HARMFUL ALGAL BLOOMS TOOLKIT FOR WATER UTILITIES

Commonwealth of Virginia

2023

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Prepared for:

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Purpose of the Toolkit

Algal blooms are the rapid growth of algae in surface water bodies, often resulting in the formation of visible blooms. These blooms can be caused by various species of algae and can be influenced by factors such as nutrient levels, temperature, and sunlight exposure. Harmful algal blooms, commonly known as HABs, are a specific type of algal bloom that can have detrimental effects on human health and the environment. HABs are characterized by the proliferation of certain algae species, such as cyanobacteria, which can produce toxins harmful to humans, animals, and the environment. HABs not only cause ecological imbalances and harm aquatic life but can pose a risk to drinking water supplies. In addition, the frequency, size, and duration of blooms have been observed to increase over time. As a result, water utilities, in Virginia and across the US, are faced with the increasing need to prepare for and respond to the threat of HABs.

The purpose of this toolkit is to enhance the ability of water utilities in Virginia to anticipate and address HABs, safeguarding the quality of drinking water and protecting public health. The toolkit offers useful resources and guidance on regulatory requirements, monitoring techniques, operational and treatment strategies, emergency planning, communication methods, and available funding.

Acknowledgments

We would like to express our gratitude to the U.S. Environmental Protection Agency (EPA) and the Virginia Department of Health (VDH) Capacity Development Program for providing the funding for the development of this HABs toolkit. Additionally, we extend our appreciation to the stakeholders involved in this initiative, including the Virginia HAB Task Force (VDH, Virginia Department of Environmental Quality, Old Dominion University, Virginia Marine Resources Commission, and the Virginia Institute of Marine Science at the College of William and Mary), the VDH Capacity Development Program North-Central Region, as well as the Town of Strasburg, Town of Woodstock, and City of Winchester. Lastly, we thank Christine Owen for her expertise and contributions to this project.

Disclaimer

This toolkit does not supersede any regulations set forth by federal and state regulating agencies. It is a supplementary tool that water utilities in Virginia can use to develop and improve their HAB monitoring and management practices. It provides useful resources by consolidating existing federal and state guidelines and incorporating current best practices.

I. Introduction to Harmful Algal Blooms

A. General Information

Algae are microscopic organisms that utilize photosynthesis to generate energy from sunlight. They occur in various water types including freshwater (lakes and rivers), saltwater, and brackish water. The rapid and excessive growth of algae in water bodies results in the formation of dense visible blooms referred to as algal blooms. These blooms can be caused by different species of algae. Their development is influenced by environmental factors such as water temperature, water chemistry (e.g., pH, dissolved oxygen, and turbidity), nutrient availability, and sunlight exposure. Additionally, human activities, including housing developments, agriculture, silviculture, stormwater runoff, wastewater discharge, road construction, etc., can increase the frequency, size, and duration of blooms.

Causes of Blooms:

The development and persistence of harmful algal blooms (HABs) are influenced by various factors such as:

1. **Nutrient availability:** Nutrients, such as nitrogen and phosphorus, are essential for the growth and reproduction of aquatic plants and algae. Excessive nutrient levels, often resulting from human activities such as agricultural runoff and wastewater discharge, can lead to frequent growths of algal blooms.

2. **Temperature:** Water temperature affects the development of algal blooms. Warm water temperatures during the spring and summer months provide optimal conditions for the growth of cyanobacteria, a common type of harmful algae.

3. **Sunlight:** Light availability and intensity affect algal growth. Blooms thrive when exposed to sporadic high light intensity but may be inhibited under prolonged exposure to high light intensity. Cyanobacteria can regulate their depth in the water column and moderate adverse effects of high light intensity, giving them an ecological advantage over other algal species.

4. **Turbidity:** Turbidity, which measures the cloudiness of water, plays a role in algal bloom formation. High turbidity occurs during high discharge events, while low turbidity allows more light to penetrate the water column, creating favorable conditions for algal growth. In turn, growing algae contributes to increased turbidity, creating a feedback loop.

Characteristics of Blooms:

Algal blooms exhibit a range of characteristics and can affect the appearance and the smell of a water body:

1. **Appearance:** Depending on the predominant species of algae present, blooms can exhibit different colors including green, blue-green, brown, or red.

2. **Size:** Blooms range from small patches to extensive surface-covering blooms.

3. **Smell:** In addition to visual changes, blooms can impact the smell of a water body. As algae die and decay, they can release gases that smell like sulfur or rotten eggs.

In freshwater environments, cyanobacterial blooms, also known as blue-green algal blooms, can manifest in different ways. They can grow on rocks beneath the water's surface or form on the water's surface, resembling foam, scum, mats, or spilled paint. These blooms can change the water color to shades of blue, green, brown, yellow, orange, or red. While some blooms are easily visible, others may be present below the water's surface, making them harder to spot.

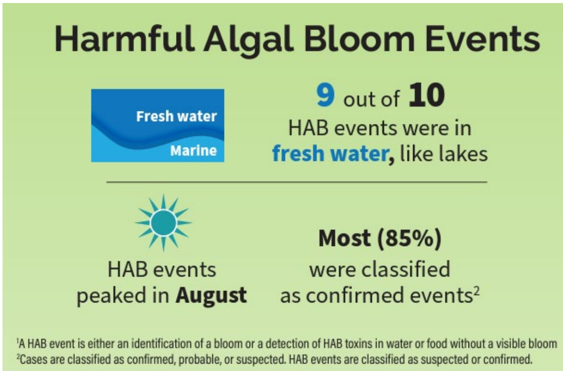
Figure 1: Photos of Cyanobacterial Bloom (CDC, 2022)

Figure 2: Photos of North Fork Shenandoah River at Strasburg Park (FOSR, 2021)

In saltwater environments, algal blooms can also change the color of the water, presenting shades of red, brown, orange, or yellow. Additional signs of saltwater algal blooms may include foam, scum, mats of algae, or the presence of dead fish or other creatures.

Figure 3: Photos of Algal Blooms in Salt Water (CDC, 2022)

While not all algal blooms are harmful, certain species of algae are capable of producing toxins, called algal toxins or cyanotoxins, that pose risks to human and animal health and the environment. These are referred to as harmful algal blooms or HABs.



HABs are commonly found in quiescent water bodies such as reservoirs, lakes, or ponds. Though less frequent than in quiescent water bodies, they also manifest in rivers or streams. According to the Center for Disease Control and Prevention (CDC), 9 out of 10 HAB events reported to the CDC in 2021 were in fresh water (CDC, 2021). In Virginia, HABs are more common in summer months when temperatures are elevated, and sunlight is abundant. In addition, the frequency, size, and duration of these blooms have been observed to increase over time in Virginia as well as across the rest of the US (VDEQ, 2021).

According to the EPA, "harmful algal blooms are mainly the result of a type of algae called cyanobacteria, also known as blue-green algae" (2023).

Cyanobacteria are a diverse group of organisms. They range from single celled organisms to filamentous, multicellular colonies. There are more than 2000 species distributed among 150 genera; the classification of cyanobacteria has historically relied on visual identification of morphological characteristics which may vary depending on the environmental and growth conditions. For decades, cyanobacteria were identified as "blue green algae" because of their ability to photosynthesize (like plants) and so the nomenclature has "stuck". In the 1990s, genetic tools led to the understanding that these blue green algae were actually bacterial species capable of photosynthesis. Cyanobacteria origins have been traced back in the fossil record to the beginning of life on earth.

B. Potential Impacts on Human Health and the Environment

HABs can have significant impacts on both human and animal health, the environment, and the economy. They pose a risk to drinking water supplies, recreational activities, and the overall ecological balance.

Human and Animal Health Impacts:

HABs may produce toxins, such as microcystins and cylindrospermopsin, which can contaminate drinking water sources. Exposure to these toxins through ingestion, inhalation, or skin contact can lead to a range of acute and chronic health effects in humans and animals, including gastrointestinal illness, liver and kidney damage, respiratory issues, skin irritation, and neurological symptoms. Vulnerable populations, such as children, the elderly, and individuals with compromised immune systems, are particularly susceptible to the health risks associated with HABs. **Table 1** below summarizes the health effects of HAB toxins on human health. Note: this table specifically focuses on toxins commonly found in drinking water and those for which health advisories have been established in Virginia.

Table 1. Effects of HABs on Human and Animal Health (AWWA, 2016 & EPA, 2023)

Type of Toxin	Environment	Exposure Pathway	Health Effects
Microcystin	Common in freshwater	Drinking, Swimming	Liver damage, gastrointestinal symptoms (vomiting, diarrhea, abdominal pain), allergic reactions (rash)
Cylindrospermopsin	Common in freshwater	Drinking, Swimming, Inhalation	Fever, headache, liver and kidney damage, gastrointestinal symptoms (vomiting, diarrhea), skin rashes, neurological effects
Anatoxin-a	Common in freshwater, brackish water	Drinking, Swimming, Inhalation	Gastrointestinal symptoms, neurotoxicity (tingling, burning, numbness, drowsiness, incoherent speech), loss of coordination, muscle paralysis, respiratory distress, or paralysis
Saxitoxin	Common in marine waters and freshwater	Ingesting contaminated food (fish, shellfish)	Neurological symptoms (tingling, burning, numbness, drowsiness, incoherent speech), respiratory failure or paralysis

Environmental Impacts:

HABs affect the ecological balance of water bodies in different ways. Algal blooms often deplete dissolved oxygen levels in water bodies when algae die and decomposes. This makes it difficult for aquatic life to survive, resulting in fish kills. Dense blooms can also affect the growth of submerged aquatic vegetation by blocking sunlight penetration. In addition, the decomposition of algae after a bloom can further impact water quality by contributing to excessive nutrient levels, organic carbon, and oxygen depletion.

Impact to Drinking Water Utilities:

Cyanobacterial blooms can have serious impacts on drinking water utilities because they can affect source water quality and treatment processes. During a HAB event, water utilities may experience:

- ❑ Unpleasant taste and odor, often characterized by earthy and musty smells,
- ❑ Interference with water treatment plant operations such as flocculation, sedimentation, coagulation, filtration, and chlorination,
- ❑ Disinfection by-product (DBP) formation due to algal organic matter which could cause an increase in the levels of DBP precursors, and
- ❑ Potential passage of cyanotoxins into the finished drinking water if appropriate measures are not taken to address the issue.

Note: Unpleasant taste and odor, interference with water treatment, and DBP formation can occur during any algal bloom and are not exclusive to HAB events.

To mitigate the risk associated with cyanobacterial blooms, the federal government, states, and local authorities have established extensive guidelines for water utilities to assess, monitor, and respond to HABs.

II. Regulatory/Compliance Requirements

A. Overview of Regulatory Framework

The regulatory framework for addressing Harmful Algal Blooms (HABs) in waterworks involves a combination of federal, state, and local regulations and guidelines. Federal regulations provide a framework for managing contaminants in drinking water. Based on federal guidance, state and local governments may also establish their own regulations and standards to protect public health and prevent HAB-related issues in water systems.

a. Federal Advisory Levels and Guidance (EPA)

The U.S. Environmental Protection Agency (EPA) addresses cyanotoxins through guidance and health advisory levels. Under the Safe Drinking Water Act (SDWA), the EPA is authorized to issue health advisories for contaminants that are not subject to the National Primary Drinking Water Regulations but are known to cause negative health effects. Cyanotoxins from HABs fall under this category.

EPA defines health advisories as nonregulatory concentrations of drinking water contaminants at or below which adverse health effects are not anticipated to occur over specific exposure durations (e.g., one-day, 10-days, several years, and a lifetime). EPA health advisories provide comprehensive technical information and advisory levels on unregulated contaminants, such as cyanotoxins from HABs, to federal, state, tribal, and local officials, as well as operators and managers of public water systems. These advisories offer guidance on appropriate actions to protect the public from potential adverse health effects associated with exposure to such contaminants.

Note: Health advisories are not enforceable standards and may be revised as new information and research becomes available.

Typically, EPA health advisories include advisory levels for different exposure durations (e.g., one-day, 10-days, several years, and a lifetime), analytical methods for detection and measurement, and relevant technical information for managing and responding to potential health risks.

In 2015, the EPA issued health advisories specifically for two types of toxins produced by cyanobacteria known as microcystins and cylindrospermopsin:

Table 2. EPA Cyanotoxin 10-day Drinking Water Health Advisories (EPA, 2022)

Cyanotoxin	**Drinking Water Health Advisory (10-Day)**	
	Bottle-fed infants and pre-school children	School-age children and adults
Cylindrospermopsin	0.7 µg/L	3.0 µg/L
Microcystins	0.3 µg/L	1.6 µg/L

If microcystin or cylindrospermopsin levels exceed the established threshold, the EPA advises water systems to take appropriate actions to protect public health, such as issuing public notices, consulting with local health authorities or environmental agencies for guidance on appropriate actions and considering treatment options to remove or reduce the toxins.

In addition, the EPA has developed Health Effect Support Documents (HESD)[1] for 3 cyanotoxins:

- anatoxin-a,
- cylindrospermopsin, and
- microcystins.

These documents provide in-depth reviews and analyses of the potential health effects associated with these toxins. HESDs are compiled using diverse information sources such as scientific studies, toxicological data, and epidemiological research, to provide a comprehensive analysis of contaminant properties, environmental occurrence, exposure pathways, human health effects, and recommended exposure limits.

HESDs may also be used by state and local officials to establish health advisories and set guidelines or regulations for contaminants in drinking water. HAB health advisories established by different states can be found in **Appendix D**.

b. Virginia Advisory Levels and Guidance

In addition to federal guidance, Virginia has state advisory levels and guidance specific to HABs. These state-level regulations and recommendations complement the federal framework and provide more localized information.

[1] HESDs are typically prepared for contaminants that are not subject to national primary drinking water regulations but are known or suspected to pose health risks.

1. Advisory Levels

The VDH's Office of Drinking Water (ODW) has adopted the following 10-day drinking water health advisory levels for the following toxins:

Table 3. Virginia Cyanotoxin 10-day Drinking Water Health Advisories

Cyanotoxin	Virginia Drinking Water Health Advisory
Cylindrospermopsin	0.7 µg/L (all ages)
Microcystins	0.3 µg/L (all ages)
Anatoxin-a	0.4 µg/L (all ages) – Draft[2]
Saxitoxin	0.2 µg/L (all ages) – Draft

If cyanotoxin levels exceed the health advisory levels, VDH advises water systems to take appropriate actions to protect public health. These recommended actions are highlighted in the sections below.

VDH has established draft drinking water health advisory levels for anatoxin-a or saxitoxin. In the event that detection of either of these cyanotoxins occurs in the finished water, the VDH ODW field office director, or designee, will coordinate with the regional epidemiologist and the Local Health Department director to confirm the Draft Health Advisory Levels remain appropriate and recommend a course of action for the waterworks.

2. Monitoring and Reporting Requirements for HABs

VDH's *2022 Source Water Manual* (included in **Appendix E**) provides comprehensive guidance for waterworks using surface water to assess, monitor, and respond to HABs. The flow chart below (**Figure 4**) provides waterworks a visual representation of the entire HAB monitoring and response process detailed in the Source Water Manual. For each step, a detailed explanation is provided in the sections below the flow chart. These sections outline the specific procedures, methodologies, and important considerations associated with each stage.

[2] The draft health advisory levels for anatoxin-a and saxitoxin are based on VDH's 2022 Source Water Manual, which has not yet been formally adopted but is currently utilized for guidance.

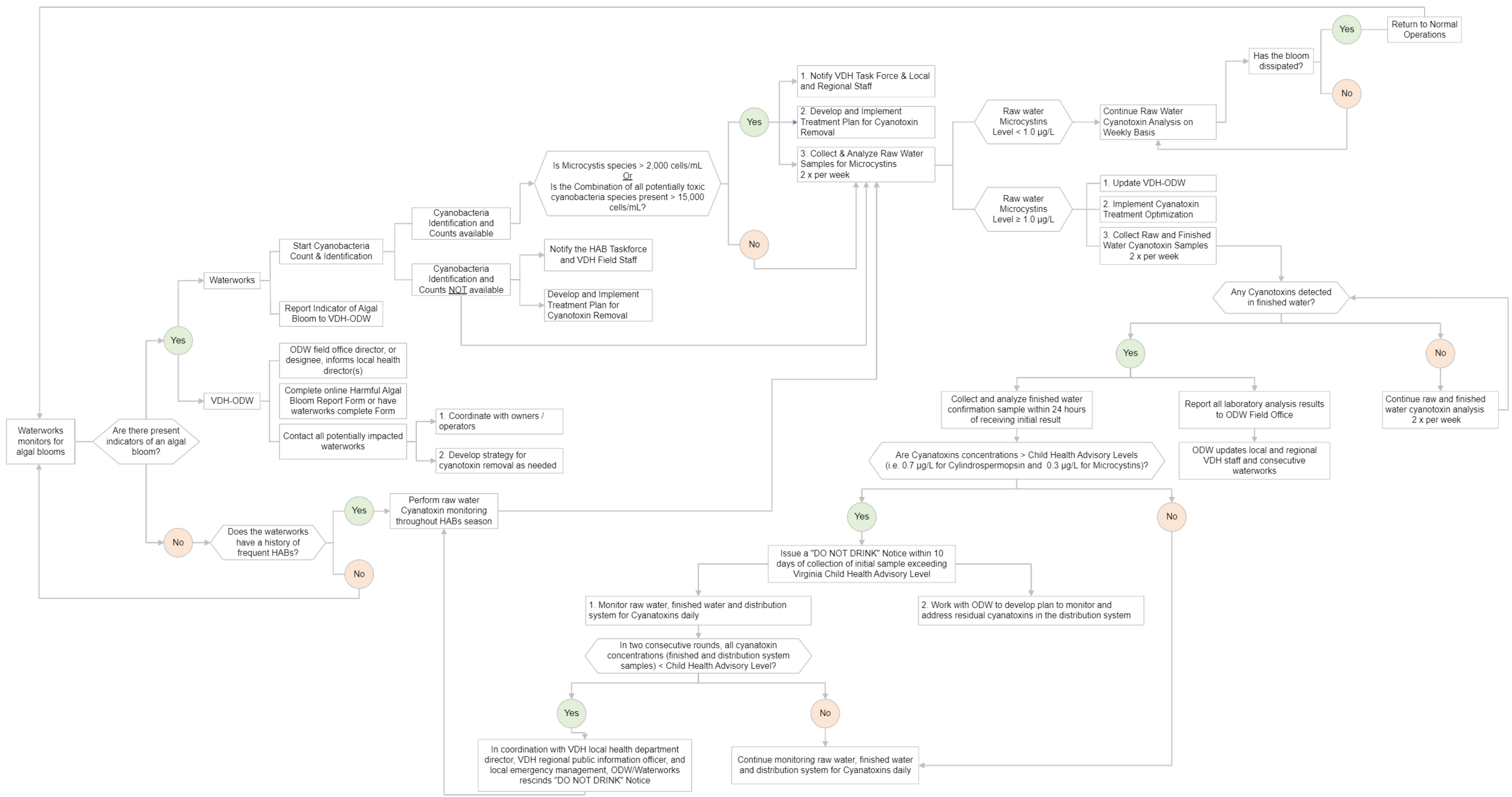


Figure 4. Summary of Virginia HAB monitoring and response process for waterworks (VDH, 2022)

Section 1: Planning for HABs

VDH strongly advises waterworks utilizing surface water to proactively prepare for and enhance their readiness to address HABs, including implementing source water protection measures to prevent HABs and developing a HAB response plan and treatment strategies to prepare for potential HAB events.

Table 4. Guidance for Planning for HABs

<table>
<tr><th colspan="2">Preventative and Planning Measures</th></tr>
<tr><td>1</td><td>HABs Response Plan: Waterworks are encouraged to develop site-specific plans based on their water source, history of HABs and treatment capabilities. A template for a response plan is included in Appendix A.

At a minimum, a HAB response plan should include:
1. Monitoring strategies, including early detection methods,
2. Identification of HAB species,
3. Communication and public notification procedures to keep VDH and the public informed of any HAB indicators or advisory level exceedances,
4. Mitigation strategies including operational or treatment adjustments,
5. Contingency plans if unexpected challenges arise, and
6. Recordkeeping and data management procedures.</td></tr>
<tr><td>2</td><td>Preventative Measures: There are several source water protection measures that waterworks can carry out to decrease the frequency and severity of HABs. These include:
- Nutrient reduction strategies such as managing agricultural, wastewater and stormwater runoffs,
- Mechanical measures to limit algae growth such as aeration, establishing buffer zones to absorb and retain excess nutrients, and algaecides or biological controls for algae (e.g., fish), and
- Public education to manage pollution and waste discharge into source water.

However, it is important to note that waterworks may be limited in their ability to manage their source water because most do not have authority to control activities in the watershed. In most cases, it is recommended that waterworks focus on regularly monitoring source water quality and establishing early warning systems to detect signs of algal blooms to allow for early intervention. See Section III for more information on establishing early warning systems.</td></tr>
<tr><td>3</td><td>Control Measures and Treatment Options: Water treatment optimization strategies should be developed and implemented to remove or inactivate cyanotoxins. Surface water treatment plants should assess their capability for cyanotoxin removal.</td></tr>
</table>

Section 2: Inspecting Source Water for Potential Algal Blooms

In Virginia, HAB season is typically March to November. During this season, waterworks are encouraged to actively look for indications of HABs in their source water such as changes in water clarity, color, and odor. In addition to visual inspections, waterworks should also monitor key water quality parameters, and utilize algal identification and counting techniques to evaluate the risk posed by an algal bloom. These guidelines are summarized in **Table 5** below:

Table 5. Inspecting Source Water for Potential Algal Blooms

Guidelines	Frequency	Process
Visual inspection of water source	At least twice a week during algal bloom season (March-November[3])	Visual indicators of a bloom can include reduced water clarity, discoloration, or surface scum formation. Surface scum is more visible early in the morning when most HAB species are near the water surface.
Raw water odor	Regularly during the algal bloom season (March-November)	Many species of algae can produce earthy or musty odors.
Key raw water parameters to monitor: **- pH[4]** **- turbidity** **- filter run times** **- coagulant dose** **- chlorine demand**	Regularly during the algal bloom season (March-November): ➔ **pH and turbidity:** monitor continuously or at least every 2-4 hours. ➔ **Filter run times:** evaluate over hours, days, and weeks. ➔ **Coagulant dose:** evaluate at least daily. ➔ **Chlorine demand** evaluate at least daily.	Raw water pH increases during daylight hours as algae grow and consume dissolved CO_2 from the water. Decreases in pH may occur at night from normal algae respiration. Turbidity, decreased filter run times, need for increased coagulant dose, and increased chlorine demand can indicate an algal bloom. These parameters may also be affected by other suspended matter in the water.
Algae identification and counts	When possible	Monitoring algae identification and counts can be useful for determining if to take action as a result of an apparent algal bloom.
Chlorophyll-a and phycocyanin concentrations	When possible	Monitoring chlorophyll-a and phycocyanin concentrations can be useful for detecting an algal bloom.

[3] Waterworks are encouraged to conduct more frequent inspections during the hottest months of the year, or during hot sunny weather following a storm.

[4] Waterworks may also monitor dissolved oxygen (DO) levels to bolster the changes seen in pH. Algal blooms can cause significant fluctuations in DO levels. During periods of algal growth/blooms, DO levels can increase due to photosynthesis causing supersaturation of DO levels at or near the surface. In contrast, following algal blooms, the respiration of primary production can reduce DO levels and increase carbon dioxide levels, potentially causing water acidification and hypoxia.

Section 3: HAB Identification and Raw Water Monitoring

Identifying bacteria in source water is initially based on morphological characteristics identified via microscopy. Cell shape, internal organelles and the appearance of cell contents are reliable keys to the identification of genera and in many cases, down to species. Cell counts using a microscope are a reliable method for detecting cyanobacteria if the microscopist is trained.

Three common counting procedures involve the use of a special slide called a counting chamber. They vary by: counting all cells within the chamber, counting only cells within transects spanning one edge of the chamber to the other, and counting cells in randomly selected fields. Accurate quantification using microscopic methods requires careful quality control and skilled microscopy (Chorus and Bartram 1999).

Phycocyanin and chlorophyll-a are two pigments found in both typical algae and cyanobacteria; they serve discrete functions in photosynthesis and may be used to assess the likelihood of a HAB and/or the possible progression of a HAB. Chlorophyll-a has been used to classify the trophic state of a water body; too much "good" algae can cause problems ranging from aesthetic issues to decreased dissolved oxygen. Phycocyanin is very specific to cyanobacteria as it supports light harvesting for photosynthesis. Phycocyanin to chlorophyll-a ratios can be used as a cyanobacteria bloom condition indicator.

Another metric found in the literature for the quantification of cyanobacteria is biovolume. Biovolume is an estimate of the actual percentage of three dimensional space the cells of a particular cyanobacterial species occupy in the water source. It is a challenging metric to assess because it requires more extensive knowledge of the geometry and configuration of cyanobacteria species. As such, utilities are generally encouraged to rely on cell counts produced by the three methods described above. Utility actions can then be triggered by cell count numbers as described below.

The specific HAB cell count that warrants action will vary depending on several factors including the type of algae, the toxins they produce, their ability to produce toxins, the body of water involved, and local guidelines. The USEPA typically defines a HAB as a bloom that has cell counts greater than 20,000 cells per mL. Generalized information gathered from the mid-Atlantic region identifies 2,000 cells per mL as a trigger for many utilities to begin more frequent sampling for cell counts, species identification and raw water toxin monitoring using test strips. Potential additional actions include closing water bodies for recreational use, monitoring water quality parameters more frequently, implementing in plant water treatment, and if warranted by cyanotoxin levels, issuing public advisories.

It is important to note that thresholds are not universal and can vary significantly depending upon the region, season, and local regulations as well as the specific risks posed by each species of cyanobacteria. State regulatory approaches vary widely; more specific information can be found on the EPA's State HABs Monitoring Programs and Resources webpage - https://www.epa.gov/cyanohabs/state-habs-monitoring-programs-and-resources

If visual or other indicators of an algal bloom are observed, waterworks should perform cyanobacteria identification and counts to evaluate the risk of cyanotoxin contamination. VDH uses the following cyanobacteria cell count action levels as a criteria for waterworks to initiate toxin sampling for raw water:

Table 6. Cyanobacteria Cell Count Action Levels (WHO, 2003)

Species	Action Level
Microcystis spp.	2,000 cells/mL
Combination of all potentially toxic cyanobacteria species present	15,000 cells/mL

If cyanobacteria cell counts exceed action levels or if cyanobacteria cell counts are not available, waterworks are advised to proceed to raw water cyanotoxin analysis two times per week through field tests and/or laboratory analyses. Sample results should be evaluated and communicated to the VDH Office of Drinking Water.

Continue raw water monitoring until cyanotoxins are not detected in the raw water and the bloom dissipates.

If cyanotoxins are detected in raw water, the waterworks must implement treatment optimization.

Additionally, new, and ongoing research may advance our understanding of cyanobacteria population dynamics and toxin production. It is important that utilities and regulatory authorities stay updated on the latest research and adjust their recommended HAB protocols as needed/warranted.

Section 4: Finished Water Cyanotoxin Analysis and Response

Based on the raw water analysis results, waterworks will either:

- ➔ Commence finished water monitoring if cyanotoxin is detected in raw water. If cyanotoxin is detected in finished water, the waterworks should promptly proceed with confirmation sampling. Based on confirmation results, the waterworks are encouraged to issue a "Do Not Drink" notice to minimize public health risk. Waterworks will also need to implement communication strategies and coordinate with VDH for response and public awareness.

Section 5: Distribution System Cyanotoxin Monitoring

After issuing a "Do Not Drink" notice, waterworks should monitor cyanotoxins in the distribution system until cyanotoxin levels are below health advisory levels for two consecutive periods, then work with VDH to notify stakeholders and issue a "Do Not Drink" notice rescission.

3. Resources & Important Contacts

The Commonwealth of Virginia offers various resources to support waterworks in surveilling, responding to and effectively managing HABs. It is crucial for waterworks to obtain up-to-date information on HABs by familiarizing themselves with these resources and by maintaining communication with key contacts.

- **The Virginia HAB Task force:** Virginia has a dedicated HAB Task Force that coordinates efforts, shares information, and provides guidance on HAB-related matters. It was formed in 1997 and is a joint effort of several state agencies and educational institutions. The mission of the Virginia HAB Task Force is to conduct monitoring and surveillance for HAB species, to respond to and investigate HAB events, utilize scientifically relevant information to advise public health and environmental resource managers, and to communicate potential health risks to the public. The HAB Task Force also manages the **HAB Hotline** and the **Harmful Algal Bloom Report Form** (described below), which allows the public to report algal blooms, fish kills, and health issues related to harmful algal blooms. Information on the roles, responsibilities, and response obligations of the Task Force members are detailed in the Virginia Harmful Algal Bloom Task Force Response Plan - https://www.vdh.virginia.gov/content/uploads/sites/12/2018/05/Virginia_HAB_Response Plan_Final_2018.pdf

- **Virginia Department of Health (VDH) and Virginia Department of Environmental Quality (VDEQ):** VDH and VDEQ co-lead the HABs Task Force activities. These agencies play a critical role in HAB monitoring, management, and compliance in Virginia.

- **Algal Bloom Surveillance Map:** Virginia maintains a HABs surveillance map that displays the locations and status of reported HABs in the State. The map is updated regularly during the months of May-October. It is a useful tool for waterworks professionals to monitor affected areas and stay informed about the extent of HAB occurrences. https://www.vdh.virginia.gov/waterborne-hazards-control/algal-bloom-surveillance-map/

- **HAB Hotline (1-888-238-6154):** VDH has a dedicated toll-free hotline, available 24-7, to report potentially harmful algal blooms. Waterworks and the public can also use this hotline to report HAB incidents, seek guidance or receive updates.

- **Waterworks After-Hours Emergency Call Center (1-866-531-3068):** This number is for waterworks with an after-hour emergency or need to reach VDH staff during non-business hours. This is a 24 hour Call Center that will take all pertinent information and contact appropriate staff.

- **Harmful Algal Bloom Report Form:** VDH has an online Harmful Algal Bloom Report Form to allow community members to report fish kills or water that has an odd color or odor and health problems related to HABs. https://www.vdh.virginia.gov/waterborne-hazards-control/harmful-algal-bloom-online-report-form/

- **Virginia Emergency Operations Center (VEOC) (1-800-468-8892):** The public can report an algal bloom, water of an abnormal color, or a fish kill.

III. Techniques for Monitoring and Detecting HABs

A. Early warning systems

Early Warning Systems (EWS) are important tools in the HAB management toolbox. They provide utilities with site specific guidance on managing their water resources and treatment while protecting staff time and managing costs. The first level of an EWS provides information that will inform a utility of a possible HAB in a timely fashion, allowing for source water and treatment adjustments if needed. This first level should also be made up of tools and techniques that are relatively inexpensive and easily performed. Tier 1 parameters/measurements may include visual inspections, turbidity, DO, optimal density, temperature, and clarity. The value of these parameters is enhanced as the utility gains experience with their water source over time. Changes in the Tier 1 parameters would trigger Tier 2 where the utility adds new or additional parameters to the source water monitoring program, including cell counts, pigment analyses, and test strips[5] for toxins in the raw water. If cell counts exceed the established site specific trigger levels or toxins are observed in the raw water, then Tier 3 actions are undertaken. Tier 3 activities include monitoring for toxins in finished water using a confirmatory laboratory method.

A variety of early warning tools are available for identifying potential and/or impending HABs. These fall generally into two categories:

1. In-situ measurements/observations, and
2. Remote sensing

1. In-Situ Monitoring Techniques

For a more comprehensive understanding of HABs, a combination of in-situ techniques and laboratory methods provides the opportunity to observe cyanobacteria directly in their environment. Commonly used in-situ techniques used to identify cyanobacteria include:

- ❑ Visual inspection
- ❑ General water quality parameters including pigment identification
- ❑ Microscopic enumeration
- ❑ Test Strip Kits

Visual Inspection

Visual inspection is a simple monitoring method that any utility can employ. It should be done daily during HABs season and preferably by a trained individual who can physically observe color, turbidity, and surface scum. It is important to note that benthic cyanobacteria would not readily be detected visually, as they are below the water line and attached to the subsurface. For visual inspections to be most useful, they should be done at the same time of day by an experienced individual and carefully documented. A visual guide for identifying algal blooms can be found in **Appendix B**.

[5] It is important that waterworks monitor the general conditions of the raw water first before using test strips to test for toxins.

General Water Quality

General water quality conditions can be used to predict the possibility of a bloom as well as indicate the active presence of cyanobacteria. For example, changes in pH and dissolved oxygen (DO) can be the direct result of cyanobacteria growth. Seasonal changes in source water temperature frequently impact algal growth. Microsensors attached to buoys and probes can be set up to measure general water quality parameters such as pH, nutrients, light intensity, and DO. This environmental information can be used to predict metabolic activity, population dynamics and possible bloom threat status. For example, many utilities report that they begin visual inspections and general water quality monitoring when water temperatures start to increase in the spring to early summer because historically HABs have been observed in the summer months. Once physical ecological parameters such as temperature are triggered, then more intense monitoring is needed. Increased water temperature, increases in cell counts and cyanobacteria species dominance are all triggers to begin toxin measurements in the raw water. These more involved monitoring techniques include cell counts, pigment measurements, toxin measurements and various genetic analyses and are described below. Increased water temperature, increases in cell counts and cyanobacteria species dominance are all triggers to begin toxin measurements in the raw water.

Pigment Measurements

Chlorophyll-a is a photosynthetic pigment that is found in cyanobacteria and algae. It is commonly used as a measure of phytoplankton biomass. Phycocyanin is a primary pigment system of cyanobacteria and functions cooperatively with chlorophyll-a in photosynthesis. Compared to measuring chlorophyll alone, using phycocyanin as an indicator is usually more precise for identifying the presence of a HAB. These pigments can be quantified in the laboratory or in the field using sensors that measure fluorescence. The laboratory methods involve lysing cells (i.e. breaking open the cells) and separating the various pigment types. The pigments can then be measured either by high-performance liquid chromatography or a spectrophotometer. Spectrophotometer-based methods have improved and are becoming more common for rapid and cost-effective analyses as well as being capable of providing meaningful reporting and detection limits.

Field sensors on buoys and probes are an easier and a more cost-effective means to obtain real-time pigment data via continuous measurements of fluorescence. These are detectable at different wavelengths with each pigment having a peak emission wavelength determined based on their unique excitation/emission spectra. The detection limits with these sensors are very low and capable of identifying cyanobacterial pigment presence at very low levels, signaling the beginning of a bloom.

Microscopic Enumeration

Microscopic enumeration is probably the most commonly used measurement to identify HABs. Fluorescence microscopy identifies algal species and counts algal cells, providing valuable information on the possible challenges a utility may face. A specific volume of water is concentrated, and the algal cells are examined under a microscope, counted and species identified by a skilled technician using a specialized counting chamber slide. This is a labor-intensive process and can take significant time to accomplish.

Alternatively, automated instruments that use flow cytometry are available (e.g., FlowCam). This process uses a camera to capture images in a water stream running through the instrument, count the images and process each image for identification. These instruments are expensive and establishing the protocol for identification requires time and effort (i.e., creating a library of images); however, many utilities find the investment saves valuable time and staff effort as compared to traditional microscopic examination. Flow cytometry is another means of identifying and quantifying biomass and species and is especially useful if the rapid analyses of algal populations is needed for mixed populations.

Test Strip Kits

Cyanotoxin test strips are rapid in situ screening tests designed for detecting the presence of cyanotoxins and are immunoassay techniques. Commercial test strip kits are available for microcystins, anatoxin-a, cylindrospermopsin and saxitoxins which provide preliminary qualitative results which should then be confirmed with more reliable methods such as LC-MS/MS. While a number of test kits exist for microcystins and cylindrospermopsin, there are limited options for saxitoxins and anatoxin-a; quantification of these toxins usually requires laboratory analysis.

When choosing a field test kit, waterworks need to ensure that it is designed to provide accurate toxin detection and results within detectable limits (i.e., close to advisory levels).

Test strips provide a quick turnaround time of less than one hour for preliminary results. VDH recommends using test strips as a screening tool during peak bloom seasons. In addition, test strips can be used during the months when blooms are expected to be less frequent (e.g., winter) or as a preemptive tool for screening source waters with low to no historical occurrence of blooms. However, if the test result is positive, further analysis needs to be performed using ELISA or LC-MS/MS for confirmation and quantification of cyanotoxins.

Table 8 provides a list of test kits that can be used for the detection of HAB toxins in freshwater. This list is not comprehensive and is subject to change as new products are introduced to the market. Note: While **Table 8** primarily features suppliers/ manufacturers of test kits, there are also distributors offering these same products such as VWR, Fisher Scientific, etc.

In addition to in-situ monitoring methods, such as field sampling and laboratory analyses, satellite imagery is an evolving tool that can be used to supplement and strengthen our understanding of algal blooms.

2. Remote Sensing

Remote sensing is the process of collecting data about an area (i.e. Earth's surface) from a distance, typically using satellites, aircraft, or drones. Remote sensing techniques such as satellite imagery and aerial photography can provide valuable information about the dynamics and distribution of cyanobacteria populations in water bodies. Routine satellite monitoring of water bodies prone to HABs can provide information used to create an early warning system. When combined with field measurements and hydraulic models, utilities can improve their ability to forecast the development, movement, and maturity of a HAB, providing timely alert to stakeholders and allowing for appropriate and effective response measures.

General Process for HABs

Through the analysis of the spectral characteristics of a water body using satellite information or aerial photos, the biomass and pigments associated with cyanobacteria can be identified. Satellite sensors can track the presence of algal blooms over large areas using wavelength data related to algal pigments and changes in water color. Algae contain chlorophyll and other pigments used for photosynthesis and by measuring the reflectance, satellite data can estimate the abundance, distribution, and the broad species category (I.e., a cyanobacteria or a relatively harmless species) of an algal biomass.

In addition, remote sensing techniques can estimate key water quality parameters, such as turbidity, relying on the principle that optically active constituents in water bodies have unique and predictable wavelength-dependent interactions with light. Changes in water quality parameters or the presence of toxic species can be tracked and quantified over time which can inform how algal blooms affect aquatic ecosystems, fisheries, recreation, and public health. Analysis of historical satellite data may allow utilities to identify trends, patterns, and possible links between HABs and environmental conditions such as temperature, nutrient levels, and anthropomorphic activities. In addition, satellite imagery allows users to create maps that show the spatial and temporal extent of algal blooms as well as possible intensity. This information is critical to understand the scale of blooms, extent of affected areas and potential impacts to humans and ecosystems.

Current Limitations

Remote sensing of cyanobacteria can be difficult in inland waters because these water bodies are often optically complex, and sensors have not had the fine detail in spatial, temporal, and spectral resolutions needed. Recent work by the USEPA and the National Oceanic and Atmospheric Administration (NOAA) as well as in the commercial sector have created improved algorithms which are publicly available for moderate to no cost. Improved sensors are refining detection capabilities via multispectral sensitivity while more frequent fly-over schedules are making data more useful for utilities. Additionally, spatial resolution has greatly improved; sub-meter resolution is now possible.

Another challenge associated with remote sensing is the expense and the resources required to undertake it. For this reason, remote sensing is an emerging tool that is predominantly utilized by larger utilities. While smaller utilities may currently lack capacity, data availability and techniques are improving and more likely to be available in the future through a series of federally supported programs such as CyAN - Cyanobacteria Assessment Network - https://www.epa.gov/water-research/cyanobacteria-assessment-network-cyan. CyAN is a collaborative project that brings together the expertise and resources of the USEPA, National Aeronautics and Space Administration (NASA), NOAA, the United States Geological Survey (USGS), and the United States Army Corps of Engineers (USACE). This program is designed to provide satellite data to the public and refine the algorithms used for interpretation.

Another emerging platform for remote monitoring of HABs is CyanoTRACKER, a cloud based integrated platform for global observations of cyanobacterial blooms. The novelty of this framework is the collection and integration of community reports, remote sensing, and digital image analytics to detect and differentiate between regular algal blooms and harmful cyanobacterial blooms. CyanoTRACKER monitors social media, cloud satellite data and remote deployed hyperspectral sensors and integrates these data sources to identify potential HABs (Mishra et al., 2020). We highlight these emerging early warning techniques here so that states and utilities can monitor availability, reliability and are aware of future opportunities

B. Advanced Analytical Laboratory Methods

Considering the wide-ranging ramifications and impacts of cyanotoxins in drinking water supplies, it is critical that reliable analytical methods are employed in confirmation. While test strips provide an opportunity to identify a potential threat quickly and relatively inexpensively, laboratory methods should be relied upon for issuing a "Do Not Drink" order.

There are a variety of advanced laboratory methods available for cyanotoxin monitoring including variations of immunoassays and chromatography. The choice of methods depends on factors such as the specific cyanotoxins of interest, available resources (staff, equipment, and funding) and the necessary method detection and reporting limits for the toxins. It is recommended to consult with experts and regulatory agencies to identify the most suitable method for cyanotoxin monitoring in a particular situation.

<u>Chromatography and LC-MS/MS</u>

Liquid chromatography/tandem mass spectrometry (LC-MS/MS) is the laboratory gold standard for qualification and quantification of cyanotoxins. LC-MS/MS methods are useful for confirmation of toxins in both finished water and source water. EPA has approved methods for measuring specific cyanotoxins. EPA Method 544 quantifies nodularin and six microcystin congeners and can be used for both intracellular and extracellular toxins in source and finished water. Sample preparation involves filtering and retaining both filtrate and the filter followed by solid phase extraction. Reporting limits range from 2.9 to 22 ng/L.

EPA Method 545 measures cylindrospermopsin and anatoxin-a, and is applicable to finished water only with reporting limits from 18 to 63 ng/L. This method is limited to finished water because organic material in raw water interferes with the analysis.

<u>Chromatography: LC-MS/MS MMPB (2-methyl, 3-methoxy, 4-phenylbutyric acid)</u>

Analytical methods based on liquid chromatography-mass spectrometry (LC-MS/MS) are highly sensitive in detecting cyanotoxins and standard methods such as EPA 544 are used to detect up to 13 toxin congeners; unfortunately, more congeners[6] do exist and so these methods do not measure total microcystins in a sample. However, advanced methods for analyzing microcystins and nodularin in water samples have been developed. One of these methods uses a process called oxidative cleavage, which is a chemical process used to break down a specific amino

[6] Congener = different variations or forms of a particular chemical compound or substance.

acid present in microcystins and nodularin to create a new substance called MMPB (2-methyl, 3-methoxy, 4-phenylbutyric acid). Since MMPB is congener independent, this method provides a reliable estimation of total microcystins and nodularin in a water sample but does not separately quantify the congener toxins. The detection limit for total microcystins and nodularin analyzed with these MMPB methods is very low; the quantification limit is 0.05 ug/L (Foss and Aubel, 2015).

Immunoassays

Enzyme-linked immunosorbent assay (ELISA) is one of several methods available for cyanotoxin monitoring. Toxins in a sample are detected based on their interaction with specific antibodies. The toxin forms a complex with the antibody which is attached to an enzyme. A substrate is added which binds to the enzyme attached to the toxin-antibody complex. The binding of the enzyme and substrate results in a color change that can be measured using a spectrophotometer to quantify the color strength and calculate the concentration of toxins based on a calibration curve. ELISA methodologies include plate-based assays and test strip kits.

Depending on the assay mechanism, ELISA can be classified into four major types: direct, indirect, sandwich and competitive.

Direct ELISA

- Direct ELISA eliminates secondary antibody cross-reactivity but has lower sensitivity.

Indirect ELISA

- Indirect ELISA can be prone to cross-reactivity resulting in false positive measurements but has higher sensitivity for the specific toxins.

Sandwich ELISA

- Sandwich ELISA assays are the most sensitive among all the types but are more time-consuming and expensive.

Competitive ELISA

- Competitive ELISA, in turn, has low specificity but is easier to perform and can measure a wider range of toxins and results in low variability.

Cross reactivity is a challenge for several of the ELISA methods. It refers to the likelihood that a chemical not intended to bind and react with the ELISA antibody system actually binds to the antibody, producing a false positive reaction and reading.
Commercially available ELISA kits are available for many types of toxins. The most common method used in the laboratories is EPA Method 546 with reporting limits in the range of 0.05 – 0.15 ug/L. For reference, the EPA established 10-day health advisory levels for microcystins and cylindrospermopsin are 0.7 μg/L and 0.3 μg/L, respectively, for infants, and 3 μg/L and 1.6 μg/L, respectively, for adults.

Microarrays

Microarrays are the next generation HAB detection tools. They are and can be used for rapid detection of cyanotoxins such as microcystins and cylindrospermopsin. A specially designed cartridge contains printed microarrays (chemical channels) that can detect one or more toxins using fluorescence. A specialized detector instrument analyzes the sample and reports the toxins levels. This method can be used for both source water and finished water samples.

Commercial instruments are available but are a significant capital cost and require expensive supplies and trained staff.

<u>Genetic Monitoring</u>

Although presently not common, genetic techniques for the early identification of cyanobacteria and their ability to produce toxins are growing in availability and use. For example, the Ohio EPA is currently evaluating a series of genetic monitoring techniques coupled with more traditional monitoring tools (as described above). One of these methods includes detecting/identifying genetic sequences needed to produce the toxins. This is important because not all cyanobacteria species produce toxins and of those that are capable of producing toxins, not all individual cells have the necessary genes to do so. Other genetic tools can identify DNA material shed by cyanobacteria into the environment and can be used to signal the presence of harmful species and assess their diversity and abundance in an ecosystem.

The analytical tools that are available for cyanotoxin identification are rapidly evolving and improving. It is critical that staff involved in monitoring select the right tools for the sample matrix (i.e., raw or finished water). It is also important for utility staff and regulators to understand the details of the various toxin analytical methods - especially the reliability of analytical results in finished water. The detection of cyanotoxins in finished drinking water may trigger a “Do Not Drink” order which has public health, social, and economic ramifications. It is important that highly reliable analytical results are used to protect the consumers and public health of a community. Laboratories available to waterworks for cyanotoxin analysis are listed in **Table 7** below.

Table 7. Laboratories Available to Waterworks for Cyanotoxin Analysis

Laboratories Available to Waterworks for Cyanotoxin Analysis						
Laboratory Name	**Location**	**Type of Analysis**	**Cost of Samples**	**Days of the Week**	**Turnaround Time**	**Website/Contact**
BSA Environmental Services, Inc	23400 Mercantile Rd. Suite 8 Beachwood, OH 44122	ELISA method for Microcystins, Anatoxin-a, Cylindrospermopsin and Saxitoxin. LC-MS/MS for the same list plus euglenophycin.	Contact lab for pricing	Samples should be shipped to arrive on a weekday.	24-48 hours after receipt of samples	www.bsaenv.com (216) 765-0582
Green Water Laboratories	205 Zeagler Drive Suite 302 Palatka, FL 32177	ELISA, LC/MS/MS	Microcystins/Nodularin ELISA-ADDA ($100), LC-MS/MS ($250). Cylindrospermopsin ELISA ($125), LC-MS/MS ($150). Saxitoxins ELISA ($125), LC-MS/MS ($250). Anatoxin-a LC-MS/MS ($200). Four toxin bundle Microcystins (ELISA-ADDA), Cylindrospermopsin (LC-MS/MS), Saxitoxins (ELISA), Anatoxin-a (LC-MS/MS) $500	Samples accepted Tuesday - Friday. If samples are collected on a Friday, lab asks for them to be sent on a Monday for Tuesday delivery.	1-2 weeks	www.greenwaterlab.com (386) 328-0882
EnviroScience	5070 Stow Road Stow, OH 44224	ELISA method for Microcystin LR, Anatoxin-a, Cylindrospermopsin and Saxitoxin.	Microcystins $120, Anatoxin-a $150, Cylindrospermopsin $130), Saxitoxin $130	Lab operates seven days per week and receives samples daily.	2 business days	www.envirosciencinc.com/services/laboratory-analysis/harmful-algal-blooms (800) 940-4025
ESML Aquatic Microbiology Lab	200 Route 130 North, Cinnaminson, NJ 08077	Microcystin, Cylindrospermopsin and Saxitoxin.	$175 per sample - 1 week turnaround. $95 per sample - 2 week turnaround.	Samples should arrive on weekdays.	1 - 2 weeks	http://www.aquaticmicrobiologylab.com/index-3.html 1-800-220-3675
Northeast Ohio Regional Sewer District	4747 East 49th Street, Cuyahoga Heights, OH 44125	ELISA, LC/MS/MS	Microcystins ELISA ADDA ($100) & LC/MS/MS EPA method 544 ($300) and modified EPA method 544 ($100). Anatoxin-a and cylindrospermopsin LC/MS/MS method 545 ($125 each or $225 for both). Saxitoxin and cylindrospermopsin by ELISA ($75). qpCR 16S rDNA ($75-$150)	Samples accepted Monday - Friday. However, in case of an emergency, arrangements can be made for delivery on Saturday.	2 weeks	www.neorsd.org/about/emsc (216) 641-6000
Wayne State University	Lumigen Instrumentation Center, Chem 79, 5101 Cass Avenue, Detroit, MI 48202	ELISA, LC-MS/MS	ELISAs ($100), LC-MS/MS (Microcystins $250 per analyses; Anatoxin-a and Cylindrospermopsin $125). We have bulk pricing. For example, if you set up a monitoring program and we will be getting 10 samples per week for 10 weeks; we will set up a special rate.	Lab is open Monday-Friday. Special arrangements can be made for emergency shipping and analyses on weekends.	48 hours upon receipt of samples	www.lumigen.wayne.edu (313) 577-2579

Microbac Laboratories	One Allegheny Square, Suite 400, Pittsburgh, PA 15212 (Offices in Baltimore, MD and Richmond, VA)	ELISA, LC/MS/MS	Contact sales department for pricing (kate.gabriele@microbac.com)	Monday to Friday	7-10 business days	https://www.microbac.com/company-news-pages/lets-talk-about-algal-toxins Baltimore, MD: 410-633-1800 Richmond, VA: 804-353-1999
US EPA Region 8 Laboratory	Laboratory Biology Team 8 TMS-L, 16194 West 45th Drive, Golden, CO 80403	Cylindrospermopsin by ELISA and LC-MS/MS, Microcystin free or total by ELISA and field test strip kits, Microcystin -LR, -YR and -RR by LC-MS/MS, Anatoxin-a by RBA and LC-MS/MS, Phycocyanin by HPLC and YSI EXO2 and microscopic ID by taxonomy.	Limited number of samples at no cost.	Samples accepted Monday through Friday 8 AM to 4 PM. Samples received on Friday will not be analyzed until the following week.	Contact lab for turnaround time	https://www.epa.gov/aboutepa/about-region-8s-laboratory-services-and-applied-sciences-division r8eisc@epa.gov 303-462-9469
Lake Superior State University	School of Physical Sciences, CRW 353, 650 West Easterday Avenue, Sault Ste. Marie, MI 49783	Cylindrospermopsin, Microcystin, and Saxitoxin by ELISA, Anatoxin-a by RBA and LC-MS/MS we use EPA Methods 544 and 545 as a confirmation method (only).	ELISA for $100 per sample, RBA anatoxin-a $100/$150, LC-MS/MS $100 per sample.	Prefer if samples arrive Tuesday through Thursday. Can accept samples on Friday if pre-arrangements are made.	Contact lab for turnaround time	https://www.lssu.edu/environmental-analysis-laboratory/#tab-id-4 906-635-2076
Celina Utilities Water Department	Water Department 714 South Sugar Street Celina, Ohio 45822	Microcystin LR using ELISA	$125 per sample	Customers can ship samples any day of the week, but samples must be received by noon on Tuesday for Thursday analysis. Analysis is only done on Thursdays.	Results are typically available by Wednesday or Thursday for samples received by Tuesday	https://www.ci.celina.oh.us/city-government/utilities/ 440-324-7669
City of Elyria	Elyria Water Works, 3628 West Erie Avenue, Lorain, Ohio 44053	Microcystins using ELISA ADDA	Contact lab for pricing	Operating hours: Monday to Thursday. However, in the event of an emergency or with prior arrangement and notice, laboratory operations may extend beyond these standard hours.	Contact lab for turnaround time	https://www.cityofelyria.org/department/utilities/ 440-326-1570
Northeast Laboratories	30 Cold Spring Rd Rocky Hill, CT 06067	See next column.	Algae ID & Enumeration (Including Blue/Green Cyanobacteria and Expanded): Standard (7-10 business days) $140, 3-5 day $210, 1-2 day $280, same day $420. Algae ID & Enumeration (Blue/Green Cyanobacteria Only): Standard (7-10 business days) $100, 3-5 day $150, 1-2 day $200, same day $300. Microcystins by Abraxis 520022 (Non-Quantitative): Standard (7-10 business days) $70, 3-5 day $105, 1-2 day $140, same day $210.	Samples should arrive on weekdays.	Please note: 1-2 day and Same Day TAT need prior notice. Same Day must arrive before 12 PM	https://www.nelabsct.com/testing-services/additional-testing/algae/ 860-828-9787

Note: The list of laboratories provided above may not be comprehensive. VDH and Moonshot Missions do not endorse or recommend any laboratory. Waterworks should thoroughly evaluate and directly contact the laboratories they are interested in to ensure they meet their specific needs.

Table 8. List of Field Test Kits Available to Waterworks for Cyanotoxin Analysis

Manufacturer	Location	Type of Test Kit	Detection Limit*	Average Run Time	Type of Analysis	Typical Shelf Life	Website	Contact Information
Attogene	Austin, TX	Microcystin Lateral Flow Kit Catalog #: AU2024-02	0.1 µg/L	15 mins	Qualitative	6 months	https://www.attogene.com/shop/microcystin-test-kit-drinking-water/	Phone: 512-333-1330 Email: sales@attogene.com or info@attogene.com
		Microcystin ELISA Kit Catalog #: EL2024-02	0.1 µg/L	75 mins	Quantitative	6 months		
		Cylindrospermopsin ELISA Kit Catalog #: EL2047-02	0.1 µg/L	75 mins	Quantitative	6 months		
Beacon Analytical Systems	Saco, ME	Microcystin ELISA Plate Kit Catalog #: 20-0068	0.1 – 2 µg/L	60 mins	Quantitative	12 months from date of manufacture	https://www.beaconkits.com/about	Phone: 207-571-4302 Email: sales@beaconkits.com or info@beaconkits.com
		Microcystin ELISA N Plate Kit Catalog #: 20-0068-N	0.2 – 5 µg/L	60 mins	Quantitative			
		Microcystin Tube Kit Two options: Catalog#: 20-0098 (40 tube kit) Catalog #: 20-0100 (100 tube kit)	0.3 – 5 µg/L	40 mins	Quantitative	12 months from date of manufacture		
		Cylindrospermopsin Plate Kit Catalog # - 20-0149-N	0.05 – 2 µg/L	90 mins	Quantitative	12 months from date of manufacture		
		Cylindrospermopsin Tube Kit Two options: Catalog #: 20-0349 (40 tube kit) Catalog #: 20-0350 (100 tube)	0.3 – 1.5 µg/L	40 mins	Quantitative	12 months from date of manufacture		
		Saxitoxin Freshwater Plate Kit (only for the detection of saxitoxin in freshwater samples.) Catalog #: 20-0173-SW	0.02 – 0.32 µg/L	60 mins	Quantitative	12 months from date of manufacture		
Gold Standard Diagnostics (Formerly Eurofins Abraxis)	Warminster, PA	ABRAXIS Cylindrospermopsin ELISA Test	0.040 µg/L	105 mins	Qualitative and Quantitative detection	Lot dependent (typically >6 months)	https://www.goldstandarddiagnostics.us/home/products/rapid-test-kits/algal-toxins	Phone: 215-357-3911 Email: sales.abraxis@us.goldstanddiagnostics.com or
		ABRAXIS Microcystins (ADDA) (EPA ETV) (EPA Method 546), ELISA	0.10 µg/L	165 mins	Qualitative and Quantitative detection	Lot dependent (typically >6 months)		
		ABRAXIS Microcystins (ADDA) OH (EPA ETV) (EPA Method 546), includes LCRC, ELISA	0.10 µg/L	165 mins	Qualitative and Quantitative detection	Lot dependent (typically >6 months)		

		ABRAXIS Microcystins (ADDA) SAES, ELISA	0.016 µg/L	165 mins	Qualitative and Quantitative detection	Lot dependent (typically >6 months)		info.abraxis@us.goldstandarddiagnostics.com
		ABRAXIS Microcystins DM (EPA ETV) (CCL4), ELISA	0.10 µg/L	135 mins	Qualitative and Quantitative detection	Lot dependent (typically >6 months)		
		Microcystins PP2A (EPA ETV), Plate	1 µg/L	30-90 mins	Qualitative	Lot dependent (typically >6 months)		
		ABRAXIS Saxitoxins (PSP), ELISA	0.015 µg/L	75 mins	Qualitative and Quantitative detection	Lot dependent (typically >6 months)		
		ABRAXIS Anatoxin-a (VFDF) Dipstick (Source Drinking Water)	0 – 2.5 µg/L	30 mins	Qualitative	Lot dependent (typically >6 months)		
		ABRAXIS Cylindrospermopsin, with QuikLyse Feature, Dipstick (Source Drinking Water)	0 – 10 µg/L	45 mins	Qualitative	Lot dependent (typically >6 months)		
		ABRAXIS Microcystins, with QuikLyse Feature, Dipstick (Source Drinking Water)	0 – 5 µg/L	65 mins	Qualitative	Lot dependent (typically >6 months)		
		ABRAXIS Microcystins Dipstick (Finished Drinking Water)	0.3 – 3 µg/L 1 – 5 µg/L	30 mins	Qualitative	Lot dependent (typically >6 months)		
		ABRAXIS Saxitoxin (PSP), in Water and Shellfish, Dipstick	0.2 – 3.0 µg/L	30 mins	Qualitative/semi-quantitative	Lot dependent (typically >6 months)		
		ABRAXIS Microcystins, Coated Tube ELISA	0.09 µg/L	60 mins	Qualitative and Quantitative detection	Lot dependent (typically >6 months)		
HACH	Loveland, CO	LightDeck MINI Algal Toxin Analyzer Note: HACH is currently out of the analyzers but plans to restock them again soon.	Microcystins: 0.5 - 5 µg/L Cylindrospermopsin: 0.7 - 3 µg/L	10 mins	Quantitative	8 months (for cartridges)	Water Quality Testing and Analytical Instruments | Hach	Phone: 800-227-4224 Email: orders@hach.com

Note: The list of products provided above is intended to showcase the variety of field test kits available in the market for HAB toxin analysis. VDH and Moonshot Missions do not endorse or recommend any specific product or supplier. Waterworks should thoroughly evaluate products to ensure they meet their specific needs.

IV. Recommended Operational Strategies and Treatment Options

A. Prevention Strategies

Source Water Management for Cyanobacteria

A variety of lake and reservoir control options are available for the management of cyanobacteria. Unfortunately, the efficacy of these treatment opportunities tends to be limited if used in flowing waters such as rivers. In the case of rivers, some source control may be possible; however, plant treatment may be the best option in such water supplies.

The decision matrix below (**Figure 5**) describes source water management options for HABs and provides brief descriptions of the advantages and disadvantages of each method. It is followed by a summary table of source water control approaches for the management of cyanobacteria (**Table 9**). This information represents industry experience and utility implementation examples. In the section succeeding **Table 9**, a more in-depth exploration of each approach's nuances and practical implications follows.

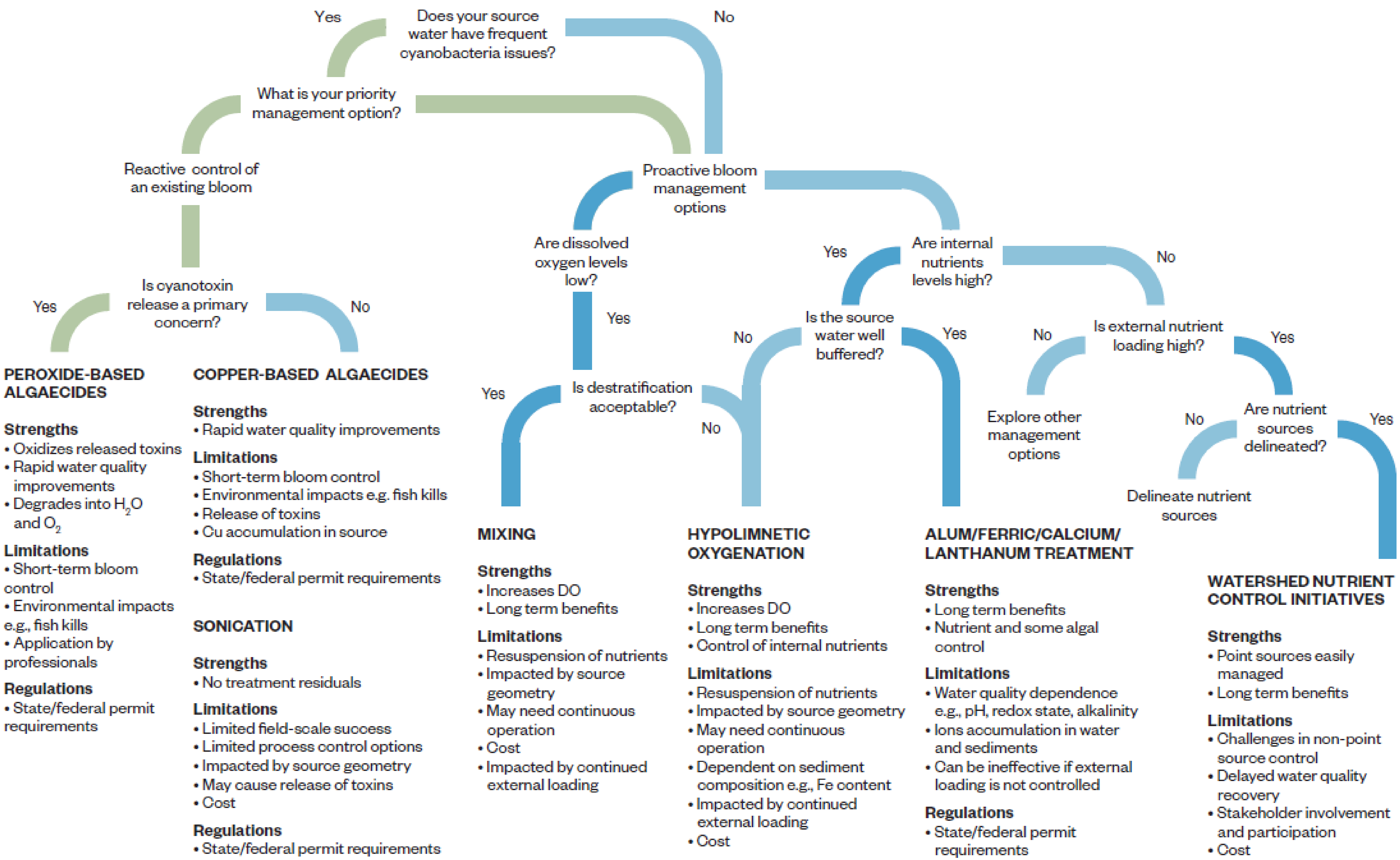


Figure 5. Decision Matrix for Source Control Approaches (WRF 4912).

Table 9. Summary Table of Source Water Control Strategies for HABs (WRF 4912)

Primary Considerations	ALGAECIDES		NUTRIENT SEQUESTRATION				Aeration	Sonication	Biological Control
	Hydrogen Peroxide	Copper sulfate	Polyaluminum Chloride	Aluminum Sulfate	Iron	Modified Clay			
Application									
Pelagic Zone (i.e., water column)	Applicable	Applicable	Applicable	Applicable		Applicable	Applicable	Applicable	Applicable
Benthic Zone (i.e., sediment surface)	Dependent on treatment method and type of chemical used	Dependent on treatment method and type of chemical used	Applicable	Applicable	Applicable	Not applicable	Not applicable	Applicable	Applicable
Benefits									
Proactive Strategy	Not applicable	Not applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Not applicable	Applicable
Reactive Strategy	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable
Nutrient Removal	Not applicable	Not applicable	Applicable	Applicable	Applicable	Applicable	Lowers release of reduced ions	Not applicable	Applicable for macrophytes
Duration of Treatment Effect	7-30 d	14-60 d	4-20 yrs.	4-20 yrs.	1 yr.	2-9 yrs.	Continuous: based on operational characteristics	Continuous: based on operational characteristics	Continuous: based on operational characteristics
Short-Term Response	80-99% reduction of cyanobacteria	>90% reduction of cyanobacteria	97% reduction in total P	30% reduction in internal P loading	Increased transparency; up to72% decline in chlorophyll-a;	<65% reduction in total P	Increased DO levels at 1 mg/L/wk. and reduced internal nutrient loading	30-90% reduction in cell counts	Increased water transparency; decreased chlorophyll-a and P
Long-Term Response	≥75% for up to 60 days	≥75% for up to 60 days	80-95% reduction in internal P loading	50-80% reduction in internal P loading	50-80% reduction in internal P loading	Up to 80% reduction in total P	Maintaining high DO levels for up to 23 yrs.	Limited field-application success	Improvement in water quality conditions
Limitations									
Treatment Residuals	None	Cu2+ residual in water column and sediments	Al3+ residual in sediments	Al3+ residual in sediments	Fe3+residual in water column and sediment	Release of trace metals, La3+ & NH4+ in water columns	None	None	None
Cell Lysis/Metabolite Release	Dose-dependent release. Oxidizes released toxins	Dose-Dependent	None	None		None	None	Can release toxins depending on operational characteristics	None
Background Interferences	None	pH sensitivity; sensitivity of cyanobacteria species to Cu; timing of treatment relative to growth stage	pH sensitivity; source water morphology and geometry; source mixing characteristics; continued external nutrient inputs	pH sensitivity; source water morphology and geometry; source mixing characteristics; continued external nutrient inputs	Redox sensitivity; continued external nutrient inputs;	pH sensitivity; source water morphology and geometry; source mixing characteristics; continued external nutrient inputs	Source water morphology and geometry; continued external nutrient inputs; sediment composition e.g., iron content of thesediment-water interphase	Source water morphology and geometry	Water quality conditions; % macrophyte cover; continued external nutrient inputs; time for community establishment at the source
Environmental Impacts	Occasional fish kills depending on treatment dosage	Occasional fish kills depending on treatment dosage	Minimal impacts on aquatic organisms	Minimal impacts on aquatic organisms	High levels of Fe can negatively impact aquatic organisms	Minimal impacts on aquatic organisms	May alter aquatic habitats due to impacts on hypolimnetic temperature;	Minimal effects on aquatic organisms	None
Acceptance Level									
Field Application History	5-15 years	>15 years	5-15 years	>15 years	>15 years	5-15 years	>15 years	5-15 years	5-15 years
Peer Reviewed Literature	3-10 papers	>10 Papers	3-10 papers	3-10 papers	3-10 papers	3-10 papers	>10 Papers	3-10 papers	3-10 papers
Ease of Implementation									
Permit Required (i.e., State-Dependent)	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Expertise and Training	Professionally applied	Professionally applied					No	No	No
Process Control (i.e., Dose, Residuals)	mg/L H_2O_2	mg/L Cu or Cu_2SO_4	mg/L Al or $Al_2Cl(OH)_5$	mg/L Al or $Al_2(SO_4)_3$	kg/ha	kg/ha	Mixing rate/ Intensity	Sonication frequency (kHz); May rely on the manufacturer to remotely adjust operational parameters	#of fish removed/ added; % macrophyte cover; g of straw/ m^3

Nutrient Control: External and Internal Sources

The most proactive and basic control strategy for cyanobacterial blooms is to control the nutrients needed for algal growth. Unfortunately, most water utilities do not have a great deal of jurisdictional control over their watersheds, thus limiting the opportunity to engage such controls. Nutrient contributions primarily originate from external sources such as wastewater treatment facilities, agricultural and urban runoff, and atmospheric deposition. External nutrient reduction likely requires management of entire watersheds including regional and national efforts (i.e., Chesapeake Bay). Control of point and non-point sources depend upon:

(1) the identification of waterbody impairment,
(2) the implementation of discharge limits for point sources and
(3) best management practice adoption for non-point nutrient sources.

The institution of such control is the purview of regulatory agencies and once implemented takes years, if not decades to yield positive results. Nonetheless, it is still recommended that external nutrient source control always be considered for HAB management.

An often-overlooked nutrient source is the opportunity for internal nutrient cycling. Sediments act as natural sinks for nutrients, especially phosphorus and even when external nutrient sources are eliminated, sediments can release legacy phosphorus accumulated over time from the previous external inputs (Sondergaard et. al., 2003).

In addition, most species of cyanobacteria are capable of fixing nitrogen from the atmosphere; this provides them with a significant ecological advantage over other preferred algal species. Dying algal cells also serve as an internal nutrient source as they sink to the sediments, releasing organic carbon and nutrients bound in the cells. These legacy sources of nutrients can frustrate the progress external nutrient control programs make and should be understood to create the best control plans for particular water resources.

Chemical coagulants and flocculants can be used to precipitate or bind excess phosphorus in a water body; this approach is generally more appropriate for lakes and reservoirs and typically not used in flowing streams. Alum, iron, calcium carbonate and bentonite clay have high affinities for phosphate, creating floc that settles down to the sediments. Unfortunately, these treatments are not permanent, and their effectiveness is moderated by time and continued external inputs. For example, alum sequestration is generally effective for 5 to 7 years after which release, and resuspension of phosphorus is possible.

Algaecides

Algaecides can provide both proactive and reactive control, depending upon the chemicals used and the timing of application. The most common algaecides used for HABs are copper based (typically copper sulfate) and hydrogen peroxide. Copper algaecides have a long history of use but may be curtailed in many states because of the sensitivity of invertebrates to copper. Additionally, residual copper may accumulate in sediment possibly creating future water quality challenges. Advantages of copper-based algaecides are cost, availability, and ease of use. Copper products (liquid or crystal) are relatively easy to apply from a boat or shoreline and comparatively less costly than hydrogen peroxide.

Hydrogen peroxide is a recent addition to the arsenal of control for cyanobacteria. This control option is ecologically friendly as it has limited adverse effects on other organisms and does not accumulate in sediments. There are two types of commercially available peroxides used to treat HABs: solid granular (sodium carbonate peroxyhydrate) and liquid (usually a mixture of hydrogen peroxide and peroxyacetic acid). When hydrogen peroxide in either form is added to water, it reacts with UV radiation to produce hydroxyl radicals. These radicals damage cyanobacteria by attacking cellular integrity and impairing their ability to photosynthesize. At appropriate doses, hydrogen peroxide is selective to cyanobacteria and does not typically harm other preferred phytoplankton species. It also degrades rapidly into water and oxygen and is devoid of persistent potent byproducts. A US ACOE case study and review of peroxide control for HABs is now available (Field Demonstration of a Peroxide Based Algaecide for Harmful Algal Bloom Control in Lake Okeechobee (2023) and provides detailed information about peroxide effectiveness and applications - http://dx.doi.org/10.21079/11681/47624).

The timing of algaecide applications can be proactive or reactive. Proactive control is possible if the chemical application is performed at early population growth stages and then repeated periodically before cell numbers dramatically increase. This requires close monitoring of the water body and quick reactions. If HAB density is high, then control tends to be more reactive and generally less effective. At high population densities, algaecides can lyse large numbers of cells, releasing large amounts of cyanotoxins which then must be treated by the water treatment plant. Resources are available that describe in detail the best monitoring and application of algaecides; an excellent overview is provided by the Interstate Technology and Regulatory Council (https://itrcweb.org).

The use of algaecides in a flowing stream can be challenging. To be effective, algaecides need to have minimum contact time with the cyanobacteria bloom which may be difficult to ascertain in a river or fast-moving stream. Their use can be effective if the HABs are located nearshore or in eddies and pools where the algaecide application can be focused.

Mechanical Controls

Mechanical controls tend to be used for the midterm control of cyanobacteria in a water source as they usually require significant planning and engineering. Examples of mechanical controls include sonication, sediment dredging (to remove sequestered nutrients), and mixing for destratification and aeration. Mechanical controls tend to be more suited for quiescent water bodies rather than flowing streams.

Sonication uses high frequency soundwaves to disrupt the gas vacuoles that cyanobacteria use to maintain buoyance and move vertically through the water column. Documentation of successful implementation is inconsistent; it appears to be more applicable in engineered reservoirs and may be dependent upon specific site characteristics. There are also questions about harmful effects on other aquatic life as anecdotal reports of zooplankton population collapse have been noted.

Dredging involves the removal of sediment from the bottom of the water body; it usually requires permits and the identification of suitable sites for the deposit of the dredged material. While in progress, it can also disrupt uses of the resources including recreation, fisheries, and water supply. It should be evaluated as part of a long-term nutrient control plan for a watershed and is not considered practical for control of an impending bloom.

Destratification through artificial mixing generally works to prevent the establishment of a thermocline and related subsequent anerobic conditions at the water sediment interface thus inhibiting the release of dissolved manganese, iron and phosphorous from the sediment.

Aeration is employed for similar reasons; the increase in dissolved oxygen throughout the water column decreases the release of metals and nutrients from the sediment. As in the case of dredging, these approaches alone are not very practical for control of an impending bloom and require planning and engineering to address permitting and construction needs. As noted above, these tools are generally more applicable to lakes and reservoirs as opposed to rivers. Unless a river has extensive reaches of slow-moving water and quiescent pools, dissolved oxygen levels usually are sufficient to prevent release of metals and nutrients from sediment and rarely have established thermoclines (Wetzel, 2001).

Biological Control and Manipulation

As with mechanical controls, biomanipulation is best considered a longer-term management approach for the control of HABs. Biomanipulation is predicated on the understanding that HABs tend to occur in disrupted and unbalanced ecosystems. Under healthy ecosystem conditions, cyanobacteria are a normal component of species diversity. It is under degraded conditions that their population numbers increase, and they pose problems. Biological control methods focus on restoring ecosystem balance resulting in more natural conditions in a water body and control of HABs. Essential to the success of a biological control approach is the control of external nutrients into the water body. Ecosystem balance is then achieved through restoration of shoreline macrophytes, food chain components and predator and prey relationships. Biomanipulation may be effective tools for controlling HABs in flowing streams if shoreline and quiescent hot spots of cyanobacteria are targeted for ecosystem improvements (Triest, Stiers, & Van Onsem, 2016).

B. Treatment Options

As treatment for HABs may be needed only intermittently for seasonal control, utilities should consider treatment approaches that best fit their risk and budget concerns. As such, it is important that waterworks first prioritize the optimization of their existing treatment processes to treat HABs. Waterworks should begin by evaluating and adjusting their existing operations to ensure they are well-equipped to address the unique challenges associated with the removal of cyanotoxins.

If treatment adjustments are not sufficient to address HABs, then waterworks can explore additional treatment options.

Water Treatment Processes for Cyanobacteria and Cyanotoxin Removal

The treatment of cyanobacteria and their toxins in a water treatment facility poses several challenges including identifying what species and toxins are involved and whether the toxins are contained within the cells of the algae (intracellular) or dissolved in the water (extracellular). Intracellular toxins can be managed by the removal of the algal cells, but care must be taken to not disrupt the cells during treatment (either by mechanical means or cell membrane oxidation). Some utilities report success in using small doses of pretreatment oxidation (potassium permanganate or chlorine) where the algal cells are not lysed, remain intact and do not release the toxins.

Algal Cells and Intracellular Toxin Removal

Conventional coagulation is effective for the removal of intracellular toxins and generally is more cost effective than wholesale toxin inactivation and degradation by chemical oxidation alone. If available, dissolved air flotation is very effective for the removal of cyanobacterial cells with minimal cellular damage and associated toxin release. In addition, if intact cells are removed via coagulation and sedimentation, water plant staff should examine the cyanotoxin levels in any sludge decant water and water released from sludge dewatering processes and decide if the sludge water should be recycled in the plant or directed elsewhere (such as to the sanitary sewer) as it likely contains dissolved cyanotoxins released from the mechanically disrupted algal cells.

Extracellular Cyanotoxin Removal and Inactivation

There are two general approaches that can be used to manage extracellular cyanotoxins in water: physical removal and oxidation/inactivation. Oxidation processes can be used to degrade or detoxify cyanotoxins thus reducing harmful effects. Oxidation methods that have been demonstrated to address cyanotoxins include chemical oxidation, advanced oxidation processes (AOP), and biological oxidation.

Chemical Oxidation

Chemical oxidation is the most common in-plant technique used. It involves the application of an oxidant such as chlorine, ozone, or hydrogen peroxide. The oxidant reacts with the toxins and breaks them down to less harmful compounds. It is critical to use the appropriate oxidant for specific toxins (see **Table 10**) and understand the ambient water quality conditions. For example, pH strongly influences the efficacy of chlorine oxidation of some cyanotoxins.

Table 10. Removal by Oxidation (Wert et al. 2019)

Oxidant	Microcystins	Microcystin-LA	Cylindro-spermospsin	Anatoxin A	Saxitoxins	GTX2, GTX3 and C1,C2	Nodularins	MIB and geosmin	BMAA
Free chlorine	pH		pH	Slow/no oxidation			pH		pH
Monochloramine	Slow/no oxidation					?			?
Chlorine dioxide	Slow/no oxidation					?			?
Permanganate						?	?	?	Slow
Ozone			pH	pH				(HO* only)	pH
Hydroxyl radical					?				pH
UV	High doses	High doses	High doses	High doses	?	?	?	High doses	High doses

Optimal   Moderate   Ineffective   ? No data or insufficient data

Chlorine Oxidation

Fortunately, chlorination is a robust mechanism for the inactivation of many cyanotoxins (an exception is anatoxin-a) when applied at pH levels less than 8.0 S.U. Chloramines do not degrade or remove cyanotoxins; however, if the pH, free chlorine contact time and dose is sufficient prior to ammonia addition, oxidation of target cyanotoxins is possible.

The following tables were developed by the USEPA using the AWWA CyanoTox calculator and provide estimated free chlorine oxidation of microcystins and cylindrospermopsin (EPA, 2016). These are only examples; results will vary for different source waters and competing oxidant demands.

Table 11. Microcystin – LR CT Table (Final target concentration of 0.3 ug/L)

pH	MC-LR conc [µg/L]	Effective CT (mg/L * min)				
		10°C	15°C	20°C	25°C	30°C
6	10	48.8	42.2	36.6	32.0	28.1
	25	61.5	53.2	46.2	40.4	35.4
	50	71.2	61.5	53.5	46.7	41.0
	100	80.8	69.9	60.7	53.0	46.5
7	10	56.9	50.1	44.3	39.5	35.5
	25	71.8	63.1	55.9	49.8	44.7
	50	83.1	73.0	64.7	57.6	51.7
	100	94.3	82.9	73.4	65.5	58.8
8	10	129.8	119.7	111.2	103.9	97.6
	25	163.7	151.0	140.2	131.0	123.1
	50	189.3	174.7	162.2	151.6	142.4
	100	215.0	198.3	184.2	172.1	161.7
9	10	466.6	421.7	382.0	346.8	315.3
	25	588.5	531.9	481.9	437.4	397.7
	50	680.7	615.3	557.4	505.9	460.0
	100	772.9	698.7	632.9	574.5	522.3

Table 12. Cylindrospermopsin CT Table (Final target concentration of 0.7 ug/L)

pH	CYL conc [µg/L]	Effective CT (mg/L * min)				
		10°C	15°C	20°C	25°C	30°C
6	10	10.3	8.1	6.5	5.2	4.2
	25	13.9	10.9	8.7	7.0	5.6
	50	16.6	13.0	10.4	8.3	6.7
	100	19.3	15.2	12.0	9.7	7.8
7	10	4.1	3.3	2.6	2.2	1.8
	25	5.5	4.4	3.6	2.9	2.4
	50	6.5	5.2	4.2	3.5	2.9
	100	7.6	6.1	4.9	4.0	3.3
8	10	8.1	6.9	5.9	5.2	4.5
	25	10.8	9.2	8.0	6.9	6.1
	50	12.9	11.0	9.5	8.3	7.3
	100	15.0	12.8	11.0	9.6	8.5
9	10	55.2	48.5	43.1	38.6	34.8
	25	74.2	65.3	57.9	51.9	46.8
	50	88.6	77.9	69.2	61.9	55.9
	100	102.9	90.6	80.4	72.0	64.9

Permanganate Oxidation

Potassium permanganate is effective for the oxidation of anatoxins and microcystins but not effective for saxitoxin and cylindrospermopsin. Studies have shown that doses of approximately 1 mg/L may result in significant oxidation of microcystins (Walker, 2015) while doses of 3 mg/L show highly variable results; results appear to be related to potential cell lysis (Ou, 2012). While Some utilities use potassium permanganate for dissolved metal control in raw water so the calculation of doses to address cyanotoxin oxidation should consider that additional oxidative demand of the metals.

Chlorine Dioxide Oxidation

At the levels typically used in drinking water treatment, chlorine dioxide is not particularly effective at managing dissolved cyanotoxins. Some utilities have anecdotally reported using chlorine dioxide as a pre-oxidant but no data on effectiveness is available.

Ozone Treatment

Research has shown that ozone is very effective for the oxidation of a range of cyanotoxins including microcystins, anatoxin-a, saxitoxin and cylindrospermopsin. Specific CT values for ozone are very dependent upon pH, temperature, and the concentration of natural organic matter in the ambient water. As the effectiveness of ozone is highly dependent on these water quality parameters and will vary by the specific cyanotoxin, it is highly recommended that a predictive tool such as CyanoTox be used to establish operating parameters regarding the use of ozone for addressing cyanotoxins at a water treatment facility. In addition, the use of ozone may be curtailed by the formation of bromate, a regulated disinfection byproduct.

Ultraviolet (UV) Treatment

UV radiation alone can degrade toxins; however, the doses required are very high, much higher than what is typically used for water treatment disinfection. UV is more effective when used in conjunction with other oxidants and is discussed in the following section.

Advanced Oxidation Processes

Advanced oxidation processes (AOPs) involve the use of highly reactive oxidants such hydroxyl radicals and includes ozonation at very high pH, ozone combined with hydrogen peroxide, ferrous iron combined with hydrogen peroxide or ultraviolet irradiation combined with hydrogen peroxide. Hydroxyl radicals can also be generated by combining an oxidant with an energy source (e.g., UV light). Examples of AOPs include UV/H202, O3/H2O2 and UV/CL2. AOPs have been demonstrated to effectively degrade a wide range of contaminants including cyanotoxins (AWWA, 2010). Specific conditions for cyanotoxin oxidation vary widely by specific AOP selection, toxins, pH, temperature, and other water quality parameters.

Cyanotoxin Removal Processes

The removal of cyanotoxins can be accomplished using adsorption or membrane treatment. Activated carbon is used to adsorb organic contaminants and can be very effective for cyanotoxin treatment. Activated carbon includes powdered activated carbon (PAC), granular activate carbon (GAC) and biological active carbon (BAC). The removal mechanism for PAC and GAC is adsorption and most products available are generally effective for the removal of microcystins, anatoxin-a, saxitoxins, and cylindrospermopsin. Industry experience has shown that the adsorption characteristics vary by carbon type, manufacturer, and ambient water quality characteristics. Each application is unique and so particular products should be tested to determine the appropriateness and effectiveness for a given situation.

PAC is typically applied at the rapid mix basin as a slurry and is removed in sedimentation. Because the toxins can then be concentrated in sludge, care should be taken concerning recycling sludge decant back to the water treatment process as well as the final deposition of dewatered sludge. This is likely a viable treatment approach for surface water treatment plants with the capacity to add PAC.

GAC is typically used in pressure vessels or contactors. The adsorptive capacity of the carbon should be tracked by monitoring for toxin breakthrough. Although not reported often, desorption of adsorbed toxins is possible under changing ambient water quality conditions, so it is prudent to periodically monitor GAC treatment effluent for cyanotoxins. This is a potentially viable treatment approach for surface water treatment plants with existing GAC contactors.

Studies have demonstrated that biodegradation of a variety of cyanotoxins, including microcystins, nodularin, cylindrospermopsin, and anatoxin-a can occur in some situations. This is dependent on water quality parameters such as temperature, the abundance of bacteria capable of degrading the cyanotoxins present, the concentration of the target cyanotoxins, the presence of organic matter in the source water, and the presence of metals in the source water. Studies have also shown that the biodegradation products of saxitoxin may result in more toxic forms (Ho et al., 2012). The removal of cyanotoxins by biologically active carbon can involve two processes – adsorption and bio-oxidation. If the carbon used in the biological filters is activated, then adsorption of cyanotoxins can occur. Biological oxidation via biofiltration has been demonstrated to degrade cyanotoxins. Some microorganisms possess enzymes that can degrade toxins. Reported results vary in effectiveness but if used in concert with other treatment processes, it may provide additional control in a multibarrier treatment scheme. This is a potentially viable treatment approach for surface water treatment plants using ozone oxidation followed by biologically active filters.

Membrane Treatment

Membrane treatment processes including microfiltration, ultrafiltration, nanofiltration and reverse osmosis effectively remove cyanotoxins through exclusion. The rejection efficacy of a membrane type is dependent upon the molecular configuration of the specific toxins. As membrane treatment creates a concentrate stream which could contain high levels of cyanotoxins, consideration of disposal options is important.

Microfiltration membranes typically have larger pore sizes and primarily are used to remove suspended particles including cyanobacterial cells. While MF may remove some larger molecular weight cyanotoxins, it is not effective for most toxin types and varieties. Ultrafiltration (UF) membranes have smaller pore sizes than MF membranes which allows them to remove smaller particles. As in MF membranes, the removal effectiveness will be dependent upon the particular molecular configuration of the targeted toxins.

Nanofiltration membranes have even smaller pore sizes than MF and UF membranes, allowing for the removal of both suspended particles and some dissolved substances (e.g., calcium and magnesium ions). Many cyanotoxins may be removed by nanofiltration membranes. Reverse osmosis membranes have the smallest pore sizes and effectively remove almost all particles, colloidal substances, dissolved substances (e.g., sodium and chloride ions). Membrane treatment of cyanobacteria and cyanotoxins is a costly investment in terms of both capital and operations as the most effective membranes (RO) are energy intensive.

There are a variety of treatment processes (**Table 13**) that can be used to treat cyanobacteria and cyanotoxins in drinking water. It is important to take into account factors such as toxin type, concentration, ambient water quality characteristics and target levels of removal/degradation. Treatment approaches need to be tailored for the specific circumstances considering the water source and the treatment processes available to the facility. In addition, regulatory requirements and safety considerations must be kept in mind when using oxidation processes for cyanotoxin control.

Table 13. Cyanotoxin removal by physical chemical processes (Stanford et.al. 2016)

	Physicochemical Processes										
	Sedimentation		Filtration				Membranes			Sorption	
	Coag/Floc/ Sed	Coag/ DAF	Direct filtration w/ coag	Direct filtration w/o coag	Bank filtration	Biofiltration	RO	NF	MF	PAC	GAC
Cyanobacteria Cell Removal	~ 90%	50 - 100%	Likely	Possible	Likely	Likely	Effective	>97%	>97%	No	Likely
Microcystin	Not Expected	Not Expected	Not Expected	Not Expected	Possible	Likely	Effective	Likely	No	Varied	Likely*
Cylindrospermopsin	Not Expected	Not Expected	Not Expected	Not Expected	Possible	Likely	Likely	Likely	No	Varied	Likely*
Anatoxin A	Not Expected	Not Expected	Not Expected	Not Expected	Possible	Possible	Likely	Likely	No	Varied	Likely*
Saxitoxin	Not Expected	Not Expected	Not Expected	Not Expected	Possible	N/A	Likely	Likely	No	Varied	Likely*
MIB and geosmin	Not Expected	Not Expected	Not Expected	Not Expected	Possible	Likely	Effective	Likely	No	Varied	Likely*

*Compound is well removed until carbon capacity is exhausted

V. Guidance for Planning for Emergencies

A. Developing an Emergency Response Plan for HAB Events

America's Water Infrastructure Act of 2018 (AWIA) Section 2013(b) requires that community water systems serving populations greater than 3,300 complete an Emergency Response Plan that incorporates findings of the risk and resilience assessment conducted under AWIA Section 2013(a) and meets the criteria outlined under AWIA Section 2013(b). A HAB response plan could be part of the Waterworks' overall ERP. This ensures waterworks professionals are prepared and have efficient coordination during emergency situations.

At a minimum, an emergency response plan:

- Describes the strategies, resources, and procedures the waterworks will use to prepare for and respond to an incident, and
- Includes information about entities that must be notified including regulators, public health officials and the public.

For HABs, waterworks can incorporate HABs into their existing emergency response plan or create a separate plan tailored to the specific challenges posed by HABs.

Medium and large waterworks can utilize the Cyanotoxin Management Plan Template provided by the EPA (https://www.epa.gov/sites/default/files/2018-11/documents/cyanotoxins_management_plan_template_and_example_plans.pdf). For small waterworks, a shorter template that can serve as a starting point and can be customized to suit the unique needs of the waterworks is enclosed in **Appendix A**.

B. Communication and coordination with stakeholders during emergencies

Effectively responding to a HAB emergency requires coordinating with the right stakeholders (regulators, customers, media, etc.) and having an effective communication plan. Waterworks should establish clear strategies for engaging and informing internal teams and external stakeholders of HAB related emergencies ahead of time. Things to consider include:

- Clearly define roles and responsibilities of staff including defining primary and backup communication leads.
- Stakeholder Identification
- Determine Communication Channels
- Detailed procedures for notifications including developing templates and standardized messaging to maintain clarity.

C. Establishing Effective Communication Strategies

Internal Communications Plan

Identifying communications stakeholders, both internal and external, prior to an event will save you time and effort once the emergency begins. Identifying external stakeholders will help inform who key internal communications stakeholders may be. These could include the town manager and leadership team, communications staff, and public-facing employees such as water customer service, the town switchboard, and possibly police and fire dispatchers.

Establish or follow existing protocol for informing key internal stakeholders. The federal Incident Command System or your existing Emergency Response Plan are two common starting points for guidance. Disseminating accurate and timely information to this group will assist in getting the message out and speaking a consistent message. It may be useful to emphasize that by speaking with one voice, this stakeholder group can help amplify the message and avoid confusion. After first contact with this group, send the harmful algal bloom fact sheet as a refresher.

Establish or follow existing protocol for updating key internal stakeholders as well. The rule of thumb among communications professionals is updates early and often. It can be part of your protocol to create a regular check-in during the event at a pace that makes sense for the phase of the event.

Provide fact sheets to all public-facing staff. The public may use several different avenues to try to gather information. Be sure to include such staff as water customer service, town manager's office, town switchboard and police/fire non-emergency dispatch, in addition to Councilmembers. Note that some of these staff, such as emergency dispatchers, may work for another agency such as the County. Coordinate with that agency prior to an event to streamline the process.

Checklist of Toolkit To-Do's:

- ❑ Identify internal and external communications stakeholders
- ❑ Create list of all public-facing staff who will receive fact sheet
- ❑ Create and follow protocol for informing internal key decision makers
- ❑ Schedule regular check-in meetings during the event
- ❑ Include fact sheet with first communication as refresher
- ❑ Provide fact sheets to all public-facing staff

External Communications Plan

Experience has taught that it is helpful to develop messages before you need them as it saves time and allows staff to think through what they want to convey. **Appendix C** includes a number of templates that can be adapted to your specific community. These templates cover the different phases of a HABs event, including a public service announcement, notification of a potential event (alert), notification of a warning, an ongoing event, and an event concluding.

The focus of your messages should be who, what, when, where, why, how, as follows:

- Who: Who is affected by the event, likely the customers of the water utility, which may or may not overlap with the town boundaries;
- What: What is happening, either an advisory or warning for a HABs event, or a "Do Not Drink" order, along with "What does it mean for me?" which can also translate to How (see below);
- When: When is it happening, what is the potential length of the event;
- Where: What locations are affected;
- Why: What is a HABs event in terms of health effects and why is avoiding contact with the toxin so important; and
- How: How do we respond, such as what does the water utility or the community have to do differently to respond to the event.

Pay particular attention to the "what does it mean for me" and "what do I have to do differently?" as those will be key points to community members. In the event of a "Do Not Drink" order, there will likely be concerns that need to be addressed thoroughly. The templates in the Appendix has different emphasis in the messages depending on the phase of the HABs event.

Your Communications Plan should also address who will be responsible for releasing the information and for responding to inquiries, both media and public, as these may be different staff. Staff should also be responsible for monitoring any social media for issues that would need a response.

It is also beneficial to collect the contact information for all the media which you wish to include on your distribution list ahead of a possible HABs event. This should include print, television, radio and any other outlet that the community frequently uses.

The Communications Plan should include developing, ahead of time, answers to anticipated Frequently Asked Questions (see Template in **Appendix C**). These questions should be framed from the perspective of community member's and are along the lines of "What does this mean for me?" Some sample questions include:

- Why can't I drink the water?
- Will boiling the water make it safe?
- Will the water be safe when the bloom has passed?
- What has Town done to proactively address this?
- How does this affect vulnerable populations?
- Why doesn't our neighboring town have these restrictions?

Social media and the Town's website can provide a more direct channel to addressing the community's questions and potential concerns. Explore whether the Town's website has the ability to post an alert banner on the front page and coordinate with the staff in charge of website functionality to understand timelines and procedures for posting.

Understand what social media presence the Town currently has and what it would utilize in other types of emergencies. Discuss with town leadership the benefits of utilizing social media, which include getting ahead of rumors. Once rumors regarding water quality and safety take hold, they are hard to combat in a reactive mode. The town staff will need to come to agreement about developing and approving what is posted, who is doing the posting and what the lead time is for going live with a post.

With a social media presence, the procedure when it comes time to broadcast the news of an alert or warning will be two-fold. After distributing the official press release to the media and posting it on the Town website, post the release to social media and pin it, then immediately post the FAQ you've developed and pin them as well. This will help community members find the information right away.

If your Town has to take the step of issuing a "Do Not Drink" order and the town or county has a Reverse 911 Calling System available, you should prepare to utilize this as well. Again, understand the procedure and timeline for activating. Write a script ahead of time and test the system reading it to make sure it is clear and concise and flows. If it is an automated voice, you may need to add additional pauses to make it more understandable.

Once the information is posted on social media, follow up will be needed as well. Ideally, a communications person would be assigned to address rumors on social media. Updates should be posted frequently and once the bloom has passed, a final update should be posted and the pins on the original alert and FAQ removed.

Checklist of Toolkit To-Do's:

- ☐ Assign staff roles
- ☐ Develop media distribution list
- ☐ Finalize templates and messaging for different phases of an event (for each media in appropriate format)
- ☐ Develop Frequently Asked Questions and answers
- ☐ Include procedure for posting to Town's website
- ☐ Document existing social media presence and codify procedure for posting.
- ☐ Add website and social media posting to roll-out procedure

- ❑ In the event of a "Do Not Drink" order, prepare to utilize a Reverse 911 Call System by understanding procedure, writing a script, and including in roll-out.
- ❑ Plan to post updates on social media as the incident evolves.

VI. Available Funding Sources

Managing HABs in source waters can increase drinking water treatment, management, and operational costs. The section below identifies available funding options for preventing and managing HABs in drinking water. These include grants and loans for source water protection, monitoring and treatment installation or adjustment.

A. Funding for Source Water Protection

VDH - SOURCE WATER PROTECTION PLAN DEVELOPMENT & IMPLEMENTATION ASSISTANCE

Funder: VDH's Office of Drinking Water (ODW) can assist waterworks serving total populations less than or equal to 50,000 with developing and implementing a Source Water Protection Plan through private consultants contracted by ODW to provide assistance.

Eligibility:
1. Community waterworks
2. Serving total populations less than or equal to 50,000
3. Waterworks processing water directly from a drinking water supply source

Eligible Projects: Develop and implement a Source Water Protection Plan. A Source Water Protection Plan identifies activities needed to mitigate existing and future threats to source water quality. Funding can also be used for the implementation of certain protection measures.

Funding Limit: $100,000

Cost to Waterworks: Assistance provided at no cost to eligible waterworks

Timeframe: Applications accepted year-round, typically with a May deadline.

Type: Non-construction

Website: https://www.vdh.virginia.gov/drinking-water/source-water-programs/source-water-protection-assistance-funding-opportunities/

Inquiries: Email the Source Water Program at sourcewater@vdh.virginia.gov

VRWA - SOURCE WATER PROTECTION PLAN DEVELOPMENT ASSISTANCE (for small waterworks)

Funder: The Virginia Rural Water Association (VRWA) can assist eligible waterworks with developing Source Water Protection Plans.

Eligibility:

1. Waterworks is a member of the Virginia Rural Water Association; and
2. Waterworks serves less than 10,000 people.

Eligible Projects: Develop and implement a Source Water Protection Plan. A Source Water Protection Plan identifies activities needed to mitigate existing and future threats to source water quality.

Funding Limit: N/A

Cost to Waterworks: No cost for eligible waterworks

Timeframe: Assistance provided year-round

Type: Non-construction

Website: https://www.vdh.virginia.gov/drinking-water/source-water-programs/source-water-protection-assistance-funding-opportunities/

Inquiries: https://www.vrwa.org/AboutUs/Services/SourceWaterProtection.aspx, or Contact VRWA at 540-261-7178.

VDEQ - NONPOINT SOURCE MANAGEMENT IMPLEMENTATION 319(h) PROGRAM

Funder: EPA – Clean Water Act Section 319 (h). Managed by the Virginia Department of Environmental Quality (DEQ), Office of Watershed and Local Government Assistance Programs

Eligibility: Local governments (including counties, cities, and towns), county health departments, Soil and Water Conservation Districts (SWCDs), Virginia institutes of higher education (universities, colleges, etc.), planning district commissions, regional commissions, nonprofit environmental organizations, and agencies/departments of the Commonwealth of Virginia.

Eligible Projects: Watershed projects, watershed roundtable activities, implementing TMDL Implementation Plans, demonstration and educational programs, and nonpoint source pollution control activities.

Funding Limit: $75,000-$300,000

Cost to Waterworks: Match may be required

Timeframe: Applications typically due in August

Type: Non-construction

Website: https://www.deq.virginia.gov/our-programs/water/water-quality/nonpoint-source-management/funding-grant-and-project-resources

Inquiries: Email npsgrants@deq.virginia.gov

B. Funding to Add New Equipment and Upgrade Existing Technologies

Under the Virginia Drinking Water State Revolving Fund (DWSRF) Program, waterworks are eligible to receive loans/grants to add new equipment and upgrade existing technologies and to receive planning and design assistance.

VDH FINANCIAL & CONSTRUCTION ASSISTANCE PROGRAMS (FCAP) - PLANNING AND DESIGN FUND

Funder: Managed by the VDH's Office of Drinking Water

Eligibility:

1. Community and nonprofit, non-transient non-community waterworks serving 10,000 or fewer people.
2. However, community and nonprofit NTNC waterworks serving more than 10,000 people may be eligible if the project design benefits a limited, discrete part of the waterworks that serves 10,000 or fewer people.
3. Note: Waterworks owned by federal, state, or tribal governments, or suspended or debarred owners are **not** eligible.
4. Funds are especially for small, disadvantaged community waterworks.

Eligible projects: Projects addressing health-based issues and non-compliance are given priority. Examples of funded project categories include engineering reports, design and specifications, source evaluation, pilot well drilling and testing, pilot studies for treatment compliance, and distribution system evaluations.

Funding Limit: Up to $45,000 per project, with a maximum of 2 grants per eligible waterworks per funding year.

Cost to Waterworks: No cost to eligible waterworks. As needed, grants may be contingent upon adjusting water rates and/or requiring savings for financial reserves.

Timeframe: Applications accepted year-round

Type: Non-construction

Website: https://www.vdh.virginia.gov/drinking-water/capacity-development/planning-and-design-fund/

Inquiries: Email DWSRF.applications@vdh.virginia.gov or contact the appropriate VDH ODW Field Office - https://www.vdh.virginia.gov/content/uploads/sites/14/2020/03/Field_Office_Alert_Information_Upated.pdf

VDH FINANCIAL & CONSTRUCTION ASSISTANCE PROGRAMS (FCAP) - CONSTRUCTION FUNDS

Funder: Managed by the VDH's Office of Drinking Water

Eligibility: Any size community waterworks or nonprofit non-community waterworks are eligible, except for state, federal, or tribal governments. Suspended or debarred owners are ineligible.

Eligible Projects: Projects correcting public health problems and ensuring compliance with the Safe Drinking Water Act and state regulations. Project to replace aging Infrastructure & Critical Assets. Projects to improve reliability, sustainability, or resiliency.

Funding Limit: Dependent on specifics of project.

Cost to Waterworks: Low interest loan with possible loan forgiveness. Waterworks meeting disadvantaged criteria may be given lower rates and longer terms. Construction loan funds are disbursed on a cost reimbursement basis.

Timeframe: Applications accepted year-round, typically with a May deadline.

Type: Construction

Website: https://www.vdh.virginia.gov/drinking-water/fcap/drinking-water-funding-program/

Inquiries: Contact the Sustainability Coordinator for your region (see the bottom of this page- https://www.vdh.virginia.gov/drinking-water/capacity-development/) or contact the appropriate VDH ODW Field Office - https://www.vdh.virginia.gov/content/uploads/sites/14/2020/03/Field_Office_Alert_Information_Upated.pdf

USDA - WATER & WASTE DISPOSAL LOAN & GRANT

Funder: United States Department of Agriculture (USDA) - Rural Development (RD)

Eligibility: Most state and local governmental entities, private nonprofits and federally recognized tribes that serve rural areas and towns with populations of 10,000 or less, tribal lands in rural areas or colonias.

Eligible Projects: Finance the acquisition, construction or improvement of drinking water sourcing, treatment, storage, and distribution.

Funding Limit: Dependent on specifics of project

Cost to Waterworks: Long term, low interest loans. Grant may be combined with loan.

Timeframe: Applications accepted year-round

Type: Construction

Website: https://www.rd.usda.gov/programs-services/water-environmental-programs/water-waste-disposal-loan-grant-program/va

Inquiries: (804) 287-1600

C. Funding to Obtain Test Kits or Laboratory Equipment for Systems to Test for HABs

VDH - DWSRF SET-ASIDES SUGGESTIONS

Funder: Managed by the VDH's Office of Drinking Water

Eligibility: Any interested individual, waterworks, or business that is not state, federal, or tribal owned is eligible to make suggestions.

Eligible Projects: VDH – Office of Drinking Water accepts suggestions for projects and programs that will benefit the regulated community.

Funding Limit: N/A

Cost to Waterworks: No cost to waterworks

Timeframe: Applications accepted year-round

Type: Non-construction

Website & Inquiries: https://www.vdh.virginia.gov/drinking-water/fcap/drinking-water-funding-program/ → scroll down to the bottom of this webpage for details and contact information.

VII. Additional Resources

A. Relevant Publications/Resources

The following list of resources and publications provides valuable strategies to prepare for and manage HAB events:

1. **American Water Works Association** (AWWA). 2016. Managing Cyanotoxins in Drinking Water: A Technical Guidance Manual for Drinking Water Professionals - https://www.awwa.org/Portals/0/AWWA/Government/Managing_Cyanotoxins_In_Drinking_Water.pdf?ver=2018-12-13-101836-763

2. **Interstate Technology and Regulatory Council** (ITRC) - https://itrcweb.org
ITRC provides comprehensive guidelines and information on innovative technologies that aid in managing and mitigating HAB-related challenges.

3. **EPA** Incident Action Checklist – Harmful Algal Blooms
https://www.epa.gov/sites/default/files/2017-11/documents/171030-incidentactionchecklist-hab-form_508c.pdf. This incident action checklist provides a structured and strategic approach to effectively prepare for, respond to and recover from a HAB incident.

B. Case Studies

Case Study 1: Toledo, Ohio

Problem: On August 2, 2014, Toledo Ohio experienced an unprecedented drinking water contamination event from a massive HAB in Lake Erie which affected more than 500,000 people. Toledo became the first US city where a toxic cyanobacteria bloom made tap water unsafe to drink. Because cyanotoxins are not removed by boiling and can enter the body through dermal exposure, the event triggered a health department "Do Not Use" order for three days as well as a longer duration recreational water advisory. The National Guard was brought in to distribute bottled water to the affected residents.

This bloom, like previous events, was dominated by several toxic cyanobacteria species, including Microcystis, and was fueled by nutrient inputs from agriculture in Lake Erie. The nutrients and warmer water temperatures have historically caused seasonal cyanobacteria blooms in western Lake Erie. The lake serves as a source of water for multiple public water systems and a large food services facility in northwest Ohio.

Residents were advised to not drink or use the potable water supply at 2 am on August 2. Raw water samples on August 1 indicated that unspecified cyanotoxins were found in the untreated water, triggering sampling and analysis of the finished water. Unfortunately, shipping, and analytical issues slowed confirmatory results for the finished water samples until Monday August 4 at 8 pm.

The instructions from the City of Toledo during this interim period were alarming. They included the following information:

DO NOT DRINK THE WATER. Alternative water should be used for drinking, making infant formula, making ice, brushing teeth, and preparing food. Pets should not drink the water.

DO NOT BOIL THE WATER. Boiling the water will not destroy the toxins – it will increase the concentration of the toxins. Consuming water containing algal toxins may result in abnormal liver function, diarrhea, vomiting, nausea, numbness, or dizziness. Seek medical attention if you feel you have been exposed to algal toxins and are having adverse health effects. Skin contact with contaminated water can cause irritation or rashes. Contact a veterinarian immediately if pets or livestock show signs of illness.

Approach and Results: Essentially the resolution to this HAB event was time; the HAB moved away from the water plant intake and resolved itself. Since 2014, the western basin of Lake Erie has experienced multiple HABs. To address this ongoing challenge, the utility has installed additional treatment to remove and oxidize cyanotoxins as well as source water surveillance tools such as buoys and in situ monitors to provide early warning of impending HAB events. Additional work highlights the need to broaden the understanding of the physical drivers that influence cyanobacterial bloom development within freshwater estuaries, the interface between river and lake ecosystems. This is particularly important in places where these estuaries fall within large metropolitan areas, such as Toledo, Ohio. Long-term physical data sets can assist in determining the likelihood of synergistic factors that may enhance cyanobacterial blooms in freshwater estuaries, improving the ability to forecast events in these habitats.

Case Study 2: Salem, Oregon

Problem: In May 2018, tests revealed dangerous levels of algae toxins from cyanobacteria blooms in Detroit Lake had made it past the City of Salem's water treatment plant into the finished tap water supply. This marked the first time algae toxins had breached a water system in Oregon. The city was caught off guard and had not developed contingency plans for algae toxin contamination despite knowing of the emerging threat.

Approach: The city issued a drinking water advisory on May 29, 2018, warning residents not to drink the tap water. The National Guard distributed bottled water to residents. The drinking water advisory remained in place for over a month until toxin levels receded.
The city has since upgraded its treatment system to better filter algae toxins using powdered activated carbon and is exploring ozone filtration. Salem also developed an in-house lab for immediate toxin testing instead of relying on out-of-state labs. New state regulations now require drinking water providers to test for algae toxins.

Results: An assessment done by a Cincinnati-based consultant found much to praise in the way Salem handled the water quality hazard. However, it also found that the City of Salem was unprepared to handle such contamination despite knowing algae toxins posed a threat. In addition, while improvements were made, Salem's water supply remains vulnerable. The incident prompted permanent changes in Oregon like more stringent testing requirements and better treatment capabilities.

Case Study 3: Central Texas

Problem: Lakes in central Texas are used for both recreation and drinking water production. Over the past decade, several lakes near Austin, TX have reported observations of floating vegetation mats and visible algal blooms. These lakes are recreational resources, surrounded by extensive park and trail systems. The local communities use the lakes extensively for lake shore recreation with pets, non-motorized boating activities, and fishing. In 2019, multiple dogs died while playing and swimming in these lakes, sparking concern for the safety of the public and resulted in the closure of the parks and lakeshores. Investigation found cyanobacteria were producing concerning levels of anatoxin. These cyanobacteria mats were growing on the lake floor, breaking loose and floating around the lake.

Approach: Access limitations and diversion of water production mitigated further public health adverse impacts. Local environmental requirements limit the use of algaecides, steering control options towards more prevention focused solutions. Sampling had identified the sediments along the shoreline where the majority of the issues were observed. Intermediate and long term solutions were evaluated and in 2020, phosphorus mitigation for sediments was selected as a potential intermediate solution to address HAB occurrence. Lanthanum modified bentonite was applied three times during the summer of 2021.

Results: Sediment phosphorus was sampled and analyzed throughout the project and demonstrated a significant decline in the biologically active forms of phosphorus in the sediment. A shift away from cyanobacteria species to beneficial algae has been observed as well as significant decreases in cyanotoxin episodes and levels. Continued efforts now focus on managing nutrient loading into these lakes as well as routine seasonal cyanobacteria and cyanotoxin monitoring.

C. Future Research Needs

Although cyanobacteria have been on earth for millennia, a great deal is still not known about their biology, control, and impacts. For example, recent work has begun to decipher the role of benthic species of cyanobacteria in ecosystems and it is evident that they likely have significant impacts on drinking water sources.

Benthic cyanobacteria are found in the environment as both floating mats and as slime attached to rocks, sediments, and submerged surfaces. Benthic cyanobacteria may explain instances where metabolites are detected in a water supply, but no HAB is visibly evident. Recent work has documented benthic species as a significant source of cyanotoxins and taste and odor issues in drinking water (Gaget et. al. 2020). Benthic species of cyanobacteria are suspected to be the dominant form of HABs, the most readily available monitoring tool would be toxin monitoring in the raw water.

Figure 6 provides guidance on determining if benthic cyanobacteria are possibly a source of observed cyanotoxins in a water source. No controlled field assessments of algaecide use (copper or hydrogen peroxide) have been published to date; however, laboratory experiments indicate that hydrogen peroxide inhibits the growth of benthic cyanobacteria at high dose rates (Chen et. al., 2016). Further research is needed to identify possible field control of these cyanobacteria species including guidelines on monitoring this group of potential HAB species.

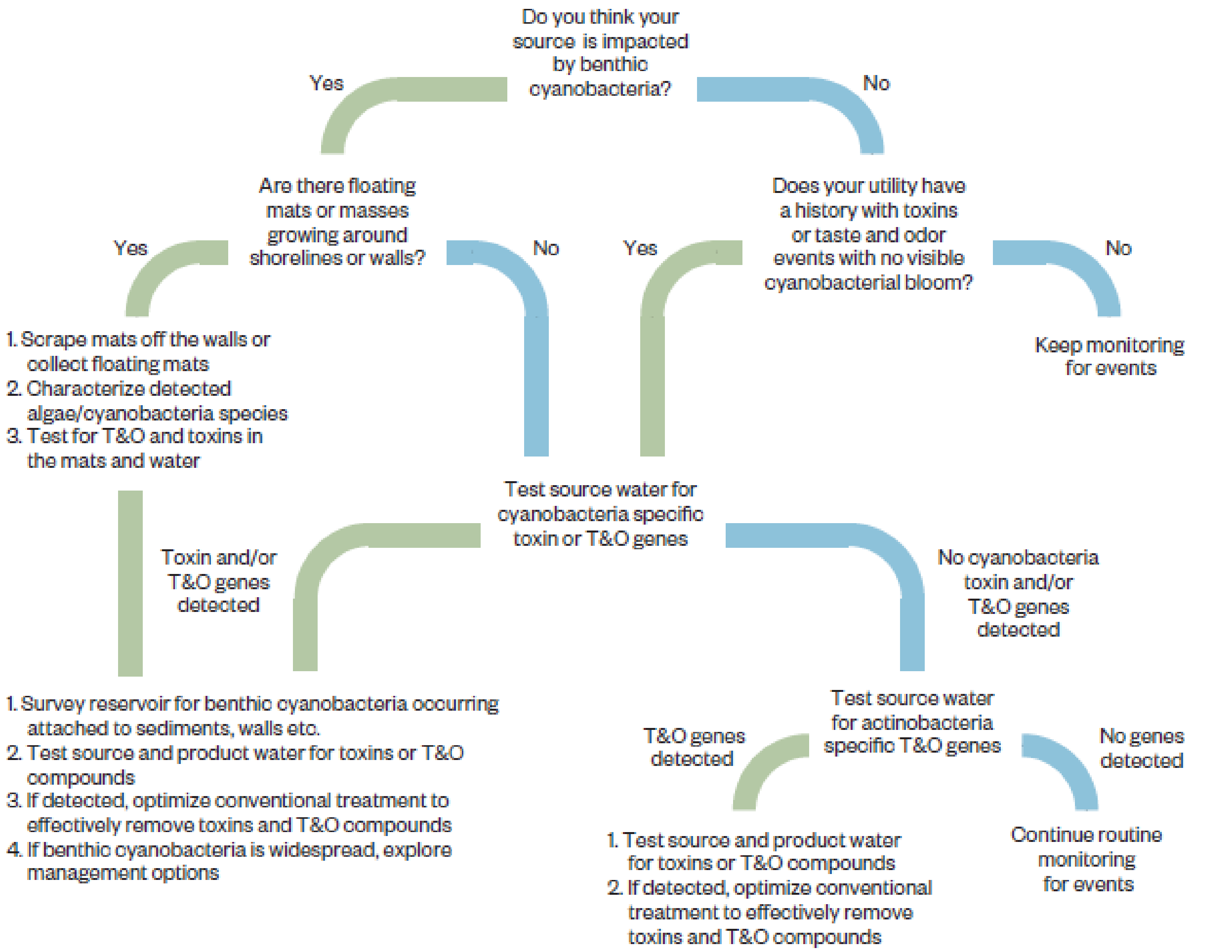


Figure 6. Decision matrix for the determination of benthic cyanobacteria in a source water (WRF 4012).

In addition to elucidating the important role of benthic cyanobacteria, future research is needed on other aspects of HABs. More reliable, cost effective, and easy to use monitoring tools for the detection of cyanobacteria and their metabolites are needed as well as real time cyanotoxin and T&O compound methodologies so that utilities can quickly assess risks to consumers. Although the CyAN program is underway, the need for more accurate predictive modeling forecasting the intensity and extent of cyanobacterial blooms in water sources is critical. Additional guidance on how to minimize external nutrient loading as well as how to manage source control strategies based on source and system characteristics would be key to improving management of HABs. The integration of cyanobacteria management into long term planning may provide the opportunity to focus on proactive strategies for the future. A critical review of the effectiveness of sonication for cyanobacteria control in source waters is needed as reports of results and effectiveness vary widely and utilities need an independent and reliable assessment of this high-cost control option.

Cyanobacteria related HABs pose a significant public health risk and their occurrence is likely to increase into the future. Climate change, urbanization, agriculture, runoff, and wastewater all have roles in the increased observations of algal blooms. Understanding what can be controlled in water sources and how to control in treatment is critical to managing exposure to cyanotoxins.

VIII. Appendices

Appendix A – HABs Response Plan Template

Appendix B – Visual Guide for Identifying Harmful Algal Blooms

Appendix C - Communications Templates

Appendix D – Health Advisory Levels by State

Appendix E – Virginia Source Water Manual

Appendix F – References

Appendix A – HABs Response Plan Template

[Waterworks Logo]
[Name of Waterworks]

Harmful Algal Blooms Response Plan Template

Last update date: [XXXX]　　　　　　　　　　Reviewed by: [XXXX]

Table of Contents

I. Overview of Water System

List of sources:
(Include all sources including emergency interconnections with other systems and alternate sources)

Source Water	Location	Intake Depth (ft.)	History of HABs	Notes
XXX lake	*Intake at Lat/Long*	*Intake at XX ft*	*Yes - 2019, 2021*	*Permanent, emergency source…*

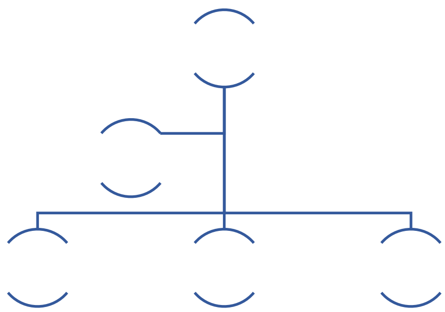
Schematic of treatment process:
This schematic all sources and treatment plant components/processes from raw water source to the entry point to the distribution system

Description of Normal Operations:

II. Preparation

A. HABs team

Organizational Chart *(insert)*



Roles and Responsibilities

List and contact information of key staff in charge of coordinating HABs monitoring and response (decision makers, staff or department responsible for managing HABs monitoring, staff responsible for emergency coordination, communication staff, etc.)

B. Monitoring Plan:

The monitoring plan should, at a minimum, include:

- *Monitoring plan or requirements*
- *Protocols for sample collection, transportation and laboratory coordination.*
- *Record maintenance – how monitoring data will be recorded, maintained, responsible staff*

Monitoring Plan or Requirements

Describe procedures for the regular monitoring of source water bodies

Process	Sampling Location	Schedule	Sampler	Method/Notes
Visual inspection of source	*Raw water intake*	*Twice a week from March 1 – Nov 30*	*Operator or sample name*	*Use visual inspection guide*
pH	*Raw water intake*	*Daily from March 1 – Nov 30*	*XXX*	*XXX*
Turbidity	*Raw water intake*	*Daily from March 1 – Nov 30*	*XXX*	*XXX*
Algal Identification & count				

Protocols for sample collection, transportation, and laboratory coordination.

Record maintenance – how monitoring data will be recorded, maintained, responsible staff

III. Response Strategies

Response Protocols

1. *Establish clear procedures for:*
   - *Action if blooms are suspected*
   - *Action if cyanobacteria is identified in raw water monitoring*
   - *Action if cyanobacteria is identified in finished water monitoring*
   - *Action if action levels or health advisory levels are exceeded*

2. *Develop Cyanotoxin Treatment Plan:*
   - *Identify treatment optimization processes (e.g., activated carbon, oxidants…)*
   - *Include process to continuously monitor water quality*
   - *Identify alternate sources*

3. *Identify staff responsible for:*
   - *Implementing treatment plan*

- *communicating with regulatory agency to report water quality data and actions taken,*
- *coordinating with regulatory agency to issue press releases and advisories, and*
- *managing communication channels, and answering questions from the public*

4. *Establish Communication Plan*
- *Step 1: Define communication channels (internal and external)*
- *Step 2: Identify communication lead/spokesperson and backup*
- *Step 3: Define clear procedures for initiating communication in response to HABs triggers & set response timeframes.*
- *Step 4: Develop template messages.*
- *Step 5: Establish review and approval process for communication materials.*
- *Step 6: Maintain up-to-date contact list of key internal and external stakeholders/customers.*
- *Step 7: Keep log of communication activities*

5. Develop list of important resources, templates, contacts and logs (see example below)

IV. Appendices

a. List of laboratories used for toxin analysis

Laboratories			
Name	Address	Days of the week samples are accepted	Contact

b. Important Contacts

Critical Customers

(List of critical customers such as hospitals, health care facilities, day care, critical industries in the area, etc. Also include any water buyers (i.e., consecutive systems) that will need to be notified of a bloom)

Customer	**Contact**	**Contact Information**		**Address**	**Method of Communication**
		Phone	Email		
XXX Hospital	*Jane Doe*	*XXX*	*XXX@hospital.org*	*XXX St, City, VA*	*Phone call followed by email and mail*

List of water system using same source

Water system name	Source	Contact Information

Regulatory Agency Contact:

Local Media

Critical vendors/suppliers

Test Kit Suppliers		
Chemical Suppliers		

c. Record Keeping

- Sampling log
- Contact log (to track all communication activities related to a HAB event)
- Communication Materials (press release template, public notice template…)

d. Other Resources

EPA Incident Action Checklist – Harmful Agal Blooms

Cyanotoxin Management Plan Template and Example Plans (epa.gov)

Planning for an Emergency Drinking Water Supply (epa.gov)

Appendix B – Visual Guide for Identifying Harmful Algal Blooms
Developed by the California State Water Resources Control Board

Non-toxic Algae & Plants	Cyanobacteria/HAB

COLOR

Algae and aquatic plants are usually green but can appear yellow or brown as they die down.

Cyanobacteria get their name from their blue-green pigment but blooms can often look green, blue-green, green-brown, or red.

ODOR

Algae and aquatic plants are usually neutral or leafy in scent, but when dying or dead smell musty/rotting.

Cyanobacteria blooms can have a distinctive smell, sometimes described as gasoline, septic or fishy.

Appendix C - Communications Templates

1. Fact Sheet Template
2. Template for Messages for Each Event Phase
3. Frequently Asked Questions Template

1. FACTSHEET TEMPLATE

Purpose: To provide to all public-facing staff so that they can better answer the public's questions.

Who: The Town of XXXX and its drinking water customers.

What: A Harmful Algal Bloom has been detected on [source water].

When: [Timeline of:

- First detection,
- Testing,
- Follow-up testing;
- Possible length of event; and
- Need to watch for potential events the remainder of the summer.]

Where: [Describe waterworks distribution system boundaries or provide map.]

Why: Algae can contain cyanotoxin, which is harmful to people and animals. Children and elderly people are especially vulnerable.
[Describe health effects of the specific cyanotoxin]

How: [Describe measures town and/or customers need to take. Examples include:
- "Customers should remain alert for additional announcement from the Town,"
- "We will notify water customers if anything changes," or
- "Customers should remain alert for possible health effects from exposure to [name of cyanotoxin].

[Graphic of sequence of how an event will unfold, if available]

2. TEMPLATES FOR MESSAGES FOR EACH EVENT PHASE

A. Potential HABs Event

1. Press Release

[town logo]

Town of XXXX Monitoring for Harmful Algal Blooms

[date]

Media Contact: [name], [phone number]

([town name], Va.) – The Town of XXXX is monitoring drinking water in response to a potential Harmful Algal bloom (HAB) on the [source water name].

HABs are caused by cyanobacteria, which can produce a variety of toxins known as cyanotoxins. Cyanotoxins can affect human health if consumed in excessive quantities over an extended period of time.

An algal bloom with the potential for harmful bacteria was first observed [distance] upstream of the Town's raw water intake on [date]. The Town will monitor source water at the point where it enters the water system to watch for potential impacts. If needed, the Town will modify its water treatment process for the removal of cyanotoxins.

The Town of XXXX is working closely with the Virginia Department of Health (VDH) and will implement recommendations and strategies to optimize water treatment, monitor water quality, and prevent health impacts from the algal bloom.

The Town will continue to monitor the drinking water for cyanotoxins for as long as the potential for a HAB event persists.

Customers with questions should contact the Town of XXXX at (XXX) XXX-XXXX.

# # #

2. Facebook/Instagram/Twitter

[photo of algae or source water]

Town of XXXX Monitoring Drinking Water for Harmful Algae

The Town of XXXX is monitoring drinking water in response to a potential harmful algal bloom on the [source water name]. The Town will test source water for potential impacts and, if needed, will modify its water treatment process.
[link to press release]

3. Talking Points for Television and Radio

- There is a potential harmful algal bloom upstream in the [water source].of the Town, which could affect its drinking water.
- Town will test its source water because of the potential for harmful toxins in the algal bloom.
- The testing at this point is a precaution.
- If we detect the toxin, we will take steps to address it through modifying our water treatment process.
- We will continue to monitor the water for algae as long as it is a possibility.
- We will keep our customers updated as we continue to monitor the situation.

B. HABs Event Starting

1. Press Release

[town logo]

Town of XXXX Protecting Drinking Water
after Harmful Algal Bloom Detected

[date]

Media Contact: [name], [phone number]

([town name], Va.) – The Town of XXXX is monitoring drinking water in response to the Harmful Algal bloom (HAB) on the [source water name]. On [date], Town officials received test results indicating that cyanotoxins have been found in the source water. Since then, the Town optimized its treatment process for the removal of cyanotoxins. Enhanced water monitoring and optimized treatment activities will continue for the duration of the algal bloom, which could continue through [date] or longer.

HABs are caused by cyanobacteria, which can produce a variety of toxins known as cyanotoxins. Cyanotoxins can seriously affect human health if consumed in sufficient quantities over a period of multiple days.

The Town of XXXX is working closely with the Virginia Department of Health (VDH) and has implemented recommendations and strategies to optimize water treatment, monitor water quality, and prevent health impacts from the algal bloom.

The Town will continue to monitor the drinking water for cyanotoxins for as long as the HAB persists.

Customers with questions should contact the Town of XXXX at (XXX) XXX-XXXX.

# # #

2. Facebook/Instagram/Twitter

[alert graphic]

Town of XXXX Protecting Drinking Water after Harmful Algae Detected

The Town's has changed its water treatment after source water tested positive for toxins from a harmful algal bloom. The water is still safe to drink. The Town will continue testing until the bloom is passed.

[link to press release]

3. Talking Points for Television and Radio

- The Town of XXXX is protecting our drinking water in response to the harmful algal bloom on the [source water name].
- On [date], Town officials received test results indicating that cyanotoxins have been found in the source water.
- Cyanotoxins can seriously affect human health if consumed in sufficient quantities over a period of multiple days. The Town implemented its Emergency Response Plan and has changed the way it treats the water in order to remove cyanotoxins.
- The Town of XXXX's tap water is safe to drink.
- We will keep testing the water until we're sure that the algal bloom has passed us.

C. HABs Do Not Drink Order

1. Press Release

[town logo]

Notice to Customers of *Name of Waterworks*

DO NOT DRINK TAP WATER

Failure to follow this advisory could result in illness.

The Virginia Department of Health in conjunction with the *Local Health Department Name* Health Department and *Name of Waterworks* are advising residents to only use bottled water for drinking and cooking purposes as a safety precaution. This precaution is necessary because *Cyanotoxin name,* a toxin produced by cyanobacteria (formerly known as blue-green algae) was detected in the drinking water from *Name of Waterworks* on *date.*

Only bottled water should be used for drinking, beverage and food preparation, making infant formula, brushing teeth, and making ice until further notice.

The tap water is safe to use for washing dishes and clothes, cleaning, flushing toilets, and bathing. However, infants and young children under the age of six should be supervised while bathing and during other tap water-related activities to prevent accidental ingestion of water.

Do not drink tap water that you have boiled. Boiling water will not remove the contamination.

Potable water is available at the following locations: *Provide locations where bottled water is available, and any special instructions.*

We will inform you when your tap water is safe to drink. We are *describe corrective actions.* We anticipate resolving the problem within *provide estimated days/date.*

For more information, call:

Waterworks contact: *contact name, address, phone*

Please share this information with all the other people who drink this water, especially those who may not have received this notice directly (for example, people in apartments, nursing homes, schools, and businesses). You can do this by posting this notice in a public place or distributing copies by hand or mail.

Date: *Date of notice*

2. Facebook/Instagram/Twitter

[warning graphic]

Town of XXXX Issues a "Do Not Drink" Order for Drinking Water after Harmful Bacteria Detected

URGENT: The Town's has issued a "Do Not Drink" order for drinking water after source water [and finished drinking water] tested positive for toxins from a harmful algal bloom. Only bottled water should be used.

[link to press release]

3. Talking Points for Television and Radio

- The Town of XXXX has issued a "Do Not Drink" order for drinking water in response to the harmful algal bloom on the [source water name].
- On [date], Town officials received test results indicating that cyanotoxins have been found in the source water.
- These toxins in the water can really hurt people if they ingest it.
- Only bottled water should be used for food preparation and hygiene purposes.
- Bottled water will be available at [location and hours].

We'll keep testing the water until we're sure that the algal bloom has passed us and will inform you when the water is safe to use again.

D. HABs Ongoing Monitoring

1. Press Release

[town logo]

Town of XXXX Continues Monitoring for Harmful Algal Blooms

[date]

Media Contact: [name], [phone number]

([town name], Va.) – The Town of XXXX is continuing to monitor drinking water in response to a potential Harmful Algal bloom (HAB) on the [source water name]. On [date], Town officials received test results indicating that cyanotoxins have been found in the source water. Enhanced water monitoring and optimized treatment activities will continue for the duration of the algal bloom, which could continue through [date] or longer.

[repeat enhanced treatment or alternative source information, if applicable]

HABs are caused by cyanobacteria, which can produce a variety of toxins known as cyanotoxins. Cyanotoxins can seriously affect human health if consumed in sufficient quantities over a period of multiple days.

An algal bloom with the potential for harmful bacteria was first observed [distance] upstream of the Town's raw water intake on [date]. The Town will continue to monitor source water at the point where it enters the water system to check for toxins.

The Town of XXXX is working closely with the Virginia Department of Health (VDH) and will implement recommendations and strategies to optimize water treatment, monitor water quality, and prevent health impacts from the algal bloom.

Customers with questions should contact the Town of XXXX at (XXX) XXX-XXXX.

2. Facebook/Instagram/Twitter

[photo of algae or source water]

Town of XXXX Continues Monitoring Drinking Water for Harmful Algae

The Town of XXXX continues to monitor drinking water in response to a harmful algal bloom. The Town is testing source water for harmful toxins. [repeat enhanced treatment or alternative source information, if applicable]

[link to press release]

3. **Talking Points for Television and Radio**

- There is a harmful algal bloom in the [water source].of the Town, which is affecting its drinking water.
- Town will continue to test its source water [and finished drinking water] because of the potential for harmful toxins in the algal bloom.
- [repeat enhanced treatment or alternative source information, if applicable]
- We will continue to monitor the water for algae as long as it is a possibility.
- We will keep our customers updated as we continue to monitor the situation.

E. HABs Event Concludes

1. **Press Release**

[town logo]

DRINKING WATER PROBLEM CORRECTED

Customers of *Waterworks name* were notified on *date of original notice* of a problem with our drinking water, and were advised to only use botted water for drinking and cooking purposes as a safety precaution. We are pleased to report that the problem has been corrected and that it is no longer necessary to only use bottled water for drinking and cooking purposes as a safety precaution. We apologize for any inconvenience and thank you for your patience.

Samples collected from *Name of waterworks* on *dates* show *Cyanotoxin name* in the drinking water at *concentration range*, which is less than the U.S. Environmental Protection Agency's national drinking water Health Advisory of *concentration.*

Because *Cyanotoxin name* may still be present within household plumbing, your taps should be flushed as a safety precaution prior to use of water for drinking and cooking purposes. Allow the water to run at each tap for 5 minutes before using it for drinking or cooking. If hot water is to be used for drinking or cooking, first drain the water heater according to the manufacturer's instructions, and then allow hot water to run at each tap for 30 seconds for 2 minutes before using it for drinking or cooking.

As always, you may contact *name* at *phone number* or *address* with any comments or questions.

Please share this information with all the other people who drink this water, especially those who may not have received this notice directly (for example, people in apartments, nursing homes, schools, and businesses). You can do this by posting this notice in a public place or distributing copies by hand or mail.

This notice is being sent to you by *Waterworks name*

Date *insert date*

2. **Facebook/Instagram/Twitter/X**

[photo of clean water]

Town of XXXX Drinking Water Problem Corrected

The Town has been monitoring drinking water in response to the harmful algal bloom on the [source water name]. It is no longer necessary to use bottled water for drinking and cooking purposes. On [date], test results indicate that harmful levels of cyanotoxins are no longer present.

[link to press release]

3. **Talking Points for Television and Radio**

- The Town has been monitoring drinking water in response to the harmful algal bloom on the [source water name].
- It is no longer necessary to use bottled water for drinking and cooking purposes.
- On [date], test results indicate that harmful levels of cyanotoxins are no longer present.

F. HABs Event Avoided

1. Press Release

[town logo]

No Toxins Found in Town of XXXX Drinking Water

[date]

Media Contact: [name], [phone number]

([town name], Va.) – The Town of XXXX is monitoring drinking water in response to the potential Harmful Algal Bloom (HAB) on the [source water name]. On [date], Town officials received test results indicating that no cyanotoxins have been found in the source water [and drinking water] at this time. The Town of XXXX will continue to monitor source water [and drinking water] for the duration of the algal bloom.

HABs are caused by cyanobacteria, which can produce a variety of toxins known as cyanotoxins. Cyanotoxins can seriously affect human health if consumed in sufficient quantities over a period of multiple days.

Potential HAB impacts were first observed [distance] upstream of the Town's raw water intake on [date]. Since then, the Town optimized its treatment process for the removal of cyanotoxins. Enhanced water monitoring and optimized treatment activities will continue for the duration of the algal bloom, which could continue through [date] or longer.

The Town of XXXX is working closely with the Virginia Department of Health (VDH) and has implemented recommendations and strategies to optimize water treatment, monitor water quality, and prevent health impacts from the algal bloom.

The Town will continue to monitor the source water [and drinking water] for cyanotoxins for as long as the potential HAB persists.

Customers with questions should contact the Town of XXXX at (XXX) XXX-XXXX.

# # #

2. Facebook/Instagram/Twitter

[photo of clean water]

No Toxins Found in Town of XXXX Drinking Water

The Town of XXXX is monitoring drinking water in response to the potential harmful algal bloom on the [source water name]. On [date], test results indicate that no cyanotoxins have been found in the source water [and drinking water] at this time.

[link to press release]

3. Talking Points for Television or Radio

- The Town has tested its water source because of an algal bloom in the [water source].
- We were looking for a toxin in the algae that can seriously affect human health if consumed in sufficient quantities over a period of multiple days.
- Fortunately, the water is testing negative for the toxin.
- We'll continue to monitor the water for algae as long as it is a possibility.
- This is good news for our customers as there will be no impact to the quality of their water.

FREQUENTLY ASKED QUESTIONS TEMPLATE

1. Why can't I drink the water?

   Because of conditions in the river, which is our water source, the water contains algae which has cyanotoxin. Cyanotoxin is a toxin that affects the neurological system, especially in vulnerable people such as children and the elderly. Drinking the water over a period of multiple days allows cyanotoxin to enter your body and cause serious health effects.

2. Will boiling the water make it safe?

   Boiling the water does not make it safe because the toxin cannot be boiled away. In fact, boiling the water may concentrate the toxin.

3. Will the water be safe when the bloom has passed?

   Yes, the water will be safe once the toxic algae is no longer coming in through the water intake.

4. What has Town done to proactively address this?

   The Town has been exploring changing the way the water is treated to avoid problems with cyanotoxin and has also been exploring alternative water sources as needed.

5. How does this affect vulnerable populations?

   Vulnerable populations such as young children and elderly adults may be more affected by cyanotoxin. EPA guidelines suggest that both the elderly and children show neurological effects at lower levels of cyanotoxin.

6. Why doesn't our neighboring town have these restrictions?

   Not all towns use the same water supply. Some towns use well water, which would not be affected by the algae present in the river. Some of our neighboring towns are also using the river as their water source and they are monitoring for toxic algae as needed.

Appendix D – Health Advisory Levels by State

Gen: General population
Sens: Children under 6 or sensitive populations

State	Total Microcystins (µg/L)		Cylindrospermopsin (µg/L)		Anatoxin-a (µg/L)		Saxitoxins (µg/L)	
	Gen.	Sens.	Gen.	Sens.	Gen.	Sens.	Gen.	Sens.
Alabama		0.3		0.7				
Alaska								
Arizona	1.6	0.3	3.0	0.7				
Arkansas	1.6	0.3	3.0	0.7				
California	0.03		0.3		4		0.5	
Colorado	1.6	0.3	3.0	0.7				
Connecticut	1.6	0.3	3.0	0.7				
Delaware								
District of Columbia	1.6	0.3	3.0	0.7				
Florida								
Georgia								
Hawaii								
Idaho	1.6	0.3	3.0	0.7				
Illinois	1.6	0.3	3.0	0.7				
Indiana	8	6	8	0.8				
Iowa	1.6	0.3	3.0	0.7	20	20	0.2	0.2
Kansas	1.6	0.3	3.0	0.7				
Kentucky								
Louisiana	1.6	0.5	3.0	0.7				
Maine	1.6	0.3	3.0	0.7				
Maryland		1.0						
Massachusetts	1.6	0.3	3.0	0.7				
Michigan	1.6	0.3	3.0	0.7				

Minnesota	0.3		0.7		0.1			
Mississippi								
Missouri								
Montana	1.6	0.3	3.0	0.7				
Nebraska								
Nevada								
New Hampshire	1.6	0.3	3.0	0.7				
New Jersey	0.3	0.07	1.0	0.2	3.3	0.7		
New Mexico	8.0		15.0					
New York	10.0							
North Carolina								
North Dakota								
Ohio	1.6	0.3	3.0	0.7	20	20	0.2	0.2
Oklahoma	1.6	0.3	3.0	0.7				
Oregon	1.6	0.3	3.0	0.7	3.0	0.7	1.6	0.3
Pennsylvania	1.6	0.3	3.0	0.7				
Rhode Island	1.6	0.3	3.0	0.7				
South Carolina	1.6	0.3	3.0	0.7				
South Dakota								
Tennessee	1.6	0.3	3.0	0.7				
Texas	1.6	0.3	3.0	0.7				
Utah								
Vermont	0.16		0.5		0.5			
Virginia	1.6	0.3	3.0	0.7				
Washington	6.0				1.0	1.0		
West Virginia	<6.0		<5.0		<80		<0.8	
Wisconsin								
Wyoming	1.6	0.3	3.0	0.7				

Appendix E – Virginia Source Water Manual

VDH's *2022 Source Water Manual* provides comprehensive guidance for waterworks using surface water to assess, monitor, and respond to HABs.

VDH - Harmful Algal Bloom Monitoring an

Appendix F – References

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