaide, South Australia. ISBN: 1876616245.

Newcombe, G. N., and B. Nicholson. 2004. Water treatment options for dissolved cyanotoxins. *Journal of Water Supply: Research and technology -AQUA* 2004. 53(4):227-239.

Newcombe, G. 2002. *Removal of Algal Toxins from Drinking Water Using Ozone and GAC.* AWWA Research Foundation, Denver, Colo.

Nicholson, B. C., Shaw, G. R., Morrall, J., Senogles, P. J., Woods, T. A., Papageorgiou, J., Kapralos, C., Wickramasinghe, W., Davis, B. C., Eaglesham, G. K. 2003. Chlorination for Degrading Saxitoxins (Paralytic Shellfish Poisons) in Water. *Environmental technology* 2003, *24* (Part 11), 1341-1348.

Nicholson, B. C., Rositano, J., Burch, M. D. 1994. Destruction of cyanobacterial peptide hepatoxins by chlorine and chloramine. *Water research* 1994, *28* (6), 1297.

Oberholster, P.J., Botha, A.M., and Cloete, T.E. 2006. Toxic cyanobacterial blooms in a shallow, artificially mixed urban lake in Colorado, USA. Lakes & Reservoirs: Research and Management. 11:2:111-123. http://dx.doi.org/10.1111/j.1440-1770.2006.00297.x.

Ohio EPA. June 2014. Draft Public Water System Harmful Algal Bloom Response Strategy. http://epa.ohio.gov/ddagw/HAB.aspx. Accessed 15 August 2016.

Onstad, G. D., Strauch, S., Meriluoto, J., Codd, G. A., Von Gunten, U. 2007. Selective oxidation of key functional groups in cyanotoxins during drinking water ozonation. *Environmental science & technology* 2007, *41* (12), 4397-404.

Oregon Health Authority. Harmful Algae Bloom Response Flow Chart for Public Water. Retrieved August 15, 2016 https://public.health.oregon.gov/HealthyEnvironments/DrinkingWater/Operations/Treatment/Documents/algae/HABResponseFlowChart.pdf.

Qin, J.-J., Oo, M. H., Kekre, K. A., Knops, F., Miller, P. 2006. Reservoir water treatment using hybrid coagulation-ultrafiltration. *Desalination* 2006, *193* (1), 6.

Rajasekhar, P., Fan, L., Nguyen, T., and Roddick, F.A. 2012. A review of the use of sonication to control cyanobacterial blooms. *Water Research* 46(14): 4319-4329.

Rapala, J., Lahti, K., Sivonen, K., Niemelae, S. I. 1994. Biodegradability and adsorption on lake sediments of cyanobacterial hepatotoxins and anatoxin-a. *Letters in applied microbiology* 1994, *19* (6), 423.

Robinson, C., Fowler, S. 2007. Fresh Ideas for Fresh Water: Using Innovative Technology to Obtain High-Quality Drinking Water from Lake Okeechobee, Florida. *Florida Water Resources Journal* 59(3):22-26.

Rodriguez, E., Majado, M. E., Meriluoto, J., and Acero, J. L. 2007. Oxidation of microcystins by permanganate: Reaction kinetics and implications for water treatment. *Water research* 2007, *41* (1), 102-110.

Rodriguez, E., Onstad, G. D., Kull, T. P., Metcalf, J. S., Acero, J. L., von Gunten, U. 2007. Oxidative elimination of cyanotoxins: Comparison of ozone, chlorine, chlorine dioxide and permanganate. *Water research* 2007, *41* (15), 3381-3393.

Rodriguez, E., Sordo, A., Metcalf, J. S., Acero, J. L. 2007. Kinetics of the oxidation of cylindrospermopsin and anatoxin-a with chlorine, monochloramine and permanganate. *Water research* 2007, *41* (9), 2048-2056.

Rositano, J., Newcombe, G., Nicholson, B., Sztajnbok, P. 2001. Ozonation of NOM and algal toxins in four treated waters. *Water research* 2001, *35* (1), 23-32.

Rositano, J., Nicholson, B. C., Pieronne, P. 1998. Destruction of Cyanobacterial Toxins by Ozone. *Ozone: science & engineering* 1998, *20* (3), 16.

Schneider, O., Weinrich, L., and Brezinski, S. 2015. Ultrasonic Treatment of Algae in a New Jersey Reservoir. *Journal AWWA* 107(10):E533-E542.

Senogles, P., Shaw, G., Smith, M., Norris, R., Chiswell, R., Mueller, J., Sadler, R., Eaglesham, G. 2000. Degradation of the cyanobacterial toxin cylindrospermopsin, from Cylindrospermopsis raciborskii, by chlorination. *Toxicon* 2000, *38* (9), 1203-1213.

Singleton, V.L. and Little J.C. 2006. Designing hypolimnetic aeration and oxygenation systems – a review. *Environmental Science and Technology*. 40(24): 7512-7520.

Teixeira, M. R. and Rosa, M. J. 2006. Comparing dissolved air flotation and conventional sedimentation to remove cyanobacterial cells of Microcystis aeruginosa. *Separation and purification technology* 2006, *53* (1), 9.

Teixeira, M.R. and Rosa, M. J. 2006. Neurotoxic and hepatotoxic cyanotoxins removal by nanofiltration. *Water research* 2006, *40* (15), 2837-2846.

Tsuji, K., Naito, S., Kondo, F., Ishikawa, N., Watanabe, M. F. 1994. Stability of microcystins from cyanobacteria: effect of light on decomposition and isomerization. *Environmental science & technology* 1994, *28* (1), 173.

US Environmental Protection Agency (USEPA). 2015. EPA 815-R-15-010. Recommendations for Public Water Systems to Manage Cyanotoxins in Drinking Water. Retrieved August 15, 2016. https://www.epa.gov/sites/production/files/2015-06/documents/cyanotoxin-management-drinking-water.pdf.

US Environmental Protection Agency (USEPA). 2014. 810-F-11-001, Cyanobacteria and Cyanotoxins: Information for Drinking Water Systems. Retrieved August 15, 2016. https://www.epa.gov/sites/production/files/2014-08/documents/cyanobacteria_factsheet.pdf.

US Environmental Protection Agency (USEPA). 2012. Contaminant Candidate List 3 – CCL. Retrieved May 28, 2014, from http://water.epa.gov/scitech/drinkingwater/dws/ccl/ccl3.cfm#microbial

US Environmental Protection Agency (USEPA). 1996. ICR Manual for Bench- and Pilot- Scale Treatment Studies, EPA 814/B-96-003. USEPA, Cincinnatti, Ohio.

Vincent, W.F. 2010. Cyanobacteria. In G.E. Likens (Ed.), Plankton of Inland Waters (pp. 226-232). Academic Press, Cambridge, Mass.

Vuori, E., Pelander, A., Himberg, K., Waris, M. 1997. Removal of nodularin from brackish water with reverse osmosis or vacuum distillation. *Water research* 1997, *31* (11), 2922.

Water Research Foundation (WRF). 2007. Reservoir Management Strategies for Control and Degradation of Algal Toxins. ISBN 13: 978-1843392088; ISBN 10: 1843392089. Water Research Foundation, Denver, Colo.

Weiqun, L., Evans; E.H., McColl, S.M.; Saunders, V.A. 2006. Identification of cyanobacteria by polymorphisms of PCR-amplified ribosomal DNA spacer region. *Microbiology Letters*. 153(1): 141-149.

Welch, G. and Gibbons, H. 2010. Aeration of Lakes and Reservoirs. Retrieved June 25, 2014 from: http://www.pigeonlake.org/PermitApplicationReply/PDF/8-9%20Scientific%20Research%20Reference%20Aeration%20of%20Lakes%20and%20Reservoirs.pdf.

Westrick JA. 2015. Bench Scale vs Full Scale Treatment of Cyanobacteria and their Toxins. *Water Supply Resources & Quality - Planning for Regulatory Changes*. Retrieved August 15, 2016. http://www.vaawwa.org/file/2015%20Water%20Supply%20Seminar%20-%20Westrick%20Cyanobacteria.pdf

Westrick, J.A., Szlag, D.C., Southwell, B.J., Sinclair, J. 2010. A review of cyanobacteria and cyanotoxins removel/inactivation in drinking water treatment. *Anal Bioanal Chem* 397(5) 1705-14. http://dx.doi.org/10.1007/s00216-010-3709-5.

Wisconsin Department of Natural Resources (DNR). 2003. Alum Treatments to Control Phosphorus in Lakes. Retrieved June 26, 2014 from: http://www.littlesaint.org/misc_documents/alum_phosphorous_control_dnr.pdf.

World Health Organization (WHO). 1999. Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring and management. Bartram, J. and Chorus, I., (eds). CRC Press, London.

Xagoraraki, I., Harrington, G. W., Zulliger, K., Zeier, B., Krick, W., Karner, D. A., Standridge, J. H., Westrick, J. 2006. Inactivation kinetics of the cyanobacterial toxin Microcystin-LR by free chlorine. *Journal of environmental engineering* 2006, *132* (7), 818.

Yang, X. and Boyer, G. 2005. In *Occurrence of the cyanobacterial neurotoxin, anatoxin–a, in lower Great Lakes*, Abstracts, International Assoc. Great Lake Research. Annual Meeting, Ann Arbor MI, 2005.

Yoo, R. S., Carmichael, W. W., Hoehn, R. C., Hurdley, S. E. 1995. *Cyanobacterial (Blue-Green Algal) Toxins: A Resource Guide*. AWWA Research Foundation and AWWA: 1995; p 229, Denver, Colo.

Zamyadi, A., Dorner, S., Sauvé, S., Ellis, D., Bolduc, A., Bastien, C., Prévost, M. 2013. Species-dependence of cyanobacteria removal efficiency by different drinking water treatment processes. *Water research* 2013, *47* (8), 2689-2700.

Zhou, L, H. Yu, and K. Chen. 2002. Relationship between microcystin in drinking water and colorectal cancer. Biomed Environ Sci 15(2):166–171.

Zhou, H. and Smith, D. 2002. Advanced technologies in water and wastewater treatment. *Journal of Environmental Engineering and Science* 1(4):247-264.

Appendix A: State Web Links with Guidance Materials for Cyanobacteria and Cyanotoxins

State	Webpage Title	Web Link	Types of Information Available
California	Blue-Green Algae (Cyanobacteria) Blooms	http://www.cdph.ca.gov/healthinfo/environhealth/water/pages/bluegreenalgae.aspx	Information on toxicological reviews of several cyanotoxins and suggested action levels, as well as multiple links to other sites (e.g., international organizations, federal government, universities, and other states) where more technical details can be found.
Illinois	Harmful Algal Blooms (HABs) and Algal Toxins	http://www.epa.state.il.us/water/algal-bloom/index.html	Resources include a volunteer monitoring program equipped with a standard Bloom Report Form that people can submit to the state when they suspect a bloom. Illinois also launched a statewide program in 2013 with three key components: educate the public; surveillance monitoring and reporting to local water managers; response planning and implementation.
Indiana	Addressing Concerns About Blue-Green Algae	http://www.in.gov/idem/algae/	While webpage content focuses on recreational impacts of cyanobacteria blooms, some of the resources can be applicable to water utilities. This includes a list of laboratories offering blue-green algae sampling and analysis services.
Maryland	Harmful Algae Blooms in Maryland	http://www.dnr.state.md.us/bay/hab/index.html	Identifies the species commonly found in Maryland's blooms, and provides additional information on the characteristics and distribution of each. State level monitoring efforts are in place to ensure major events are identified and appropriate actions taken. These activities can be tailored to a water utility's local needs.
Massachusetts	Algae Information	http://www.mass.gov/eohhs/gov/departments/dph/programs/environmental-health/exposure-topics/beaches-algae/algae-information.html	Advisories, fact sheets, and educational materials translated into various languages. The state Department of Public Health developed a protocol for evaluating the health concerns when cyanobacteria are present in recreational freshwater bodies. The recommended thresholds and monitoring plans can be a useful source of reference for assessing risks in drinking water bodies.

State	Webpage Title	Web Link	Types of Information Available
Nebraska	2013 Toxic Blue-green Algae and Bacteria Sampling Results	http://www.deq.state.ne.us/Beaches.nsf/LakeSampling13	Results of regular sampling from May through September in recreational lakes show what level of microcystin will trigger health alerts or advisories. History of algae sampling in Nebraska explains types of analyses in seasonal and spatial variability were conducted to determine these levels.
New Hampshire	Recreational Exposure to Cyanobacteria (Blue-Green Algae)	http://des.nh.gov/organization/divisions/water/wmb/beaches/cyano_bacteria.htm	Guidance on how to identify cyanobacteria bloom, overview of morphological characteristics, and general guidance to water utilities on managing cyanobacteria. The state's Groundwater and Drinking Water Source Protection Program works closely with utilities, residents, and organizations to ensure awareness of cyanotoxins.
Ohio	Harmful Algal Blooms: Information for Public Water Systems	http://epa.ohio.gov/ddagw/HAB.aspx	Fact sheets on cyanobacteria blooms, guidance on recognizing blooms and sample analysis, recommended toxin levels that can be used to make advisory decisions.
Oregon	Algae Resources for Drinking Water	http://public.health.oregon.gov/HealthyEnvironments/DrinkingWater/Operations/Treatment/Pages/algae.aspx	Guidance materials for drinking water providers, including background on cyanotoxins, monitoring guidelines, state recommended toxicity values for certain cyanotoxins, treatment options, and public notice templates when toxicity values are exceeded. Oregon has a system to issue advisories for potential risks from microcystin exposure in recreational waters.
Vermont	Cyanobacteria: Blue Green Algae	http://healthvermont.gov/enviro/bg_algae/bgalgae.aspx	Guidance materials providing assessment tools for local communities to implement low-cost monitoring programs or determine potential risks to public health. These tools are intended for local communities but some components may be integrated into a utility's management plan. Vermont has a tiered system for addressing risks from microcystin exposure in recreational waters.
Washington	Blue-Green Algae	http://www.doh.wa.gov/CommunityandEnvironment/Contaminants/BlueGreenAlgae.aspx	Basic FAQ and technical information on cyanobacterial species their toxins and symptoms. Washington is developing recreational guidance values for several cyanotoxins.

State	Webpage Title	Web Link	Types of Information Available
FAQs and Basic Information Regarding Potential Health Risks Only			
Kansas	Harmful Algal Bloom (HAB)	http://www.kdheks.gov/algae-illness/index.htm	Basic FAQ
Florida	Blue-green Algae	http://www.dep.state.fl.us/water/bgalgae/health.htm	Basic FAQ
Maine	Cyanobacteria (Blue-Green Algae)	http://www.maine.gov/dep/water/lakes/cynobacteria.htm	Basic FAQ
Michigan	Algae: A Naturally-Occurring Phenomena	http://www.michigan.gov/documents/deq/deq-oea-nop-algae_378413_7.pdf	Basic factsheet
Minnesota	Blue-green Algae and Harmful Algal Blooms	http://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	Basic FAQ with images of cyanobacteria blooms
Montana	Toxic Algae Factsheet	http://www.deq.mt.gov/toxicalgaefactsheet.mcpx	Basic FAQ
New Mexico	Understanding Exposure and Health Effects: Blue Green Algae	https://nmtracking.org/media/cms_page_media/12/Blue%20Green%20Algae%20Fact%20Sheet8.09.pdf	Basic factsheet
New York	Blue-Green Harmful Algal Blooms	http://www.dec.ny.gov/chemical/77118.html	Basic FAQ
North Carolina	Cyanobacteria (Blue-green Algae)	http://epi.publichealth.nc.gov/oee/a_z/algae.html	Basic information

State	Webpage Title	Web Link	Types of Information Available
Oklahoma	Potential for Human Illness Associated with Blue-green Algae Blooms in Oklahoma	http://www.ok.gov/health/Disease,_Prevention,_Preparedness/Acute_Disease_Service/Disease_Information/Blue-Green_Algae.html	Basic information
Texas	Harmful Algal Blooms (HABs)	http://www.tpwd.state.tx.us/landwater/water/environconcerns/hab/	Basic FAQ
Virginia	Harmful Algal Blooms	http://www.vdh.state.va.us/epidemiology/DEE/habs/	Basic FAQ, including in Spanish
Wisconsin	Blue-Green Algae	http://dnr.wi.gov/lakes/bluegreenalgae/Default.aspx	Basic but comprehensive FAQ