# Cyanobacteria and Public Water Systems
# MassDEP Guidance

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**Massachusetts Department of Environmental Protection**
**Bureau of Water Resources**

**COMMONWEALTH OF MASSACHUSETTS**
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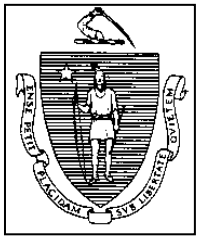

## Executive summary

Cyanobacteria are photosynthetic bacteria that share similar characteristics with algae and are normally present in all types of waterbodies throughout Massachusetts, including Public Water System (PWS) surface water sources. Like algae, cyanobacteria can multiply quickly in response to conditions that are favorable for their growth resulting in "blooms." Harmful algal blooms composed of cyanobacteria can contribute to taste and odor issues for PWSs with surface water sources, but they also have the potential to produce toxins that can be harmful to public health. Because of the potential toxicity concerns associated with cyanobacterial blooms, the Massachusetts Department of Environmental Protection (MassDEP) is recommending that PWSs with surface water sources take preemptive actions to prevent cyanobacterial blooms, as well as to develop a protocol to address a bloom, should one occur.

Surface water source protection is the first line of defense against cyanobacterial blooms. Maintaining high water quality through source water protection will help to prevent conditions that are conducive to the rapid formation of a bloom. In PWS surface water sources with a history of algal blooms, or for suppliers of water who are concerned about the potential for cyanobacterial blooms, this document is intended to provide them with information regarding general cyanobacteria facts, monitoring, and appropriate responses should a bloom occur. MassDEP is recommending that suppliers of water with surface water sources update their surface water supply protection plans, source water monitoring strategies, algal control plans, and emergency response plans (ERP) to address potential cyanobacterial blooms. Specific actions and recommendations are outlined in this guidance document, which is available on the MassDEP website at http://www.mass.gov/eea/agencies/massdep/water/drinking.

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# Introduction: Purpose and Scope of Guidance

## Purpose for Guidance:

Massachusetts Department of Environmental Protection (MassDEP) considers cyanobacteria and cyanotoxins to be emerging contaminants, warranting additional attention and action. Recent and predicted changes in precipitation, storm frequency and magnitude, as well as changes in air and water temperatures affect and can enhance cyanobacteria growth. As a result, more cyanobacterial blooms are being documented both in Massachusetts and nationwide. MassDEP has developed this guidance document for Public Water Systems (PWSs) with surface water sources to help assess, monitor for, prevent, and respond to cyanobacterial blooms. The specific objectives of this guidance are as follows:

- provide comprehensive information on cyanobacteria, including: a description of the most commonly found species in Massachusetts, the causes for cyanobacterial blooms, the cyanotoxins they may produce, their health effects, and the risk these blooms pose to PWS customers;
- provide PWSs with tools to assist with the identification of cyanobacterial blooms and recommended next steps;
- provide recommendations to surface water suppliers for updating their Surface Water Supply Protection Plans to include strategies for managing cyanobacteria populations;
- provide general information on treatment options for in-reservoir applications that may minimize the potential for cyanobacterial blooms, and treatment processes for use within the facility;
- provide PWSs with a PWS Bloom Tracking Form for voluntary use as a tool in identifying and tracking algal blooms to better assess risk, and provide pertinent information for use with amending their current PWS Emergency Response Plan (ERP) as applicable; and
- provide PWSs with MassDEP contact information for cyanobacteria questions and additional resource materials.

Over the past several years, the Massachusetts Department of Public Health (MDPH) and MassDEP have documented and responded to approximately 20 to 25 cyanobacterial Harmful Algal Blooms (HABs or CyanoHABs) in recreational waterbodies annually. MDPH and MassDEP have also been notified of several CyanoHABs in surface waters that serve municipal PWSs. It is likely that there have been additional CyanoHABs that were not reported.

MDPH has developed health-based guidance levels for recreational exposure to cyanobacteria. MDPH recommends that beaches be posted and individuals limit all contact with a waterbody if the waterbody has cyanobacteria cell counts exceeding 70,000 cells/milliliter (mL) or microcystin concentrations (a toxin produced by cyanobacteria) that meet or exceed 14 micrograms per liter (µg/L) (MDPH 2008). The U.S. Environmental Protection Agency (US EPA) released draft guidance recommending that values for primary contact recreation exposure should not exceed 4 µg/L for microcystin and 8 µg/L cylindrospermopsin (US EPA 2016). However, cyanobacteria, and the cyanotoxins these microbes have the potential to release in drinking water (DW), are not currently regulated by the US EPA or MassDEP.

In 2015, US EPA released 10-day DW health advisory (HA) levels for two cyanotoxins – microcystins and cylindrospermopsin. The HAs are non-regulatory concentrations at which adverse health effects are anticipated to occur by oral ingestion of DW over specific exposure durations. Typically, HA values are developed for 1-day, 10-

day, and/or lifetime exposure durations, and 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 (US EPA, 2008). A HA value is determined by US EPA using the best available information on health effects, exposure and other relevant data. The US EPA HA values for the two cyanotoxins are shown below.

**Table 1. US EPA DW Health Advisories**

| Cyanotoxin | US EPA 10-day HA | |
|---|---|---|
| | Bottle-fed infants and pre-school children | School-age children and adults |
| Microcystins | 0.3 µg/L | 1.6 µg/L |
| Cylindrospermopsin | 0.7 µg/L | 3 µg/L |

For additional US EPA information on cyanobacteria, cyanotoxins and the HAs, please see the US EPA 2014 Fact Sheet (U.S. EPA, 2014), view the 2018 Edition of Drinking Water Standards and Health Advisories (US EPA, 2018), or visit the US EPA CyanoHABs in water website at: https://www.epa.gov/nutrient-policy-data/cyanobacterial-harmful-algal-blooms-water

In compliance with US EPA's fourth round of the Unregulated Contaminant Monitoring Rule (UCMR4), PWSs nationwide will begin sampling ten cyanotoxins in 2018 through 2020 (total microcystins, microcystin-LA, microcystin-LF, microcystin-LR, microcystin-LY, microcystin-RR, microcystin-YR, nodularin, anatoxin-a, and cylindrospermopsin). Data from the UCMR serves as a primary source of research information, which US EPA utilizes to develop regulatory decisions. Further information on US EPA's UCMR4 can be accessed through this link: https://www.epa.gov/dwucmr

## Scope of Guidance:

It is important to note that there is a wealth of information regarding cyanobacteria, but more information is necessary to sufficiently evaluate cyanobacteria and its associated public health threats. MassDEP has developed this guidance document using available scientific data from a variety of local, state, federal and international organizations, and acknowledges that a multiple barrier approach through watershed protection, monitoring, and treatment are currently the most effective methods for preventing and mitigating CyanoHABs in PWS surface water sources. The guidance also introduces "to do" lists for watershed best management practices and recommended baseline data collection for easy, at-a-glance use.

This Guidance is specific to PWSs with surface water sources only and is not designed for PWSs designated as Groundwater Under the Direct Influence of Surface Water (GWUI) or PWSs using only groundwater sources. This document is intended to help PWSs with surface water sources assess, monitor for, prevent, and respond to cyanobacterial blooms. The Guidance does not dictate specific emergency response actions as PWS sources, treatment plant capabilities and distribution systems are highly variable, which will require active discussion and explicit direction to best meet public safety. As new information becomes available, MassDEP will provide updates to this Guidance.

# Cyanobacteria: An Introduction

## What are cyanobacteria?

Cyanobacteria are often referred to as blue-green algae; however, they are a group of microorganisms, which have similar characteristics as algae and the ability to perform photosynthesis, like green plants using the chlorophyll in their cells. They may occur as single cells, thread-like filaments, or as colonies of various sizes and shapes composed of groups of many filaments or cells. Cyanobacteria are naturally occurring in all waterbodies with some species growing as benthic populations in sediments, while others are planktonic cyanobacteria that can regulate their buoyancy using specialized intracellular gas vesicles that allow them to move vertically within the water column to optimize growth (Porat et al., 2001).

There are thousands of species of cyanobacteria and they are an important constituent of a reservoir's algal community. Typically, cyanobacteria are found in low numbers when exposure to nutrients, particularly nitrogen (N) and phosphorus (P), is minimal. However, when there is a buildup of nutrients in the waterbody from anthropogenic sources, combined with other favorable environmental conditions, such as increased water temperature, cyanobacteria can reproduce rapidly.

*Figure 1. An example of a cyanobacterial bloom forming a surface scum at East Monponsett Pond-Halifax, MA. Aug-2013 (photo G. Zoto, MassDEP)*

In addition to excessive nutrients flowing into waterbodies, the expansion of human populations and agricultural areas has led to the depletion of wetlands, which serve as buffer zones and filter nutrients before they enter the water, further exacerbating the nutrient problem (Hudnell, 2010). Other factors such as the presence/abundance of other algal species and grazers in the aquatic ecosystem may also influence the dominance of a given species (Anderson et al., 2002).

Seasonal changes, drought conditions, storms and increased runoff, loss of wetlands and predatory fish populations can all impact CyanoHAB development. A dramatic cyanobacteria population increase due to one or more of these factors, may color an affected waterbody bright green or blue-green, forming a surface scum, a discoloration of the water column, or even a mat on its bottom sediments. The discoloration of the water can extend several inches below the water surface, frequently without a scum, or accumulate near shorelines and in coves from onshore wind action (Figure 1.). These surface scums or discolored waters are commonly called blooms, or CyanoHABs, and may look like pea soup or spilled, green paint. Cyanobacteria under these bloom conditions can cause dissolved oxygen (DO) swings that may result in plant and animal die-off, pH changes, taste and odor issues, and can cause potential public health issues from the cyanotoxins they may release.

Although they may occur at any time of year, CyanoHABs are most common during the summer and early autumn when water temperatures generally exceed 25$^0$C (77$^0$F), and in waterbodies that have a long residence time with

limited flushing capacity (i.e., shallow, unstratified lakes and impoundments). While some blooms may only last for several days, others remain for prolonged periods, and some may even survive after ice has formed on the waterbody.

Not all surface scums result from cyanobacterial blooms. There are other conditions, such as floating mats of pollen that may look similar to a cyanobacterial bloom. These pollen mats can be misidentified as potentially toxic cyanobacteria leading to unnecessary actions by PWS managers and public alarm. For this reason, it is critical to correctly identify cyanobacterial blooms. For further information on visually identifying cyanobacteria and standard sampling procedures for cyanobacteria identification and enumeration, see Appendix 1.

## How fast can a CyanoHAB occur?

Cyanobacteria are generally always present in low numbers in surface waterbodies. However, when conditions are amenable, cyanobacteria cell count doubling times can range from one week to less than two days (Global Water Research Coalition, 2009). For example, an initial cyanobacteria cell concentration of 1,000 cells/mL has the potential to increase to 16,000 cells/mL within seven days and >25,000 cells/mL by 14 days under conditions ideal for growth. The sooner a PWS is able to recognize an increased growth rate in the cyanobacteria population of a surface water source, the more flexibility it will retain in responding to a CyanoHAB. Table 2 provides further information on cyanobacteria doubling times and resulting cell counts.

**Table 2. Cyanobacteria doubling times and resulting cell counts**

| **Initial cell concentration (cells/ml)** | **Growth rate, population doubling time in days** | **Cyanobacteria density (cells/ml)** | | | |
|---|---|---|---|---|---|
| | | At 3 days | At 7 days | At 14 days | At 28 days |
| 100 | 6.93 (slow) | | 200 | 400 | 1,500 |
| 100 | 1.72 (fast) | | 800 | 6400 | |
| 1000 | 6.93 (slow) | | 2000 | 4000 | >15,000 |
| 1000 | 1.72 (fast) | 3,500 | 16,000 | >25,000 | |

Source: Global Water Research Coalition 2009 chapter 3 and WHO 1999.

## What are cyanotoxins?

Some cyanobacteria are known to produce toxins, known as cyanotoxins, which can impact both recreational and DW users. Cyanotoxins can exist in two forms, intracellular and extracellular, and can have a variety of human health effects ranging from acute symptoms to long-term effects. Many bloom-forming cyanobacterial species can produce cyanotoxins; however, not all bloom-forming cyanobacteria are toxic, and even bloom-forming cyanobacterial species that have the ability to produce toxins, do not produce toxins under all conditions. In most cases, cyanobacteria toxins exist intracellularly, or within the cell; however, when the cell dies or breaks (lysis), the cell membrane ruptures, and releases any toxins into the water (extracellular toxins). Adding to their overall complexity, there are toxic and non-toxic strains of cyanobacteria, even within the same species, which often coexist in the environment (Davis et al., 2009). While planktonic cyanobacteria may be the most observed due to their visibility, surface water suppliers should also be aware of benthic cyanobacteria and their capacity to produce cyanotoxins, as their growth often coat bottom sediment and rocks within eutrophic river sources (Quiblier et.al., 2013). As a precaution, CyanoHABs should be considered toxic, as evidence shows that up to 75 percent of blooms are toxic (Chen, Burke & Prepas, 2011).

## How can exposure to cyanotoxins occur?

The most common exposures to cyanobacteria and their toxins occur during recreational activity in waterbodies through oral, dermal and inhalation routes, but these exposures, primarily ingestion, may also occur via the consumption of cyanotoxin-contaminated DW. Exposure through DW may also occur if the water is used for dialysis treatment at home or at medical facilities (EPA 2016).

## What are the health effects of cyanotoxins?

The health effects of cyanotoxins can be grouped into three types based on their potential impacts to the body: dermatological (skin irritants), hepatotoxins (liver), and neurotoxins (nerve synapses). Their impact depends on the concentration of the toxin present and on the type of exposure. Cyanotoxins can enter the body orally through two basic modes. The first method is by direct ingestion of the cells followed by the lysis of the cells in the digestive system and subsequent release of toxins to the body. The second mode is oral entry of the toxin that has already been released into water from lysed cyanobacteria cells.

USEPA has summarized the adverse health risks humans face from acute exposure to cyanotoxins caused by the most common toxin producing cyanobacteria. Health risks may range from a mild skin rash to serious illness or death, while microcystin and cylindrospermopsin could cause liver and kidney damage. These health effects are shown below in Table 3; however, it is important to note that the table does not represent all known cyanobacteria and cyanotoxins.

**Table 3. USEPA Human Health Risks to Cyanotoxins Exposure: https://www.epa.gov/nutrient-policy-data/health-and-ecological-effects#what1**

| CYANOTOXINS | ACUTE HEALTH EFFECTS IN HUMANS | MOST COMMON CYANOBACTERIA PRODUCING TOXIN |
|---|---|---|
| **Microcystin-LR** | Abdominal pain, Headache, Sore throat, Vomiting and nausea, Dry cough, Diarrhea, Blistering around the mouth, and Pneumonia | *Microcystis, Anabaena, Nodularia, Planktothrix, Fisherella, Nostoc, Oscillatoria, and Gloeotrichia* |
| **Cylindrospermopsin** | Fever, Headache, Vomiting, Bloody diarrhea | *Cylindrospermopsis raciborskii, Aphanizomenon flos-aquae, Aphanizomenon gracile, Aphanizomenon ovalisporum, Umezakia natans, Anabaena bergii, Anabaena lapponica, Anabaena planctonica, Lyngbya wollei, Rhaphidiopsis curvata,* and *Rhaphidiopsis mediterranea* |
| **Anatoxin-a group** | Tingling, Burning, Numbness, Drowsiness, Incoherent speech, Salivation, Respiratory paralysis leading to death* | *Chrysosporum (Aphanizomenon) ovalisporum, Cuspidothrix, Cylindrospermopsis, Cylindrospermum, Dolichospermum, Microcystis, Oscillatoria, Planktothrix, Phormidium, Anabaena flos-aquae, A. lemmermannii Raphidiopsis mediterranea (*strain of *Cylindrospermopsis raciborskii), Tychonema* and *Woronichinia* |

*Symptoms observed in animals.

### Cyanobacteria risks to PWSs:

The potential presence of cyanobacteria and cyanotoxins in PWS surface water sources demonstrates the overall importance of establishing baseline monitoring to assess source vulnerability to cyanobacteria populations. There have been documented reports of dog, bird and livestock deaths resulting from consumption of surface water sources with cyanobacterial blooms. In addition, cyanobacteria and their toxins can increase treatment chemical demand, microbial growth, and disinfection by-product (DBP) formation within the PWS (Westrick et al., 2010).

MassDEP recognizes that it is critical for PWSs with surface water sources to first identify whether a cyanobacteria problem exists for their source(s), and then establish ways to reduce the presence of cyanobacteria cells (and their toxins) within the surface water source and PWS treatment facility. If cyanobacterial blooms are identified early, the options available to PWSs to treat the bloom and take preventative measures are greatly enhanced.

In addition, operator safety is an important component to consider when working in and around surface waters, particularly waterbodies with elevated levels of cyanobacteria. MassDEP utilizes various guidance documents for field sampling activities including safety considerations within the 2008 USGS Guidelines for Design and Sampling for Cyanobacterial Toxin and Taste and Odor Studies in Lakes and Reservoirs found at https://pubs.usgs.gov/sir/2008/5038/; and, the 2015 National Field Manual for the Collection of Water-Quality Data, Chapter A9 (Safety in Field Activities) found at https://water.usgs.gov/owq/FieldManual/. Because of the potential cyanotoxins that cyanobacteria may produce, MassDEP recommends that operators take the following precautions when responding to a CyanoHAB event with particular care taken when collecting any samples:

- Avoid direct and indirect skin and eye contact with water and scum, by wearing appropriate personal protective equipment (PPE) that may include: safety glasses or goggles, gloves, protective clothing (Tyvek suits, apron, etc.), and safety boots or waders (depending on where the sampling will be done). At a minimum, PPE selection should be based on the hazards likely to be encountered during the sampling activities.
- Skin contact with a scum, contaminated or potentially contaminated water should be rinsed immediately with clean water.
- Avoid ingesting water and scum; do not eat or drink while sampling.
- Avoid falling into the water by wearing safety boots or waders (depending on where the sampling will be done).
- Avoid going into the water if possible, use an extendible sampling pole if available.
- Do not attempt to wade into a stream for which values of depth multiplied by the velocity equal or exceed 10 $ft^2/s$. If wading into the water is required, wear a personal flotation device (PFD), and use a wading rod during wading activities.
- If samples are to be preserved, care should be taken when adding and using Lugol's solution (gloves and eye protection should be used as it can be an irritant to the skin and eyes).
- Decontaminate sample bottles before storing for transport, sampling equipment, re-usable PPE and any contaminated surfaces as soon as possible.
- Properly dispose of any waste including disposable PPE.
- Wash hands with soap and water after removing PPE.

## Watershed Management – The PWSs First Line of Defense:

MassDEP recommends that effective watershed management, including a water supply protection plan update or development, baseline monitoring of critical factors to assess CyanoHAB vulnerability, and Emergency Response

Plan (ERP) revision to include CyanoHAB response, be established for all surface water suppliers following the recommendations within this Guidance.

All PWSs with surface water sources that are required to maintain a Surface Water Supply Protection Plan as defined by 310 CMR 22.20C1(d)(4), must ensure that it is updated every three years. In addition, MassDEP recommends that all PWSs with surface water sources develop a Surface Water Supply Protection Plan. Guidance for developing this plan can be found at: http://www.mass.gov/eea/docs/dep/water/drinking/alpha/i-thru-z/surfprot.pdf. MassDEP has also developed a fact sheet on cyanobacteria and watershed management, which is available in Appendix 2.

As previously identified, low concentrations of cyanobacteria do not necessarily pose a health risk; however, when populations begin to multiply, risk levels increase. Because cyanobacteria are naturally found in all waterbodies, establishing baseline monitoring to assess source vulnerability to cyanobacterial blooms is an important tool in the prevention of a CyanoHAB and its potential impact to a PWS. MassDEP recommends that surface water suppliers review the EPA Harmful Algal Bloom Incident Action Checklist, which can be found at: https://www.epa.gov/waterutilityresponse/incident-action-checklists-water-utilities. The checklist includes a section on "Actions to Prepare to Respond to a Harmful Algal Bloom Incident." Completion of the EPA checklist, coupled with baseline monitoring of a surface water source will assist as a starting point for your PWS in assessing risk and responding to potential cyanobacteria events.

The best means of controlling cyanobacteria populations is to practice effective watershed management measures that reduce blooms from occurring in the surface water source at the outset. Watershed best management practices (BMPs) can help to reduce nutrient loading to a surface water supply, thereby helping to reduce the frequency of cyanobacterial blooms. MassDEP recognizes it is important to note that the source of nutrient loadings may be attributed to land uses or upstream tributaries that are not within a PWS's or the respective community's jurisdiction; however, identifying the nutrient loading source(s) is key to moving forward with potential solutions and implementation of BMPs. Watershed BMPs include:

- maintaining a wooded buffer around the surface water source;
- efforts to reduce the use of fertilizers at golf courses, homes, and agriculture in or near the surface water source;
- frequent pumping of surrounding septic tanks;
- preserving as much as possible of the watershed in forested land use, which reduces erosion and nutrient contributions in runoff from paved areas and agricultural lands;
- reducing impervious surfaces, redirecting stormwater, and treating or eliminating stormwater discharges; and
- minimizing reservoir elevation drawdowns and herbicide treatments (Scheffer et.al., 2001, Bakker et. al, 2013, Hilt et.al., 2017).

Many PWSs already perform routine inspections of their surface water sources as part of their watershed management programs. These examinations may include inspecting surface water supply levels, screen positions, spillway condition and stop logs, and prohibiting illicit uses of the source and activities within the watershed protection area. Often, these visual inspections may be conducted on a regular basis, but are not necessarily documented. Documentation in written format is an important component of watershed management as it provides an historical account of the source conditions observed by all PWS staff, past, present and future. In

addition, because composition of a cyanobacteria population can change quickly, it is important to have a plan readily available in the event that a CyanoHAB occurs. MassDEP requires that all PWSs prepare and keep an ERP per 310 CMR 22.04(13), and recommends that all PWSs with surface water sources recognize the impact that a CyanoHAB may have on their system, and develop a cyanobacteria strategy as part of their ERP.

### Watershed Management - Recommended To Do List:

- Identify and map untreated direct discharges of stormwater to your reservoir and tributaries. Start in the Zone A of your reservoir.
- Talk to representatives from the municipal Department of Public Works (DPW) for local roads, and the Massachusetts Department of Transportation (DOT) for state roads; and, request that they make improvements to reduce, redirect, treat or eliminate direct discharges when any road work is planned. Provide your request in writing and include a map of the discharges. Develop contacts at these departments and keep in touch with them to identify future projects. Plans are usually developed far in advance of the work starting, and the planning phase of the project is the best time to collaborate on proposed work.
- Educate residents and businesses within the watershed to pick up dog waste, reduce fertilizer use, and maintain septic systems.

MassDEP's Source Water Protection fact sheets are located at: http://www.mass.gov/eea/agencies/massdep/water/drinking/source-water-protection-for-drinking-water-supplies.html. Contact MassDEP's Drinking Water Program at 617-292-5770 or email at program.director-dwp@state.ma.us for assistance.

## Baseline Data Collection of Critical Factors:

In order to recognize whether or not your source water is at risk for potential impacts caused by cyanobacteria, MassDEP recommends that specific source water baseline information should be obtained and recorded as part of routine watershed management. This baseline data is of particular importance because the knowledge of general water quality information for your specific source(s) will assist in determining the risk, or lack thereof, for CyanoHAB potential.

There are several factors that increase the potential risk that a surface water source will experience toxic cyanobacterial blooms or taste and odor problems caused by cyanobacteria (Newcombe et. al., 2010). These critical risk factors include: a history of cyanobacterial blooms, high water temperatures, elevated water or sediment phosphorous levels, and thermal stratification (thermocline), along with taste and odor issues, wind, long residence time, and pH changes. The potential for a bloom to occur at a given waterbody, including a PWS surface water source, is largely dependent on how many of these factors occur within that waterbody, and the intensity of those factors. While it is possible to have a range or combination of variables that can lead to a moderate risk of cyanobacterial blooms, there are four predominant indicators of their potential occurrence. Table 4 contains these predominant critical factors, and the general risk levels associated with them.

| Table 4. Potential for cyanobacterial blooms in waterbodies based upon environmental factors. | | | | |
|---|---|---|---|---|
| **Bloom Risk level** | **History of Blooms** | **Water Temp °C** | **Total Phosphorous (in water) micrograms per liter (µg/L)** | **Thermal Stratification** |
| Very low | No | <15 | <10 | Rare or never |
| Low | Yes | <15-20 | <10 | Infrequent |
| Moderate | Yes | 20-25 | 10-25 | Occasional |
| High | Yes | >25 | 25-100 | Frequent and persistent |
| Very high | Yes | >25 | >100 | Frequent and persistent/strong |
| Based on Newcombe et.al., 2010 | | | | |

Ideally, baseline data should be obtained from the water column at locations throughout the reservoir, and where blooms have previously occurred; however, MassDEP recognizes this may not be a viable option for many PWSs. Baseline monitoring collected from the source water intake is a reasonable alternative if additional reservoir monitoring is not feasible. Collecting and recording baseline data on the critical factors that contribute to bloom formation will also help the PWS determine the need for and development of any specific cyanobacteria monitoring program. Ultimately, this information will aid your system in planning for and responding to potential CyanoHAB events if necessary.

The following sections further detail recommended baseline data collection to assess your risk of CyanoHABs.

### History of Blooms and Toxins

A surface water source that has had past blooms or cyanotoxin problems can help inform a PWS's approach for addressing any future blooms and the presence of toxins. Prior blooms increase the likelihood that a bloom event will occur again, if conditions are ideal for CyanoHAB growth. Blooms and the presence of toxins may occur at the same time each year, or may be composed of the same genera year after year. Some genera of cyanobacteria produce cells called akinetes, which are dormant cells that are often referred to as being in a "resting stage." Akinetes can accumulate in the sediments and then germinate at some later time when conditions are conducive for germination in the surface water source. Documenting bloom patterns is straightforward and simple.

**Recommended To Do List:**

- Begin with visual inspections of the surface water source on a routine basis (weekly, bi-weekly, or monthly) initially in spring and summer.
- Document those observations and evaluate patterns over time.

### Nutrients *(Total Phosphorus, Total Nitrogen)*

Most PWSs do not routinely monitor nutrient levels within their surface water source(s); however, as noted earlier in this Guidance, nutrients, particularly phosphorus, are critical contributing factors for the growth of algae and cyanobacteria. The Vollenweider lake model, a widely used eutrophication model, shows a clear relationship between the predicted increases of phytoplankton biomass with increasing concentrations of phosphorus. The level representing a moderate risk of cyanobacteria growth is a total phosphorus level of 10-25 micrograms per liter (µg/L) (Newcombe et. al., 2010). While there are currently no nitrogen concentrations that represent specific risk levels, excessive nitrogen loads are a large concern in mediating freshwater eutrophication and HABs,

including CyanoHABs. As such, a dual-nutrient reduction strategy should be considered when developing measures to control eutrophication (Conley et. al., 2009). Therefore, MassDEP recommends that baseline total phosphorus and total nitrogen sampling be conducted and documented within surface water sources, particularly during spring turnover and summer stratification.

**Recommended To Do List:**

- Collect and analyze total nitrogen and total phosphorus samples throughout the reservoir
    - Sampling will be system specific; however, typical monitoring for general study objectives should identify site locations, sample frequency and sample type. For further guidelines, please see USGS Guidelines for Design and Sampling for Cyanobacterial Toxin and Taste-and-Odor Studies in Lakes and Reservoirs Scientific Investigations Report 2008-5038.
    - Sampling of tributaries in close proximity to areas of the water supply where cyanobacterial blooms have occurred or in tributaries near drinking water intakes should be considered for nutrient monitoring inclusion when possible.
- Document the data and evaluate patterns over time with particular attention to elevated nutrient levels in relation to the sampling location(s) surrounding land use.

### Water Temperature

Cyanobacteria populations are very responsive to warm water temperatures; more responsive than most algae. As a result, cyanobacteria are able to out-compete other algae for nutrients, further enhancing their ability to grow quickly. Water temperatures above $25^0$C also contribute to an increase in cell division, which may lead to the increased formation of cyanobacterial blooms. Water temperature should be measured and recorded regularly during the spring and summer. Many PWSs already monitor the temperature of their source water for treatment purposes, so historical trends in water temperature for a source water may be readily available. Documenting water temperature, and reviewing historical trends, can serve as an additional indicator for source water changes associated with potential cyanobacterial blooms and the effect of seasonality on CyanoHABs.

**Recommended To Do List:**

- Collect water temperature readings throughout the reservoir at the same sampling locations identified for nutrients
- Document the data and evaluate patterns over time

### Thermal Stratification (Thermocline)

With higher summer water temperatures comes an increased potential for thermocline development. The thermocline is the layer that separates the densities of the warmer-lighter/surface layer from its cooler-denser/deep layer, and is a frequent result of the surface water heating during summer months. This division of a waterbody into a warmer upper layer and a distinct lower temperature deeper layer has a dramatic impact on waterbodies, and how nutrients move within them. Specifically, if a waterbody is stratified, it influences whether nutrients are available for the growth of cyanobacteria and aids in the formation of surface blooms. Thermal stratification typically occurs in deeper waterbodies (greater than 5 meters for small waterbodies and 10 meters for larger waterbodies) and generally occurs as waters warm during the summer. Conversely, when surface water temperatures decrease in the autumn, the stratification decreases and the layers become mixed once again.

Understanding thermal stratification is an important component of predicting and responding to potential cyanobacterial blooms. An example of the varying waterbody layers is shown in Figure 2.

Further information on thermal stratification may be found in Appendix 8.

**Recommended To Do List:**

- Identify reservoir characteristics and identify general timeframe of thermocline development, if applicable.
- Document and evaluate patterns over time.

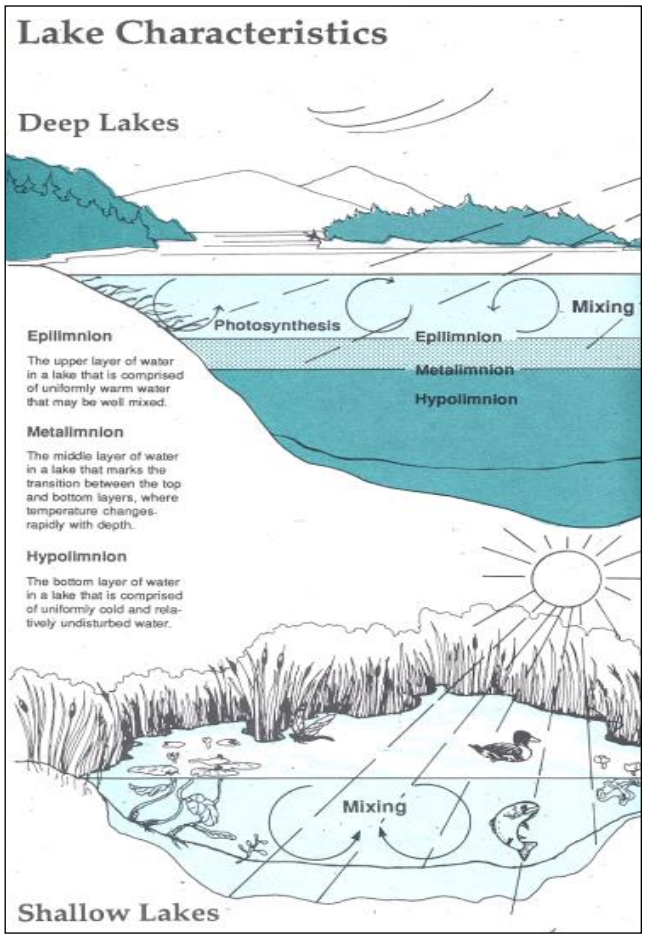


Figure 2. Lake Characteristics – Thermal stratification in lakes from Michaud, J.P.1994.

## Wind

Cyanobacteria are often distributed unevenly in a water body, both vertically and horizontally. Wind plays a crucial role in mixing reservoirs by cooling the surface waters, and mixing buoyant cyanobacterial cells throughout the water column. In addition, onshore wind conditions can concentrate CyanoHAB surface scums on the windward side of the waterbody, typically along the shoreline. Any PWS documentation of a bloom or other critical factors should also identify general weather conditions with specific attention to wind direction.

**Recommended To Do List:**

- Document wind directions when blooms occur and evaluate patterns over time.

## Taste & Odor

Cyanobacterial blooms can cause taste and odor issues in DW, which although undesirable, can serve as indicators for the presence of toxin in DW (Graham et al., 2008). A US EPA study conducted by James Sinclair (USEPA, 2012) showed that of 243 samples tested for taste and odor, 82 percent contained microcystin. The American Water Works Research Foundation (AWWRF, 2000) also conducted a study including 45 utilities that found a strong relationship between water samples from supplies, intakes, and treated water that had taste and odor issues, also tested positive for the cyanotoxin microcystin. It is important to note that the most common compounds which cause taste and odor problems are geosmin and 2-methylisoborneol (MIB), which are not toxic, but cause earthy-musty smells, and are also produced by a range of cyanobacteria (WQRA, RR 74). There are many other algae that can cause blooms that lead to taste and odor problems, and clog and impact PWS filtration systems. Taste and odor issues are not solely associated with the presence of cyanobacteria, but should be seriously considered by the PWS as an initial indicator for the presence of cyanobacteria and associated cyanotoxins.

**Recommended To Do List:**

- Record taste and odor problems.

- Sample and analyze for MIB and geosmin during taste and odor events ensuring analyses are completed using Standard Method (SM) 6040D.
- Evaluate any patterns of customer complaints regarding taste and odor for comparison to other critical factors.

### pH Changes

Similar to the pH increases that commonly occur in water with algae growth in general, an increase in pH typically occurs during a CyanoHAB event as well. Therefore, it is important to recognize that pH changes in a water body may be indicative of potential CyanoHAB development. This is of particular importance for systems that may use in-source algaecide treatment such as copper sulfate, because dosage rates and effectiveness depend upon pH levels in addition to alkalinity and dissolved organic carbon levels.

**Recommended To Do List:**

- Record pH changes, particularly at the raw water or filter influent.
- Evaluate any patterns of pH changes and use for comparison against any increased turbidity and taste and odor problems.

### Long Residence Time

The hydrological conditions that affect the flow of water (reservoir input(s) and output(s)) determine the retention or residence time of a surface water source, with longer residence times playing a significant role in CyanoHAB development. Understanding the fate and transport of any contaminant, including CyanoHABs, in your surface water body, and how it may impact drinking water quality is important to developing appropriate emergency response and corrective actions. Various water quality models can be used to simulate contaminant scenarios and predict contaminant travel time based on hydrologic and watershed characteristics. This process begins with determining the reservoir's bathymetry and overall characteristics including natural and controlled inflows and outflows.

**Recommended To Do List:**

- Determine the residence time of your surface water source.
    - Very simply, residence time is the average time water spends in the reservoir in a steady state condition; the volume of the reservoir can be divided by either the inflow or outflow (or sum of inflows or outflows) to obtain the residence time.
    - The residence time will be unique to your reservoir, and can be complex and varied depending upon many factors. In addition, the United States Geological Survey (USGS) determined the safe yield of all public water supply reservoirs to determine available storage capacity, which can be found at https://pubs.usgs.gov/sir/2011/5125/
    - If only natural water inputs are present (i.e., no pipes and/or diversions going into the reservoir from areas outside the natural watershed), one can also delineate the watershed and obtain stream flow statistics using the USGS StreamStats Water Resources Web Application to assist in determining flow rates. The USGS StreamStats flow estimator is available online at: https://water.usgs.gov/osw/streamstats/massachusetts.html

### *Cyanobacteria Monitoring Strategy*

Critical factor data gathered by a PWS will inform the actions and responses that a supplier needs to take (if any) to address cyanobacteria and blooms. Should further cyanobacteria monitoring be deemed necessary, additional information for developing a monitoring program is included in Appendix 4. Appendix 4 provides general information that should be considered in developing a monitoring program including equipment needs and additional monitoring parameters, such as phycocyanin (PC) – a pigment specific to cyanobacteria, and Secchi disk depth readings - a measurement of water clarity.

Appendices to this document also address the use of other data, such as cyanobacteria identification and sampling protocol (Appendix 1), cyanotoxin testing (Appendix 6), and cyanobacteria enumeration (Appendix 7), which are all helpful in documenting changes within PWS surface water sources to determine when a bloom is occurring.

## Surface Water Management and Treatment

The North American Lake Management Society (NALMS) identifies that watershed nutrient control BMPs are an important means to control blooms in surface water supplies; however, there has never been a large nutrient impaired waterbody restored by watershed BMPs alone. Watershed BMPs are important and should always be implemented prior to in-lake treatments; however, should a PWS surface water source determine it is vulnerable to blooms, in-lake treatments should be considered as an important tool for nutrient controls (NALMS Position Statement 9).

Watershed nutrient control BMPs versus in-lake controls have been analyzed within the Eutrophication and Aquatic Plant Management in Massachusetts Final Generic Environmental Impact Report (GEIR, 2004) developed for MassDEP and the Department of Conservation and Recreation (DCR). MassDEP recommends all PWSs utilizing in-source treatment options follow recommendations within the GEIR, which can be accessed at http://www.mass.gov/eea/agencies/agr/pesticides/aquatic-vegetation-management.html.

### Algaecides

The primary goal of a PWS with a potential or existing cyanobacterial bloom should be to keep the cyanobacteria cells from entering the PWS treatment facility. One common method of controlling blooms within surface water sources is through the use of algaecides, which cause the cyanobacteria cells to lyse, and reduce cyanobacteria counts, thereby disrupting the bloom when caught early. It is important to note that algaecide use for treating a bloom in the PWS surface water source should only occur when cell counts are low enough to avoid potentially releasing high concentrations of cyanotoxins. A number of PWSs have had success using algaecides before a bloom occurs; however, using algaecides successfully depends on an appropriate algal monitoring program, which includes routine inspections of the PWS surface water source, tracking of baseline data changes, and cyanobacteria identification. This will provide PWS staff with sufficient information to make informed decisions regarding source water treatment for cyanobacteria.

Pursuant to 310 CMR 22.20B(8), no person shall apply herbicides to any surface water body including but not limited to any reservoir and their tributaries, which serve as a source of public water supply without a license issued by the Department pursuant to M.G.L. c. 111, § 5E. This MassDEP required license (BRPWM-04) serves two major functions: 1) provide a review of chemical treatment to aquatic systems to ensure they are being implemented utilizing currently acceptable procedures and chemicals; and, 2) provide a means for keeping

records of chemicals that have been introduced into specific areas. While the license applies to all water bodies, there are three exceptions. One of these exceptions includes treatment undertaken with algaecides containing copper by legally established water supply agencies to control taste and odors. Therefore, the license requirement does not apply to the application of algaecides containing copper by PWSs; however, the PWS is required to notify MassDEP in writing prior to the application of such algaecides. A PWS planning to use any other chemical in their source(s) must obtain a MassDEP BRPWM-04 license prior to application. For further information regarding the MassDEP WM-04 license, please go to: https://www.mass.gov/how-to/wm-04-herbicide-application.

In addition, PWSs applying algaecide are required to submit an electronic Notice of Intent (eNOI) for NPDES permit coverage under the USEPA 2016 Pesticide General Permit if the annual treatment area threshold of 80 acres is exceeded. The permit covers weed and algae pest control, mosquito and other flying insect pest control, animal pest control, and forest canopy pest control. The PWS must track and report the use of algaecide, and report annually through the eNOI reporting tool. For more information regarding the permit requirements, go to: https://www.epa.gov/npdes/pesticide-permitting-2016-pgp.

Historically, the most common type of algaecide used by PWSs has been copper sulfate (CuSO4). CuSO4 or other algaecides should be used with caution, prior to bloom formation, if at all, due to the concerns associated with their use. Concerns include: the potential release of intracellular toxins by killing the cyanobacteria cells; a drop in DO levels as microbial break-down of the cells occur; taste and odor issues; unpredictable ecological effects, such as nutrient release leading to subsequent algae blooms; and the potential development of copper-resistant organisms. PWSs which apply CuSO4 on an annual or frequent basis should also be aware that copper concentrations in the sediment of these water supply sources can accumulate to a concentration where aquatic life thresholds are exceeded. Therefore, before applying CuSO4, all potential impacts should be weighed carefully and other treatment options should be considered. Table 5 depicts cyanobacteria susceptibility to CuSO4.

**Table 5. Relative toxicity of copper sulfate (CuSO4) to cyanobacteria**

| Group | Very Susceptible | Susceptible | Resistant |
|---|---|---|---|
| **Cyanobacteria** | Anabaena<br>Microcystis (Anacystis)<br>Aphanizomenon<br>Gomphosphaeria<br>Rivularia | Cylindrospermum<br>Planktothrix (Oscillatoria)<br>Plectonema | Nostoc<br>Phormidium |

Global Water Research Coalition 2009; Palmer, 1962.

## Nutrient Treatments

There are additional treatment techniques that should be considered by the PWS beyond CuSO4. These include measures that reduce the phosphorus levels available for uptake by changing dissolved phosphorus into a precipitate, such as aluminum sulfate (Al2(SO4)3), ferric salts or lime. In all cases, the PWS should require that any chemical used for in-source treatment meet National Sanitation Foundation/American National Standards Institute (NSF/ANSI) 60 certification. In addition, there are non-chemical technologies available that focus on manipulating conditions that affect cyanobacteria by creating habitats that are not ideal for growth, including the

use of aerators and mechanical mixers to reduce stratification of the water column, therefore decreasing the availability of nutrients (Global Water Research Coalition 2009). Other measures include ultrasonic sound wave equipment, hydrogen peroxide, sediment removal or dredging, and biological controls, such as floating wetland islands, barley straw and biomanipulation through predatory fish stocking.

### Infrastructure Modifications

While not practical for all sources, and keeping in mind that buoyant cyanobacteria may move readily throughout the water column, some surface water suppliers can reduce concentrations of cyanobacteria and cyanotoxins reaching their PWS treatment facility by altering the location of the intake(s). If feasible, drawing water from locations or depths with lower concentrations of cyanobacteria could greatly reduce the probability of cyanobacteria cells and cyanotoxins being drawn into the PWS treatment facility. This can be accomplished by:

- adjusting the level of the PWS treatment facility intake to avoid the bloom, if possible;
- containing the bloom by segregating the bloom or surface scum with surface booms in an area away from the PWS treatment facility intake; and
- diverting surface scums or blooms away from the PWS treatment facility intake by diverting flows through a spillway.

MassDEP recognizes that CyanoHAB events will be system specific and response efforts may be variable. All treatment options should be reviewed and considered by the PWS to best determine the suitability of the application for a particular surface water source.

## Additional Treatment Options

If proper watershed management and in-reservoir treatment application is not conducted by the PWS when warranted, there is a greater potential that cyanobacteria cells and cyanotoxins may enter the PWS treatment facility. Should this occur, the PWS should be aware of the treatment options available for both intracellular and extracellular cyanotoxins, as different treatment methods will be necessary to ensure finished DW has not been contaminated. In all cases, the use of an alternative DW source or blending DW sources should be utilized if possible during any potential cyanobacteria contamination of a PWS treatment facility.

Table 6 contains information regarding various treatment efficiencies for both cyanobacteria cell and toxin removal methods. These treatment methods may also decrease compounds that cause taste and odor problems. Ideally, PWSs should attempt cyanobacteria cell removal without causing cell rupture and toxin release; however, if toxins are released within the facility, the PWS staff should be knowledgeable of the treatment options they possess or can adjust for removing the soluble toxins. This table may be referred to when assessing and developing your PWSs treatment strategy for potential cyanobacteria contamination. In addition, US EPA's Recommendations for PWSs to Manage Cyanotoxins in Drinking Water (US EPA 2015) identifies strategies beyond conventional filtration methods that should be referred to when evaluating treatment options including minimizing pre-oxidation of the raw water, adding or increasing powdered activated carbon (PAC), and increasing post-chlorination. Further management strategies to reduce cyanotoxin production in source water and effective treatment techniques for removing cyanotoxins while balancing drinking water compliance is available within the September 2016 document, "Managing Cyanotoxins in Drinking Water: A Technical Guidance Manual for Drinking Water Professionals" developed by American Water Works Association and Water Research Foundation (AWWARF).

For further information on treatment within a PWS facility for cyanobacteria and cyanotoxins, including cyanotoxin inactivation and chlorine contact times, please see Appendix 5. **PLEASE NOTE - your DEP Drinking Water Program (DWP) Regional Office must be notified of any plans to adjust treatment within your facility to ensure treatment compliance continues.**

| Table 6. Matrix for Water Treatment Processes and Dominant Cyanobacteria | | | | |
|---|---|---|---|---|
| **Process** | **Genera of Cyanobacteria** | | | |
| | **Microcystis** | **Anabaena** | **Aphanizomenon** | **Planktothrix** |
| **Methods for removing cells** | | | | |
| Coagulation-sedimentation-filtration | Yes (90 %) | Yes | Yes | Yes |
| Coagulation-dissolved air flotation (DAF) | Yes (40-80 %) | Yes (90-100%) | No (best with buoyant cells) | No (best with buoyant cells) |
| Powdered activated carbon (PAC) adsorption | Yes-can remove Microcystis with no release of toxin | Better for toxin removal | Better for toxin removal | Better for toxin removal |
| Membrane filtration | Study data are scarce, but may be assumed as generally effective for cell removal provided frequent backwashing and removal of backwash material from process stream. | | | |
| **Methods for toxin removal** | | | | |
| Chlorination | Yes (up to 100%); lowering pH to 6 makes chlorination most effective, lowest removal at pH 9 | No | Yes | Yes |
| Ozonation | Yes (up to 100 % removal) | Yes (up to 92% removal) | Yes | Yes |
| Potassium permanganate | Yes (up to 95%) | Yes | No | Yes |
| Hydroxyl radical | Yes | Yes | Yes | Yes |
| Powdered activated carbon adsorption (PAC) | Yes (85%)-higher concentrations are needed to effectively remove toxins | Yes (98%) | Yes | Yes |
| Granular activated carbon (GAC) | Yes (95 %) | Yes (less effective than for microcystin) | Yes (less effective than for microcystin) | Yes (95%) |
| Membrane filtration | Yes, (up to 95% potential removal of microcystin) but toxin removal dependent upon the material, membrane pore size and water quality. Nanofiltration and ultrafiltration likely effective in microcystin removal, while reverse osmosis (RO) filtration may only remove some cyanotoxins like cylindrospermopsin. Further research is required. | | | |
| Ultraviolet | Yes (but higher doses are required than is practicable) | Yes (but higher doses are required than is practicable) | Yes (but higher doses are required than is practicable) | Yes (but higher doses are required than is practicable) |
| **Table based on Westrick 2011, Xagoraraki, I. 2007, USEPA 2012 and Newcombe et. al. 2010, Hart and Stott 1993** | | | | |

## Methods Available for Detecting Cyanobacteria and Cyanotoxins.

The cyanobacteria present during a CyanoHAB should be taken into account when considering cyanotoxin analysis, and there is a diverse range of monitoring, rapid screen tests, and laboratory methods that may be used to detect and identify cyanobacteria cells and cyanotoxins in water. These methods can vary greatly in their degree of complexity, specificity, time for results and costs, while the ability of some techniques to identify the cyanotoxins is limited by the lack of standard analytical methods capable of detecting the range of cyanotoxins known to exist.

Cyanobacteria contain two major photosynthetic pigments: chlorophyll a (Chl a) and phycocyanin (PC). While Chl a is common to phytoplankton including cyanobacteria, PC is unique to cyanobacteria in freshwater environments. Therefore, PC measurement is a useful tool in rapidly determining the presence of cyanobacteria, and may be used to assist a PWS in determining further actions, such as cyanotoxin analysis. Further details on equipment for measuring phycocyanin and/or chlorophyll a concentrations is located in Appendix 4.

There are various cyanotoxin measurement methods including biological assays such as animal tests (e.g., mice), enzyme-linked immunosorbent assays (ELISA), protein phosphatase inhibition assays (PPIA), polymerase chain reaction (PCR), quantitative real-time PCR (qPCR), and chromatographic methods such as reversed-phase high performance liquid chromatographic (HPLC) methods combined with mass spectrometry or ultraviolet/photodiode array detectors. The various methods each have strengths based on sample type and purpose; however, for detection of cyanotoxins in DW (and required for all UCMR4 analysis), EPA developed three methods listed below that can also be found at: https://www.epa.gov/nutrient-policy-data/detection#what3

- Method 544 - Determination of Microcystins and Nodularin (combined intracellular and extracellular) in DW by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS)
- Method 545 - Determination of Cylindrospermopsin and Anatoxin-a in DW by Liquid Chromatography Electrospray Ionization Tandem Mass Spectrometry (LC/ESI-MS/MS)
- Method 546 - Determination of Total Microcystins and Nodularins in DW and Ambient Water by Adda Enzyme-Linked Immunosorbent Assay (ELISA)

Depending on the type of method used, laboratory analysis can be expensive (up to 500 dollars per analysis); however, rapid tests such as immunochromatographic strip tests (Strip Tests or Dipsticks) and ELISA field kits are more affordable and commonly used as a screening tool for initial cyanotoxin detection. Strip tests are very easy to use and can provide preliminary qualitative test results for Total Microcystins, Nodularins, Cylindrospermopsin, and Anatoxin-a. ELISA field kits are also easy to use and can provide semi-quantitative test results; however, the tests do not detect all cyanotoxins present because they cannot identify and quantify various individual microcystin variants (also known as “congeners”). While rapid screening tests do not require expensive equipment or extensive training, they provide results within 30 to 60 minutes with minimal costs (30 to 100 dollars per analysis), and may assist PWSs with identifying treatment options and removal efficiencies during a bloom event.

MassDEP recommends that when available, PC measurements and cyanobacteria identification/enumeration be used in conjunction with cyanotoxin analysis; and, that rapid screening tests with positive results be confirmed by more precise, quantitative methods that achieve the lowest levels of detection such as the EPA methods

developed for drinking water. In addition, the same cyanotoxin analytical methods should be used for all corresponding raw and finished water samples collected. **PWSs should contact their regional MassDEP office for assistance upon discovery of a potential CyanoHAB for direction on algal toxin screening or for assistance with sampling for cyanotoxin analysis.** Further information on cyanotoxin analysis is provided in Appendix 6.

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Water Quality Research Australia: Management Strategies for Cyanobacteria (Blue-Green Algae) and their Toxins: A Guide for Water Utilities, Research Report 74, June 2010

Westrick, J.A., Szlag, D.C., Southwell, B.J., and Sinclair, J. 2010. A review of cyanobacteria and cyanotoxins removal inactivation in drinking water treatment. Analytical and Bioanalytical Chemistry.

Westrick, J. 2011. Cyanotoxin Removal in Drinking Water Treatment Process and Recreational Waters. Chlorine concentrations and exposure times needed to reduce Microcystin to 1 ug/L. 2011 Northeast Regional Cyanobacteria Workshop. New England Interstate Water Pollution Control Commission.

World Health Organization. 1999. Toxic Cyanobacteria in Water: A Guide to Their Public Health Consequences, Monitoring and Management. Edit I. Chorus and J. Bartram. Spon Press, London.

Xagoraraki, I. 2007. Cyanotoxins and Drinking Water. Civil and Environmental Engineering, Michigan State University.

Yoo, R.S., Carmichael, W.W., Hoehn, R.C and Hrudey, S.E. 1995. Cyanobacterial (Blue-Green Algal) Toxins: A Resource Guide. American Water Works Assoc. Research Foundation. Denver. 229.

# Appendix 1 – Cyanobacteria Identification and Sampling Protocol

As noted in the Guidance, there are environmental conditions that may be misidentified as a CyanoHAB, such as pollen accumulation, which is why proper, typically microscopic, identification is critical. In addition, it is sometimes difficult to differentiate between an algal bloom and small, common aquatic plants, such as duckweed, which can cover the surface of a waterbody. Alternatively, because of the bright blue or blue-green color the ruptured cells release following the "crash" of a cyanobacterial bloom, CyanoHABs can be mistaken as possible industrial dumping of paint or dye. Misidentified, these situations may cause a PWS to erroneously activate their ERP with no benefit to public health, while a correct identification can establish if an in-reservoir treatment application is warranted. Therefore, to avoid misidentification, one of the first steps in identifying a CyanoHAB is typically visual, and will most often be initiated by PWS staff during routine monitoring of its source(s).

The information in this section provides basic information on cyanobacteria identification; however, it is important to note that visual field observations should be confirmed through proper microscopic identification. The field of algal taxonomy is highly specialized and continually changing; therefore, PWSs should ensure that experienced phycologists provide expert identification to the lowest practical level, and enumeration (cell counts) for any quantitative analysis.

### In-house options for field observation:

MassDEP recommends PWS staff be responsible for routine source observation and monitoring to familiarize themselves with the factors that promote CyanoHABs, and how to recognize the early stages of cyanobacterial blooms. A PWS may consider utilizing their own staff to initially identify cyanobacteria since DW operators are most familiar with their source waters. MDPH provides guidance for identifying cyanobacterial blooms, both with and without scums present, on their website. This can be found at www.mass.gov/dph/algae under the heading, Algae Information.

The following is a quick reference question set for identifying a cyanobacteria accumulation from the Vermont Department of Health. See Appendix A within:
http://www.healthvermont.gov/sites/default/files/documents/2016/12/ENV_RW_CyanobacteriaGuidance.pdf

It is **NOT** cyanobacteria if:

1. You can see leaf-like structures or roots
2. The material is long and stringy, or can be lifted out of the water on a stick
3. It is firmly attached to plants, rock(s) or the bottom (e.g., you can't lift it out)

It **MAY** be potentially hazardous cyanobacteria if:

1. The material consists of small particles that are pinhead size or smaller
2. The material is collecting in a layer at the surface or along the shoreline
3. The water is murky and colored a brownish green, milky green or blue

### Additional resources for in-house identification:

As previously noted, correctly identifying and counting cyanobacteria is specialized, but important in determining the type of toxin potentially present. If your PWS already maintains in-house expertise for algal identification and enumeration, then it benefits from:

- already established sampling procedures;
- increased flexibility of sampling (weekends, holidays);
- increased number of samples that can be collected and analyzed;
- reduced per sample cost for higher numbers of samples per year; and
- greater flexibility in any response efforts.

The microscopic pictures shown in Figures 3 and 4 below offer images of common cyanobacteria, but there are many additional resources for learning how to correctly identify cyanobacteria to both genus and species levels, which can build in-house expertise on algal identifications. These include courses that are periodically offered through organizations such as American Water Works Association (AWWA), including the *Identification of Algae in Water Supplies CD-ROM,* and the book, *Algae Source to Treatment*.

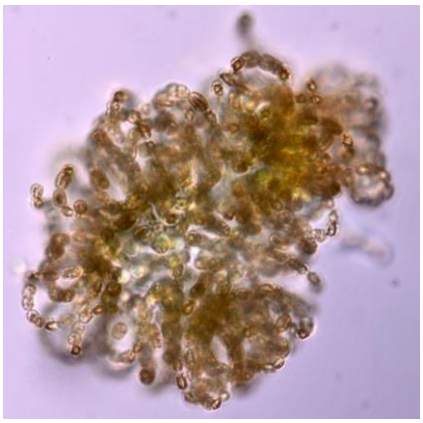

Figure 3. Cyanobacteria: Anabaena, 20 Olympus BH2 (image J. Beskenis, MassDEP)


Figure 4. Cyanobacteria: Aphanizomenon from the Charles River (image J. Beskenis, MassDEP)

In addition, the US EPA initiated a program called the Cyanobacteria Monitoring Collaborative (CMC), which combines three, coordinated, volunteer monitoring projects to better locate and understand cyanobacteria. The CMC offers standardized practices for three levels of cyanobacteria monitoring, which increases in commitment and complexity beginning with citizen science based programs to:

1. photograph and report cyanobacterial blooms using a smartphone app (bloomWatch),
2. collect cyanobacteria samples for microscopic identification to learn more about their distribution (cyanoScope); and,
3. monitor cyanobacteria populations over time through chlorophyll and phycocyanin analysis (cyanoMonitoring).

It's important to note that data developed under BloomWatch and cyanoScope are submitted within public domains and therefore, accessible by the public. Data developed under cyanoMonitoring is submitted directly to

EPA. For further information about the CMC, including a new, image based taxonomic cyanobacteria guide, please go to: https://cyanos.org/

The University of New Hampshire (UNH) Center for Freshwater Biology has also developed an online guide for common cyanobacteria of New England, known as "The Dirty Dozen." The easily accessible guide provides a photographic gallery of microscopic images for the most common cyanobacteria genera typically observed in New England lakes, with introductory descriptions of each. In addition, the Genus List provided on the same website offers reported taste and odor issues associated with the twelve Genus groups, which may be useful information to PWSs receiving customer complaints. See "The Dirty Dozen" through: http://cfb.unh.edu/CyanoKey/indexCyanoQuickGuide.html

There are also additional websites that may serve as helpful resources, which are listed below:

- Cyanosite: http://www-cyanosite.bio.purdue.edu/
- Green Water Lab: http://greenwaterlab.com/algal-id.html
- Phycotech, Inc. On-line images http://phycotech.smugmug.com/organize/PhycoTech-Algae-and and DVD images http://www.phycotech.com/products.html#Micro
- The Algal Web: http://www.algalweb.net/
- University of Maine: *A Field Guide to Aquatic Phenomenon* http://umaine.edu/mitchellcenter/files/2012/06/Field_Guide-4.pdf
- Vermont Department of Health http://healthvermont.gov/enviro/bg_algae/photos.aspx#other

### Contract Services:

Since most PWSs do not maintain in-house expertise on algal identification and enumeration, they may choose to utilize contract services. Currently, algal identification and enumeration services are offered by a number of contract laboratories throughout the country. These laboratory services may change frequently; therefore, a list of vendors that provide cyanobacteria/cyanotoxin services is available on the MassDEP website, which can be accessed at this link: https://www.mass.gov/guides/cyanobacterial-harmful-algal-blooms-cyanohabs-water Please note that the list is not necessarily comprehensive, subject to change, and inclusion on the list does not indicate an endorsement from MassDEP.

### Sampling Procedures:

Regardless of whether or not your PWS decides to utilize in-house expertise or contract services, MassDEP recommends that DW operators with surface water supplies familiarize themselves with the proper procedures for cyanobacteria sampling with particular attention paid to safety. These sampling procedures may vary slightly depending upon in-house standard operating procedures (SOPs), contract laboratory sampling instructions, and sampling locations and type (i.e., grab samples, discrete depth, or integrated depth samples); however, MassDEP offers the following cyanobacteria sample collection procedure for identification/enumeration purposes.

#### *Collecting a Cyanobacteria Water Sample (wading and from a boat)*

Cyanobacterial blooms are most often first observed in quiet bays or washed up along the shore at the downwind side of a reservoir. Grab samples taken directly from these areas can be obtained by wading into the water to approximately knee depth. While standing in place until any sediment that was initially stirred up has settled,

uncap an amber, plastic, 250 ml (typical minimum volume) bottle, invert the bottle, push it through the water column to a depth of approximately 9 inches (0.25 meters), bring back up and recap the bottle. **DO NOT** just skim the water surface when collecting the sample, or push any floating surface material away prior to sampling as this will skew the results either positively or negatively potentially losing valuable information. Since cyanobacterial blooms (and algal blooms in general) are often patchy and at other times uniformly distributed, multiple samples collected from additional shore locations around the reservoir is ideal.

Open water sampling is generally a better predictor of the water body's algal population. A boat is necessary to sample the open water of a reservoir, and sometimes may be necessary for sampling around the DW facility intake. Sampling around the intake and from the raw water tap within the treatment plant is particularly important in determining the cyanobacteria population that may enter the plant as well, while the raw water tap is an option for systems that do not have access to a boat. Samples collected in open water and around the intake may be collected as integrated depth samples using an integrated tube sampler, or at specific depth(s) using a Kemmerer water sampler (a device used for collecting water samples at depth). Open water sample collections that utilize an integrated tube sampler should be lowered into the water column from the surface to a depth of three meters (which is fairly representative as the depth to sunlight penetration that supports primary production and development of bloom forming cyanobacteria). Discrete depth samples are recommended around the intake to better ascertain the cyanobacteria population at specific depths, particularly for systems that have the ability to alter intake levels.

Samples that will be examined and counted within 24 hours of sample collection do not require any preservation, but should be stored on ice (never frozen) for transport and then refrigerated and kept in the dark until identification and enumeration. To ensure that samples held over 24 hours remain in a condition suitable for the identification and enumeration of cyanobacteria, a sufficient volume of Lugol's iodine preservative solution should be added at the time of collection. If using contractor services, the laboratory will provide you with specific preservation volumes and instructions. Samples preserved at the time of sampling in the field do not require additional treatment (e.g., chilling) prior to enumeration, but PWSs should follow their specific laboratory instructions.

All sample bottles should be appropriately labeled with a unique identification number that identifies the date and time of sample collection, along with a completed Chain of Custody (COC) form for contracted services. Systems utilizing in-house expertise for microscopic identification and enumeration should already have an SOP in place that dictates sample collection and all required record keeping.

Please note that MassDEP has also provided additional information on cyanobacteria enumeration (cell counts) in Appendix 7, and recommends reviewing that information if performing in-house analysis, or utilizing contracted services.

## Appendix 2 - Watershed Management Document: PWS Fact Sheet

### Cyanobacteria and Public Drinking Water Supplies in Massachusetts
### September 2018

**What are cyanobacteria?** Cyanobacteria are microscopic, photosynthetic, single-cell bacteria, once called blue-green algae, which are found naturally in low numbers in all waterbodies. When certain conditions are present, cyanobacteria may reproduce rapidly, forming "blooms" that are most commonly green or blue-green in color (but may appear as other colors). The water may look like pea soup or like green paint has been spilled. The bloom may appear as a scum that floats on the surface of the water or as mats that rest on the bottom. Their location may vary with wind direction, time of day, and depth of the waterbody; they are most common in the summer and early fall. Blooms composed of cyanobacteria may also be referred to as Cyanobacterial Harmful Algal Blooms (CyanoHABs). CyanoHABs may occur at different depths below the surface of the waterbody.

Cyanobacterial Bloom - photograph by Daniel Davis, MassDEP

**Why are cyanobacteria a concern for public water systems?** The presence of higher amounts of cyanobacteria may lead to taste and odor complaints from customers. In addition, certain cyanobacteria may produce toxins that can be harmful to public health. Known as cyanotoxins, they can cause skin irritations, diarrhea, vomiting, dizziness, and other health effects in people and animals. In severe cases, they may cause damage to the liver, kidneys, or nervous system. Exposure to cyanobacteria and their toxins occurs primarily during recreational activity through oral, dermal, and inhalation routes. Exposure may also occur through ingestion of cyanotoxin-contaminated drinking water. When cyanobacterial cells are ingested, they are destroyed by digestive juices, which release the toxin into the gastrointestinal tract. Alternatively, cyanobacteria cells can die and release their toxins into the surrounding waterbody, water from which may then be ingested. Cyanobacteria are primarily a concern at PWSs with surface water sources, specifically those using lakes, ponds, and reservoirs due to the potential conditions that may exist in those waterbodies. PWSs with groundwater or groundwater under the influence of surface water (GWUI) are not considered to be at significant risk of cyanobacteria issues at this time.

There is often visual evidence of a CyanoHAB; however, CyanoHABs can look similar to other non-harmful algae blooms, and confirmation can only be made by observing cells under a microscope. The presence of toxins can only be confirmed using analytical laboratory tests. In addition, toxins may remain or even spike in the water after a bloom is no longer visible. Identifying cyanobacteria and treating CyanoHABs may necessitate hiring a consultant, laboratory, or other professional service.

**How widespread are cyanobacterial blooms?** Cyanobacterial blooms are increasing in frequency in New England. Blooms usually occur during the summer and early fall when water temperatures are higher, and flow into a waterbody may be reduced. Scientists believe that warmer water temperatures and drought conditions associated with climate change may cause more blooms in the future.

**How should I address cyanobacteria at my public water system?** MassDEP has determined that a preventative approach, which includes source water protection, reservoir management, and emergency response planning,

is the best way to address future CyanoHABs. Some water supply treatment processes may remove cyanobacteria cells or cyanotoxins; however, the effectiveness of various drinking water treatment processes in removing cyanobacteria cells and cyanotoxins varies. The evolving science behind the efficacy of various treatment systems to remove cyanobacteria cells and cyanotoxins underlines the need for source water protection to help prevent CyanoHABs. MassDEP has developed additional guidance on cyanobacteria for PWSs, which provides further detail. The MassDEP Cyanobacteria Guidance is currently available on the MassDEP website at https://www.mass.gov/lists/contaminants#cyanobacteria.

**Source Water Protection**

Cyanobacteria thrive on the nutrients nitrogen and phosphorus. Nitrogen and phosphorus enter surface water through stormwater flowing off streets, parking lots, lawns, septic systems, cultivated fields, areas containing dog, geese or livestock wastes, decaying vegetation, from septic systems, and from fertilizer associated with other land uses in a watershed. The following actions can be taken to reduce nitrogen and phosphorus loading into your water supply's watershed.

**Conduct Public Outreach and Education**

Examples of measures to reduce nitrogen and phosphorus in the watershed include:

- eliminating, treating, or diverting stormwater away from the reservoir and tributaries; and
- educating the public about proper lawn care; picking up dog waste in the watershed; and maintaining septic systems.

Fact sheets that address source water protection are located on MassDEP's web site at:

https://www.mass.gov/lists/drinking-water-supply-source-protection

**Develop a Local Surface Water Supply Protection Plan**

Protection plans address potential impacts from existing and future land uses and other activities. To start writing your protection plan, refer to your system's assessment report, recommendations, and Geographic Information System (GIS) maps that were provided by MassDEP's Source Water Assessment and Protection (SWAP) Program. Copies of the SWAP reports are available on MassDEP's web site at:

- https://www.mass.gov/service-details/the-source-water-assessment-protection-swap-program

MassDEP's guidance document titled *Surface Water Supply Protection Plan Development is* located at:

- https://www.mass.gov/lists/groundwater-wellhead-protection-and-surface-water-supplies

In addition, Source Water Protection staff in the Drinking Water Program can help you write or revise a surface water supply protection plan. Please send your request for assistance to:

- program.director-dwp@mass.gov or call 617-292-5770.

**Monitor Water Quality**

Many public water systems monitor for nutrients and water flow in the watershed, or partner with watershed organizations or other groups that perform monitoring. Building a database to maintain historic water quality information within the watershed may be helpful in supporting forecasts of potential CyanoHAB occurrence.

**Apply for Grants to Purchase Water Supply Land and Conservation Restrictions**

The Massachusetts Drinking Water Supply Protection Grant Program awards funds to public water systems to purchase land and conservation restrictions for water supply protection and groundwater recharge:

https://www.mass.gov/service-details/drinking-water-supply-protection-grant-program-1

**Reservoir Management**

CyanoHABs at PWS surface water sources are an emerging issue, but there are preemptive and remedial measures that may be conducted within the source before and after blooms occur. These range from physical controls like aeration and mechanical mixing, to chemical controls such as algaecide application. PWS operators are typically most familiar with the use of algaecides like copper sulfate; however, there are concerns associated with algaecide use due to the potential toxin release from ruptured cyanobacterial cells, and algaecide toxicity to other organisms. Therefore, algaecides should be used only in the early stages of a bloom. The effectiveness of biological controls, known as biomanipulation, is also being considered for in- source treatment due to fewer detrimental effects on other aquatic organisms. Biomanipulation typically requires consistent monitoring to ensure that it is effective and not causing unintentional consequences as well. Ideally, development of baseline water quality data within your source(s) will provide information to assess the risk of CyanoHAB occurrence, which will better inform management decisions. Further information on baseline data collection and in-source treatment is available in the MassDEP Cyanobacteria Guidance.

**Emergency Response Planning**

MassDEP has developed a "PWS Bloom Tracking Form" designed as a technical assistance tool to help PWSs identify and track all algal blooms, including potential CyanoHABs within their surface water source(s). Use of the PWS Bloom Tracking Form is voluntary; however, MassDEP encourages all PWSs with surface water sources to routinely monitor their reservoirs for changes, and recommends recording all algal blooms or potential CyanoHABs observed. The form may be used to maintain PWS internal records regarding this emerging issue, or used by the PWS to identify and communicate potential issues to MassDEP DWP staff when technical assistance is needed. Information discovered from use of the form may also assist PWSs with identifying potential updates within their Emergency Response Plan (ERP) required pursuant to 310 CMR 22.04(13). Although the MassDEP guidance is focused on prevention of CyanoHAB occurrence, it is possible for CyanoHABs to develop and enter a water treatment plant. While various treatment processes are effective in removing both intracellular toxins (toxins within the cyanobacterial cell) and/or dissolved or extracellular cyanotoxins, the PWS should have a plan in place to respond to a CyanoHAB in their source(s). This may include monitoring efforts, actions taken within the source, treatment changes within the plant, use of other source(s) and communication steps.

**Who is working on cyanobacteria in drinking water?** MassDEP, Massachusetts Department of Public Health (MDPH), U.S. Environmental Protection Agency (US EPA), American Water Works Association (AWWA), New England Interstate Water Pollution Control Commission (NEIWPCC), and numerous others are working to further

understand cyanobacteria, their impacts on public health, and to develop uniform standards for sampling, identification, prevention, and treatment.

There are currently no federal or state regulations for cyanobacteria or cyanotoxins; however, in 2015, the US EPA released drinking water health advisory (HA) levels for two cyanotoxins – microcystins and cylindrospermopsin. For further information on cyanobacteria and US EPA's HA levels, please go to: https://www.epa.gov/ground-water-and-drinking-water/cyanotoxins-drinking-water.

Ten cyanotoxins will be sampled as part of US EPA's Unregulated Contaminant Monitoring Rule (UCMR) 4; PWSs nationwide will begin sampling as part of UCMR4 in 2018. Data from UCMR serves as a primary source of research information that US EPA utilizes to develop regulatory decisions.

**Where can I get more information about cyanobacteria and source water protection?** For more information about preventing cyanobacterial blooms, contact MassDEP's Drinking Water Program at program.director-dwp@mass.gov or call 617-292-5770.

**What should I do if I suspect a cyanobacterial bloom in my source water?**
Contact the Drinking Water Program in your MassDEP Regional Office to report a suspected or confirmed bloom during normal business hours.

| | | | |
|---|---|---|---|
| Northeast Regional Office | Wilmington | Tom Mahin | 978-694-3226 |
| Southeast Regional Office | Lakeville | Richard Rondeau | 508-946-2816 |
| Central Regional Office | Worcester | Robert Bostwick | 508-849-4036 |
| Western Regional Office | Springfield | Deirdre Doherty | 413-755-2148 |

For emergencies outside of normal business hours, please contact the Emergency Response Hotline at 1-888-304-1133.

## Appendix 3 – PWS Bloom Tracking Form

**Massachusetts Department of Environmental Protection**
Bureau of Water Resources – Drinking Water Program

# PWS Bloom Tracking Form

This algal bloom tracking form was created as a technical assistance tool intended to support Public Water Systems (PWSs) with identifying and tracking all algal blooms, including potential cyanobacterial harmful algal blooms (CyanoHABs) within their surface water source(s). MassDEP encourages all PWSs with surface water sources to routinely monitor their reservoirs (ponds or lakes) for any changes, and recommends recording all algal or potential cyanobacterial (blue-green) blooms observed. The information obtained by completing this form during events and tracking the information internally over time will help better assess the risk to your PWS treatment facility, aid in appropriate response efforts, and support both in-source treatment applications and/or in-plant treatment process changes if necessary.

**Who Can I Contact For Assistance With Completing This Form?**
Please contact Kristin Divris of the Water Utility Resilience Program (WURP) at 508-849-4028 or Kristin.Divris@state.ma.us, or your MassDEP Regional Office listed below:

NERO (Wilmington): Tom Mahin - 978-694-3226
CERO (Worcester): Robert Bostwick - 508-849-4036
SERO (Lakeville): Richard Rondeau - 508-946-2816
WERO (Springfield): Deirdre Doherty - 413-755-2148

## A. PWS Information

**Important:** When filling out forms on the computer, use only the tab key to move your cursor - do not use the return key.



PWS ID _____ PWS Name _____

Source Location Name & ID # _____

Name of person completing form _____

Name & phone number of person reporting bloom to PWS (if applicable) _____

## B. General Bloom Information

**Important**: If a resident has reported a bloom to the PWS, then PWS staff should observe the source, suspected bloom, and plant conditions to record applicable information. This information may be maintained internally to document trends.

1. Date Bloom Initially Observed: 2. Time Bloom Observed:

3. Attached map with bloom location noted (e.g. Google Map image): ☐ Yes ☐ No

4. Digital Photos Collected? (MassDEP highly encourages including digital photographs of any suspected blooms in close-up and landscape formats to assist with identification)
☐ Yes ☐ No

5. Weather Observations:

a. Air Temperature: b. Wind Direction:

c. Precipitation: ☐ Yes ☐ No d. Surface Water Conditions:

e. Other:

6. Bloom Description:

a. Describe the location of the bloom in the surface water source with easily identifiable landmarks if possible (e.g. northern side of reservoir, at boat dock, etc.)

b. Identify approximate size of the bloom (sq. ft.) and the extent of the area affected (e.g. entire reservoir, shoreline accumulation, etc.…)

c. Identify any color(s) observed in the water column:

☐ Green ☐ Blue ☐ Red ☐ Rust ☐ Brown ☐ Milky White ☐ Purple ☐ Black

Other/Description:

**Important:** Staff examining any algal bloom should take appropriate safety precautions to avoid direct contact. Any examination or sampling of blooms should be done with gloves and safety goggles to protect exposed skin and eyes. Masks are recommended to avoid inhalation of water spray caused by boats, wind or other water surface disturbances.

d. Identify any odor(s) observed in the source water:

☐ Earthy/Musty ☐ Fishy Other (please describe):

e. Identify if a surface scum is present (an accumulation at the surface) or if algae is floating near the water surface. (Algal blooms floating at the surface can look like grass clippings, green cottage cheese curds or spilled paint) ☐ Yes ☐ No ☐ Uncertain

f. Visually examine the bloom to determine if it may or may not be a potential CyanoHAB:

**MAY BE A CyanoHAB:**

Material consists of small particles ☐Yes ☐No

Material is collecting in a layer on the surface or along a shoreline ☐ Yes ☐ No

**NOT A CyanoHAB:**

Material has any leaf-like structures ☐ Yes ☐ No

Material can be lifted out of the water on a stick ☐ Yes ☐ No

Material is firmly attached to plants, rocks or bottom ☐ Yes ☐ No

h. Identify the distance of the bloom from the drinking water intake:

i. List any known approved or unapproved recreational use for the source, or if there is a public beach nearby that may be impacted by diverted water from the reservoir:

## C. Treatment Facility Operation

**Important:** Treatment for cyanotoxins vary depending upon whether toxins are intracellular or extracellular. PWSs should be aware of their treatment capabilities and update their ERP

1. Identify any observed odor(s) in the raw water within the plant:

☐ None ☐ Earthy/Musty ☐ Fishy Other (please describe):

2. Increase in the raw water pH: ☐ Yes ☐ No

If yes, specify changes:

3. Increase in the filter Influent turbidity: ☐ Yes ☐ No

4. Increase in the filter Effluent turbidity: ☐ Yes ☐ No

to include response to a CyanoHAB event.

5. Identify if there are decreased filter run times: ☐ Yes ☐ No

If yes, identify specific run time changes:

6. Increased need for coagulant dosage: ☐ Yes ☐ No

7. Increase in chlorine demand: ☐ Yes ☐ No

8. Decreased chlorine residual at the finished water tap: ☐ Yes ☐ No

9. Any customer complaints about taste and odor: ☐ Yes ☐ No
If yes, please explain:

## D. Sampling Information

**1. List any sampling performed within source water for algal identification and enumeration** (or attach lab results)**:**

Sample Location(s): Sample Date:

Sample Type: ☐ Surface Grab ☐ Discrete Depth ☐ Integrated Tube

Sample Depth(s) if applicable:

Analysis Lab Name Sample Result(s)

**2. List any cyanotoxin samples collected and analyzed** (or attach lab results)**:**

**Important:** Cyanotoxin sampling should be performed in consultation with your MassDEP regional office.

Sample Location(s):

Sample Date: Sample Location ID (LOCID) if within plant (i.e., RW-01S)

Cyanotoxin Type: ☐ Microcystins ☐ Cylindrospermopsin ☐ Other:

Analysis Type: ☐ Strip Test ☐ ELISA (EPA 546) ☐ LC/MS/MS (EPA 545)

Analysis Lab Name Sample Result(s)

**3. List any additional source water sampling performed:**

a. Phycocyanin (PC): ☐ Yes ☐ No Location(s):

PC - Date(s) & Result(s):

b. Chlorophyll a: ☐ Yes ☐ No Location(s):

Chlorophyll a - Date(s) & Result(s):

c. Secchi Disk Depth (SD): ☐ Yes ☐ No Location(s):

SDD - Date(s) & Result(s):

d. Water Temperature: ☐ Yes ☐ No Location(s):

Temp. - Date(s) & Result(s):

e. pH: ☐ Yes ☐ No Location(s):

pH - Date(s) & Result(s):

f. Dissolved Oxygen (DO): ☐ Yes ☐ No Location(s):

DO - Date(s) & Result(s):

g. Total Phosphorus Concentration: ☐ Yes ☐ No Location(s):

TP: Date(s) & Result(s):

h. Total Nitrogen Concentration: ☐ Yes ☐ No Location(s):

TN - Date & Result:

---

**E. Ongoing Event Information:** Use this section to track any changes observed (i.e., weather changes and bloom movement) or additional monitoring performed for the same event over various hours, days or weeks.

Date: Time: Operator/Staff Name:

Observations/Monitoring Conducted:

Date: Time: Operator/Staff Name:

Observations/Monitoring Conducted:

Date: Time: Operator/Staff Name:

Observations/Monitoring Conducted:

Date: Time: Operator/Staff Name:

Observations/Monitoring Conducted:

Date: Time: Operator/Staff Name:

Observations/Monitoring Conducted:

Date: Time: Operator/Staff Name:

Observations/Monitoring Conducted:

Date: Time: Operator/Staff Name:

Observations/Monitoring Conducted:

# Appendix 4 - Monitoring Program Development

If a PWS recognizes that their source is at risk for cyanobacteria based upon historical baseline data, taste and odor issues, and changing watershed characteristics including documented land use changes, alterations of drainage flow, or indications of poorly operating septic systems or other sources of nutrients, MassDEP recommends developing a cyanobacteria monitoring program. A PWS cyanobacteria monitoring program should include staff responsibilities, safety procedures, required equipment, sampling parameters, written monitoring and analysis procedures, treatment procedures and any restrictions and limitations; and, should always be developed prior to initiating routine sampling for cyanobacteria. The monitoring program should be reviewed and updated when new information becomes available, and when there are changes within the watershed that may indicate an increased potential for a cyanobacterial bloom. In addition, a monitoring program should be reviewed and updated after any bloom events to ensure that the procedures identified are adequate for response.

The first step in developing a cyanobacteria monitoring program will be deciding whether the PWS will commit in-house personnel to the task, hire an experienced, outside consultant to perform the work, or utilize a combination of the two. These three options are best decided by the individual PWS since management and operators best know their own system, resource availability (including staff), and the sources' potential for a cyanobacterial bloom. In order to establish which option a PWS may implement, recognition and an understanding of the resources necessary for identifying, sampling and analyzing cyanobacteria are all important. MassDEP recommends collaborating with other PWSs that have identified the need for a monitoring strategy to potentially coordinate shared resources. The following information should be considered during development of a PWS cyanobacteria monitoring plan:

- Potential frequency of cyanobacterial blooms
- Development of SOPs and resource material
- Costs for lab equipment
- Costs for sampling equipment
- Costs of initial staff training
- Costs for potential additional staff training (i.e., to respond to high bloom potential periods)
- Turnover of staff (potential for retraining with some frequency)
- Potential coordination with other PWSs for shared expertise or sample processing
- Availability and cost of continuous monitoring equipment for high risk waterbodies

## Equipment Needs (General)

Equipment needs will vary depending upon the intensity of your monitoring program and whether or not your PWS contracts outside services. This section identifies the various types of equipment needs for baseline water quality and cyanobacteria monitoring.

- Secchi disk
- Hip waders
- Thermometer
- pH meter
- Dissolved oxygen meter
- Boat (oars, life vests, anchor)
- Clipboard
- Digital camera

- GPS (optional)
- Sample bottles (250 ml or 500 ml)
    - Plastic, amber wide mouth bottles/jars are suitable for cyanobacteria; if amber unavailable, cover bottle with aluminum foil
    - Amber glass bottles/jars for toxin testing (or clear glass covered with aluminum foil)
- Labels, chain of custody sheets, log book
- Sampling pole, Kemmerer sampler, integrated tube sampler
- Cooler with ice, refrigeration
- Personal Protective Equipment (PPE) (gloves, eye protection)

## Equipment Needs (Microscopes)

A compound microscope with a minimum 100x magnification (preferably higher) is necessary for initial cyanobacteria identifications and counts. These range in cost from 1,500 to 2,000 dollars, and can be obtained online. In addition, battery operated microscopes with magnification up to 400x are available, and have the advantage of being utilized in the field. MassDEP does not endorse any particular vendor for this equipment, but offers examples of microscopes with sufficient power for cyanobacteria identifications:

- Home Science Tools - http://www.hometrainingtools.com/digital-microscopes-and-cameras/c/129/
- Microscope World (1-800-942-0528) http://www.microscopeworld.com/c-273-high-power-digital-microscopes.aspx
- Microscope World https://www.microscopeworld.com/p-1735-richter-optica-f1-elementary-microscope.aspx

The use of Smartphones and digital cameras mounted on microscopes are also a popular method of quickly exchanging images to one or several people at a time. MassDEP does not endorse any particular vendor for this equipment, but offers examples with relatively low costs:

- Motic - Moticam X Wifi camera - http://www.motic.com/As_Moticam_CMOS/product_458.html
- Microscope.com – Microscope cameras and Carson HookUpz Universal Smartphone Adapter – http://www.microscope.com/microscope-cameras/

In addition, some DW treatment facilities, particularly those that are at higher risk for CyanoHABs may consider purchasing equipment that provides real-time particle imaging and analysis, which can automatically detect and record the presence of algal cells. This type of equipment, such as FlowCAM from Fluid Imaging Technologies, can monitor raw water entering the treatment facility, classify algae according to different parameters and determine concentrations among other analyses. Further information on this technology can be found at: http://www.fluidimaging.com/applications/algae-technology

## Water Quality Monitoring (Probes/Sondes, Fluorometers & Other Equipment)

The presence of cyanobacteria can also be indirectly determined by using probes or sondes for the detection of chlorophyll a or phycocyanin – pigments that cyanobacteria contain. Use of these probes may be helpful as screening tools for some facilities – particularly those with frequent or prolonged blooms. Once they have been properly calibrated against known standards, these probes can be used to quickly check for ongoing bloom activity, or serve as a surrogate to detect a cyanobacterial bloom in its early stages. However, each type of probe has its efficiencies and drawbacks, and require training to operate them properly. As a screening tool, they can be particularly useful in the field for in vivo (in the water) measurements if the water body has several coves or different depths that require

frequent monitoring. Probes can be helpful in obtaining quick, real time data essential for risk management and emergency response. While there is a high initial cost to purchase these probes, the benefits can be justified for sites that require frequent sampling throughout the year.

***Chlorophyll a Probes -*** Cyanobacteria contain the pigment chlorophyll a (Chl a) as do all algae and plants. The measurement of chlorophyll fluorescence is one lake monitoring technique frequently used to determine the abundance of phytoplankton (microscopic plants) in a waterbody. Chl a can be measured either in a laboratory by breaking up or rupturing cells to extract the chlorophyll, or in the field by using a probe to measure chlorophyll in vivo. Following microscopic confirmation of a cyanobacterial bloom, probe measurements of Chl a concentrations can be used as a surrogate for cyanobacteria enumeration/counts when taken over time. Correlating probe readings of Chl a to cell counts, can then be used as a method to determine when a cyanobacterial bloom is underway, or increasing to a level that requires action by the water supplier. The development of a calibration curve enables the probe to provide meaningful instantaneous data from both the waterbody surface and at depth. It is important to collect these measurements at different depths because these organisms often move throughout the water column.

While the use of a Chl a probe provides the opportunity to quickly obtain many chlorophyll readings, and quantifies increases or decreases in pigment concentrations that accompany a bloom's spatial dimensions, care should be made when interpreting the results of a Chl a probe reading because the probe does not differentiate between the Chl a from cyanobacteria and from other forms of phytoplankton. It is important to note that one potential weakness of this type of probe is that it measures chlorophyll a in both potential toxin producing cyanobacteria, and other cells in the water column. As a result, there is potential to overstate the impact of a bloom by pooling toxic and non-toxic chlorophyll a types into a single reading. Conversely, a low reading would still indicate low potential for toxin producing species.

***Phycocyanin Probes -*** A more direct and specific way to determine the presence and estimate the concentration of cyanobacteria in a sample involves the use of a phycocyanin (PC) probe. Unlike the chlorophyll probe that measures the algal biomass of all algae, the phycocyanin probe measures the pigment found specifically in all cyanobacteria. Therefore, it is currently the most specific analysis for estimating the abundance and concentration of cyanobacteria. Because of this, it has the potential of replacing the more commonly used Chl a measurements as a surrogate for cyanobacteria enumerations. Again, careful probe calibration in conjunction with a series of cyanobacteria enumerations may offer an alternative for cyanobacteria enumerations, and serve as an early warning system for cyanobacteria presence.

Deploying or using the PC probe in the field requires careful planning; however, it does not require highly trained personnel to use once setup is complete. Initial and ongoing calibration of the probe, use of the software, accurate species identification and cell counts all require trained personnel. As with chlorophyll a probes, cyanobacteria identification should still be considered necessary to determine if potentially toxic species are present.

***Probe Benefits -*** The data from probes has several benefits. They can:

- Serve as an early warning for potential taste and odor problems. Several species of cyanobacteria produce taste and odor compounds such as geosmin (musty odor) and methylisoborneol (MIB) including *Anabaena (*geosmin), and *Aphanizomenon (*geosmin and *Planktothrix*-MIB).
- Provide continuous real-time monitoring of the water supply, which over time can help identify the early stages of a bloom and the timing they may reoccur on a regular schedule (i.e., under the same conditions of seasonal timing, temperature, year after year).

- Serve as a surrogate for deciding when to perform enumeration of the water sample for a cell count, after the probe has been calibrated against known cell count/biovolume.
- Alert operators to the presence and increase of potentially toxic cyanobacteria cells that may be used for treatment decisions.

Many of the chlorophyll a and phycocyanin probes can be deployed on water intake structures for long-term monitoring trends, and can be programmed to signal an alarm when a certain cell density is reached, which allows a useful way of monitoring a remote or not easily accessible intake. For further information on automatic monitoring, and the use of Chl a and PC data from deployed probes, see the following State University New York – College of Environmental Science and Forestry (ESF) "Automatic and Near-Real Time Monitoring for Cyanobacteria" presentation: http://www.neiwpcc.org/neiwpcc_docs/9Boyer-Automatedmonitoringtechniques.pdf

The cost for these probes and data units will vary, ranging from approximately 6,000 to over 25,000 dollars. These examples do not necessarily represent all possible manufacturers and MassDEP does not recommend one manufacturer or model over another; however, vendors known to supply submersible probes that measure Chl a and PC include:

- bbe-Moldaenke - http://www.bbe-moldaenke.de/en/ (1-978-834-0505)
- TriOS (www.trios.de/ email info@trios.de)
- Turner Designs - www.turnerdesigns.com (1-877-316-8049)
- YSI Inc. - www.ysi.com (1-800-897-4151)

### *Fluorometers*

Turner Designs and Beagle Bioproducts (http://beaglebioproducts.com) also make handheld fluorometers for phycocyanin and chlorophyll analysis. The handheld units require less training to use and calibrate than the submersible probes, but function on the same principals and are considerably less expensive. The handheld fluorometers can be used to obtain chlorophyll or phycocyanin readings depending upon the filter setups purchased, and the information provided by them is the same as listed above for the probes. These units are useful for collecting a sample in the field and obtaining a reading that can assist in determining if cyanobacteria are present and if additional samples need to be collected.

### *Probes/Fluorometers Comparison*

Ohio EPA developed a comparative listing of probes and fluorometers for public water systems that provides added detail about specific products' measurement ranges, needed power source(s), and further information. This listing should not be considered complete or an endorsement of any particular vendor, but can be found at: http://epa.ohio.gov/Portals/28/documents/habs/ProbeComparison.pdf

### *Secchi Disk Depth Monitoring*

A change in the transparency of the waterbody may be the first indication that a cyanobacterial bloom is underway in the reservoir. One simple and lost-cost way of determining transparency is to use a Secchi disk, which many drinking water filtration plants already have on hand. A Secchi disk can be easily made from an 8 inch wooden disk painted with contrasting black and white in a pattern similar to quadrants (Figure 5). In the center of the disk an eye bolt is needed to attach a plastic line that has been previously marked off at meter increments. The disk can be used from a dock, shore or from a boat with the same basic technique. Work with your back to the sun and lower the disk by hand into the water to the depth at which it vanishes from sight. Record this depth and then raise the disk until it becomes visible again and record this depth. These two values can be averaged. The clearer the water, the greater the measured depth of the

visible Secchi disk is in the water column. If a reservoir is experiencing a bloom of cyanobacteria, which may often be at the surface of the water, the readings can be very small, less than 1 meter.

Figure 5. Secchi disk, an 8 inch disk painted in contrasting black and white pattern to determine level of light extinction.

# Appendix 5 – PWS Treatment Facility Options

## Treatment within the PWS facility

Many PWS treatment processes can reduce cyanobacteria and cyanotoxins by either removing the cyanobacteria cells without causing them to lyse and release cyanotoxins, or through removing the cyanotoxin directly. The efficiency of the treatment technologies will depend on the treatment process specific to the PWS facility, as well as the cyanobacteria species and cyanotoxin present. Since cyanobacteria come in many different sizes and shapes, their physical attributes will determine the ability of various treatment processes to effectively remove the cells. In addition, some treatment processes may also remove cyanotoxins more effectively than other treatment processes. For these reasons, correctly identifying the most prevalent species of cyanobacteria will assist the PWS in properly assessing the potential effectiveness of the PWS's current treatment processes on cell or cyanotoxin removal

It is possible to remove cyanobacteria cells through coagulation, clarification, and filtration before they lyse and release any potential cyanotoxins into the PWS treatment facility. These cell removal methods appear to be effective for most cyanobacteria. Membrane filtration is also very effective in removing cyanobacteria cells provided it is accompanied by increased backwash frequency so the cells do not lyse while attached to the membrane and release cyanotoxins (all backwash water should be disposed of as wastewater as typical for normal operations).

Granular activated carbon (GAC) filters are most effective when organic carbon concentrations are low or have been reduced by other treatment processes. If organic carbon concentrations have not been reduced, sites for toxin adsorption will be blocked and GAC cannot remove the cyanotoxins. Use of powdered or granular activated charcoal is also very effective in removing cyanotoxins, including microcystin, anatoxin, cylindrospermopsin and saxitoxin. However, it should be noted that tannin stained waters can interfere with different methods for oxidizing the cyanotoxins. These humic substances, and other organic compounds, must be oxidized before cyanotoxins can be oxidized. Once accomplished, oxidation by ozonation is a highly effective process for inactivating most cyanotoxins. Table 7 below identifies cyanotoxin removal and inactivation by oxidants used in the PWS treatment process.

| Table 7. Checklist and Summary of Cyanotoxin Inactivation by Oxidants | | | | |
|---|---|---|---|---|
| **Cyanotoxin removal by Treatment Process** | | | | |
| | **Microcystin** | **Anatoxin-a** | **Cylindrospermopsin** | **Saxitoxin** |
| Microfiltration/ultrafiltration | No | No | No | No |
| PAC | Yes | Yes | Yes | Yes |
| GAC | Yes | Yes | Yes | Yes |
| Nanofiltration | Yes | Has not been investigated | Yes | Has not been investigated |
| **Cyanotoxin removal/inactivation by oxidants** | | | | |
| Chlorine | Yes | No | Yes | Yes |
| Ozone | Yes | Yes | Yes | No |
| Chloramine | No | No | No | Has not been investigated |
| Chlorine dioxide | No | No | No | Has not been investigated |
| Hydroxyl Radical | Yes | Yes | Yes | Has not been investigated |
| Potassium Permanganate | Yes | Yes | No | No |
| Source: based upon Westrick, J. 2011. Cyanotoxin Removal in Drinking Water Treatment Process and Recreational Waters. 2011 Northeast Regional Cyanobacteria Workshop. New England Interstate Water Pollution Control Commission | | | | |

It is important to note that although DW treatment procedures often cause cells to lyse, procedures such as chlorination can also degrade microcystins. Chlorination is effective at inactivating microcystin-LR, but not anatoxin-a. Chlorination is most effective at a pH 6 (contact time of at least 15 milligrams – minute per liter (mg-min/L)), while losing effectiveness at pH 9 (Westrick 2011). Table 8 contains temperatures and pH values that are most effective for microcystin removal by chlorination (Westrick 2011).

| Table 8. Chlorine concentrations and exposure times needed to reduce microcystin to 1 µg/L (Westrick 2011) | | | | | |
|---|---|---|---|---|---|
| | | **CT-values mg/L min** | | | |
| **ph** | **Microcystin-LR µg/L** | **10 $^0$C** | **15 $^0$C** | **20$^0$C** | **25$^0$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 | 187.2 | 161.3 | 139.8 | 121.8 |
| | 10 | 110.3 | 94.9 | 82.3 | 71.7 |
| 9 | 50 | 617.2 | 526.0 | 458.6 | 399.1 |
| | 10 | 363.3 | 306.6 | 269.8 | 234.9 |

If your PWS surface water source has any microcystin producing genera (*Microcystis* sp., *Anabaena* sp. or *Planktothrix* sp.), the microcystin test kits noted in this Guidance and in Appendix 6, could be used at the intake to initially determine if the bloom is toxic. Since the death of the cyanobacterial cells can result in the release of any cyanotoxins present, the cyanotoxins which are slow to degrade may be present in the waterbody even after a bloom disappears. If toxicity is present, the test kit may be used to screen for microcystin throughout the treatment facility and determine the efficacy of cyanotoxin removal. Cyanotoxin analysis of water as it moves through the PWS treatment facility will also indicate

how each treatment process works with different species of cyanobacteria and may be used to mark any decline or eventual disappearance of toxins; thus, determine any risk present to PWS consumers. It is important to remember that cyanotoxins other than microcystin may still be present as they cannot be detected by a microcystin specific test. The type of cyanotoxin that may be present is always determined by the type of cyanobacteria present.

# Appendix 6 – Cyanotoxin Testing

MassDEP recommends PWSs refer to the Cyanobacteria and/or Cyanotoxin Analyses and Services List found at https://www.mass.gov/guides/cyanobacterial-harmful-algal-blooms-cyanohabs-water for contract laboratory services available and associated costs, as there are both quantitative, US EPA approved methods for drinking water analysis of cyanotoxins and semi-quantitative and qualitative screening tests for cyanotoxins. This appendix provides further information and resources for these toxin tests.

***Cyanotoxins: EPA Approved DW Methods*** – As noted on page 20 of this Guidance, US EPA developed three, approved laboratory methods for drinking water analysis of cyanotoxins. These methods are required for all cyanotoxin monitoring performed under UCMR4.

- Method 544 - Determination of Microcystins (selected) and Nodularin: https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=306953

- Method 545 - Determination of Cylindrospermopsin and Anatoxin-a: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NGHH.txt

- Method 546 - Determination of Total Microcystins and Nodularins: https://www.epa.gov/sites/production/files/2016-09/documents/method-546-determination-total-microcystins-nodularins-drinking-water-ambient-water-adda-enzyme-linked-immunosorbent-assay.pdf

### *Cyanotoxins: Qualitative Screening Methods*

There are now several cyanotoxin test kits available for fresh water analysis of microcystins, nodularins, cylindrospermopsin, and Anatoxin-a, including easy to use strip tests or dipsticks, which are rapid immunochromatographic tests that provide preliminary, qualitative results. These strip tests may be used in the field without laboratory equipment providing results in approximately 35 minutes, and are now available with lower detection levels specifically for screening in raw and finished drinking water. Cyanotoxin strip tests are typically the least expensive means of screening for cyanotoxins, and several samples can be analyzed with a single kit typically costing less than 200 dollars. There are also cyanotoxin screening tube or plate kits that are not as easily used in the field and require more analysis time; however, they provide semi-quantitative results. MassDEP does not endorse any particular vendor for equipment; however, two companies that offer screening test kits include:

- Abraxis, LLC - http://www.abraxiskits.com/products/algal-toxins/ (1-215-357-5232)
- Envirologix, Inc. - http://envirologix.com/artman/publish/index.shtml (1-866-408-4597)

# Appendix 7 – Cyanobacteria Enumeration

For most decision making purposes, cyanobacteria identification to genus are sufficient; however, species level identification will provide the most specific information about toxicity or environmental preferences, and may be helpful in developing a mitigation strategy. In terms of planning for contract laboratory services, costs can vary greatly for identification and/or enumeration services. MassDEP recommends PWSs refer to the Cyanobacteria and/or Cyanotoxin Analyses and Services List found at https://www.mass.gov/guides/cyanobacterial-harmful-algal-blooms-cyanohabs-water for contract laboratory services available and associated costs.

Regardless if a PWS utilizes in-house expertise or contract laboratory services, all laboratory personnel performing cyanobacteria identification and enumeration should demonstrate that they have received training specific to cyanobacteria.

## Laboratory equipment/procedure recommendations

- The laboratory should own or have access to a standard compound microscope with at least 100x magnification for general identification, but higher magnification is required for any enumeration.
- The microscope must be equipped with a Whipple grid or similar way of demarcating and measuring the area under a glass slide that is examined, such as a gridded Sedgwick-Rafter counting chamber, which requires a 200x magnification.
- Laboratory staff should identify organisms to genus level at a minimum, present the results in a written report that clearly identifies the cyanobacteria, and preferably separates this data from any other algal groups that were observed.
- Laboratories should report all counts in cells/mL unless a different request is made by MassDEP.
- Laboratories should maintain a Standard Operating Procedures (SOP) for cyanobacteria counts and identifications; a copy of which should be sent to the PWS and MassDEP if requested.
- Suitable keys for identification should be available as well as access to on-line sites that have libraries of cyanobacteria photographs. Some of these resources are listed in Appendix 1.

## Units

As part of the cyanobacteria enumeration process, MassDEP recommends that cell counts should be presented in cells/mL of water as opposed to Areal standard units (Units/mL), which is also a unit of measurement used in the evaluation of the number of aquatic plankton, frequently algae, in water. With a Units/mL count, the sample is examined microscopically with one areal standard unit being equal to four small squares in a Whipple grid at a magnification of 200, and representing the number per unit volume. Although some DW treatment facilities may have historically used Units/mL, the scientific standard is shifting to cells/mL both nationally and internationally. To provide consistency with interpreting and comparing results from year to year for each location, throughout the state, and in determining treatment efficiencies, cell counts should be performed using cells/mL. PWSs that choose to maintain Units/mL for continuity with internal procedures should recognize that cell counts in cells/mL may be necessary in addition to Units/mL.

## Laboratory procedures for cyanobacteria counts

MassDEP maintains an internal standard operating procedure for cyanobacteria enumeration (CN 150.1) developed and approved by MassDEP's Watershed Planning Program, and employs staff that may be available to answer identification/enumeration questions. As standard practice, MassDEP directs those performing cyanobacteria counts to the Standard Methods for the Examination of Water and Wastewater Part 10000, Biological Examination.

# Appendix 8 - Additional Resources beyond this Document

There are many state, interstate, federal, and international agencies and organizations that have developed the science, recommendations, and workgroups relative to understanding and responding to cyanobacterial harmful algal blooms. In addition to the sources cited within this document, there are many resources available for review. A selection of these resources is listed in this section for ease of access with links.

American Water Works Association and Water Research Foundation (AWWARF): A Water Utility Manager's Guide to Cyanotoxins 2015. Retrieved September 2017, from http://www.waterrf.org/PublicReportLibrary/4548a.pdf.

AWWARF: Assessment of Blue-Green Algal Toxins in Raw and Finished Drinking Water (project #256), 2000. Retrieved September 2017, from http://www.waterrf.org/PublicReportLibrary/90815.pdf

AWWARF: Managing Cyanotoxins in Drinking Water: A Technical Guidance Manual for Drinking Water Professionals, 2016. Retrieved September 2017, from http://www.waterrf.org/PublicReportLibrary/4548b.pdf

Centers for Disease Control and Prevention (CDC): About Cyanobacteria, May 2004. Retrieved September 2017, from http://www.cdc.gov/hab/cyanobacteria/pdfs/about.pdf and Drinking Water Advisory Communications Toolbox, 2013: http://www.cdc.gov/healthywater/emergency/dwa-comm-toolbox/

Global Water Research Coalition and Water Quality Research Australia: International Guidance Manual for the Management of Toxic Cyanobacteria, 2009. Retrieved September 2017, from http://www.waterra.com.au/cyanobacteria-manual/PDF/GWRCGuidanceManualLevel1.pdf

Health Canada: Cyanobacterial Toxins – Microcystin LR Guidelines, 2000. Retrieved September 2017, from http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/cyanobacterial_toxins/index-eng.php#s1

Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health: Scientific Assessment of Freshwater Harmful Algal Blooms, 2008. Retrieved September 2017, from https://www.whoi.edu/fileserver.do?id=41023&pt=10&p=19132

Land and Water Resources Research and Development Corporation (LWRRDC): A Phytoplankton Methods Manual for Australian Freshwaters, October 1999. Retrieved September 2017, from http://phytobioimaging.unisalento.it/Portals/7/Documents/General_Documentation/A%20Phytoplankton%20Manual%20methods%20Australia.pdf

Massachusetts Department of Public Health (MDPH) has developed Guidelines for Cyanobacteria in Freshwater Recreational Water Bodies, Fact Sheets, Brochures (in numerous languages), Presentations and additional articles. Retrieved February 2017, from http://www.mass.gov/eohhs/gov/departments/dph/programs/environmental-health/exposure-topics/beaches-algae/algae-information.html

New England Interstate Water Pollution Control Commission (NEIWPCC) coordinates an HAB workgroup to share lessons learned, facilitate collaboration and identify solutions on HAB-related issues. Retrieved September 2017, from http://www.neiwpcc.org/harmfulalgalblooms.asp NEIWPCC also offers a comprehensive group of presentations from the 2013 Cyanobacteria Monitoring and Analysis Workshop: http://www.neiwpcc.org/cyanobacteria_workshop.asp

New Hampshire Department of Environmental Services (NHDES) Environmental Fact Sheet - Cyanobacteria and Drinking Water: Guidance for Public Water Systems, 2009. Retrieved September 2017, from http://des.nh.gov/organization/commissioner/pip/factsheets/dwgb/documents/dwgb-4-15.pdf.

Oregon Health Authority (OHA) provides Algae Resources for Drinking Water. Retrieved September 2017, from http://public.health.oregon.gov/HealthyEnvironments/DrinkingWater/Operations/Treatment/Pages/algae.aspx

Vermont Division of Environmental Health: Cyanobacteria (Blue-Green Algae) website includes Fact Sheets, monitoring information, Cyanobacteria Tracker Map, and Guidance for Vermont Communities. Retrieved September 2017, from http://www.healthvermont.gov/enviro/bg_algae/bgalgae.aspx

US Environmental Protection Agency (USEPA) CyanoHABs website offers compiled information on freshwater CyanoHABs including causes, detection, treatment, health and ecological effects, current research activities in the US; and, policies and regulations for cyanotoxins at the state and international levels. Retrieved July 2018, from http://www2.epa.gov/nutrient-policy-data/cyanobacterial-harmful-algal-blooms-cyanohabs

US EPA 2018 Edition of the Drinking Water Standards and Health Advisories Tables. The document contains the 2012 Drinking Water Standards and Health Advisories (DWSHA) tables that were amended in March 2018 to fix typographical errors and add health advisories published after 2012, including those for cyanotoxins. Retrieved July 2018, from https://www.epa.gov/dwstandardsregulations/2018-drinking-water-standards-and-advisory-tables

US EPA Cyanobacteria Monitoring Collaborative (CMC) is a nationwide program that coordinates three, voluntary monitoring projects to locate and understand harmful cyanobacteria by providing consistency in sampling equipment and methods that generate data. Retrieved November 2017, from https://cyanos.org/

US EPA DRAFT Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin, December 2016. Retrieved September 2017, from https://www.epa.gov/sites/production/files/2016-12/documents/draft-hh-rec-ambient-water-swimming-document.pdf.

US EPA Cyanotoxin Management Plan Template and Example Plans, November 2016. Retrieved September 2017, from https://www.epa.gov/ground-water-and-drinking-water/cyanotoxin-management-plan-template-and-example-plans

US EPA Fact Sheet: Cyanobacteria and Cyanotoxins: Information for Drinking Water Systems, September 2014. Retrieved July 2018, from http://www2.epa.gov/sites/production/files/2014-08/documents/cyanobacteria_factsheet.pdf

US EPA Recommendations for Public Water Systems to Manage Cyanotoxins in Drinking Water, June 2015. Retrieved September 2017, from https://www.epa.gov/ground-water-and-drinking-water/recommendations-public-water-systems-manage-cyanotoxins-drinking

U.S. Geological Survey (USGS) Harmful Algal Blooms Fact Sheet 2006-3147, January 2007. Retrieved September 2017, from http://pubs.usgs.gov/fs/2006/3147/

USGS Guidelines for Design and Sampling for Cyanobacterial Toxin and Taste and Odor Studies in Lakes and Reservoirs, Scientific Investigations Report 2008-5038, 2008. Retrieved July 2018, from https://pubs.usgs.gov/sir/2008/5038/

USGS Refinement and Evaluation of the Massachusetts Firm-Yield Estimator Model Version 2.0, Scientific Investigations Report 2011-5125, 2011. Retrieved December 2017, from https://pubs.usgs.gov/sir/2011/5125/

Water Quality Research Australia: Management Strategies for Cyanobacteria (Blue-Green Algae) and their Toxins: A Guide for Water Utilities, Research Report 74, June 2010 provides detailed information on cyanobacteria, drinking water; and, the detection, identification, and removal of cyanobacteria/cyanotoxins from drinking water sources. Retrieved July 2018, from http://www.waterra.com.au/publications/document-search/?download=106

Wisconsin Department of Natural Resources (WI DNR) Cyanobacteria and Drinking Water website. Retrieved September 2017, from http://dnr.wi.gov/lakes/bluegreenalgae/Default.aspx?show=drinking

World Health Organization: Toxic cyanobacteria in water: A guide to their public health consequences, monitoring and management, Edited by Ingrid Chorus and Jamie Bartram, 1999. Retrieved September 2017, from http://www.who.int/water_sanitation_health/publications/toxicyanobact/en/