Recommendations for Public Water Systems to Manage Cyanotoxins in Drinking Water

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Abbreviations and Acronyms

ASDWA	Association of State Drinking Water Administrators
AWWA	American Water Works Association
CDC	Centers for Disease Control and Prevention
CMP	Cyanotoxin Management Plan
CT	Concentration (oxidant) x Contact Time
CWA	Clean Water Act
DAF	Dissolved Air Flotation
DBP	Disinfection Byproduct
DWACT	Drinking Water Advisory Communication Toolbox
DWMAPS	Drinking Water Mapping Application for Protecting Source Waters
ECHO	Enforcement and Compliance History Online
ELISA	Enzyme Linked Immunosorbent Assay
EPA	Environmental Protection Agency
GAC	Granulated Activated Carbon
HAAs	Haloacetic Acids (HAA5)
HAs	Health Advisories
HABs	Harmful Algal Blooms
LC/MS/MS	Liquid Chromatography/Mass Spectrometry/Mass Spectrometry
MCL	Maximum Contaminant Level
MF	Microfiltration
NF	Nanofiltration
MIB	Methylisoborneol
NOAA	National Oceanic and Atmospheric Administration
NPDAT	Nitrogen and Phosphorus Data Access Tool
NPDES	National Pollution Discharge Elimination System
NTU	Nephelometric Turbidity Unit
PAC	Powdered Activated Carbon
PWS	Public Water System
RO	Reverse Osmosis
SDWA	Safe Drinking Water Act
STORET	STOrage and RETrieval
SWC	Source Water Collaborative
TMDL	Total Maximum Daily Load
TTHMs	Total Trihalomethanes
UF	Ultrafiltration
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV	Ultraviolet
WHO	World Health Organization
WRF	Water Research Foundation

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Executive Summary

This cyanotoxin management document is a companion to the United States Environmental Protection Agency's (EPA) Health Advisories (HAs) for microcystins and cylindrospermopsin. Human exposure to cyanotoxins can result in a host of adverse health effects, including gastroenteritis, liver damage and kidney damage. The HA values represent concentrations in drinking water below which adverse noncarcinogenic effects are not expected to result from the ingestion of drinking water. Derivation of the HAs is described in detail in the final EPA HA documents for these cyanotoxins.

Cyanotoxins can enter drinking water supplies as a result of the growth of harmful algal blooms (HABs) in surface water sources or ground water sources under the direct influence of surface water. The formation of algal blooms is dependent upon a number of environmental conditions, including the presence of nutrients (such as nitrogen, phosphorus), climate, and stratification of the water source.

This document is intended to assist public drinking water systems (PWSs) that choose to develop system-specific plans for evaluating their source waters for vulnerability to contamination by microcystins and cylindrospermopsin. It could also serve as a model for addressing potential concerns from other cyanotoxins in the future. The document provides a stepwise approach PWSs could use to inform their decisions on whether and how to monitor and (or) treat for microcystins and cylindrospermopsin and when and how to communicate with stakeholders. The stepwise approach includes the following five steps:

- Step one involves conducting a system-specific evaluation for vulnerability to blooms;
- Step two suggests activities for preparing and observing for potential blooms;
- Step three describes monitoring activities to determine whether cyanotoxins are present in the raw water, and recommended communication and treatment activities if cyanotoxins are found in the raw water;
- Step four describes monitoring activities to determine whether cyanotoxins are present in finished water and recommended communication and treatment activities if cyanotoxins are found; and
- Step five describes continued finished water monitoring (confirming the initial finished water sample in Step 4), treatment and communication activities if cyanotoxins are found in the finished water above acceptable levels.

This document provides information and a framework that PWSs may consider if they choose to develop a system-specific cyanotoxin management plan (CMP). This document includes a three-tiered, traffic light strategy as an example of an approach that could be used to provide information to the public about algal toxin levels in local drinking water. Clear and effective communication is critical to support informed choices about how to best protect the public from adverse health impacts from HABs. It can also support the states in assisting PWSs and other stakeholders in their cyanotoxin risk management efforts. The recommendations in this document may be updated over time as EPA receives new relevant information related to

effective strategies for monitoring, treatment and communication with stakeholders regarding management of cyanotoxins in drinking water.

A. Introduction

Cyanobacteria, also known as blue-green algae, naturally occur within marine and fresh water ecosystems. Some cyanobacteria are capable of producing toxins, called cyanotoxins, which can pose a risk to human health (U.S. EPA, 2014a). Under certain conditions cyanobacteria can grow rapidly, producing cyanobacterial blooms, often referred to as HABs. A bloom is a rapid and excessive growth of cyanobacteria (AWWA and WRF, 2015). It is not possible to determine solely upon visual observation if a bloom is producing toxins, thus any bloom is potentially dangerous. When blooms occur, the risk of cyanotoxin contamination of the surface water increases, placing potential risk to drinking water sources (U.S. EPA, 2014a).

The purpose of this document is to provide information to public water systems (PWSs), state and local authorities, and other stakeholders to assist with the management of cyanotoxin occurrence in drinking water. This document is a companion to EPA's HAs for microcystins and cylindrospermopsin.

This document is not a regulation; it is not legally enforceable; and it does not confer legal rights or impose legal obligations on any party, including EPA, states, or the regulated community. This document describes approaches PWSs can consider in developing a system-specific plan. This document includes recommendations for coordination, preparation, monitoring, treatment responses and communication. Some aspects of this approach may also be useful when responding to the occurrence of other cyanotoxins in addition to microcystins and cylindrospermopsin. The recommendations in this document may be updated over time as EPA receives new relevant information related to effective strategies for monitoring, treatment and communication with stakeholders regarding management of cyanotoxins in drinking water.

In some states, primacy agencies may already have existing programs for addressing cyanotoxins; the information provided in this document can be used to supplement these programs, as appropriate. EPA also recognizes that states and PWSs may have collected relevant information through source water monitoring or assessments and may have other information (for example, watershed-level information) that can help the PWS manage risks from cyanotoxins in drinking water.

Increases in cyanobacterial blooms are driven by a number of factors, including excess nutrient loading from anthropogenic sources (Paerl and Otten, 2013; Conley et al., 2009, Glibert et al. 2014) and climate change that produces conditions that favor bloom formation (Paerl and Huisman, 2009). In addition, Doblin et al. (2007) demonstrated that cyanobacteria that produce HABs can be transported in ballast water from shipping from a port where active blooms occur to other locations when ballast water is discharged.

A critical step for reducing human health risks from algal toxins is coordinated action by multiple groups and organizations to reduce the anthropogenic inputs that can lead to algal blooms. Reducing nitrogen and phosphorus pollution can reduce cyanobacterial blooms, thereby reducing treatment costs to utilities and human health risks caused by cyanotoxins in sources of drinking water (Paerl, 2014). This document discusses tools that can be useful for protecting source waters from excess nutrient loading.

B. What is a Health Advisory?

EPA Health Advisories (HAs) provide technical guidance on health effects, analytical methodologies and treatment technologies associated with contaminants that are known or expected to occur in drinking water. Under the Safe Drinking Water Act (SDWA), EPA may publish Health Advisories for contaminants that are not subject to any national primary drinking water regulation. 42 § 300g-1(b)(1)(F)[1]. HAs are not legally enforceable under SDWA, but serve as technical guidance to assist federal, state, and local officials and drinking water system owners and operators in managing drinking water resources and achieving public health goals (U.S. EPA, 2012a). While EPA recognizes there are multiple water quality concerns related to cyanotoxins, EPA has only developed drinking water HAs at this time. EPA intends to develop criteria under Section 304(a) of the Clean Water Act (CWA) to address recreational exposure to cyanotoxins in the future.

Typically, HA values are developed for One-Day, Ten-Day, and (or) Lifetime exposure durations. HA values are an estimate of the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for the period of exposure. HAs are intended to serve as informal recommendations for federal, state, and local officials and water system managers during emergency spills or contamination situations for a specific chemical that is otherwise not often found in drinking water supplies (U.S. EPA, 2008). A HA value is determined using the best available information on health effects, exposure and other relevant data. For more information on HAs, please visit the EPA Health Advisory website (U.S. EPA, 2014b) or view the 2012 Edition of Drinking Water Standards and Health Advisories (U.S. EPA, 2012a).

EPA released Ten-day HA values for microcystins and cylindrospermopsin concurrent with the release of this document. EPA recommends that systems take actions to protect the public from exposure to microcystins and cylindrospermopsin as soon as practicable, recognizing that the response to the detection of cyanotoxins may take a few days. Development of a system-specific management plan can help water systems prevent cyanotoxin levels from reaching levels of public health concern in drinking water. The Ten-day HA recommended concentrations for total microcystins are 0.3 µg/L for bottle-fed infants and young children of pre-school age (less than six years of age) and 1.6 µg/L for all other ages. The HA for microcystins was developed based on studies of microcystin-LR; for the purposes of the HA, microcystin-LR is considered a surrogate for all microcystins. The Ten-day HA recommended concentrations for cylindrospermopsin are 0.7 µg/L for bottle-fed infants and young children of pre-school age and 3.0 µg/L for all other ages. For more information on Health Advisories for the microcystins and cylindrospermopsin, please see (U.S. EPA, 2015a,b). For more in-depth discussion of the science used to develop the Health Advisories, please see the Cyanotoxin Health Effects Support Documents (U.S. EPA, 2015c,d,e).

[1] "The Administrator may publish health advisories (which are not regulations) or take other appropriate actions for contaminants not subject to any national primary drinking water regulation." 42 § 300g-1(b)(1)(F)

C. Cyanotoxin Management Plan Development

EPA encourages PWSs to carefully consider their potential vulnerability to HABs and to consider developing a system-specific cyanotoxin management plan (CMP) prior to any projected algal bloom occurrence. In much of the U.S., blooms typically occur seasonally, but in some climates blooms can occur throughout the year. PWSs may want to periodically evaluate and modify their CMPs as their understanding of the specific challenges related to HABs facing their system evolves.

The first step for some systems to consider in developing a CMP is coordination across the various parties that would participate in the response to a HAB event. Systems developing CMPs are likely to benefit from coordination with individuals with experience in all aspects of the drinking water treatment process including source water intake, sample collection, treatment and distribution, as well as on-site laboratory personnel or contacts from outside laboratories capable of analyzing cyanotoxins. Systems are also likely to benefit from coordination with communications specialists, representatives from state and local public health agencies, state and local environmental agencies, local government personnel and other local entities that are likely to be involved in a response to a HAB event. The system may also want to designate a team leader or other official to identify the roles and responsibilities of each member of the team, evaluate and update these roles and responsibilities as needed and take responsibility for overseeing development of the CMP.

This document presents EPA recommendations for one possible approach to developing a CMP, (see Figures 1 and 2) including components for determining if and when a PWS is vulnerable to cyanotoxins, monitoring for cyanotoxins, suitable treatment actions, and communication strategies. There is a model of this approach in section D of this document. The potential management steps are intended to provide a stepwise process that allows a PWS, as it deems appropriate, to take action to reduce the likelihood of cyanotoxin occurrence in finished water. The following paragraphs discuss each of the elements of this CMP approach.

Monitoring

A PWS may benefit from incorporating different types of monitoring in its CMP. Source water and system observations can inform system decisions about when to start cyanotoxin monitoring in raw and finished water, when and how to adjust treatment plant operations, and when to communicate with external stakeholders and the public. EPA does not currently regulate cyanotoxins and PWSs are not required to monitor for cyanotoxins in their drinking water (unless required by their primacy agencies). If a PWS decides to monitor, it should consider maintaining records of any monitoring occurring as part of a CMP, as historical data can be valuable to a PWS (and nearby systems) for determining their vulnerability to cyanotoxins. Sampling frequencies are useful to include in a CMP. Monitoring information and related resources are discussed in each of the potential cyanotoxin management steps.

Treatment

EPA recommends that a PWS identify treatment and management strategies as part of a CMP to address cyanotoxins in drinking water in the context of its other drinking water treatment goals (for example, turbidity control, disinfection byproduct (DBP) control, disinfection, taste and odor

control, corrosion control, etc.). The PWS may also want to consider potential strategies for source water protection as well as control measures at the water treatment facilities to remove cyanotoxins from the drinking water. A PWS can evaluate the existing treatment capabilities and make short- and long-term improvements as needed before the bloom season so that it can respond to detections of cyanotoxins in raw and (or) finished water as soon as possible. This document provides an overview of different treatment and management options, and general information on treatment adjustments and improvements based on information from published literature, research reports, guidance manuals and other resources. Additional treatment information is provided with each step in the potential management steps. More comprehensive literature review of treatment technologies and a water utilities' guide can be found elsewhere (WHO, 1999; Newcombe, 2009; Newcombe et al., 2010; Westrick et al., 2010; AWWA and WRF, 2015).

Communication

EPA recommends that drinking water systems consider communications to be an integral part of every step of a CMP. Important communications to consider as a part of a CMP include sharing of information with the primacy agency, contract laboratories, neighboring drinking water systems, local officials and the public. For public communications, it may also be beneficial to ensure that communication strategies take into consideration the media and non-English speakers, as well as segments of the public that are likely to take the greatest interest in messaging on cyanotoxins (such as parents of bottle-fed infants and young children of pre-school age [less than six years old], including bottle-fed infants). Partnerships to aid in communication with sensitive populations would be helpful to include as part of a CMP, such as with day care centers and pediatricians.

A useful tool to utilize when developing a communication strategy is the Drinking Water Advisory Communication Toolbox (DWACT) (CDC, 2013) and EPA's Developing Risk Communication Plans for Drinking Water Contamination Incidents (U.S. EPA, 2013a). These tools can help to prepare for communicating about cyanobacterial blooms and cyanotoxin occurrence. The toolbox includes tips on what to do before, during, and after issuing public notices. It also describes with whom to consider collaborating before issuing public notices and how to work with the media. The risk communication guidance document has information and templates for communicating with the public during a drinking water contamination incident. PWSs can also consult with their primacy agency for additional available communication tools and resources as appropriate. For example, Ohio and Oregon have public messaging templates available (Ohio EPA, 2014; Oregon Health Authority, 2013). Appendix D contains potential language for use in cyanotoxin public notification and social media alerts. Local source water assessment or protection organizations may also be leveraged to communicate key messages to the drinking water community; a few of these watershed groups can be found through the Source Water Collaborative "How to Collaborate Toolkit" (SWC, 2015a). Additional communication strategies are discussed throughout this document as the different steps in the potential management steps are discussed.

D. Potential Cyanotoxin Management Steps

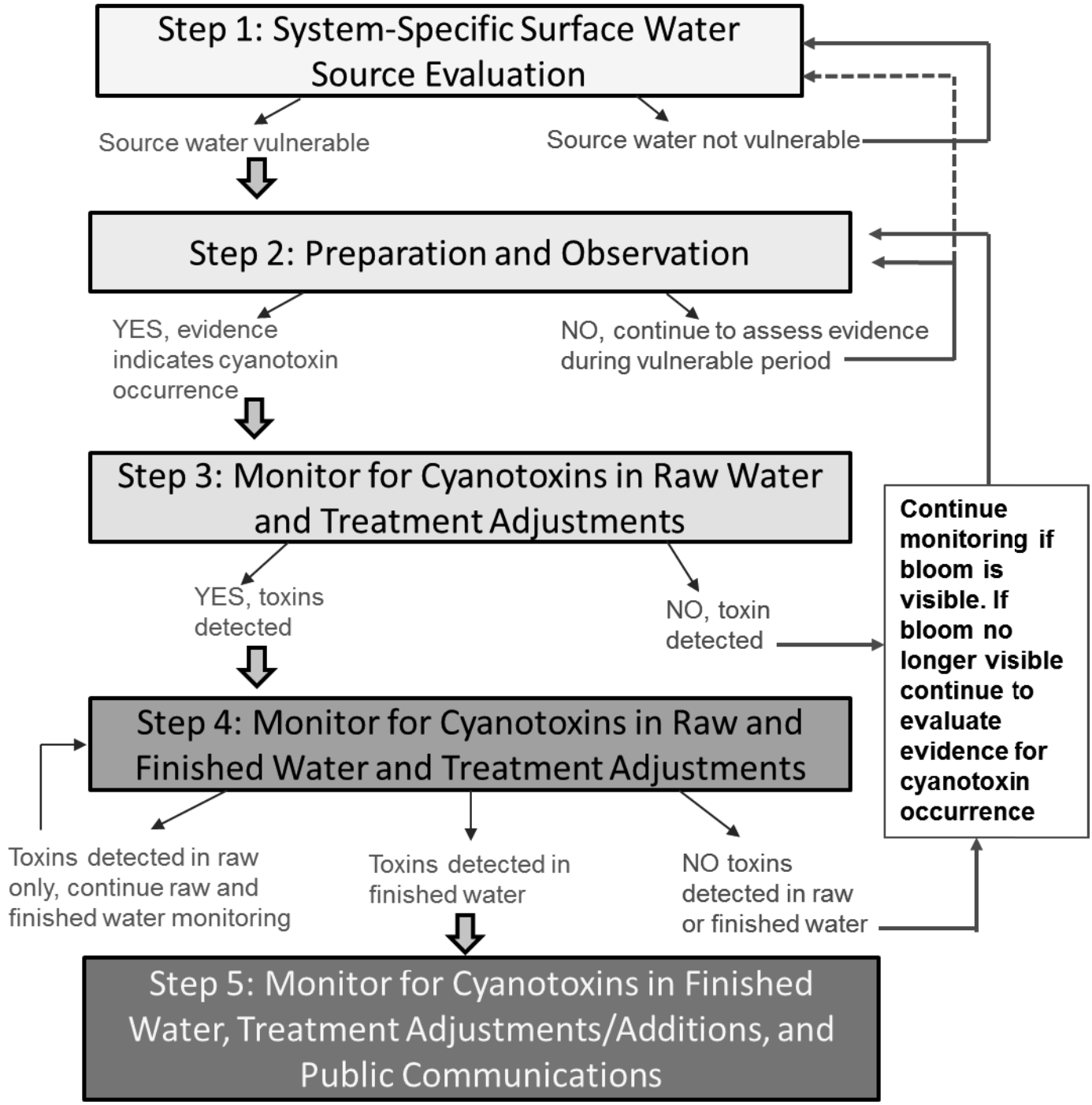

Figure 1. Potential management steps public surface water systems may use to determine whether cyanotoxins are present in raw water or finished drinking water.

Figure 1 depicts potential management steps public surface water systems may use to determine whether cyanotoxins are present in raw water or finished drinking water. The potential management steps contain suggested actions for monitoring, treatment and communication. Step 1 involves conducting a system-specific evaluation to determine if and when a PWS is

vulnerable to cyanotoxin occurrence. Step 2 involves preparing for possible cyanotoxin occurrence and observations to detect potential for cyanotoxin occurrence in source waters, including visual bloom observation, treatment plant effects and source water indicators. If a PWS observes indications of a HAB that may impact their drinking water system, raw water monitoring is recommended (Step 3). If raw water monitoring indicates the presence of cyanotoxins, the PWS may elect to initiate finished water monitoring (Step 4). If cyanotoxins are detected in finished water, PWSs are encouraged to confirm the presence of cyanotoxins in finished drinking water (Step 5). Treatment and potential communication actions are provided based on the concentration of algal toxins detected in finished water. Each of the steps will be described in further detail in subsequent sections. The primary goal of a CMP is to prevent cyanotoxins from entering the finished drinking water. The potential management steps follow a multi-barrier approach starting with source water protection to ensure that public health is not impacted by the presence of cyanotoxins in finished drinking water. Drinking water systems that develop a CMP are encouraged to tailor their approach based on local knowledge of bloom history and growth conditions to ensure effective use of resources and be flexible to accommodate changing conditions the PWS may experience.

1 Step 1: Conduct System-Specific Surface Water Evaluation

An essential component of the long-term solution to impacts of algal toxins on drinking water supplies will be effective source water protection strategies to limit excess nutrients in surface water. Step 1 of the potential management steps involves a system-specific evaluation of source water to determine if there are vulnerabilities to cyanotoxin occurrence. A variety of information can be considered in this evaluation including the type of source water, historical cyanotoxin occurrence, weather data, seasonal patterns of cyanobacterial blooms, land use patterns, nutrient levels, chlorophyll-a and phycocyanin levels, point and nonpoint sources of contamination upstream, water quality impairments and information gathered as part of source water assessments. Determining source water vulnerability to cyanotoxins is important so that the PWS can be prepared to respond to cyanotoxin occurrence if needed. The outcome of the system-specific evaluation of source water will help a PWS determine whether to proceed to Step 2 of the potential management steps (preparation and observations for possible bloom events).

Cyanobacterial blooms can increase the amount of cyanotoxins in source waters to levels that can be harmful to human health. Blooms occur when conditions in source waters are conducive to growth based on a variety of factors (WHO, 1999). A PWS may wish to take a weight of evidence approach to identifying source water vulnerability, as there are no single predictors of the likelihood of bloom occurrence. Examples of the types of information to review in the system-specific evaluation include:

- Source Water Characteristics
- Water Quality Parameters
- Source Water Assessment Information
- Climate and Weather Information
- Land Use
- Nutrient Levels

Some source waters will have greater vulnerabilities than others based on source water characteristics. For example, ground water systems (not directly influenced by surface water) are not anticipated to have vulnerabilities to cyanotoxins. Likewise, fast flowing, nutrient-poor rivers are less vulnerable than nutrient-rich lakes and reservoirs. Water quality parameters can help to determine if the source water has had a history of blooms or bloom indicators such as cyanobacterial cell counts or chlorophyll-a levels. Elevated nitrogen and phosphorus levels will be important to consider in a system-specific evaluation. Source water assessments, including a consideration of the predominant land use in the watershed and potential nutrient sources that may lead to cyanobacterial growth, will provide useful information for a system-specific evaluation. Similarly, climate and weather information such as water temperature and intensity of precipitation events can help a system determine if a source water has conditions conducive to cyanobacterial growth. Each of these factors are discussed in greater detail in Appendix A of this document. Additionally, links to data sources and tools that may be helpful in conducting a system-specific vulnerability evaluation are provided in Appendix A.

A PWS may wish to conduct a system-specific evaluation for all drinking water sources utilized by the PWS and collaborate with other PWSs using the same source water. A PWS may also consider collaborating with other source water stakeholders who may have additional information that could be included in a system-specific evaluation. The Source Water Collaborative's "How to Collaborate Toolkit", as discussed in the introduction, is also a useful resource to help watershed stakeholders form partnerships (SWC, 2015a). EPA recognizes that some of the information discussed in this section and Appendix A may not be available for every drinking water source.

EPA recommends systems evaluate available data on their source water to make a weight of evidence determination about their vulnerability to cyanotoxins. If the PWS determines their source water is vulnerable, EPA recommends that the system proceed to Step 2 of the process. If a PWS determines that their source water is not vulnerable to cyanotoxins, the PWS may want to consider periodically reassessing its source water as watershed characteristics could change over time.

2 Step 2: Preparation and Observation

If a PWS has determined they have vulnerabilities to cyanotoxins, EPA recommends that the PWS consider preparing and observing for possible cyanobacterial blooms and cyanotoxin occurrence. A PWS can prepare by determining when blooms are most likely to occur, evaluating the current treatment process to determine susceptibility and vulnerabilities, and determining if long-term mitigation strategies are available to prevent the blooms from occurring and cyanotoxins from reaching drinking water sources. A PWS can observe source waters for possible bloom occurrence by visual inspection, evaluating system effects, and recognizing bloom indicators.

2.1 Preparation

Seasonal Variation

If the PWS determines that their watershed is vulnerable to HABs, it will be useful for the PWS to determine when their source water is likely to be at greatest risk for the presence of cyanotoxins. Cyanobacteria and cyanotoxin occurrence can have seasonal variation depending on the location and condition of the watershed. In many parts of the U.S., this peak season occurs from late May to early October, but may be longer or shorter, depending on local conditions. Some cyanobacteria can persist during colder temperatures; for example, in some cases, the State of Ohio has documented peak toxin concentrations occurring in November and December. Climate conditions and short-term weather events can greatly impact the timing and duration of bloom occurrences. If the season of greatest vulnerability is unknown in a watershed that has had previous bloom events, monitoring can help the PWS determine when this is likely to occur.

EPA encourages the PWS to use all available information and consult with the primacy agency to perform the system-specific evaluation described in this section. The combined information can help the PWS determine if and when blooms may occur. Once the PWS has identified the timing of greatest vulnerability to cyanotoxins, the PWS can take steps to observe for possible blooms during this period (included in this Step).

Existing Treatment Evaluation

If a PWS finds that it is vulnerable to cyanotoxins, it may want to consider evaluating whether it has effective measures in place to respond to cyanotoxins in drinking water that are compatible with meeting other treatment goals. For example, the PWS may want to examine its raw water supply and treatment process to determine the likelihood of toxin release from intact cells either in the reservoir or at the raw water intake and the level of protection provided by the existing treatment (WHO, 1999). Examples of treatment evaluation questions that could be asked include:

- Is the existing treatment a conventional coagulation, clarification and filtration process that is likely to be effective for intact cell removal?
- Can the existing system handle more frequent backwashing and more sludge in the event of a cyanobacterial bloom?
- Are there any conditions such as pre-oxidation that could lead to cell lysis?
- Is chlorination being operated adequately to oxidize cyanotoxins?
- Can powdered activated carbon (PAC) be added at adequate doses?
- Are there any advanced water treatment facilities with ozonation and (or) granular activated carbon (GAC) that can be used to effectively remove dissolved toxins?

A PWS that is particularly concerned with the potential presence of algal toxins in their source water may want to consider performing bench and pilot studies to simulate the full-scale system operation under a cyanobacterial bloom condition.

In general, systems that are impacted by cyanotoxins on a seasonal basis may want to consider the use of temporary supplementary treatment, such as PAC, which can be added intermittently to the existing treatment process as part of an immediate response to cyanotoxins in drinking

water. Systems that are impacted by cyanotoxins on a recurring basis or throughout the year may want to consider installing permanent treatment as a long-term, cost-effective alternative, such as GAC, ozonation, and membrane filtration, if they have not already done so. It is important to remember that all treatment options have specific trade-offs that must be considered before implementation (U.S. EPA, 2014d). More information on treatment options are described later in this document, as well as in EPA's HAs for microcystins and cylindrospermopsin (U.S. EPA, 2015a,b).

2.2 Observation

If a PWS has determined that its source water is vulnerable to cyanotoxins, the PWS may want to begin regular observation for possible blooms (Step 2). A bloom can have extremely high cell densities of phytoplankton (extremely high densities are typically defined as greater than 20,000 to 100,000 cells per mL). Proliferation of phytoplankton is typically dominated by a single or a few species (Loftin et al., 2008). Cyanobacterial blooms may float on the water surface or be mixed throughout the photic zone, epilimnion or water column (Loftin et al., 2008).

There are multiple indicators of the potential presence of a HAB, including: 1) visual indicators and phytoplankton identification, 2) system effects and 3) other bloom indicators. Visual indicators include both visual confirmation of a bloom at or near the raw water intake, and confirmed reports of blooms by the public and phytoplankton identification. Routine microscopic phytoplankton identification can provide information when blooms are not visually apparent and to help determine the type of bloom. System effects of bloom occurrence involves a weight of evidence approach looking at multiple elements within the drinking water treatment system such as increased pH, shortened filter run times or taste and odor events. Potential source water indicators of bloom events include increased turbidity, increased nutrient levels, increased cyanobacterial cell counts, increased chlorophyll-a or phycocyanin levels and increased temperature in source water. Each of these parameters is discussed in greater detail below. Tracking multiple indicators can help the PWS prepare for cyanotoxin occurrence in source water.

If no indication of a bloom has occurred, EPA encourages the PWS to continue observing for possible blooms throughout the vulnerable season determined previously as part of this Step. If any of the three types of observations indicates a bloom is occurring near the source water intake, the PWS may want to begin monitoring its raw water for toxins (Step 3).

2.2.1 Visual Inspection and Phytoplankton Identification

What is visual inspection?

Visual inspection involves looking for visual signs of a possible bloom, such as water clarity, discoloration and scum formation near a water intake (Newcombe, 2009). Colors can range from grey or tan, to blue-green or bright blue or reddish. The appearance of blooms may also be described as fine grass clippings or small clumps. In general, a healthy cyanobacterial scum will appear like bright green or olive green paint on the surface of the water. Scums look blue or red in color when some or all of the cells are dying and release their pigments into the surrounding water (Newcombe et al., 2010). Some cyanobacteria produce a distinctive earthy and musty odor, related to the production of geosmin or Methylisoborneol (MIB) that can often be smelled

at some distance before the bloom can be seen. Not all blooms will give off a recognizable odor, as many cyanobacteria are not capable of producing taste and odor compounds. Visual inspection provides valuable information on cyanobacterial growth and is an important part of any monitoring program (Newcombe et al., 2010).

Who should conduct a visual inspection?

A bloom may be observed or reported by the PWS operators, state or local stakeholders, or the general public. Properly trained professional staff might conduct field inspection of drinking water sources regularly throughout the year, focusing on specific seasons the source water was previously determined to be vulnerable.

The general public is also encouraged to notify their states or the PWSs as soon as they see a bloom. For example, Ohio EPA encourages individuals reporting potential blooms to fill out a Bloom Report Form on their website and email the form, with attached digital photographs (if available), to a designated mailbox (Ohio EPA, 2014). Individuals are encouraged to report the bloom location, color, size, and appearance, nearby public beach or drinking water plant intake(s) (if any), as well as any other available water quality information. The State of New York has a Suspicious Algae Bloom Report Form and a program for citizens to send in photos of the suspected blooms (New York, 2015). The PWS may want to consider creating outreach tools for their community to educate the public on blooms and what to do if they see a bloom. PWSs should also consider partnering with outside organizations, such as the local health department, who may be conducting recreational water monitoring for potential blooms and can inform the PWS when blooms may be headed towards intake structures.

When, where, and how often should visual inspection be conducted?

A PWS may want to conduct a visual inspection regularly throughout the vulnerable season as determined by the PWS in the system-specific evaluation (Step 1). This peak season usually occurs in the Midwest from late May to early October, but may be longer in other areas, depending on local conditions. The distribution of cyanobacteria depends on the morphological, hydrogeological, meteorological and geographic characteristics of a given water body. For example, accumulations are normally observed at the downwind end of a reservoir, lake or river reach. Cyanobacteria may also migrate throughout the water column during the day; inspection could focus on those times the bloom is most likely to be at the surface. A visual tool that could be used includes the Secchi disk, a tool used to measure water transparency (Tilzer, 1988). A change in Secchi disk depth over time (where the water becomes more turbid or has decreased clarity) could indicate bloom occurrence (WHO, 2000).

The frequency of visual inspection may vary depending on seasonal and weather conditions. PWSs may want to conduct a visual site inspection at daily, weekly, or biweekly intervals during bloom season and increase to more frequent intervals if cyanobacteria begin to proliferate.

Limitations of visual inspection

The visual inspection method may not detect some cyanobacteria, such as *Planktothrix* or *Cylindrospermopsis,* which do not form a scum or those cyanobacteria that bloom along the thermocline (Newcombe, 2009). The only indication of a *Planktothrix* or *Cylindrospermopsis*

bloom may be a slight green or brown discoloration of the water. For non-bloom forming cyanobacteria, it is important to collect samples for analysis to determine the abundance of cyanobacteria in the water body if the PWS believes it is vulnerable to cyanotoxin occurrence. Cyanobacterial blooms may be confused with scums or mats of filamentous green algae. There are blooms of other phytoplankton that look very similar to cyanobacterial blooms, but these cannot be readily distinguished without microscopic evaluation. It is important to note that not all blooms will produce cyanotoxins, and cyanotoxins can occur when blooms are not visible. It may be useful for systems to conduct some monitoring if conditions are favorable for the production of algal blooms but visual inspection is insufficient to determine the potential presence of algal toxins in source water.

Routine Phytoplankton Monitoring

In addition to visual inspection, water systems may want to consider routine phytoplankton identification. Routine phytoplankton monitoring can:

- Help visually distinguish green algae and diatom blooms from potentially harmful cyanobacterial blooms.
- Provide information on cyanobacteria that may be present at intake depths, but not visually apparent at the water surface.
- Catch *Planktothrix* and other non-scum forming blooms that would be less likely to be visually apparent.
- Detect lower concentrations of cyanobacteria that may not be visually apparent. This could aid in reservoir management strategies and help trigger early treatment adjustments.
- Aid in identifying targets for monitoring of cyanotoxins in raw and finished water.
- Help meet other treatment objectives. Increases in diatoms can cause fishy odors, clog filters, increase chlorine demand and lead to problems with disinfection byproducts.

A PWS should ensure that staff are properly trained prior to attempting phytoplankton identification.

2.2.2 System Effects

A bloom may impact water quality and treatment plant operations. The changes commonly associated with a cyanobacterial bloom are listed below. If a PWS determines that a bloom may be occurring through a weight of evidence evaluation of system effects, the PWS may want to proceed with raw water monitoring (Step 3), even if the plant intake does not show visual signs of a bloom being present.

- **Increased taste and odor**. Some cyanobacteria can produce MIB and geosmin, which can cause taste and odor issues within the treatment plant and distribution system during cyanobacterial blooms. Other taste and odor impacts may not be associated with cyanobacteria (for example a fishy odor is typically associated with a diatom bloom, which would not produce cyanotoxins).
- **Increased pH**. As cyanobacteria draw carbon dioxide out of the water during photosynthesis, pH tends to rise. Therefore, pH increases are more often observed when

cyanobacterial growth is expanding in water. Diurnal pH swings may also occur. As cyanobacteria draw carbon dioxide out of the water during photosynthesis, pH may increase throughout the day. Increases in pH could also be caused by green algae blooms, but routine phytoplankton monitoring would help distinguish between the two.

- **Increased turbidity**. Treatment plants may experience higher turbidity, in some cases, in filter influent and effluent due to cyanobacterial growth and cell production.
- **Decreased filter run times**. Treatment plants may experience shortened filter run times during cyanobacterial blooms to varying degrees depending on the species. For example, although not entirely the result of cyanobacteria, one water treatment plant reported that the average filter run time was every 24 to 48 hours in the summer – notably less than the 72 hours or more in the winter (Kommineni et al., 2009).
- **Need for increased coagulant dose**. A higher coagulant dose is often needed, potentially due to increased turbidity and total organic matter in water during a cyanobacterial bloom or the tendency for some cyanobacteria to float and inhibit settling. One treatment plant reported an approximately 50 percent increase in its average alum dose in the summer (Kommineni et al., 2009).
- **Increased chlorine demand or decreased chlorine residual**. The increased organic matter loading during a cyanobacterial bloom, if not adequately removed, could result in a higher chlorine demand. Treatment plants reported that the chlorine residual was decreased during algal growth events (Kommineni et al., 2009).

2.2.3 Other Bloom Indicators

Environmental monitoring of physical, chemical and biological variables indicating bloom-formation potential is important but can be resource intensive if data are not already available. Those key indicators can include cyanobacterial cell counts, biovolumes (the volume of cells in a unit amount of water, mm^3/L), chlorophyll-a and phycocyanin concentrations, presence of cyanotoxin production genes in source water, nutrient concentrations (nitrogen and phosphorus), changes in hydrophysical conditions and new weather patterns (such as increased temperature and (or) rain) (Izydorczyk et al., 2005; Ohio EPA, 2014). National Oceanic and Atmospheric Association (NOAA) satellite imagery data are also being used to predict blooms in western Lake Erie and the Gulf of Mexico (Florida and Texas). NOAA, U.S. EPA, United States Geological Survey (USGS), and NASA are partnering on the Cyanobacteria Assessment Network (CyAN) project, which includes making satellite data processed for cyanobacteria abundance available for large inland lakes nationwide once new satellite sensors come online and the data has been evaluated. EPA encourages PWSs to use all available data, as discussed in Step 1, as part of a weight of evidence approach to determine if recent changes have occurred, possibly indicating bloom occurrence. Bloom indicators can be used to inform a decision whether a PWS should proceed with toxin analysis. The World Health Organization has a resource available that contains some details on specific parameters such as cyanobacterial cell counts or chlorophyll-a levels, which may indicate a severe bloom compared to a moderate or minor bloom (WHO, 1999).

The partnerships discussed in section 1 could be helpful for gathering data on the occurrence of certain HAB indicators. For example, having partnerships in place with watershed stakeholders could allow for quick dissemination of monitoring information and potential changes in source water quality within the watershed. As an example of one possible volunteer monitoring program, the Sierra Club of Ohio has a Water Sentinel Program, which enlists volunteers to

monitor waterways for a variety of pollutants (Ohio Sierra Club, 2015). Another example of a volunteer monitoring program is the Ohio Lake Management Society's Citizen Lake Assessment and Monitoring (CLAM) program. Citizen-collected cyanotoxin data from this program triggered cyanotoxin sampling at a public water supply that was not experiencing any operational or water quality issues at the time. Even though a visible bloom was not apparent at the intake, the water system sampling revealed microcystins were present at the intake depth, and continued to be detected at elevated concentrations for several months (OLMS, 2014). The U.S. Army Corps of Engineers (USACE) also has an extensive lake monitoring program that could provide valuable information to water systems with USACE source waters (USACE, 2015).

2.3 Communication

If any of the key indicators suggest the potential for bloom formation, the PWS may want to begin sampling the raw water for cyanotoxins (Step 3). Systems may also want to consider communicating with the primacy agency and state and local officials to make them aware of the potential bloom so that those agencies can be ready to assist if cyanotoxins are detected at the PWS. Communications might include notifying the laboratory of pending raw water samples (if using an outside laboratory), and informing the system's public affairs personnel so they can be prepared in the event cyanotoxins are detected at levels of concern in the finished water. The PWS may also want to consider informing other users of the source water to let them know that a bloom has been detected or has likely occurred, such as for recreational purposes or animal uses.

If a PWS determines they may be impacted by a bloom, the PWS could consider working with public health officials to raise awareness about HABs. Information on source water protection activities that could reduce the likelihood of HABs could also be provided.

2.4 Source Water Mitigation

Systems that have observed a possible bloom in the source water may also want to consider taking initial actions to eliminate or mitigate the bloom before it impacts the drinking water intake. Various treatment and management strategies are available to control cyanobacterial blooms. EPA recommends PWSs consult with their state and local governments and primacy agencies as some of these treatment and management strategies discussed below could have various requirements, such as permit requirements, as well as unintended impacts on the source water.

Intake Relocation and Alternative Source

Some systems have the ability to adjust the depths of their intakes (WHO, 1999) and draw from multiple intake depths at one intake tower, which can be used to minimize the intake of cyanobacterial cells that have accumulated on the surface or at certain depths (Newcombe et al., 2010). For example, a reservoir may have multiple intake depths to choose from and can use water quality monitoring data to determine which intake to utilize. However, this may not be an option for avoiding cell uptake in some shallow waters (Vermont Environmental Conservation, 2014). Also, some systems may be able to locate their raw water intakes away from areas where blooms have accumulated, such as sheltered bays, or provide temporary extensions to existing intakes (WHO, 1999). Some systems may have multiple reservoirs, and can discontinue use of

one source during a bloom event and rely on other sources, including blending with ground water.

Bypassing pre-sedimentation ponds

Some systems on rivers have pre-sedimentation ponds or reservoirs. Many of these pre-sedimentation ponds were not designed to be drained and cleaned and are now their own sources of nutrients. Even when the original source waters do not contain blooms, it is possible that conditions within the ponds can support the formation of blooms. Systems that are experiencing bloom formation in pre-sedimentation ponds can develop a process to bypass these pre-sedimentation ponds for the duration of the bloom. Long-term solutions include eliminating pre-sedimentation ponds from the treatment train, dividing the pond or reservoir in half, or installing drains and linings. This will allow the system to take one side out of service while power washing and draining the sediments out of the other side.

Ultrasonic Treatment

Ultrasonic treatment has the potential to help prevent blooms from forming and has been used as an inexpensive measure in some instances to disrupt gas vesicles within the cells, as well as to interfere with photosynthesis and cell division (Rajasekhar et al., 2012). While this treatment demonstrated a 93.5 percent destruction of *M. aeruginosa* when coupled with coagulation (Tokodi et al., 2012), in some cases this treatment can increase the release of intracellular toxins, (U.S. EPA, 2014d) and practicing coagulation in the raw water source may be difficult. Therefore, PWSs are encouraged to consult with their state and local governments before installing this treatment in the source water.

Algaecides

One strategy that has seen widespread use is the addition of algaecides to the source water, which may kill off the cyanobacteria and prevent operational problems in the water treatment plant. Examples of algaecides include copper sulfate, copper citrate and hydrogen peroxide formulations (U.S. EPA, 2014d). However, EPA does not encourage the use of algaecides in drinking water sources. Until recently algaecides were added without a complete understanding of the potential environmental concerns (for example, toxicity to aquatic life). Copper-containing compounds may create water quality concerns for both the aquatic environment and the drinking water source. Furthermore, microcystin-producing cyanobacteria have been demonstrated to have the potential to develop resistance to copper if treatments are repeatedly applied (Garcia-Villadra et al., 2004).

Another concern with using algaecides in general is that cell death can lead to the release of the intracellular toxins; hence, algaecides are only recommended to be used as an emergency measure in the early stages of a bloom, when the resultant toxin concentrations that may be released are likely to be low (U.S. EPA, 2014d). Australian guidance recommends against using copper sulfate due to the potential ecological effects (Newcombe, 2010). The World Health Organization suggests using copper sulfate only in dedicated water supply reservoirs (WHO, 1999). To protect against environmental concerns, some state governments require coverage under a general permit prior to applying algaecides to a source of drinking water, and some states may have specific algaecide prohibitions. PWSs should consult with their state and local governments (and primacy agency) before the application of algaecides.

Coagulants

The addition of a coagulant (such as alum) to the source water has been shown to lead to the precipitation of phosphorus to the source water's sediment layer and can coagulate cells out of the water. There are mixed opinions on whether cell lysis results from coagulation applied in the source water, and there have been reported depth limitations. Once the phosphorus is settled, the sediment can be capped to prevent re-release (U.S. EPA, 2014d).

Skimming

Skimming the surface of a source water containing a bloom can remove the cells but the effectiveness is dependent on the species of cyanobacteria present. This strategy is often used as an emergency measure to respond to later stages of a bloom (U.S. EPA, 2014d), but may also present a possible additional strategy for the initial response to early bloom detection.

Aeration

Aeration can be an effective cyanobacteria management tool in source water. Aeration pumps air through a diffuser near the bottom of a source water body, releasing a plume that rises to the surface. This plume causes mixing of the water column that disrupts the migration behavior of the cyanobacterial cells and limits the accessibility of nutrients. Aeration has been shown to be successful in small water bodies, but is highly dependent on airflow rate and the degree of stratification of the water body (U.S. EPA, 2014d).

Mechanical Mixing

Typical mechanical mixers are surface mounted, and either move water from the surface downwards, or draw water from the bottom to the surface. This mixing of the water column disrupts the cyanobacteria migration and limits the availability of nutrients. Mechanical mixing has been found to have some success in water bodies in the U.S. The devices can have a limited range, so areas further away from the device may remain stratified (U.S. EPA, 2014d).

3 Step 3: Monitor for Cyanotoxins in Raw Water and Treatment Adjustments

3.1 Sampling and Analysis for Cyanotoxins

3.1.1 Raw Water Sampling

If a cyanobacterial bloom is observed and (or) inferred by means of visual inspection, system effects, or other bloom indicators (Step 2), EPA encourages the PWS to sample the raw water for cyanotoxins (Step 3). EPA suggests the PWS collect raw water samples at the plant intake prior to any treatment. Samples that may have been exposed to chlorine or other oxidants should be quenched immediately upon sampling. Temporary surface blooms may be observed early in the morning, but some blooms may disperse as winds increase and (or) mix back into the water column during the day. PWSs may want to consider sampling at the worst case area of the bloom in the source water around the intake to determine the maximum levels of toxins produced. If water systems are contemplating algaecide application, the surface scum (if visible) should also

be sampled to provide an indication of the potential for release of toxins as a result of the algaecide application.

Where a bloom is observed or inferred, PWSs may want to consider sampling the raw water at least two to three times per week. If there is limited evidence of a bloom, or the source water does not have a history of periodic cyanobacterial blooms, systems could consider monitoring less frequently and increase monitoring if cyanotoxins are found in raw water. A PWS is encouraged to choose a raw water sampling frequency considering the following factors: past frequency of occurrence of blooms and cyanotoxins in the water source or nearby water bodies; current toxin concentrations in source water (elevated concentrations could trigger increased sampling frequency), bloom dynamics (history of highly variable toxin concentrations, impacts of wind-induced mixing, currents, etc.), characteristics of the water body (for example, size, depth, thermal stratification); source water quality (for example, nutrient levels); growth rate of the cyanobacteria; weather and seasonal influences (for example, temperature rainfall); and adequacy of treatment and capacity of the treatment plant to treat cyanotoxins.

If monitoring results indicate the presence of cyanotoxins in the raw water, EPA recommends that the PWS continue to Step 4, monitoring for cyanotoxins in raw and finished water. EPA encourages the PWS to conduct sampling under Step 4 within 24 hours after the detection of cyanotoxins in the raw water collected under Step 3. Furthermore, the PWS may want to communicate with their stakeholders as described in section 3.2 and adjust treatment as described in section 3.3. If no cyanotoxins are found in the raw water, the PWS may want to continue to observe for possible blooms (Step 2), unless a bloom is observed visually. In cases where raw water monitoring (Step 3) is triggered by visual confirmation of blooms near the intake (that is microscopically confirmed to be caused by cyanobacteria), EPA encourages the PWS to continue raw water sampling until the bloom is no longer visually identifiable.

3.1.2 Sampling Logistics

Samples should be handled properly to ensure reliable results, whether analyzing the samples using a field kit or shipping to a laboratory. EPA recommends that a PWS follow sample collection and handling procedures established by the method or laboratory performing the analysis (U.S. EPA, 2014a). For laboratory analysis, EPA encourages the PWS to use laboratory-provided sample containers to collect water samples. Laboratories may not accept containers not provided by the laboratory, or they may invalidate results. Amber glass containers are typically used to avoid potential cyanotoxin adsorption associated with some plastic containers and to minimize exposure to sunlight (U.S. EPA, 2014a). Raw water samples that have been exposed to any oxidants should be quenched immediately upon sampling. Samples should be cooled immediately after collection, during shipping, and pending analysis at the laboratory. Ideally, samples should be shipped on the same day they are collected. Samples generally should be analyzed within five days from the time of collection. EPA encourages systems to contact the appropriate laboratory prior to shipping samples for additional sample handling instructions. More information is available in USGS *Guidelines for Design and Sampling for Cyanobacterial Toxin and Taste-and-Odor Studies in Lakes and Reservoirs* (2008).

3.1.3 Analytical Methods

Analysis of cyanotoxins may require sample preparation, depending on the form of the cyanotoxins (intra- or extracellular), and the specific analytical methods (U.S. EPA, 2015a,b). Analytical methods measure dissolved (extracellular) cyanotoxins. Therefore, to determine total (intracellular and extracellular) cyanotoxin concentrations, sample preparation should include cell lysis so that the intracellular toxins can be quantified (U.S. EPA, 2015a,b). It can be helpful to analyze for both extracellular toxin (may involve an additional filtration step) as well as total toxin concentrations for a raw sample, to inform treatment adjustments.

Enzyme-linked immunosorbent assays (ELISA) are commonly used to detect cyanotoxins. ELISA results quantify total microcystins and can directly be compared to the HA level for total microcystins. ELISAs are non-specific in that they cannot, however, identify and quantify various individual microcystin variants (sometimes referred to as "congeners"). For raw water monitoring (Step 3), ELISA field kits could be used if they can meet the quantitation limits the PWS or state deems necessary as outlined by a CMP or alternative cyanotoxin management approach. These kits can provide rapid results of the potential presence and semi-quantitative amounts of microcystins or cylindrospermopsin in raw water samples.

The PWS could also consider using a quantitative laboratory ELISA test for total microcystins, such as the ADDA specific ELISA. Standard Operating Procedures for this method developed by Ohio EPA are a useful resource in providing additional helpful advice for quality-control and sample-handling measures (Ohio EPA, 2015). For additional information on analytical methods for microcystins and cylindrospermopsin, please also see the analytical methods discussion under Section 5 of the HAs (U.S. EPA, 2015a,b). To assess the performance of unit processes within treatment plants, the same analytical method should be used for the paired raw and finished water samples.

3.2 Communications

If a PWS detects cyanotoxins in the raw water, the PWS may want to consider communicating their findings with state and local officials. The PWS may also want to consider working with public health officials to develop messaging for the public on the proactive measures the PWS is taking. This would keep the public health officials aware of the nature and degree of the concern prior to detections in finished water. The PWS could also prepare a communication message for the public in the event the PWS receives public inquiries on visible blooms in source waters. If the source water has public access, such as for recreational purposes or animal uses, the PWS may want to consider informing other source water managers to let them know cyanotoxins have been detected.

3.3 Treatment

If cyanotoxins are detected in the raw water in Step 3, it is important to determine whether they are intracellular or extracellular before a PWS begins implementing any treatment strategies. Raw water samples collected in this Step should be analyzed for both extracellular and total (intracellular and extracellular) toxins to inform proper treatment strategies. Information on how to collect and analyze samples for both total and extracellular toxins is provided in section 3.1.

The following treatment strategies are commonly used by PWSs to respond to cyanotoxins in raw or finished drinking water:

1. Removing intact cells first
2. Minimizing pre-oxidation of raw water
3. Adding or increasing powdered activated carbon
4. Increasing post-chlorination

These treatment strategies can be implemented easily and quickly to provide immediate response to any cyanotoxins detected in raw or finished water and prevent cyanotoxins from breaking through into treated water. A system that has detected cyanotoxins in their source water will likely not be able to design, construct and start up a new permanent treatment system in time to address the HAB.

When selecting these treatment strategies, it is important for a PWS to evaluate any potential impacts on their ability to meet all other treatment goals (for example, turbidity removal, DBPs precursor control, disinfection, taste and odor control, corrosion control, etc.) and associated operational issues (such as filter backwash and sludge handling). Each of the treatment strategies is discussed individually below in more detail.

Treatment Strategy 1: Removing intact cells first

Conventional treatment, defined as coagulation, flocculation, sedimentation and filtration processes, is widely used by surface water treatment plants to reduce particulate material. Conventional treatment can be very effective to remove whole cells that contain intracellular cyanotoxins (WHO, 1999; Newcombe, 2009; Newcombe et al., 2010; Newcombe et al., 2015). If cyanotoxins are released from the cells (the extracellular form), treatment becomes more complicated and costly because conventional treatment has limited ability to remove extracellular cyanotoxins (WHO, 1999; Westrick et al., 2010; Hitzfeld, et al., 2000). Therefore, ensuring that cells are not lysed before they are removed should be considered as the first treatment response taken by a PWS during a cyanobacterial bloom (Newcombe et al., 2015).

Operational considerations for removing whole cells through the conventional treatment process are similar to those considered for achieving effective particulate removal, such as coagulants, pH, and mixing (Newcombe et al., 2015). The source water quality and cyanobacterial morphology (such as individual cells, filamentous, etc.) also strongly affect the treatment efficiency (Kommineni et al., 2009; Newcombe, 2009). Detailed operational guidance on how to improve the removal of cyanobacterial cells (containing intracellular toxin) by conventional treatment can be found in Newcombe (2009) and Newcombe et al. (2010; 2015).

During a cyanobacterial bloom, water plant operators may want to consider altering treatment processes and operational parameters (such as chemical doses, coagulation, pH, filter backwash frequency and loading rates) to account for the increased loading of whole cells. Jar tests are commonly used to simulate conventional treatment and can be used to help determine appropriate coagulation chemicals, pH level, and operational parameters at a coagulation and filtration plant to improve toxin reduction. Jar tests are relatively simple, low-cost, and can be completed in a short timeframe (Lytle, 1995). When conducting jar tests, the operator can

measure the decrease in settled water turbidity (for high turbidity water > 10 Nephelometric Turbidity Units (NTU)), chlorophyll-a (or phycocyanin), or cell count as a surrogate for cell removal (Sklenar et al., 2014; Newcombe et al., 2015). However, the use of turbidity as an indicator of treatment efficiency is not recommended for low turbidity water (< 10 NTU) due to poor correlations between the decrease in turbidity and cell removal (Newcombe et al., 2015). A PWS is encouraged to conduct its own tests to determine appropriate treatment parameters before full-scale application. Once applied to the full-scale operation, the PWS is encouraged to measure toxins by ELISA to help understand what is happening in the treatment train or identify treatment breakdown.

Residuals produced by the conventional treatment process, including sludges and backwash water, should be properly handled and removed from the system to minimize the release of intracellular and extracellular toxins into the surrounding water (Kommineni et al., 2009; Zamyadi et al., 2012; Newcombe et al., 2015). During a cyanobacterial bloom, treatment sludge should be frequently removed from the sedimentation basin (daily if possible) and any sludge or backwash supernatant recycling should be discontinued until the cyanotoxins have degraded or been diluted (Newcombe et al., 2015). Cells can accumulate in the filters, which can potentially lead to a significant amount of extracellular microcystins released into the filtered water. Frequent backwashing has been recommended to minimize the risk of cells breaking through into filtered water (Newcombe, 2009). Additionally, backwash water from the filters may contain cyanobacterial cells and (or) extracellular microcystins. Therefore, operators may wish to consider a filter-to-waste cycle following backwashing that is long enough to flush out any residual toxins remaining in the filter.

Treatment Strategy 2: Minimizing pre-oxidation of raw water

Oxidants, such as chlorine, ozone or potassium permanganate, applied to raw water containing intact cells can lyse cells or stimulate the release of intracellular toxins in un-lysed cells, resulting in the release of cyanotoxins. However, the amount of oxidant dosed may not be sufficient to oxidize the released toxins. Therefore, caution should be taken when using pre-oxidation. For example, Australian guidelines recommend not practicing pre-chlorination or pre-ozonation without additional processes to remove the released toxins (Newcombe et al., 2010), or adding a sufficient dose to oxidize the cyanotoxins as well as to lyse the cells (Newcombe et al., 2015). Another study indicated that pre-oxidation would only be considered acceptable when the total intracellular and extracellular toxin concentrations are so low as to be irrelevant (House et al., 2004).

Some water systems practice pre-oxidation with potassium permanganate followed by PAC to improve coagulation, control zebra mussels and (or) reduce taste and odor compounds. However, EPA's research demonstrated that potassium permanganate at low levels (for example, at a dose of 1 mg/L) could have the potential to stimulate the release of intracellular toxins from cyanobacteria, thus increasing potential downstream risks. Therefore, the PWS can consider discontinuing the pre-oxidation with potassium permanganate during a cyanobacterial bloom.

Treatment Strategy 3: Adding or increasing powdered activated carbon

PAC is regarded as an effective treatment for microcystins and cylindrospermopsin as well as taste and odor compounds (Westrick et al., 2010; Cyanocenter UBA, 2015). PAC is generally

considered an episodic treatment for cyanotoxins and can be added intermittently to the conventional treatment process to respond to periodic or seasonal spikes of cyanotoxins in a fairly cost-effective approach (Westrick et al., 2010). PAC can be added either at the intake (after pre-oxidation with potassium permanganate or other oxidants) and removed during clarification, or it can be added to the settling tanks and removed through filtration. When placed after potassium permanganate, PAC adsorbs not only the released toxins but also the permanganate residual. Thus, a higher PAC dose may be needed. EPA is conducting research to provide water utilities with a better understanding of how pre-oxidation with potassium permanganate followed by PAC affect cyanobacterial cells and their toxins.

The efficiency of PAC adsorption depends on the carbon type (for example, pore size) and the presence of natural organic matter (NOM) in water (U.S. EPA, 2014a). Mesoporous carbon (such as wood-based PAC) has been demonstrated to be the most effective at removing microcystins and cylindrospermopsin (WHO, 1999; U.S. EPA, 2014a; Sklenar et al., 2014; Westrick et al., 2010; Drikas et al., 2002). A PAC dose in excess of 20 mg/L would be required for cyanotoxin removal, significantly higher than what is typically used in drinking water treatment (Jurczak et al., 2005; Tokodi et al., 2012; U.S. EPA, 2014a). Since the removal varies by carbon type, source water quality and treatment objectives, systems may consider conducting jar tests to select the appropriate PAC type, dose and feed point prior to full-scale application (Sklenar et al., 2014).

Treatment Strategy 4: Increasing post-chlorination

In general, microcystins are readily oxidized by chlorine (Newcombe et al., 2010). Effectiveness of chlorine in microcystin oxidation is highly dependent on pH, temperature and the initial microcystin concentration (Acero et al., 2005; Ho et al., 2006a). Oxidation of extracellular cyanotoxins is most effective when the pH is below 8 (Acero et al., 2005; U.S. EPA, 2014a). This is especially the case for microcystins (Westrick et al., 2010; Acero et al., 2005). Cylindrospermopsin can be effectively oxidized by chlorine when the pH ranges from 6 to 9 (Westrick et al., 2010). Chloramines and chlorine dioxide are not effective for microcystins or cylindrospermopsin oxidation at typical contact times used in drinking water application (U.S. EPA, 2014a; Nicholson et al., 1994; Westrick et al., 2010).

It is important to understand the effectiveness of the existing chlorination process for oxidation of cyanotoxins. Disinfectant effectiveness (to inactivate pathogenic organisms, such as *Giardia*), is commonly expressed as CT (in mg/L-min), which is calculated by multiplying the disinfectant concentration (C, in mg/L) by the contact time (T, in minutes). Researchers developed chlorine CT values for oxidizing microcystin-LR (Acero et al., 2005) and compared these CT values with those needed for inactivating *Giardia* cysts (Acero et al., 2005; Ho et al., 2006a; Westrick, 2008). (See Section 4.10 of the "Drinking Water Health Advisory for the Cyanobacterial Toxin Microcystin" (U.S. EPA, 2015a) for the use of microcystin-LR as a surrogate for total microcystins). Table 3-1 shows the chlorine CT values required to reduce microcystin-LR concentrations from 50 or 10 µg/L to 1 µg/L in a batch or plug-flow reactor (Acero et al., 2005). Table 3-2 shows a subset of the chlorine CT values required for 99.9% (3-log) of inactivation of *Giardia* cysts at a residual chlorine concentration of 1 mg/L (typical of the primary disinfection) (U.S. EPA, 2003).

Table 3-1. Chlorine CT values for reducing microcystin-LR concentration to 1 μg/L in a batch or plug-flow reactor

pH	Initial Microcystin-LR Concentration (μg/L)	CT Value (mg/L-min)			
		10 °C	15 °C	20 °C	25 °C
6	50	46.6	40.2	34.8	30.3
	10	27.4	23.6	20.5	17.8
7	50	67.7	58.4	50.6	44.0
	10	39.8	34.4	29.8	25.9
8	50	187	161	140	122
	10	110	94.9	82.3	71.7
9	50	617	526	459	399
	10	363	310	270	235

Source: (Acero et al., 2005)
CT (mg/L-min) = residual disinfectant concentration (mg/L) x contact time (min)

Table 3-2. Chlorine CT values for 99.9% (3-log) inactivation of *Giardia* cysts at a residual chlorination concentration of 1 mg/L

pH	CT Value (mg/L-min)			
	10 °C	15 °C	20 °C	25 °C
6	79	53	39	26
7	112	75	56	37
8	162	108	81	54
9	234	156	117	78

Researchers suggested that, at a pH value below 8, the chlorine CT values required to reduce microcystin-LR to below 1 μg/L were comparable to those required for achieving 99.9 percent (3 log) inactivation of *Giardia* cyst (Acero et al., 2005). However, well-operated surface water filtration plants can achieve at least a 2 to 2.5-log removal of *Giardia* cysts through filtration and only need 1 or 0.5-log additional removal via disinfection to meet the overall treatment requirement of 3-log *Giardia* removal and inactivation (U.S. EPA, 1991). Therefore, the chlorine CT values applied at many water treatment plants, such as to achieve 1 or 0.5-log inactivation of *Giardia* cysts, will likely be a fraction of the CT values required for 3-log inactivation shown in Table 3-2.

Since the chlorine CT values in Table 3-1 are based on reducing microcystin-LR concentrations from 50 or 10 μg/L to 1 μg/L, higher CT values would be required to further reduce the microcystin-LR concentration to below the HA value for bottle-fed infants and young children of pre-school age (0.3 μg/L). Assuming that the same reaction kinetics and the same equation for calculating CT values still apply when reducing microcystin-LR to 0.3 μg/L, the CT values in Table 3-1 should be modified by a multiplier of 1.3 and 1.5 for the initial microcystin-LR concentration of 50 and 10 μg/L, respectively. These multipliers are derived from the original equation (Acero et al., 2005):

$CT = -\ln([MC] / [MC]_0) / k_{app}$, where [MC] and $[MC]_0$ are the final and initial concentrations of microcystin-LR, respectively. k_{app} is the apparent second-order rate constant for the chlorination of microcystins at a given temperature.

Using this equation, CT values for reducing microcystin-LR from 50 to 0.3 µg/L can be calculated by:

$$CT_{0.3\text{-}\mu g/L} = \ln(50/0.3) / \ln(50/1) \times CT_{1\text{-}\mu g/L} = 1.3\ CT_{1\text{-}\mu g/L}$$

Similarly, CT values for reducing microcystin-LR from 10 to 0.3 µg/L can be calculated by:

$$CT_{0.3\text{-}\mu g/L} = \ln(10/0.3) / \ln(10/1) \times CT_{1\text{-}\mu g/L} = 1.5\ CT_{1\text{-}\mu g/L}$$

Therefore, the CT values required for oxidizing microcystin-LR (and by assumption, total microcystins) may be higher than those required for inactivation of *Giardia* cysts, depending on pH, temperature and initial concentration of microcystins. The PWSs may consider increasing their chlorine dose or contact time to reduce total microcystins to below the HA value for bottle-fed infants and young children of pre-school age. Literature reported CT values for oxidizing microcystins may be used by water utilities as a guide to benchmark their existing treatment practices (Westrick, 2008); however, any CT recommendations should be treated with caution and not be used to replace direct sampling and analysis of treated water for cyanotoxins.

The presence of NOM will decrease the efficiency of chlorine oxidation of cyanotoxins (Rodriguez et al., 2007a) and increase the formation potential of chlorinated DBPs. The systems should assess the impact of an increased chlorine dose on the DBP formation potential and avoid the running annual average concentrations of total trihalomethanes (TTHMs) and haloacetic acids (HAA5) exceeding the respective Maximum Contaminant Levels (MCLs) of 0.080 mg/L and 0.060 mg/L.

4 Step 4: Monitor for Cyanotoxins in Raw and Finished Water and Treatment Adjustments

4.1 Monitoring

If cyanotoxins are detected in raw water, EPA suggests that the PWS monitor both raw water and finished water for cyanotoxins. EPA recommends using a quantitative laboratory ELISA test for total microcystins for finished water samples, using sampling and analysis procedures described in section 3.1. As noted for raw water samples, finished water samples that have been exposed to any oxidants should be quenched immediately upon sampling. EPA suggests PWSs continue collecting raw water samples at the same locations as described in Step 3 (section 3) to allow for comparison. PWSs may want to consider collecting finished water samples at the entry point to the distribution system. If paired raw and finished water samples are collected to assess the treatment performance, then samples should be staggered to account for the time it takes for the increment of sampled raw water to travel through the treatment plant.

Cyanotoxin analysis in raw and finished water can result in one of three outcomes. If no cyanotoxins are detected in either raw or finished water, EPA recommends that the PWS continue raw water sampling two to three times per week until the cyanobacterial bloom is no longer visually detectable, Step 3. If cyanotoxins are detected in the raw water but not the

finished water, EPA recommends that the PWS continue raw water and finished water sampling two to three times per week, until cyanotoxins are no longer found in the raw water (Step 4). Factors to consider for sampling frequency include: toxin concentration, treatment capabilities (historically able to remove high levels of toxins or not) and bloom dynamics (history of highly variable toxin concentrations, impacts of wind and currents, etc.). If a system detects cyanotoxins in the finished water, EPA recommends that the system monitor to confirm the presence of cyanotoxins in finished water within 24 hours (Step 5). The PWSs may also consider providing communications to their stakeholders (see section 4.2) and treatment (see section 4.3).

4.2 Communications

If PWSs confirm the presence of cyanotoxins in finished water, EPA encourages PWSs to continue to Step 5 and communicate their findings with state and local officials to help prepare for possible actions they may choose to take after the confirmation sampling of finished water has been completed. EPA recommends PWSs confirm the presence of cyanotoxins in finished water with at least one additional finished water sample before notifying the public. Section 5.2 discusses an approach for communication depending on the concentrations of cyanotoxins found in finished water. If additional raw water sampling continues to detect cyanotoxins, the PWS may wish to consider informing other source water managers as well.

4.3 Treatment

If a system detects and positively confirms cyanotoxins in the finished water, it indicates that cyanotoxins have broken through the treatment barriers. It is important to monitor the performance of individual unit processes across the treatment train to help understand what is happening in the treatment train or identify possible treatment breakdown. PWSs should continue implementing the treatment strategies described in section 3.3 and consider further testing and adjustments to improve treatment performance. These treatment changes can be implemented easily and quickly and will decrease the likelihood of toxin occurrence at the household tap.

5 Step 5: Monitor for Cyanotoxins in Finished Water, Treatment Adjustments or Additions, and Public Communications

If cyanotoxins have been detected in finished water (Step 4), EPA recommends that PWSs take at least one additional sample to confirm the results as soon as possible within the first 24 hours under Step 5. Although the HAs for microcystins and cylindrospermopsin are Ten-Day HAs, the PWSs may want to consider proactively communicating the findings to state, local and public health officials as soon as cyanotoxins are confirmed in finished drinking water. EPA anticipates it may take multiple days to go from observing a bloom to detecting cyanotoxins in raw water to confirming their presence above HA values in a finished water sample. Therefore, the PWS would have the opportunity to adjust and add treatment as necessary prior to communicating with stakeholders and issuing notices to the public as appropriate. A CMP can help a PWS be prepared to take action to help reduce the likelihood of cyanotoxins reaching the finished water. Step 5 contains suggested communication actions, treatment actions and additional monitoring based on the concentrations of cyanotoxins found in the finished water. Figure 2 depicts a recommended three-tier traffic light system, including actions EPA recommends once

cyanotoxins have been confirmed in finished drinking water. (This figure focuses on microcystins, but a similar approach would also be appropriate for cylindrospermopsin.) A PWS may want to develop a similar response plan, to allow the PWS to act quickly if cyanotoxins are found in finished water.

5.1 Monitoring

EPA suggests PWSs continue to analyze finished water samples with a quantitative laboratory ELISA test for total microcystins. If a PWS detects microcystins in its finished water, it could also consider sampling for cylindrospermopsin to ensure no co-occurrence in finished water. If a system wants to detect and quantify individual microcystin variants, a more selective method, such as liquid chromatography/tandem mass spectrometry (LC/MS/MS) can be used (recognizing this method does not identify the majority of microcystin congeners and may underestimate the total concentration of microcystins in the sample). More information on analytical methods is available in section 5 of the EPA HAs for microcystins and cylindrospermopsin (U.S. EPA, 2015a,b).

If cyanotoxins have been initially detected in finished water, the PWS is encouraged to confirm the presence of cyanotoxins in finished water with additional finished water samples as soon as possible within 24 hours of detection. EPA suggests the PWS consider continuing monitoring the finished water until cyanotoxins are no longer detected in finished water. This includes monitoring during and after implementing treatment and (or) management strategies to remove cyanotoxins from the finished water. PWSs are encouraged to base their sampling frequency on the concentration of cyanotoxins detected in the finished water. The PWS may want to collect finished water samples at least two to three times per week for systems with cyanotoxin concentrations that have been reduced below detection levels in the finished water sampling under Step 5, until levels are below quantification in at least 2-3 consecutive samples in raw water. For systems that continue to detect concentrations above the HA value for bottle-fed infants and young children of pre-school age but below the HA value for school-age children through adults in the finished water sampling under Step 5, the PWS may want to consider daily finished water sampling. PWSs that detect concentrations above the HA value for school-age children through adults should consider sampling at least daily. Using the same sampling and analytical procedures for all finished water sampling conducted under Step 4 and 5 of the potential management steps will help provide comparable results.

If an increase in cyanotoxin concentrations is seen in finished water, the PWS may want to increase sampling based on the new concentrations detected. For example, PWSs sampling finished water at least two to three times per week might consider increasing to daily monitoring if concentrations increase to levels above the HA value for bottle-fed infants and young children of pre-school age but below the HA value for school-age children through adults. The PWS may want to take into consideration local conditions (such as high proportion of susceptible populations and weather events) to determine the need for samples in excess of the recommended frequencies. Also, distribution system monitoring could be considered, for example Ohio EPA encourages PWSs in Ohio to address distribution modeling and sampling in their contingency plan (Ohio EPA, 2014). Depending on the concentration of cyanotoxins initially detected in finished water, toxins could persist in the distribution system at levels of concern even after it is non-detect at the entry point. Distribution system monitoring may be a key component of any effort to characterize potential threats to the public.

It is important to consider specifying (within a CMP) when finished water monitoring is no longer recommended. EPA suggests that the PWSs continue finished water sampling until at least two consecutive samples, 24 hours apart, show concentrations of cyanotoxins below 0.3 µg/L for microcystins and 0.7 µg/L for cylindrospermopsin. A PWS may also want to consider characterizing cyanotoxin levels throughout the distribution system while considering appropriate communications with the primacy agency and the public. After a PWS has two consecutive samples below 0.3 µg/L for microcystins, PWSs may want to consider returning to Step 3 to determine if cyanotoxins are still present in the raw water.

5.2 Communications

PWSs are not required to notify their customers of any bloom or cyanotoxin occurrence and are not required to include detections as part of a system's Consumer Confidence Report under any National Primary Drinking Water Regulations . PWSs should consult with their primacy agency to determine if they are subject to any state or tribal notification requirements. Although not required, PWSs may want to consider communicating with their consumers if cyanotoxins in finished water are confirmed in additional samples. This communication may be received more positively if PWSs have engaged in prior communication with the public about HABs. The PWS is encouraged to tailor their communications based on the levels detected as detailed below. EPA anticipates that multiple days may pass between the initial observation of a bloom and a confirmation of the presence of cyanotoxins above HA values in finished water. This framework allows for time to adjust or supplement treatment prior to using the communication strategies discussed below.

Below HA Value for Bottle-Fed Infants and Young Children of Pre-School Age
If a PWS confirms concentrations at or below the HA value for bottle-fed infants and young children of pre-school age (less than six years old), (0.3 µg/L for microcystins; 0.7 µg/L for cylindrospermopsin), in finished water in either an initial or secondary sample, EPA recommends that the PWS communicate with their primacy agency and local public health agencies on the monitoring results and that the PWS does not issue any advisories to the public, unless otherwise directed by the primacy agency.

Above HA Value for Bottle-Fed Infants and Young Children of Pre-School Age but Below HA Value for School-Age Children through Adults
If a PWS confirms concentrations above the HA value for bottle-fed infants and young children of pre-school age but below the HA value for school-age children through adults (above 0.3 µg/L but below 1.6 µg/L for microcystins; above 0.7 µg/L but below 3.0 µg/L for cylindrospermopsin) in additional finished water samples under Step 5, EPA recommends that the PWS consult with their primacy agency and the local public health agency to determine when and how to notify drinking water consumers who may be more susceptible to adverse outcomes (such as bottle-fed infants and young children of pre-school age) within 24 hours, to advise them to use alternate sources of drinking water. After at least two consecutive finished water samples are below the HA level for bottle-fed infants and young children of pre-school age, EPA recommends notifying consumers that drinking water has returned to acceptable levels. PWSs can consider developing targeted outreach for sensitive populations though partnerships with others, such as communicating with pediatricians and day care centers. Tools are available to help PWSs in

develop their communication messages such as Center for Disease Control's (CDC) DWACT(CDC, 2013) and EPA's Developing Risk Communication Plans for Drinking Water Contamination Incidents (U.S. EPA, 2013a). The CDC is currently updating their Drinking Water Advisory Toolbox and intends to include cyanotoxin specific information in that update.

Above HA Value for School-Age Children through Adults
If a PWS confirms concentrations above the HA value for school-age children through adults (1.6 µg/L for microcystins; 3.0 µg/L for cylindrospermopsin) in the additional finished water samples collected under Step 5, EPA recommends that the PWS consult with their primacy agency as well as the local public health agency to determine when and how to issue a 'Do Not Drink/Do Not Boil Water' advisory to the general public served by that water supply within 24 hours. After at least two consecutive samples are below the HA level for school-age children through adults, EPA recommends that the PWS remove the 'Do Not Drink/Do Not Boil Water' advisory. EPA suggests the PWS notify water customers who may be more susceptible to adverse outcomes (such as bottle-fed infants and young children of pre-school age) within 24 hours, to advise them to use alternate sources of drinking water until two consecutive samples are below the HA value for bottle-fed infants and young children of pre-school age. The PWS may want to also consider evaluating the distribution system levels before removing the notification to ensure these levels have been reduced as well.

PWS may want to describe in their communication efforts they are undertaking to address the problem and the expected duration of the elevated levels of cyanotoxins. EPA also encourages PWSs to identify alternatives customers have available if they receive a 'Do Not Drink/Do Not Boil Water' advisory. For PWSs where source waters have public access for recreation, the system's notice may include statements about recreational use of waters with cyanobacterial blooms to prevent exposure of humans and animals to cyanotoxins. (Note: EPA is developing water quality criteria for recreational water that will provide additional information about levels of cyanotoxins in source waters.)

5.3 Treatment

If a system detects cyanotoxins in the additional finished water samples collected under Step 5, the PWS is encouraged to continue adjusting the treatment as discussed in section 3.3, to return cyanotoxin concentrations to below HA levels as soon as possible. The PWS might also monitor individual treatment processes to better understand or to determine which treatments are effective at cyanotoxin removal.

Providing an alternate water source may be useful as a temporary management strategy following the detection of cyanotoxins in the finished water. This can include other sources under the purview of the system or providing for an interconnection to another system. When using this strategy, EPA recommends that systems be aware of any primacy agency regulatory implications that may result.

If the PWS is frequently challenged by cyanotoxins in source waters and modifications to its existing treatment system do not sufficiently reduce cyanotoxin levels to below HA values, it may consider installing permanent treatment as appropriate to address cyanotoxin occurrence in future years (see Appendix E).

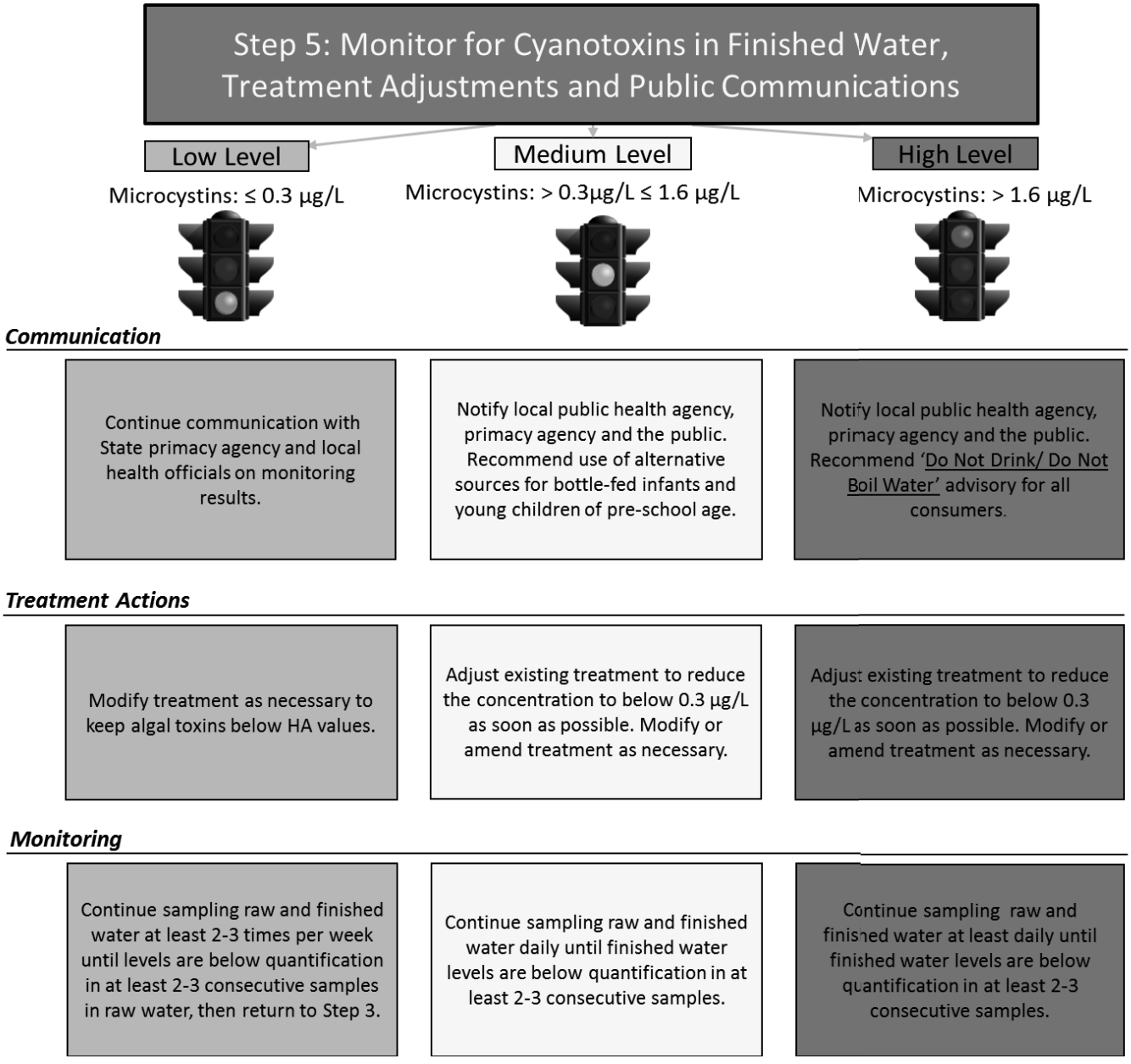

Figure 2. Traffic light approach to support communication and other actions in response to elevated concentrations of cyanotoxins in finished drinking water.

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Appendix A System-Specific Evaluation Information, Tools, and Resources

Appendix A contains a more detailed discussion of the types of information a PWS could consider when conducting a system-specific evaluation for cyanotoxin vulnerability in source waters. Resources and tools that could be useful in conducting the system-specific evaluation and developing a CMP are also discussed; a more extensive table is available at the end of this appendix. Tools listed vary in their complexity and purpose. Some users may prefer user-friendly tools that provide summary information about key areas, while others may prefer more complex and (or) comprehensive databases or models. This list of tools discussed in this appendix may not be fully comprehensive and other useful tools and information sources are available. For example, some U.S. states also have resources and tools that could also provide PWSs with assistance in developing a CMP.

Source Water Characteristics

Source water type is an important factor in a system-specific evaluation. Certain types of source waters will have greater vulnerabilities than others. For example, lakes and reservoirs are expected to have greater vulnerabilities than moving waters such as free-flowing rivers. Lakes and reservoirs typically have conditions that are more favorable to cyanobacterial growth (as discussed below) than rivers, although some rivers can have vulnerabilities under certain conditions such as drought causing slow moving water. Most ground water is generally not expected to be at risk; however, ground water under the direct influence of surface water may be at risk. If toxins are released after a surface water bloom in a lake, a proportion of the dissolved toxins may accompany any surface water that is induced by pumping well action to passage from lake water to nearby well water. A study by Ueno et al., (1996) found microcystins in four percent of shallow wells, with no occurrence in deeper wells.

As part of a system-specific evaluation, PWSs might want to consider other source water body characteristics, such as size and depth of the source water. In some cases where the source is a large body of water, such as the Great Lakes, different locations within the body of water can have different characteristics and therefore different vulnerabilities to cyanotoxins. Information on source water type and hydrology can often be found in a state's Source Water Assessment, a source water analysis that states completed for all PWSs after the 1996 Amendments to the SDWA, as explained in "Source Water Assessment Information" below. A useful tool on surface water and watershed characteristics is the NHDPlus (National Hydrography Dataset). This tool can provide for general mapping and analysis of surface water systems (see discussion below) (NHDPlus, 2015).

Vertical stratification can be a contributing factor to bloom formation in source waters. Vertical stratification can be determined by measuring vertical profiles of temperature within the source water (WHO, 1999). Some common cyanobacteria can move throughout the water column due to their buoyancy regulation ability. It is believed that cyanobacteria use this buoyancy to move throughout the water column to overcome the separation of nutrients and light (Ganf and Oliver, 1982; Reynolds et al., 1987). During low mixing events in the source water, such as those due to low wind, the buoyant cyanobacteria can float towards the surface (Walsby et al., 1997; Paerl and Huisman, 2009). Some cyanobacterial strains, such as strains of *Microcystis*, regulate their buoyancy based on light intensity, leading to increased cyanobacterial growth (Thomas and Walsby, 1985). Studies have shown that cyanobacteria can migrate on a diurnal pattern with cells

rising to the surface overnight and sinking throughout the day (Ganf and Oliver, 1982; van Rijn and Shilo, 1985; Ibelings et al., 1991). Wind patterns, slow moving waters, and reduced source water mixing, along with vertical stratification, are important factors to consider as part of the weight of evidence evaluation (Jacoby et al., 2000).

Water Quality Parameters

Data on the PWS's source water quality is helpful for a system-specific evaluation. Historical data showing cyanobacterial cell occurrence and (or) cyanotoxin occurrence in source water or finished water is the most direct indication of source water vulnerabilities to cyanotoxins. Other useful information in determining source water vulnerability include: phycocyanin, chlorophyll-a, Secchi depths, geosmin and MIB taste and odor problems (sometimes caused by cyanobacteria) and nutrient concentrations (see nutrient section for more specific information on evaluating nutrient impacts).

For example, cyanobacteria contain chlorophyll-a as well as other pigments for photosynthesis that can serve as an indicator for cyanotoxins in source water (Cheung et al., 2013). The pigments allow cyanobacteria to produce energy when light intensity is low as well as in varying light spectra not typically used by other phytoplankton species. This gives cyanobacteria an advantage over other phytoplankton in turbid waters (WHO, 1999). Source waters with sustained high levels of chlorophyll-a may have vulnerabilities to cyanotoxin occurrence. Phycocyanin is another pigment produced by cyanobacteria that is not produced by other algae (Lee et al., 1995). A study by Izydorczyk et al., (2005) found a positive correlation between phycocyanin fluorescence and cyanobacterial biomass in a drinking water reservoir during a *Microcystis aeruginosa* bloom. Phycocyanin could also be an indicator of cyanotoxin occurrence. Satellite or hyperspectral imagery from aircraft that have been processed based on chlorophyll-a or phycocyanin concentrations are also a useful indicator of cyanobacteria occurrence.

Systems without their own historical data can consider consulting with their primacy agency to determine if other sources of historical data are available. Multiple federal agencies (EPA, USACE, United States Geological Survey (USGS)) and state agencies, have assessed waters for cyanotoxins as part of assessment and research projects and may have additional data not known to the PWS. The EPA and State National Aquatic Resource Surveys include algal toxin and indicators; for example cyanobacteria and microcystins are part of the National Lakes Assessment (U.S. EPA, 2013b). Many state water quality agencies monitor for cyanobacteria or microcystins and make that data available through the Water Quality Data Portal. Another source of water quality data is satellite imaging, such as the Lake Erie HABs tracker by National Oceanic and Atmospheric Association (NOAA, 2014). Historical information on past wild and domestic animal poisonings surrounding the source water could also provide information on past blooms (Carmichael, 1986; Codd, 1995). Other water quality parameter information that can be helpful include the dominant cyanobacterial species within a source water (to help determine which cyanotoxins may be produced) as well as presence of zebra mussels, which could be a possible contributing factor of blooms (Knoll et al., 2008). In addition, it would be helpful to consult with nearby PWSs to determine if they have had past issues with blooms or cyanotoxins in their raw or finished water.

Source Water Assessment Information

In the absence of historical data on cyanobacterial blooms, or cyanotoxin occurrence, a useful starting place is to review the PWS's Source Water Assessment information. The 1996

amendments to the Safe Drinking Water Act (SDWA) Section 1453 required primacy agencies to develop and implement Source Water Assessments. The Assessment delineates the Source Water Protection Area of every PWS, creates an inventory of the significant potential sources of contamination within the Protection Area, and evaluates the susceptibility of each system to contamination (U.S. EPA, 1997). Some states update their Source Water Assessments on a regular basis, while others have not conducted updates in recent years. While updates may vary by state and system, Source Water Assessments remain a useful resource to help PWSs devise an approach to conduct system-specific evaluations. The Assessment may contain relevant information to cyanotoxin vulnerability, such as the locations of nutrient dischargers and flow patterns. The Source Water Assessment may also contain information relevant to the other types of information discussed later in this section that PWSs might consider for inclusion in the system-specific evaluation. States may also want to update Source Water Assessments with new information on cyanotoxin vulnerabilities, as local stakeholders often use the Assessment as a baseline for source water protection plans and activities. For example, the Colorado Department of Public Health and Environment (CDPHE) has helped Colorado water providers and their communities develop nearly 150 protection plans with an additional 50 plans in progress. These plans lay out a roadmap of targeted protection activities that can help curb cyanotoxin incidence.

EPA is developing a new tool to help states and utilities update source water assessment and protection plans called *Drinking Water Mapping Application for Protecting Source Waters* (DWMAPS). DWMAPS is a Web-based mapping tool that will allow users to identify and analyze potential risks to local source waters. For example, the tool will display possible bloom risk factors within Source Water Protection Areas, such as point sources of nutrients upstream, land use factors (integrated from the National Land Cover Dataset), and county-level nitrogen and phosphorus loading from agricultural lands. DWMAPS can also show which source waters are listed as impaired for nutrients (and other causes) under the Clean Water Act (CWA) and allow PWSs to easily and securely retrieve drinking water data specific to their own system on intakes, wells, treatment plants and source water protection areas. Features of the map also inform protective actions: for example, one feature of the tool will map projects funded through CWA Section 319 to reduce nonpoint sources of pollution. DWMAPS will also offer "Web services" that allow users to import data and GIS shapefiles from DWMAPS into their own GIS platforms. The tool is expected to be available to states, utilities and the public in 2015.

Another useful piece of information is the impairment status of a source water. Under section 303(d) of the CWA, states, territories and authorized tribes develop lists of impaired waters. These are waters that are too polluted or otherwise degraded to meet the water quality standards set by states, territories or authorized tribes. Waters are prioritized and a Total Maximum Daily Load (TMDL), must be developed for those waters. EPA's MyWaters Mapper (U.S. EPA, 2011) and How's My Waterway each provide information about whether a water is listed as impaired under section 303(d) of the CWA (U.S. EPA, 2015g). See the below table for links to these tools.

Climate and Weather Information

Evaluating climate and weather related events are also a key factor in assessing a PWS's vulnerability to cyanobacterial blooms and cyanotoxin occurrence. Warm ambient temperatures, increased source water temperatures, rainfall events, drought and heavy winds can impact the timing and duration of cyanotoxin occurrence. Some cyanobacteria have optimal temperatures at which they will grow, increasing the likelihood of cyanotoxin occurrence. Optimal temperatures will depend on the cyanobacteria genus and species (Robarts and Zohary, 1987; Mehnert et al.,

2010). Climates can impact vertical stratification within water bodies with temperate climates having seasonal stratification, whereas tropical climates more typically exhibit a diurnal stratification pattern (WHO, 1999).

Weather patterns, such as high intensity rainfall events, can increase runoff into source waters, thus potentially increasing nutrient loading levels that may lead to increased production of cyanobacteria and cyanotoxins (Paerl, 2008). Drought can also lead to conditions that favor cyanobacterial production. For example, drought was a major factor that caused low flow conditions in the Barwon-Darling River, contributing to the growth of a large bloom in 1991 (Bowling and Baker, 1996). Climate change can also increase bloom occurrence and expand the geographic range as water temperatures increase and new weather patterns emerge, such as changes in the frequency and intensity of rainfall events (Parmesan, 2006; Paerl and Huisman, 2009; Markensten et al., 2010).

PWSs are encouraged to take into account changes in climactic conditions impacting their source water when conducting the system-specific evaluation. EPA has developed a Climate Ready Water Utilities (CRWU) initiative to assist the water sector, including drinking water, in addressing climate change impacts (U.S. EPA, 2015f). There are multiple tools available within the initiative including the Climate Resilience Evaluation and Awareness Tool (CREAT) (U.S. EPA, 2013c). CREAT is a software tool designed to assist users (including PWSs) understand the potential impact of climate change on their utility. The tool can assist users by identifying climate change projections for a utility, such as annual total precipitation and annual average temperature, and evaluate possible adaptation options. Additional information can be found in EPA's factsheet on *Impacts of Climate Change on the Occurrence of Harmful Algal Blooms* (U.S. EPA, 2013d).

Land Use

EPA suggests PWSs consider land use information in the source watershed as part of the system-specific evaluation. Certain land uses are more closely linked to cyanotoxin occurrence, particularly those that result in excess nutrient discharges. A study by Beaver et al. (2014) found strong associations between agricultural land cover and microcystins occurrence in three ecoregions. Certain other land uses can increase nutrients in source waters, leading to increased bloom activity. For example, if a PWS's source water is vulnerable to nutrient rich runoff from agriculture or urban areas, the PWS may be vulnerable to cyanotoxins as well. Modification of watersheds by agriculture, urban and industrial development can lead to cyanobacterial blooms (Paerl, 2008). Hydrological changes, such as construction of impoundments, damming rivers, and water extraction for irrigation purposes, can also impact the sources waters (Bowling and Baker, 1996; Paerl, 2008; WHO, 1999). A helpful tool to determine land use activities around source waters is the National Land Cover Database (NLCD). This database was developed by a consortium of federal agencies that generate land cover information at the national scale for a wide variety of applications such as land management and modeling (MRLC, 2015). NLCD indicates land cover by wetlands, open water, forested lands, pasture lands, cropland, urban areas and many more use categories. Another useful tool that incorporates some of the features of the NLCD is the NHDPlus. NHDPlus offers a watershed delineation tool that could be helpful in determining the entire watershed area surrounding a source water. A user can also look at the local catchments that buffer the water body and calculate various attributes available in NHDPlus including percent land use, drainage area features, and flow volume and velocity estimates through source water protection areas (NHDPlus, 2015).

Several tools exist that help communities plan land use in order to mitigate impacts on source waters. Advice Worth Drinking: A Planner's Guide outlines a variety of simple steps that land use planners can take to integrate source water protection into regular planning activities and "Smart Growth" strategies like Visioning and zoning. Many local groups like the Salmon Falls Watershed Collaborative have successfully implemented land conservation practices to curb the impacts of urbanization on water quality. The Source Water Collaborative website outlines funding mechanisms that can help PWSs work with local communities to finance land conservation in source water protection areas. In addition, the Collaborative's Conservation Partners Toolkit outlines steps for working with U.S. Department of Agriculture (USDA) programs and Conservation Districts to implement agricultural "best management practices" in lands impacting drinking water.

Nutrient Levels

As part of the weight of evidence evaluation for source water cyanotoxin vulnerabilities, PWSs may want to include water quality parameters such as nutrient levels. These factors can be anthropogenic or naturally occurring. For the purpose of a system-specific evaluation, PWSs might evaluate water quality parameters based on available data and on the conditions typically seen in the source water. A change in water quality parameters that may occur leading to a bloom is discussed earlier in Appendix A.

Source water nutrient levels could be important to examine as part of a system-specific evaluation. Nutrients, specifically nitrogen and phosphorus, play a large role in bloom occurrence (WHO, 1999; Jacoby et al., 2000, Dolman et al., 2012, Yoshida et al., 2007). Increases in nitrogen and phosphorus are mainly due to nonpoint source pollution (such as from agricultural or urban runoff), point source pollution (such as wastewater treatment plants and agricultural and municipal discharges) and subsurface drainage from groundwater and septic systems (Paerl, 2008). A recent analysis of a national dataset indicated that total nitrogen and chlorophyll-a concentrations were strong predictors of microcystin occurrence (Yuan et al., 2014). Cyanobacteria are also capable of fixing nitrogen in low nitrogen conditions and can store phosphorus (Mitsui et al., 1986, Paerl and Otten, 2013).

There are many available tools a PWS can use to evaluate water quality parameters to inform vulnerability findings such as EPA's MyWaters Mapper, which provides snapshots of Office of Water program data including water impairments and water monitoring data (U.S. EPA, 2011) and How's My Waterway, which provides conditions of local waters quickly and in plain language (U.S. EPA, 2015g). The Water Quality Data Portal contains source (raw) water monitoring data for a range of physical, chemical and biological parameters. The data in the Portal come from federal, state and tribal water quality agencies, volunteer groups and academia (U.S. EPA, 2012b). The DWMAPS mapping tool to be released in 2015, as described above, also compiles information on point and nonpoint sources of nutrients in source waters, which can be used to help a system evaluate source water. For those systems wishing to conduct modeling analyses, the USGS has a modeling tool called SPARROW that is useful in modeling and mapping nutrient loading in watersheds across the U.S. (USGS, 2011). Similarly, EPA's BASINS modeling framework provides a platform for analyses for users wishing to conduct simple nutrient loading analyses, to more complex water quality modeling (U.S. EPA, 2013e). Yet another available tool is EPA's Nitrogen and Phosphorus Pollution Data Access Tool (NPDAT). This tool draws from multiple sources to provide focused information on the extent and

magnitude of nitrogen and phosphorus pollution in U.S. water and potential sources of the pollutants (U.S. EPA, 2014c). USGS has a National Water Quality Assessment Program (NAWQA) that can help provide information on nutrients, among other water quality parameters, including how conditions are improving or getting worse over time (USGS, 2015).

Additional tools can be used to identify point sources of pollution in source waters. EPA's Enforcement and Compliance History Online (ECHO) tool contains information and maps of facility inspections, enforcement and violation history. For example ECHO can provide information on National Pollutant Discharge Elimination System (NPDES) dischargers in noncompliance and significant noncompliance (U.S. EPA, 2015h). EPA's Discharge Monitoring Report (DMR) Loading Tool can provide information on nutrient discharge volumes at NPDES-permitted facilities, as well as facilities under the Toxics Release Inventory. It is designed to help determine who is discharging and what, where and how much they are discharging (U.S. EPA, 2015i). This may be a useful source of information about upstream contributions of nutrients to source water protection areas.

Table A-1. List of Resources and Tools

Resource and Tool	Organization	Link
CyanoHABs: Cyanobacterial Harmful Algal Blooms Website	United States Environmental Protection Agency	http://www2.epa.gov/nutrient-policy-data/cyanohabs
Drinking Water Advisories and Health Effects Support Documents (2015)	United States Environmental Protection Agency	http://www2.epa.gov/nutrient-policy-data/health-and-ecological-effects
Opportunities to Protect Drinking Water Sources and Advance Watershed Goals Through the Clean Water Act: A Toolkit for State, Interstate, Tribal and Federal Water Program Managers (2014)	Association of Clean Water Administrators, Association of State Drinking Water Administrators, Ground Water Protection Council and United States Environmental Protection Agency	http://www.asdwa.org/document/docWindow.cfm?fuseaction=document.viewDocument&documentid=3007&documentFormatId=3779
Drinking Water Advisory Communication Toolbox (Updated 2013) (*includes communication outreach tools*)	United States Centers for Disease Control and Prevention	http://www.cdc.gov/healthywater/pdf/emergency/drinking-water-advisory-communication-toolbox.pdf
How to Collaborate Toolkit	Source Water Collaborative	http://www.sourcewatercollaborative.org/how-to-collaborate-toolkit/
Developing Risk Communication Plans for Drinking Water Contamination Incidents (2013)	United States Environmental Protection Agency	http://water.epa.gov/infrastructure/watersecurity/lawsregs/upload/epa817f13003.pdf
Water Security Initiative: Interim Guidance on Developing Consequence Management Plans for Drinking Water Utilities (2008)	United States Environmental Protection Agency	http://www.epa.gov/watersecurity/pubs/guide_interim_cmp_wsi.pdf

Resource and Tool	Organization	Link
A Water Utility Manager's Guide to Cyanotoxins	American Water Works Association and Water Research Foundation	http://www.waterrf.org/PublicReportLibrary/4548a.pdf
Optimizing Conventional Treatment for the Removal of Cyanobacteria and Toxins	Water Research Foundation	WRF Report 4315
Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring and management (1999)	World Health Organization	http://www.who.int/water_sanitation_health/resourcesquality/toxcyanbegin.pdf
Cyanobacterial Toxins Microcystin – LR Guideline (Updated 2002, currently undergoing revision)	Health Canada	http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/water-eau/cyanobacterial_toxins/cyanobacterial_toxins-eng.pdf
International Guidance Manual for the Management of Toxic Cyanobacteria (2009)	Global Water Research Coalition, Water Quality Research Australia	http://www.waterra.com.au/cyanobacteria-manual/PDF/GWRCGuidanceManualLevel1.pdf
Management Strategies for Cyanobacteria (blue-green algae): A Guide for Water Utilities (2010) *(includes drinking water cyanotoxin values for various countries)*	Water Quality Research Australia	http://www.waterra.com.au/publications/document-search/?download=106
Bloom Characterization Guide	Ohio Environmental Protection Agency	http://epa.ohio.gov/portals/28/Documents/HAB/BloomCharacterizationGuide-DRAFT.pdf
Drinking Water Mapping Application for Protecting Source Waters (DWMAPS)	United States Environmental Protection Agency	(Anticipated release in 2015)
National Hydrography Dataset (NHDPlus)	Horizon Systems Corporation (in coordination with EPA and USGS)	http://www.horizon-systems.com/NHDPlus/NHDPlusV1_tools.php
Climate Ready Water Utilities (CRWU)	United States Environmental Protection Agency	http://water.epa.gov/infrastructure/watersecurity/climate/index.cfm

Resource and Tool	Organization	Link
Climate Resilience Evaluation and Awareness Tool (CREAT)	United States Environmental Protection Agency	http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm
National Land Cover Database (NLCD)	Multi-Resolution Land Characteristics Consortium	http://www.mrlc.gov/
MyWaters Mapper	United States Environmental Protection Agency	http://www.epa.gov/waters/mywatersmapper/
How's My Waterway	United States Environmental Protection Agency	http://watersgeo.epa.gov/mywaterway/
STORET (STOrage and RETrieval)	United States Environmental Protection Agency	http://www.epa.gov/storet/
BASINS (Better Assessment Science Integrating point & Nonpoint Sources)	United States Environmental Protection Agency	http://water.epa.gov/scitech/datait/models/basins/index.cfm
Nitrogen and Phosphorus Pollution Data Access Tool (NPDAT)	United States Environmental Protection Agency	http://www2.epa.gov/nutrient-policy-data/nitrogen-and-phosphorus-pollution-data-access-tool
Preventing Eutrophication: Scientific Support for Duel Nutrient Criteria (2015)	United States Environmental Protection Agency	http://www2.epa.gov/sites/production/files/documents/nandpfactsheet.pdf
SPARROW (Surface Water Quality Monitoring)	United States Geological Survey	http://water.usgs.gov/nawqa/sparrow/
National Water Quality Assessment Program	United States Geological Survey	http://water.usgs.gov/nawqa/
Enforcement and Compliance History Online (ECHO)	United States Environmental Protection Agency	http://echo.epa.gov/
Discharge Monitoring Report (DMR) Loading Tools	United States Environmental Protection Agency	http://cfpub.epa.gov/dmr/
Advice Worth Drinking: A Planner's Guide	Source Water Collaborative	http://www.sourcewatercollaborative.org/guide-for-land-use-planners/

Resource and Tool	Organization	Link
Source Water Protection funding tools	Source Water Collaborative	http://www.sourcewatercollaborative.org/how-to-collaborate-toolkit/maintaining/sustainable-funding/
Source Water Protection and Conservation Partners Toolkit	Source Water Collaborative	http://www.sourcewatercollaborative.org/swp-conservation-partners-toolkit/

Appendix B Examples of Water Utility and Community Responses to Harmful Algal Blooms

The following short examples highlight instances where a bloom impacted drinking water supplies and may have resulted in adverse public health effects. These case studies highlight the potential technological and policy options that were implemented. These studies represent examples that have been cited in peer-reviewed publications; there are likely many more anecdotal examples.

Carroll Township, Ohio
In September 2013, microcystins concentrations at Carroll Township's intake on Lake Erie increased to >5 µg/L, the highest concentration observed at the intake in four years of monitoring. A finished water sample collected at the same time had a microcystins concentration of 1.4 µg/L, which exceeded Ohio EPA's microcystins threshold of 1 µg/l. Repeat samples had a source water concentration of 13 µg/L and a finished water concentration of 3.6 µg/L. Ohio EPA recommended that the water system issue a Do Not Drink Advisory and transition to an emergency connection with a neighboring utility. The advisory impacted over 2,200 people and lasted approximately 48 hours. The water system remained on their emergency connection for several weeks, until microcystins source water concentrations improved and treatment was demonstrated to be effective. The water system utilizes conventional surface water treatment with pre-ozonation. After the event, the system spent approximately $250,000 on plant upgrades, including new ozone generators and concentrators that enabled them to increase their ozone dose. In 2014, the upgraded and optimized plant was able to effectively treat source water microcystins concentrations of up to 18 µg/L, with no finished water detections.

Toledo, Ohio
In early August 2014, microcystins concentrations at Toledo's intake on Lake Erie rapidly increased to 14 µg/L. The microcystins concentration in the finished water was 2.5 µg/L and repeat samples run by two different analysts verified the above-threshold levels. Ohio EPA recommended that the city issue a Do Not Drink Advisory. Microcystins were also detected above Ohio EPA thresholds in eight distribution samples.

After the finished water detections, Toledo optimized the plant for microcystins removal by increasing powder activated carbon (PAC) from 6.3 to 15 mg/L, and increasing alum and chlorine doses. Microcystins concentrations in the finished water decreased to near the detection limit and the city lifted the advisory. The advisory affected approximately half a million people and lasted 55 hours. Eleven days after the advisory was lifted, microcystins concentrations at Toledo's intake increased to >50 µg/L, the highest concentration observed at the intake in five years of monitoring. At that point the water system was already optimizing for microcystins removal, with increased carbon dose and chemical feeds. While microcystins was again detected in finished water samples, concentrations did not exceed the 1.0 µg/L threshold. The city is undergoing extensive plant rehabilitation and upgrades, including increasing the PAC feed capacity to 40 mg/L and installing additional PAC feed locations. Costs for initial upgrades were estimated at $4.4 million. The city is also planning to pilot the use of ozone as part of more comprehensive long-term plant upgrades.

Lake Taihu, Wuxi, China (Zhang et al., 2010)
A bloom of *Microcystis aeruginosa* developed on Lake Taihu in May 2007, resulting in color, taste, and odor issues for approximately two million people who depend on the lake for drinking water. The bloom was likely the result of eutrophication and industrial and domestic wastewater discharges. The drinking water issues led to a shortage of bottled water, public panic, and economic impacts in the area. In response to the bloom, an emergency drinking water treatment process was developed to prepare for future incidents and the local government developed stricter standards for waste discharges and increased efforts for wetland restoration surrounding the lake. The treatment process resolved the odor issues and consisted of adding potassium permanganate at the intake and powdered activated carbon in the treatment plant. Microcystin-LR levels were reduced in the source waters from 7.59 μg/L on May 30 to 0.73 μg/L on June 2.

Sulejow Reservoir, Lodz, Poland (Jurczak et al., 2005)
Sulejow Reservoir is frequently subject to blooms due to eutrophication, which impacts the water quality of the nearby cities of Lodz and Tomaszow. Testing was conducted in the summers of 2002 and 2003 to determine the microcystins removal effectiveness of water treatment processes. During this time, the peak concentrations of microcystins in raw water samples were 4.7 μg/L dissolved and 3.3 μg/L cell-bound. The treatment plant for the Sulejow-Lodz system employed pre-oxidation, coagulation, filtration, ozonation and chlorination. This treatment train sufficiently removed microcystin levels to below detection limits in drinking water samples, especially during the filtration process. To further reduce the levels of microcystins in the raw water, the water utility utilized more ground water sources.

Solomon Dam, Queensland, Australia (Griffiths and Saker, 2003)
Over 100 children on Palm Island exhibited gastroenteritis in November 1979. Following the hospital admissions, local officials hypothesized that the outbreak could be connected to the local water supply source at Solomon Dam and cyanotoxins such as cylindrospermopsin. An epidemiological study (Bourke et al., 1983) later examined the link between the outbreak and the water supply and suggested that the use of copper sulfate in the water supply may have increased the exposure to cyanotoxins in the treated water. The reservoir had recently been treated for an algal bloom using copper sulfate, which can lyse cyanobacterial cells and release extracellular toxins, which are not effectively removed by filtration.

Darling-Barwon River, New South Wales, Australia (Herath, 1995)
A cyanobacterial bloom affected more than 1,000 kilometers of the Darling-Barwon River in Australia in 1991. Estimates for the economic losses were more than $1.3 million in direct treatment and water supply costs, one million people-days of drinking water, and 2,000 site-days of recreation that were valued to be at least $10 million. The local government appointed a Blue-Green Algae Tasks Force in response, which recommended various policies to reduce the impacts and occurrence of blooms in the future. One of the primary targets was reducing phosphorus loadings in the river basin that originated from detergents and other cleaning agents that end up in sewage treatment plants. A phosphorus permit trading program was also suggested as a potential policy solution to control nutrient inputs.

Appendix C Key Questions and Answers

Where in the country are harmful algal blooms a problem?
Harmful algal blooms (HABs) are a national concern. HABs have impacted waters across many regions of the U.S. EPA recommends that drinking water systems in all areas of the country that use surface water sources, such as lakes and reservoirs, assess their water source's vulnerability to HABs. EPA estimates that lakes and reservoirs that serve as sources of drinking water for between 30 and 48 million people may be periodically contaminated by algal toxins.

How do cyanotoxins produced by some harmful algal blooms affect drinking water quality?
HABs can occur in source waters used for drinking water. Winds and water currents can potentially transport HABs within proximity to drinking water intakes at treatment plants. If not removed during drinking water treatment, exposure to cyanotoxins in tap water could potentially affect human health. Algal blooms may also cause aesthetic problems (earthy and musty smell) and affect the taste of treated drinking water.

What are the health effects from exposure to cyanotoxins in drinking water?
Effects including gastroenteritis, and liver and kidney damage have been reported in humans following acute or short-term exposure to cyanotoxins in drinking water. Recreational exposure to cyanobacterial blooms has been reported to lead to allergic reactions, including hay fever-like symptoms; skin rashes; and gastrointestinal distress. However, more research is needed to quantify these effects.

What about using water with elevated algal toxins for showering and other uses?
The Health Advisory values for two key algal toxins (microcystins and cylindrospermopsin) are specifically for consumption of drinking water. Exposure to cyanobacteria and their toxins may also occur by ingestion of toxin-contaminated food, including consumption of fish, and by inhalation and dermal contact during bathing or showering. While these types of exposures cannot be quantified at this time, they are assumed to contribute less to the total cyanotoxin exposures than ingestion of drinking water. While information is not currently available to determine safe concentrations for showering, bathing, or other uses, EPA expects that it is unlikely that showering or bathing in water with cyanotoxin levels near or below the Health Advisory will present a health risk. As our understanding of algal toxin health effects continue to develop, EPA will continue to evaluate their health effects for other uses.

Are immunocompromised individuals or infants fed by nursing mothers at risk?
Populations such as nursing mothers and pregnant women, the elderly, and immune-compromised individuals or those receiving dialysis treatment may be more susceptible than the general population to the health effects of microcystins. As a precautionary measure, immunocompromised individuals and nursing mothers may want to consider following the recommendations for bottle-fed infants and young children of pre-school age.
For additional information please see Section 4 on Risk Characterization in the Health Advisories for microcystins and cylindrospermopsin for additional information available at http://www2.epa.gov/sites/production/files/2015-06/documents/microcystins-report-2015.pdf and http://www2.epa.gov/sites/production/files/2015-06/documents/cylindrospermopsin-report-2015.pdf

Are the Health Advisory values safe for all children (regardless of age)?
The microcystins and cylindrospermopsin HA values are set at levels at which adverse health effects are not expected to occur. EPA would not expect adverse health effects for children who are school-aged when microcystins concentrations in drinking water are at or below 1.6 µg/L and cylindrospermopsin concentrations are at or below 3 µg/L. EPA would not expect adverse health effects for bottle-fed infants and young children of pre-school age (less than six years old) when microcystins concentrations in drinking water are at or below 0.3 µg/L and cylindrospermopsin concentrations are at or below 0.7 µg/L.

Why is EPA's value different from the World Health Organization's (WHO) value?
In 1998, the World Health Organization (WHO) released a provisional guideline of 1 µg/L for microcystin-LR in drinking water. The derivation of this value differs from EPA's Health Advisory guideline derivation in two ways: the duration of exposure and exposure parameters (body weight and drinking water consumption) used for the calculation of the values.

WHO's guideline is based on risk from a lifetime of consumption and was calculated using data from a study of longer duration (13 weeks). EPA based the HA on a more recent study of shorter duration (28 days). EPA believes that this shorter exposure duration is more representative of how people may be exposed to cyanotoxins in their drinking water, from sporadic blooms rather than exposure over a lifetime of consumption.

The exposure parameters used for the WHO guideline for body weight (60 kg) and average water intake (2 L/day) are different from the parameters EPA used (adult average body weight of 80 kg consuming 2.4 L/day). EPA's exposure values are based on statistics of the U.S. population, and are routinely used for risk assessment purposes.

Why has EPA developed Health Advisories for two cyanotoxins: microcystins and cylindrospermopsin?
Cyanobacteria and their toxins have been found in drinking water systems and recreational waters in the U.S. Many states have expressed concerns regarding the presence of cyanotoxins in tap water and in surface waters, causing use impairments due to near-shore algae buildup. Currently, there are no U.S. federal water quality criteria or standards, or regulations concerning the management of HABs in drinking water under the Safe Drinking Water Act (SDWA) or in ambient waters under the Clean Water Act (CWA).

Based on the toxicology and epidemiology data, EPA found there are adequate data to develop HAs for microcystins and cylindrospermopsin. EPA issued these Health Advisories to assist state and local authorities in their efforts to address cyanotoxin risks.

What happens if you exceed the Health Advisory level? If it is a Ten-day value, what happens if you exceed for a smaller number of days?
The Health Advisory levels for microcystins and cylindrospermopsin are non-regulatory concentrations of drinking water contaminants at which adverse health effects are not anticipated to occur over a Ten-day exposure period. Because it is difficult to determine in advance the duration of elevated algal toxin levels, EPA recommends that water systems begin to take actions once the elevated levels have been confirmed by additional samples. Additionally, because of time needed to process sequential analytical tests, it can take several days following the detection of a bloom and/or cyanotoxins before concentrations above the HA values are confirmed in

finished water. Therefore, EPA recommends initiating the response activities as soon as practicable.

What about pets exposed to cyanotoxins through drinking water?
Pets are at greatest risk from exposure to cyanotoxins from consuming scum and mats, licking their fur after swimming in contaminated water, and drinking water from a water body contaminated by cyanobacteria. However, pets could also get sick if they drink tap water contaminated with high concentrations of cyanotoxins.

What is EPA doing to address problem of cyanotoxins in drinking water sources and other waters?
EPA has developed Health Advisories that will provide states, drinking water utilities and the public with information on health effects of cyanotoxins, and methods to sample and treat cyanotoxins in drinking water. EPA will continue to work with states, local communities and stakeholders to provide technical support on key steps that can be taken to protect the public from exposure to algal toxins.

EPA is planning to develop ambient water quality criteria for the protection of human health for recreational uses for microcystins, cylindrospermopsin, and anatoxin-a, if adequate data are available.

EPA is working diligently with its partners to address nitrogen and phosphorus pollution (known to create environmental conditions favorable to HABs) including:

- Providing states with technical guidance and resources to help them develop water quality criteria for nitrogen and phosphorus as part of their water quality standards for surface waters.
- Working with states to identify waters with nitrogen and phosphorus pollution and to develop Total Maximum Daily Loads (TMDLs) to restore the waters by limiting allowable nutrient inputs.
- Awarding grants to states for operating nonpoint source management programs.
- Administering a permit program that restricts the amount of nitrogen and phosphorus released to the environment from point sources, such as wastewater treatment plants.
- Providing funding for the construction and upgrading of municipal wastewater facilities and the implementation of nonpoint source pollution control and estuary protection projects.
- Working with state and federal partners on the Mississippi River and Gulf of Mexico Watershed Nutrient Taskforce to reduce hypoxia.
- Conducting and supporting research on nitrogen and phosphorus pollution-related topics.

EPA has worked closely with the U.S. Department of Agriculture (USDA) to focus investment in priority watersheds across the country through the National Water Quality Initiative. In addition, USDA funds are available through a variety of programs to control agricultural sources of runoff through suites of conservation practices, and many states are partnering with USDA to do so.

EPA is working to help educate the public and stakeholders about nutrients and HABs, leading a HABs public awareness campaign, including expert webinars and publications.

Are there point-of-use treatment devices consumers can use at their home or workplace to protect themselves from cyanotoxins in drinking water?
EPA is unaware of point-of-use devices that have been demonstrated to be effective for removal of cyanotoxins from drinking water. Third-party organizations are currently developing certification standards to test point-of-use devices and evaluate how reliably they can remove cyanotoxins from drinking water.

Can algal blooms and their toxins affect ground water wells?
Typically no, unless they are "Ground Water Under the Direct Influence of Surface Water" wells. Cyanobacteria require sunlight to survive. Most groundwater wells are not expected to be impacted by cyanotoxins.

What research is EPA doing on harmful algal blooms?
EPA researchers are conducting HAB research on water quality, human and ecological health effects, monitoring and analytical methods for rapid detection, and drinking water treatment research related to HABs.

Specifically for drinking water treatment, EPA researchers are conducting a Lake Erie field study that monitors cyanobacteria at numerous treatment plants to define the start and end of bloom events, and the water quality changes that take place through the treatment plant. In addition, the researchers are working on science to improve the ability of existing treatment processes to remove cyanobacterial toxins and to improve the performance of existing operations by modifying the locations where treatment chemicals are applied, and the types and concentrations of chemicals applied.

EPA is partnering with NOAA, USGS, and NASA on the Cyanobacteria Assessment Network (CyAN) project that includes making satellite data processed for cyanobacteria abundance available for large inland lakes nationwide once new satellite sensors come online and the data has been evaluated.

What funding sources are available to states for HAB monitoring?
Eligible federal funding sources for source water monitoring include CWA Section 106 base funding and the 106 monitoring initiative enhancement funds received annually, CWA Section 604(b) and potentially CWA Section 319. There are also funds for specific geographic programs, like the Great Lakes, Lake Champlain and Lake Pontchartrain, which received targeted funds that may be available for HAB monitoring. In addition, the Drinking Water State Revolving Fund (DWSRF) set-asides may be used as part of a state's strategy to build technical, financial, and managerial capacity of public water systems. For example, these funds may be used for demonstration purposes to build the capacity of the system for activities such as monitoring.

Appendix D Potential Language for Use in a Cyanotoxin Public Notification and Social Media

Above Health Advisory Value for Bottle-Fed Infants and Young Children of Pre-School Age but Below Health Advisory Value for School-Age Children through Adults

We are providing this notice to make you aware of the presence of low levels of [*insert specific cyanotoxin*] in your treated drinking water. [*insert specific cyanotoxin here*] is a cyanotoxin, created by certain types of harmful algal blooms in the source water of your drinking water supply. The cyanobacteria in harmful algal blooms that produce [*insert specific cyanotoxin here*] can grow rapidly when certain environmental conditions are favorable for their growth. Since not all 'blooms' produce these cyanotoxins, we sampled the treated drinking water to determine if cyanotoxins were present when a suspected bloom was occurring. The sampling conducted on *insert date* and confirmed on *insert date* indicated that the cyanotoxins are present in treated drinking water. We are adjusting our treatment operations to reduce concentrations of [insert specific cyanotoxin here] as quickly as possible.

Insert boundaries of service area affected

The cyanotoxins were detected at levels that may present a risk to bottle-fed infants and young children of pre-school age if ingested. Some consumers who have a suppressed immune system may also be at risk. We recommend that bottle-fed infants and young children of pre-school age and consumers with suppressed immune systems use an alternative source of water for ingestion and the preparation of infant formula use an alternative source of water until further notice.

Boiling water will not remove the cyanotoxins. The water is considered safe for humans for bathing, showering, washing hands, watering yards and gardens, washing dishes, flushing toilets, cleaning, laundry, and shaving.

We are working diligently to correct this problem, and do not expect this problem to last more than *insert number of days*. We will provide further notice when the water is again safe to use for all purposes. Additional information can be found at *insert link to additional information*. If you have any questions or concerns please contact us at *insert phone number*.

Above Health Advisory Value All Consumers

We are providing this notice to make you aware of the presence of [*insert specific cyanotoxin*] in your treated drinking water. [*insert specific cyanotoxin here*] is a cyanotoxin, created by certain types of harmful algal blooms in the source water of your drinking water supply. The cyanobacteria in harmful algal blooms that produce [*insert specific cyanotoxin here*] can grow rapidly when certain environmental conditions are favorable for their growth. Since not all 'blooms' produce these cyanotoxins, we sampled the treated drinking water to determine if cyanotoxins were present when a suspected bloom was occurring. The sampling conducted on *insert date* and confirmed on *insert date* indicated that the cyanotoxins are present in treated drinking water. We are adjusting our treatment operations to reduce concentrations of [insert specific cyanotoxin here] as quickly as possible.

Insert boundaries of service area affected

The cyanotoxins were detected at levels which may present a risk to all consumers. We recommend that you use an alternative source of water for ingestion and in the preparation of infant formula until further notice.

Boiling water will not remove the cyanotoxins. The water is considered safe for humans for bathing, showering, washing hands, watering yards and gardens, washing dishes, flushing toilets, cleaning, laundry, and shaving.

We are working diligently to correct this problem, and do not expect this problem to last more than *insert number of days*. We will provide further notice when the water is again safe to use for all purposes. Additional information can be found at *insert link to additional information*. If you have any questions or concerns, please contact us at *insert phone number*.

Potential Twitter Notice

Above Health Advisory Value for Bottle-Fed Infants and Young Children of Pre-School Age but Below Health Advisory Value for School-Age Children through Adults

Insert name of area served by the contaminated water's tap water may contain low levels of [insert specific cyanotoxin here], a toxin. Please see *insert website link* for more information. (Link would be to the full notices described at the beginning.)

Above Health Advisory Value All Consumers

Insert name of area served by the contaminated water's tap water may contain [insert specific cyanotoxin here], a toxin. Do not drink until further notice. See *insert website link* for more information. (Link would be to the full notices described at the beginning.)

Appendix E Long Term Mitigation Strategies and Treatment Options

Source Water Protection

PWSs may want to consider including long-term source water protection actions as part of a CMP to help prevent blooms and reduce source water vulnerability. This is especially important when source waters are determined to have ongoing cyanotoxin vulnerabilities and recurrence of blooms is likely (WHO, 1999). These actions occur at the watershed level to provide sustained protection of the source water and mitigate conditions that are conducive to cyanobacterial growth. Perhaps the most important source water protection step to address blooms is reduction of nutrient inputs, including both nitrogen and phosphorus.

Implementing source water protection strategies can reduce costs to the PWS, as watershed protection programs are often much less expensive than having to employ additional drinking water treatment (WRI, 2013). The Source Water Collaborative, a group of 26 national organizations dedicated to protecting sources of drinking water, provides detailed information on specific actions that can help prevent nutrient pollution. The Collaborative's "How to Collaborate Toolkit", previously described in the introduction and section 1 of this document, helps watershed stakeholders form partnerships to implement source water activities and includes information on funding source water protection work and planning for investment (SWC, 2015a). The Source Water Collaborative's "How to Collaborate Toolkit" also includes a section on implementing pilot projects. It provides profiles on examples of source water management practices like manure storage systems, land conservation and GIS decision-support (SWC, 2015a). Another resource is the Source Water Collaborative's Conservation Partners toolkit, designed for source water protection officials. This toolkit offers a step-by-step guide for understanding conservation programs and how to collaborate with key partners like Soil and Water Conservation Districts and U.S. Department of Agriculture (USDA) State Conservationists (SWC, 2015b). The Source Water Collaborative also provides a Planner's Guide that outlines land use decisions that can affect current and future drinking water supplies, either intentionally or inadvertently. This guide describes how urban and land use planners can integrate source water protection into regular planning activities (SWC, 2015c).

Controlling nutrient inputs requires the cooperation of many programs and stakeholders. *Opportunities to Protect Drinking Water Sources and Advance Watershed Goals through the Clean Water Act* is a toolkit that describes ways PWSs can coordinate with SDWA and CWA programmatic activities, such as point source permitting, water quality standards, listings, Total Maximum Daily Loads (TMDLs) and Section 319 program funding to protect drinking water sources (ASDWA, 2014).

Please see Appendix A for a list of tools and their links referenced in this document, including the tools mentioned above.

Alternative Drinking Water Sources

A long-term option PWSs could consider is to switch to an alternative drinking water source either permanently or during known bloom seasons, if available. PWSs could also consider utilizing or installing multiple drinking water intakes (at various depths or locations) in a source water, especially when the source water is a large body of water. For example, a bloom occurring

on a lake may not be impacting the entire lake and multiple intakes may allow water to be drawn from an unaffected section of the lake or unaffected depth within the lake. Intakes in shallow water may be at more risk than deeper intakes, especially in areas prone to high cyanobacterial densities (Loftin et al., 2008).

Permanent Treatment Options

If PWSs are frequently challenged by cyanotoxins in source waters and modifications to their existing treatment systems do not sufficiently reduce cyanotoxin levels to below HA values, they may consider installing permanent treatment systems as long-term, cost effective alternatives to address cyanotoxin occurrence in future years. These permanent treatment systems will likely require significant capital investment and long-term resource planning. PWSs may want to consult with the states and primacy agencies on plan review and approval requirements. PWSs may need to conduct an evaluation of different treatment technologies to select the most cost-effective option and associated design and operational parameters to achieve multiple treatment goals including cyanotoxins removal.

Permanent treatment options that are effective for removing intracellular cyanotoxins include dissolved air flotation (DAF), microfiltration (MF), and ultrafiltration (UF). Permanent treatment options that can be effective for removing extracellular cyanotoxins include ozone, GAC, biological filtration, nanofiltration (NF), reverse osmosis (RO), ultraviolet (UV) with hydrogen peroxide, and other emerging technologies. Each of these technologies is briefly described below. More details can be found in the literature (Westrick et al., 2010; Newcombe et al., 2010; WHO, 1999).

Treatment Options for Intracellular Toxin Removal

Dissolved Air Flotation. DAF is effective particularly for light cells and species containing gas vesicles, which typically form surface scums. Waters of high color and low turbidity are best suited for flotation processes (Sklenar et al., 2014; U.S. EPA, 2014a; Tokodi et al., 2012, Markham et al., 1997; Mouchet and Bonnélye, 1998).

MF and UF. Membrane filtration technologies have demonstrated the ability to remove cyanobacterial cells and their extracellular toxins from drinking water to varying degrees. For systems having these technologies at their disposal, using them during a bloom could prove beneficial. MF and UF are highly effective and can be used alone or as a replacement for conventional filtration in the removal of intact cyanobacterial cells (Westrick et al., 2010). These membranes have been reported to remove more than 98 percent of whole cells (Chow et al., 1997; Teixiera and Rosa, 2006).

Treatment Options for Extracellular Toxin Removal

Ozonation. Use of ozone, after removing the cells through a physical process, is the most efficient process for the destruction of extracellular microcystins and cylindrospermopsin (Newcombe et al., 2010; WHO, 1999; U.S. EPA, 2014a; Rodríguez et al., 2007b). Ozone is effective under most water quality conditions, contact times and doses (0.5-1.1 mg/L) encountered in drinking water treatment (Alvarez et al., 2010). The effectiveness of ozone is negatively impacted by the dissolved organic carbon concentrations (Alvarez et al., 2010).

Australian guidance recommends a CT value of 1.0 mg/L-min at a pH of 7 or higher to treat for microcystins and cylindrospermopsin (Newcombe et al., 2010). Use of ozone can result in biodegradable organics and bromate. Bromate is an inorganic DBP regulated by EPA (EPA, 1999). Water systems should conduct system-specific tests to determine the optimal ozone dose that maximizes toxin degradation and also ensures that the running annual average bromate MCL of 0.01 mg/L would not be exceeded.

Granular Activated Carbon (GAC). GAC removes microcystins through adsorption to the media and (or) biodegradation by microorganisms residing on the filter media (Wang et al., 2007). Like PAC, GAC effectiveness is dictated by the carbon type, source water chemistry, contact time and pore capacity. An empty bed contact time of no less than 10 minutes is recommended for adequate microcystin-LR removal in most cases (Alvarez et al., 2010). While GAC can remove cylindrospermopsin, its effectiveness is less than that for microcystins (Alvarez et al., 2010; U.S. EPA, 2014a). Australian guidelines recommend using an adsorption step (for example, GAC) or oxidation as a follow-up to conventional treatment for removing cylindrospermopsin (Newcombe et al., 2010). The GAC media can become spent within weeks (Sklenar et al., 2014) to at least six months, depending on water quality and other factors (Alvarez et al., 2010). Like many other treatments, PWSs may want to conduct tests prior to full-scale use to account for variations in carbon type and water quality conditions (Sklenar et al., 2014). GAC can also be used as a substrate for a biological process by allowing bacterial growth on GAC media in rapid gravity filters to degrade cyanotoxins.

Biological Filtration. Biologically active slow sand filtration, river bank filtration and GAC have been reported to effectively remove extracellular microcystins and taste and odor compounds due to very long contact times and high biological activities in these processes (Ho et al., 2006b, 2012), but full-scale studies are limited (Grützmacher et al., 2002; Rapala et al., 2006). These processes would also be effective for cylindrospermopsin removal (Ho et al., 2012). Cyanobacteria and toxins are biodegraded in these processes to varying degrees depending on conditions, such as type and concentration of microcystin degrading bacteria, concentration of microcystins, natural organic matter in source water and temperature (Ho et al., 2012).

Slow sand filtration can remove cyanobacterial cells, but also has the ability to biodegrade some toxins in the schmutzdecke on the surface of the filtration media. However, waters containing cyanobacteria can lead to rapid blocking of the filtration media (WHO, 1999), which can result in the retention of a large proportion of cells (Cyanocenter UBA, 2015) and blocking of the filter. The ability of slow sand filters to degrade some cyanotoxins may vary with the season; achieving a 95 percent removal of extracellular microcystins and cylindrospermopsin in the summer but less than 65 percent in the autumn (Westrick et al., 2010). River bank filtration may also be effective for the removal of microcystins (Lahti et al., 1998; Schijven et al., 2002; Grützmacher et al., 2002).

Membrane Filtration. NF and RO are tighter membranes than MF and UF and can remove a high percentage of extracellular cyanotoxins. Tokodi et al. (2012) found that NF can completely remove cyanobacterial cells and their associated extracellular toxins. Removal of extracellular cyanotoxins by NF and RO is important because cell lysis is highly likely during the process (Connecticut Department of Public Health, 2015). Westrick et al. (2010) reported a range of microcystins removal from 82 percent to complete removal by NF and RO. Dixon et al. (2010,

2011), found that cylindrospermopsin was removed at a 90-100 percent efficiency using NF and RO. The exact removal efficiencies by NF depend on the membrane material for NF (Westrick et al., 2010), and on the membrane pore size and water quality for NF and RO (Gijsbertsen-Abrahamse et al., 2006). Systems should test cyanotoxin removal through individual membrane pilot tests (Sklenar et al., 2014).

Ultraviolet with Hydrogen Peroxide. Ultraviolet (UV) treatment alone requires impractically high UV doses for effective cyanotoxin oxidation (U.S. EPA, 2014c; Westrick et al., 2010; WHO, 1999). For example, only 58 percent microcystin oxidation was achieved at 300 mJ/cm^2 using UV (Alvarez et al., 2010). While UV alone is ineffective in cyanotoxin removal, requiring dosages that are orders of magnitude higher (as high as 20,000 mJ/cm^2) than needed for disinfection (Westrick et al., 2010), UV treatment at 100 mJ/cm^2 with hydrogen peroxide addition at 2 mg/L as part of an advanced oxidation process showed 50 percent microcystin-LR removal in one study (Alvarez et al., 2010). Alvarez et al. (2010) studied a range of UV doses from 33–1,000 mJ/cm^2 and hydrogen peroxide doses of 1-4 mg/L, and reported that the effectiveness of UV with hydrogen peroxide was dictated by the hydrogen peroxide concentrations and availability. UV and hydrogen peroxide can achieve disinfection, oxidation and photolysis. The needed dose should be determined by bench-scale studies (Alvarez et al., 2010).