



An Analysis of Cyanobacteria Harmful Algal Blooms in Massachusetts and Methods of Prevention & Event Response

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Abstract

Cyanobacteria harmful algal blooms (CyanoHABs) can produce cyanotoxins which cause serious health effects, including death. Climate change and land use are two important factors that have led to an increase in CyanoHABs. The Massachusetts Department of Environmental Protection (MassDEP) lacks info about blooms in surface drinking water supplies and the preparedness of Public Water Systems (PWS) for cyanobacteria. Through the completion of this project, we made a historical overview of cyanobacteria events in surface drinking water supplies in Massachusetts since 2015, identified and compared the prevention and response methods for cyanobacteria events, and developed informational materials for MassDEP and PWSs. We suggested actions MassDEP could take to improve cyanobacteria preparedness.

Executive Summary

In 2015, the World Health Organization (WHO) estimated that 29% of the global population, nearly 1.8 billion people, were without immediate access to safe, potable water (WHO, 2016). The inability to access safe drinking water forces people to consume unsanitary water which can cause a variety of illnesses. These illnesses, which include cholera and dysentery, are responsible for over 3 million deaths a year (Vestergaard, 2014). Meanwhile in the United States, nearly all Americans have access to safe drinking water (Riggs, 2018). For over 100 million Americans, this accessibility to safe water in the United States is due to extensive infrastructural systems which are maintained by Public Water Systems (PWSs; Riggs, 2018), and overseen by state and federal authorities.

While PWSs greatly reduce the risk of waterborne illness, their effectiveness can be hampered by the effects of climate change and contaminants. Increase in precipitation due to climate change (NASA, 2011) coupled with urbanization and agricultural land use allows greater amounts of nutrients to runoff from the land after rainfall and into water bodies. These factors promote the formation of a cyanobacteria harmful algal bloom (CyanoHAB; Beaton, Suuberg, & Fine, 2018). Cyanobacteria, such as *Anabaena* and *Microcystis*, are native to all water bodies and may produce cyanotoxins such as microcystin and cylindrospermopsin as a part of regular cell functions (Beaton et al., 2018). When toxin producing cells die, the cyanotoxins are released, and can cause serious illness including vomiting, pneumonia, liver failure, and death (EPA, 2019). While human deaths and illness from cyanobacteria are rare, 52 patients at a Brazilian dialysis treatment facility died following use of water with high levels of cyanotoxins (Carmichael et al., 2001). Additionally, between 2000 and 2013, 108 dogs have died from cyanotoxin poisoning (Backet, Landsberg, Miller, Keel, Taylor, 2013).

Because of the health risks of cyanobacteria, the Environmental Protection Agency's (EPA) Fourth Unregulated Contaminant Monitoring Rule (UCMR4) requires PWSs to monitor for 10 cyanotoxins. However, the Commonwealth of Massachusetts has only developed guidance for PWSs to use in preventing, monitoring, and responding to cyanobacteria blooms in surface drinking water supplies. While this guidance is helpful, PWSs are not required to enact the methods outlined in the guidance. Additionally, MassDEP does not have a standardized method for reporting and recording a CyanoHAB.

The goal of this project was to create a historical overview of cyanobacteria events in the Commonwealth of Massachusetts in order to develop outreach materials that will be targeted toward PWS which use surface water sources. Through the completion of this project, we assessed instances of cyanobacteria events in surface drinking water supplies in Massachusetts since 2015, identified and compared the prevention methods recommended by the Massachusetts Department of Environmental Protection (MassDEP) and utilized by PWSs for cyanobacteria events, identified the response methods developed and utilized by MassDEP and PWSs for cyanobacteria events, and developed informational materials for MassDEP and PWSs.

Methods

To achieve the goal of our project, we completed four objectives which involved:

- Assessing instances of cyanobacteria events in PWSs which utilize surface drinking water supplies;
- Identifying and comparing the cyanobacteria prevention methods recommended by MassDEP and utilized by PWSs;
- Identifying the response methods developed and utilized by MassDEP and PWSs for cyanobacteria events and
- Developing informational material for MassDEP and PWSs.

Our team accomplished these objectives by analyzing the Cyano Tracking Database (CTD) which was created as a personal initiative of our sponsor and contains information on reported cyanobacteria events in surface drinking water supplies since 2015. During this process, the team determined various topics of interest which included location of bloom, event type, preventative maintenance, response, emergency response plan, and resolution. We then formed these topics of interest into a template to be used when recording a bloom event to ensure consistent record keeping.

After the completion of this outline, we developed survey and interview questions to obtain additional information about the reported events. Additionally, we developed survey questions to determine the existence of non-reported cyanobacteria events, and the steps taken by both MassDEP and PWSs in preparing for and responding to cyanobacteria events.

From the information gathered during our 8 MassDEP employee interviews, 3 PWS employee interviews, 4 survey results, and research, we developed informational materials for PWSs and MassDEP.

Findings

By completing our first three objectives and analyzing our results, we identified seven findings relevant to cyanobacteria's presence in the Commonwealth. We categorize our findings under: Perspectives on Cyanobacteria, PWS Preparedness for Cyanobacteria, Treatment and Monitoring of Surface Water Supplies.

Perspectives on Cyanobacteria:

- Finding 1: Existence of an Algal Monitoring Plan is associated with PWS level of concern.
- Finding 2: There are mixed opinions among MassDEP and PWS employees about whether publicity of Cyanobacteria impacts their work.

Treatment and Monitoring of Surface Water Supplies

- Finding 3: There is concern regarding current methods used to treat cyanobacteria events
- Finding 4: MassDEP and PWS employees believe Phycocyanin (PC) monitoring is an appropriate method to monitor raw water
- Finding 5: MassDEP and PWS employees highlighted uncontrolled runoff entering a PWS' watershed and water source as a concern

- Finding 6: PWSs do not fully utilize their resources provided by the MassDEP for response, such as FAST

Recommendations

We proposed the following recommendations to both MassDEP and PWSs for preventing, monitoring, and responding to cyanobacteria events.

MassDEP should suggest the monitoring of phycocyanin (PC) as part of best watershed management practices

If MassDEP suggests PC monitoring through in-vivo fluorescence as part of best watershed management practices, the risk of cyanobacteria for drinking water supplies can be further minimized. PC, a pigment unique to cyanobacteria, can be used to quickly determine the cyanobacteria population in the water source. Two out of 11 individuals interviewed have already implemented In-vivo fluorescence monitoring of PC when monitoring for or responding to a cyanobacteria event.

MassDEP should develop a standardized, inter-regional database for recording cyanobacteria events specific to surface drinking water supplies

Kristin Divris tracks cyanobacteria events as a personal initiative. However, such tracking databases only include events reported to MassDEP, and do not all include important information about a bloom, such as cell counts and toxin levels. The development of a standardized, inter-regional database would allow MassDEP to better record and understand the details of cyanobacteria events in Massachusetts. A standardized database should include information such as:

- the way the bloom was discovered and reported;
- the cell count and toxin levels;
- the site's preventive protection plan;
- the chemical or non-chemical response to the event;
- changes to their Emergency Response Plan that occurred due to this event and
- a write up of the way the bloom resolved including total length of event and any shutdowns that occurred.

MassDEP could use an organized database to understand any emerging trends in bloom events, the frequency of events and their impact. Additionally, this system would allow PWSs to use historical information when developing their prevention, monitoring, and response plans and methods.

MassDEP should investigate the effects of treatment methods, such as copper sulfate

An investigation into the long-term effects of current treatment methods can potentially prevent future health implications. Copper containing algaecides are frequently used by PWSs in order to treat or prevent a bloom. However, some MassDEP officials expressed concern of the long-term effects of copper loading on the water source. We recommend that MassDEP investigate the effects of the treatment methods used by PWSs. If research shows that copper loading will cause health concerns in the future, MassDEP will need to research and identify different treatment methods to be used throughout the regions.

MassDEP should assess how FAST can be used in response to cyanobacteria events

While the FAST team normally handles waste and hazardous spills, they have the capability to address cyanobacteria events. However, we found that there is a misunderstanding with FAST's purpose and capabilities, between those who run and those who use the program. Interviewees working on the FAST program feel they should be receiving more requests, with their program's capability. With the ability to provide PWS with additional resources, such as amino acid tests for toxin concentrations, FAST can be an asset if used properly. However, we believe that MassDEP needs to work with FAST and identify their intent regarding cyanobacteria.

MassDEP should assess challenges preventing PWSs from addressing non-point source runoff

Addressing runoff is an example of best watershed management, as the introduction of nutrients promotes cyanobacteria growth. Four of the 11 interviewees stated runoff is a major concern for water quality, yet none of our four survey respondents have addressed storm water discharge. To alleviate MassDEP employee concern and understand the extent of Guidance implementation, MassDEP should assess how non-point source runoff is being addressed by PWSs. In doing so, they can determine if the Guidance documents are helping or if another approach needs to be taken for watershed management.

MassDEP should redistribute our survey to draw additional conclusions

In creating our PWS survey, we wanted to gauge concern and preparedness of PWS with surface water supplies around the Commonwealth. Although we gathered sufficient data through in-person and phone interviews, we relied on the PWS survey for un-biased results. However, with our limited survey responses, our claims are preliminary. It would be beneficial for the MassDEP to distribute a similar survey, to possibly relate level of concern to the existence and content of monitoring and emergency response plans, how PWS regional location influenced cyanobacteria efforts, and the extent that the MassDEP Guidance had been implemented.

Conclusion

Access to potable drinking water is necessary for all life. The consumption of unsafe water can lead to a variety of serious illnesses that have killed many people. While drinking water infrastructure can significantly improve water quality, infrastructure has not eliminated all water contaminants. The blue-green algae known as cyanobacteria poses a threat to all forms of life as it can form into a CyanoHAB and produce dangerous cyanotoxins. This threat has grown in recent years as the effects of climate change and land use promote conditions conducive to CyanoHAB development.

This project cannot singlehandedly reduce the threat of cyanobacteria in surface drinking water supplies in Massachusetts. However, we hope that our work with MassDEP has helped to provide a better understanding of the history of cyanobacteria events in surface water supplies in the commonwealth. As the effects of climate change become more apparent, we hope that our findings and recommendations will continue to assist MassDEP and PWSs in the state with preparing for and responding to cyanobacteria.

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Appendices

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Chapter 1 Introduction

In 2015, the World Health Organization (WHO) estimated that 29% of the global population, nearly 1.8 billion people, were without immediate access to safe, potable water (WHO, 2016). In addition, WHO estimated that 844 million people, over double the population of the United States (Census, 2018), lacked access to convenient, safe water sources. Because of this, they are more likely to draw water from unsanitary sources, such as contaminated wells and rivers. Consumption of unsanitary water can cause a variety of illnesses, including diarrhea, cholera, dysentery, and typhoid fever, which are responsible for over 3 million deaths a year (Vestergaard, 2014). While it is easy to imagine that these issues only exist in developing countries, nearly 1.6 million Americans lack access to basic water infrastructure such as a toilet or running water, placing them at a higher risk of consuming unsanitary water (Riggs, 2018).

While there are Americans that do not have access to basic water infrastructure, most Americans can reliably draw safe drinking water in their own homes. For over 100 million Americans, this accessibility to safe water in the United States is due to extensive infrastructural systems which greatly reduce the risk of illness from unsanitary drinking water (Riggs, 2018). These systems, which can include water treatment facilities, distribution systems, and reservoirs and storage facilities, are maintained by Public Water Systems (PWSs; Riggs, 2018). In the Commonwealth of Massachusetts, PWSs are overseen by the Massachusetts Department of Environmental Protection (MassDEP) who assist PWSs with providing safe drinking water to the communities they service.

While PWSs greatly reduce the risk of waterborne illness, their effectiveness can be hampered by the effects of climate change and contaminants, both of which promote the growth of cyanobacteria (Beaton, Suuberg, & Fine, 2018). Cyanobacteria, such as *Anabaena* and *Microcystis*, are native to all water bodies and may produce cyanotoxins such as microcystin and cylindrospermopsin as a part of regular cell functions (Beaton et al., 2018). However, an increase in precipitation due to climate change (NASA, 2011) coupled with land usage allows greater amounts of nutrients to runoff from the land after rainfalls and into water bodies, especially from urban and agricultural area. Additionally, climate change has led to an increase in surface water temperatures (NASA, 2011). These factors enable cyanobacteria to grow into harmful algal blooms (CyanoHABs) which, in turn, may produce larger quantities of cyanotoxins (Beaton et al., 2018). The toxins produced during a bloom can have adverse health effects including gastrointestinal issues, liver failure, neurological issues and, in some cases, death following consumption of the water for all animals, including humans (Paerl, 2013). While human illnesses and deaths from cyanobacteria are rare, 108 dogs died between 2000 and 2013 from cyanotoxin poisoning (Backet, Landsberg, Miller, Keel, Taylor, 2013). As the number of cyanobacteria events has increased since 2015 in both the United States generally and Massachusetts in particular, risk of illness from cyanotoxins has also increased (Brown, 2018).

Though CyanoHABs represent a growing threat, there are currently no federal regulations in the United States pertaining to cyanobacteria and cyanotoxins for PWSs with surface water supplies (MassDEP, 2019). In Massachusetts, the MassDEP and the Massachusetts Department of Public Health (MDPH) which oversees recreational water bodies, have developed guidelines for ensuring that both the drinking water delivered to consumers and the recreational water bodies are safe from dangerous levels of cyanobacteria and cyanotoxins. The MassDEP guidelines advise PWSs to develop prevention and response plans for their surface drinking water sources, outline the health effects caused by the cyanotoxins, and describe the concentration of toxins which pose a risk to human health (Beaton et al.,

2018). However, PWSs are not required to implement the guidance suggested by MassDEP and are not required to have a cyanobacteria response plan written in their Emergency Response Plan (ERP).

The gap between oversight and implementation of policies has resulted in a scarcity of documentation regarding the history of CyanoHABs in the Commonwealth of Massachusetts. The MassDEP lacks understanding of the scope of the cyanobacteria threat throughout the state and the steps taken by PWSs to prevent and respond to a cyanobacteria event. This knowledge is essential for developing plans to manage the cyanobacteria threat. The goal of this project was to create a historical overview of cyanobacteria events in the Commonwealth of Massachusetts in order to develop outreach materials that will be targeted toward PWS which use surface water sources. We addressed this goal through:

- Assessing instances of cyanobacteria events in PWSs which utilize surface drinking water supplies;
- Identifying and comparing the prevention methods recommended by MassDEP and utilized by PWSs with regards to cyanobacteria;
- Identifying the response methods developed and utilized by MassDEP and PWSs for cyanobacteria events and
- Developing informational material for MassDEP and PWSs.

By completing these objectives, we provided MassDEP with an analysis of cyanobacteria events in Massachusetts since 2015 as well as outreach materials for PWSs in the Commonwealth. We hope that both the deliverables and the recommendations for improving cyanobacteria preparedness will help to improve awareness and preparedness for cyanobacteria events in Massachusetts.

Chapter 2 Background

In this chapter, we examine the health effects of the blue-green algae that is cyanobacteria. This will be followed by a discussion on the factors which promote the growth of Cyanobacteria Harmful Algal Blooms, or CyanoHABs. Next is a discussion on cyanobacteria's presence in the Commonwealth of Massachusetts and actions taken by MassDEP to prepare the state's drinking water infrastructure. We close with a discussion on why toxin production necessitates various preventive and response protocols.

2.1 Cyanobacteria Toxins and their Health Effects

Consumption of unsafe drinking water can be dangerous to people and animals. However, these dangers can be significantly reduced through the usage of infrastructural systems which include filtration and chemical applications to purify the water. Despite this, these systems do not eliminate every threat to water quality and public health. One threat is the blue-green algae known as cyanobacteria. Cyanobacteria are native to all water bodies, including drinking water reservoirs, and naturally produce O₂ the air we breathe. Additionally, some cyanobacteria species such as Anabaena and Microcystis produce cyanotoxins as part of their normal cell functions (Beaton et al., 2018). These toxins, such as Cylindrospermopsin and Microcystin, are released after the cells lyse, or die, which can occur during the water treatment process and during digestion if consumed (WHO, 2015).

Regardless of how the bacteria dies, the released toxins can have serious health effects if consumed in sufficient concentrations (Beaton et al., 2018). In 2015, the Environmental Protection Agency (EPA), which oversees PWSs and the state environmental protection agencies, published 10-day health advisory (HA) values for Microcystins and Cylindrospermopsin in finished drinking water (Beaton et al., 2018). These values, listed in Table 1, show the quantity of cyanotoxins in drinking water that may cause adverse health effects if consumed over a 10-day period. A school-age child or adult will begin to develop illness after consuming water with microcystin levels at or above 1.6 µg/L for a 10-day period. Illness from cyanotoxin ingestion can include abdominal pain, nausea and vomiting, diarrhea, pneumonia, and, in some cases, death (EPA, 2019).

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

Table 1. Cyanotoxins with 10-day Health Advisory. Note. From *MassDEP Guidance: Cyanobacteria and Public Water Systems*.

Although cyanotoxins from cyanobacteria can cause serious illness and deaths, the number of human cases of cyanotoxin related illness in the United States is not known (CDC, 2019). However, 215 dogs have died in the United States from cyanotoxin poisoning between the 1920s and 2013, with 108 of these deaths occurring between 2000 and 2013 (Backet, Landsberg, Miller, Keel, Taylor, 2013). Meanwhile, there have been human fatalities related to cyanotoxins in Brazil. In one famous case in Brazil, patients were attached to dialysis machines which contained water contaminated with 19.5 µg/L of microcystins, or over twelve times the EPA 10-day health advisory (Carmichael et al., 2001). Of the

131 patients treated, 116 suffered symptoms from exposure to microcystins, and 52 patients died from poisoning (Carmichael et al., 2001).

2.2 Factors Promoting Cyanobacteria Growth

Cyanobacteria exist naturally in nearly all bodies of water in small quantities which do not cause adverse health effects. However, certain conditions can promote an excessive growth known as a CyanoHAB which may produce the quantity of toxins needed to cause illness. During a CyanoHAB, cyanobacteria rapidly reproduce in a short amount of time. This can result in a visible blue-green surface scum, and an odor near the water body and in the water treatment facility (Beaton et al., 2018). The factors, as shown in Figure 1, which promote the development of a CyanoHAB, are due to a variety of causes including environmental factors, changes in land usage surrounding a water body, and environmental characteristics.

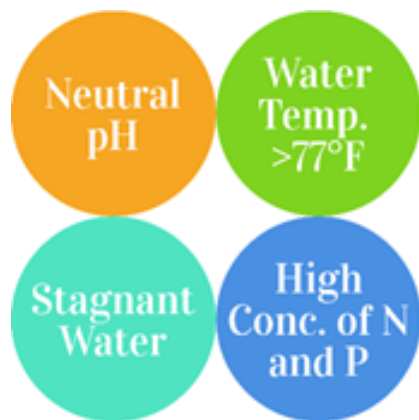


Figure 1. Infographic of Factors Which Contribute to CyanoHAB Development.

The usage of land in the region surrounding a PWS's surface water source is an important factor in CyanoHABs development. If the watershed has large amounts of suburban areas and farmlands, the site is at an increased risk of nutrient loading. In agricultural areas, use of fertilizers containing phosphorous and nitrogen in addition to manure are the main culprit in spurring cyanobacteria blooms (Beaton et al., 2018). Meanwhile in suburban areas, as more land is developed and replaced with impermeable surfaces, runoff can collect debris and pollutants including fertilizers which runoff into water sources.

In addition to land usage, cyanobacteria growth also relies on environmental conditions that are becoming more common due to climate change. The increasing ambient temperatures due to climate change allows water bodies to reach higher water temperatures, especially at the surface (Backet et al., 2013). This condition favors surface bloom-forming cyanobacteria as they are adapted to water temperatures in excess of 25°C or 77°F (Paerl, 2013). Additionally, climate change is also causing an increase in precipitation (IPCC, 2011). Elevated amounts of precipitation can increase the previously mentioned amount of runoff entering the water body from the surrounding areas. When natural filtration does not occur, this runoff can be rich in nitrogen and phosphorus further promoting cyanoHAB development (Paerl, 2013).

Further, environmental characteristics such as neutral pH levels and stagnant water also promote CyanoHAB growth (K. Divris, personal communication, September 2019). Higher residency times, the amount of time that the water stays in the water body, allows nutrients to accumulate and allows the water body to be warmed more easily (G. Zoto, personal communication, September 16, 2019). Certain cyanobacteria species, such as Anabaena and Microcystis, can exploit these advantages by relocating themselves in the water column to a location with optimal levels of nutrients, temperature, and sunlight (WHO, 2016).

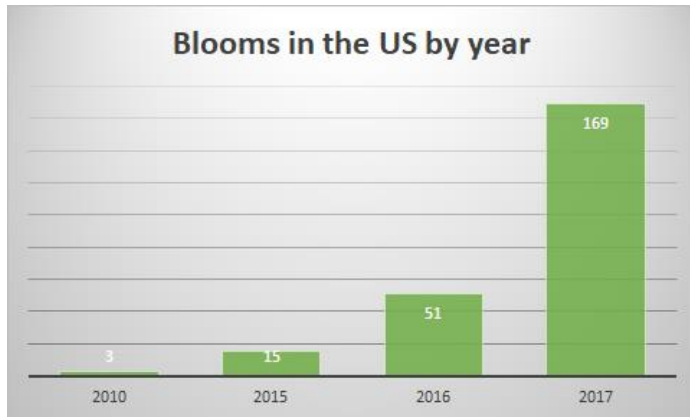


Figure 2. The Number of Reported Cyanobacteria Blooms for Selected Years. Note. From *The Algal Bloom Poisoning U.S. Lakes Tripled in Number Last Year*, New Food Economy

In part due to climate change, land usage, and environmental characteristics, harmful algal bloom reports have significantly increased in frequency during the past decade in the United States (Brown, 2018). As shown in Figure 2, in 2010, there were only 3 total reports, in 2015 there were 15 reports, in 2016 there were 51 reports, and in 2017 their amount was tripled to 169 blooms in the US (Walker & Wathen, 2018). Cyanobacteria most commonly occurs during late summer or early fall, as the conditions are the most amenable to rapid cyanobacterial reproduction.

2.3 Regulation of Cyanobacteria Surface Water Supplies in Massachusetts

Despite the adverse health effects of cyanobacteria and its cyanotoxins, there has been little regulation implemented by Massachusetts and the U.S. Federal Government (MassDEP, 2019). However, publicity of a major cyanobacteria event has spurred policy making on the state and federal levels. In August of 2014 the widely publicized Toledo, Ohio bloom in Lake Erie propelled national reform and increased awareness among the general population to the topic of cyanobacteria. This bloom event, as seen in Figure 3, affected over 400,000 people in the Toledo area. Local water suppliers that drew water from Lake Erie issued a “do not drink” order due to elevated toxin counts in the



Figure 3. Satellite Image of an Algal Bloom Event in Lake Erie, September 29, 2014. Note. From NOAA

drinking water plants’ finished water (Circle of Blue, 2014). Following the Toledo incident, the EPA published 10-day health advisories, which can be seen in Table 1, for two cyanotoxins in finished drinking water in June of 2015 (EPA, 2015). A year later in December, the EPA published the Fourth Unregulated Contaminant Monitoring Rule, or UCMR4, which for the first time included 10 cyanotoxins in a list of contaminants to be monitored by PWSs across the country, including PWSs in Massachusetts (EPA, 2018). While the EPA never directly stated that the Toledo incident led to the

development of the 10-day health advisories and the addition of cyanobacteria into the UCMR4, these actions were taken immediately after the highly publicized Toledo incident.

Following the EPA, MassDEP developed cyanobacteria specific guidance to support PWSs in the Commonwealth (Beaton et al., 2018). PWSs under normal operational conditions are not required to test and maintain the quality of their raw water, that is, the water that has not been treated. PWSs need only test their finished water to ensure that it passes governmental regulations and it is safe to

drink. Because the EPA and MassDEP have not developed regulations for cyanobacteria and its toxins, response to cyanobacteria growth in surface water supplies is up to the discretion of the PWS' manager (MassDEP, 2019). PWS managers are not required to notify MassDEP of concerns unless they apply a chemical solution (R. Kubit, personal communication, September 24, 2019).

MassDEP provides support to all PWSs in the form of response and guidance. Although many surface water sources are required to have a "Surface Water Supply Protection Plan as defined by 310 CMR 22.C1(d)(4)" (Beaton et al., 2018), the MassDEP advises that all suppliers should have a Protection Plan. The Bureau of Water Resources provides documentation with guidance on the creation of such plans, as well as watershed management practices, basic data collection, and surface water treatment in hope of limiting cyanobacteria growth in the raw water. In the event of a full bloom event, PWSs can contact MassDEP for further situational guidance if they require assistance to manage the bloom (MassDEP, 2019).

In order to operate, a PWS is required to have an Emergency Response Plan (ERP; K. Divris, personal communication, September 23, 2019). These plans must adhere to certain sections of the EPA's Harmful Algal Bloom Incident Action Checklist. However, there is no requirement for the ERP to contain provisions directed at managing cyanobacteria blooms. Additionally, PWSs are not required to provide their ERP to MassDEP for evaluation. Instead MassDEP mandates that it is notified of changes to a PWS's ERP (K. Divris & A. Lowery, personal communication, September 6, 2019).

While fewer than 20 cyanobacteria events in surface drinking water supplies have been documented in Massachusetts since 2015, the MassDEP considers cyanobacteria and their resulting toxins as emerging contaminants (Beaton et al., 2018). The guidance on preventative and emergency response plans urges all PWSs to be proactive and understanding of the risk of cyanobacteria in their surface water supplies. Going forward, it is likely that stricter regulations for cyanobacteria will be created, which will help PWS with maintaining the water to specific standards (J. Fitzgerald, personal communication, September 26, 2019).

2.4 Management of CyanoHABs

There are two major stages in the management of CyanoHABs: bloom prevention and bloom response (Beaton et al., 2018). Prevention consists of all testing, measuring, and routine treatment done when a PWS does **not** have knowledge of any existing bloom. Bloom response includes actions that a PWS undertakes after a bloom is detected. Bloom response also consists of the stage where a PWS no longer considers the bloom to be a credible threat and are rescinding any public notices, restoring shutdowns, and any other actions taken before normal management and preventive measures return.

2.4.1 Preventative Measures

In order to limit the growth of naturally occurring cyanobacteria in a drinking water site, PWSs with surface water sources in Massachusetts can utilize various preventative measures. These measures include watershed management practices, nutrient level control, algal monitoring programs, and forms of active prevention.

2.4.1.1 Watershed Management

The most passive form of cyanobacteria bloom prevention is watershed management practices (Beaton et al., 2018). The main premise behind watershed management is limiting the inflow of contaminants and excess nutrients from areas surrounding the surface drinking water source. This can be achieved through maintaining a wooded region as a buffer zone around the drinking water site.

Buffer regions act as natural filters for runoff, absorbing nutrients from septic systems, agricultural areas, and home lawns and gardens (Beaton et al., 2018). If it is feasible, many PWSs attempt to gain control of the land surrounding their site in order to protect the land (K. Divris, personal communication, September 23, 2019). This can be achieved by using land acquisition and Conservation Restrictions which are processed through the Executive Office of Energy and Environmental Affairs (Romero, personal communication, September 24, 2019). Maintaining a buffer region also helps by reducing erosion and nutrient contributions in runoff from paved areas, as impermeable surfaces more easily allow nutrient rich water to flow into drinking water sources (Beaton et al., 2018). In some cases, such as Monponsett Pond in Halifax, MA, land acquisition is not feasible, as a state highway, Route 58, runs through the center of the two ponds.

2.4.1.2 Nutrient Level Control

Nutrient Level Control involves actively limiting or reducing the amount of specific nutrients in a water body. In the case of cyanobacteria, phosphorous and nitrogen are critically important to bloom events. Phosphorous plays a key role in the physical formation of cyanobacteria blooms, so controlling this nutrient is necessary for sustainable long-term management of cyanobacteria in drinking-water sources (WHO, 2016). Additionally, a PWS can measure the nitrogen and phosphorous levels of the water source to determine the risk of cyanobacteria bloom development. This allows PWSs to determine if preventative measures, such as sulfate treatment, are necessary to reduce the risk of cyanobacteria blooms.

2.4.1.3 Algal Monitoring

In addition to testing nutrient levels of the water, a PWS may also routinely test the water to ensure that cyanobacteria populations are not at an elevated level as part of an algal monitoring program (Beaton et al., 2018). One simple cost-effective way to check for cyanobacteria is through the jar method (MPCA, 2018). Ideally, though, a PWS could use a more scientific method of measurement such as Turner Designs' Cyanofluor™ which can quickly measure the phycocyanin to chlorophyll-a ratio of a water sample. Phycocyanin to chlorophyll-a ratios are an accurate and useful indicator of bloom events, as phycocyanin is unique to freshwater cyanobacteria (Ahn, Chung, & Oh, 2002). Routine monitoring can also include visual inspections, where employees observe the site and identify any forming blooms, and the use of Secchi disks to measure suspended solids, another indicator of a bloom. Knowing the state of cyanobacteria population in the water body is an important part of prevention, as PWS can make appropriate management decisions based on this information.

2.4.1.4 Artificial Mixing

Artificial mixing is an active measure that involves mixing the body of water. This disturbs the water column and inhibits cyanobacteria that are capable of movement to optimal temperature and light conditions (Visser & Ibelings, 2015). In a well-mixed system, the buoyant bacteria's ability to float to illuminated areas is mitigated. Artificial mixing also breaks up small blooms that are forming, preventing the growth of a dangerous bloom. While this method can be effective it is not a feasible method for all bodies of water as the water body needs to have an appropriate depth to suit the elaborate equipment necessary. Additionally, mixing is only practical as a preventative measure. Once a full bloom has occurred artificial mixing will not be able to break up the bloom

2.4.2 Bloom Response

If preventive actions fail and a bloom develops, a PWS will need to deploy more robust responses. The use of a bloom response to mitigate the impact of a bloom or kill the cells outright is essential to managing a potentially dangerous CyanoHAB. The main methods of response to cyanobacteria events are algaecide application, utilization of alternate sources during the bloom event, and relying on infrastructural elements to avoid the negative consequences of a bloom.

2.4.2.1 Algaecide

Algaecide usage is an effective way to both reduce cyanobacteria populations and to stop a bloom from expanding (Beaton et al., 2018). The two main forms of algaecide that are used to treat drinking water sites are aluminum sulfate and copper sulfate. Aluminum sulfate reduces phosphorus levels available to the bacteria, slowing growth (Beaton et al., 2018). Meanwhile, copper sulfate causes the cyanobacteria cells to lyse, or die, and reduce cyanobacteria counts. Because the bacteria release their toxins upon their death, use of algaecides when cell counts are high can potentially lead to the release of high concentrations of cyanotoxins in the short term (J. Hobill, personal communication, October 1, 2019). For this reason, it is important that water treatment facilities monitor the levels of cyanotoxins during the treatment process to prevent consumption of dangerous levels.

2.4.2.2 PWS Specific

PWSs with multiple sources to draw from can use an alternative source during an algal bloom without disrupting their ability to deliver safe drinking water. In some cases, a PWS may apply large amounts of sulfate to alleviate the bloom, as was the case in 2018 for Chestnut Hill reservoir, without having to worry about cyanotoxin levels. Alternatively, a PWS may wait until the bloom population dwindles naturally, as was the case in 2017 for Chestnut Hill reservoir. In either case, conducting intermittent testing and monitoring the water source during the bloom detection and treatment phases is essential in monitoring the status of the bloom (K. Divris, personal communication, September 23, 2019).



Figure 4. An Emergency Spillway Being Used in Texas. Note. From Spillway, Wikimedia Commons

2.4.2.3 Source Specific

Infrastructural elements of a specific drinking water source can also be utilized in bloom response. If a site has a spillway, as seen in Figure 4, they can utilize it to remove water that is known to have surface scum or full blooms through drainage. While this does not kill the cells, the main objective is to remove cyanobacteria from the water body. Meanwhile, if a drinking water source has multiple intake locations, they can simply utilize alternate intakes that are distant from bloom events (G. Alt, personal communication, September 23, 2019). This allows the PWS to ensure that the water is coming from a safe location with low toxin concentration (Beaton et al., 2018).

2.5 Conclusion

Cyanobacteria and their cyanotoxins are a growing risk to surface drinking water supplies and to public health. Climate change and land usage create conditions more conducive to cyanobacteria development. Meanwhile, the bacteria's ability to relocate within the water column allows the bacteria to more easily outcompete other organisms. All these factors are compounded in water bodies with high residency time, where nutrient content and water temperature are at a maximum, and the bacteria can easily relocate to a location for optimal growth. Because of the growing risk of cyanobacteria, MassDEP has developed guidance for PWSs with surface drinking water supplies to prepare for cyanobacteria. However, PWSs are only accountable for their finished water quality, not their raw water. Additionally, MassDEP is missing organized information pertaining to the history of cyanobacteria bloom events in drinking water. They are also unaware of the specific ways that PWS are prepared to respond to cyanobacteria blooms.

Chapter 3 Methodology

The goal of this project was to create a historical overview of cyanobacteria events in the Commonwealth of Massachusetts in order to develop outreach materials that would be targeted toward PWS which use surface water sources

We achieved this goal through:

- Assessing instances of cyanobacteria events in PWSs which utilize surface drinking water supplies;
- Identifying and comparing the prevention methods recommended by MassDEP and utilized by PWSs with regards to cyanobacteria;
- Identifying the response methods developed and utilized by MassDEP and PWSs for cyanobacteria events and
- Developing informational material for MassDEP and PWSs.

Objective 1: Assessed instances of cyanobacteria events in PWSs which utilize surface drinking water supplies

To understand the history of cyanobacteria blooms, we worked to describe recorded bloom events since 2015, and identify those which occurred prior. To know what we needed to obtain from the post 2015 events, we sorted through the cyanobacteria data that was already available to us.

Statewide, there is a document that records all reported cyanobacteria events. However, there is currently no option for the Drinking Water Program to track cyanobacteria through their Water Quality Tracking System (WQTS; Kristin Divris, personal communication, October 6, 2019). Without a standardized way to document reports, MassDEP employees have developed their own methods for recording cyanobacteria events. The Cyano Tracking Database (CTD) we used was created as a personal initiative of our sponsor.

We determined various topics of interest: location, event type, preventative maintenance, response, emergency response plan, and resolution. We gathered this information from the CTD, interviews, and personal contacts.

Knowing the limitation of the CTD, we interviewed 8 MassDEP employees from the Northeast (NERO), Southeast (SERO), Central (CERO), and Western (WERO) regional offices who have helped respond to cyanobacteria events. In addition to a standard question set, we created supplementary event specific questions for each regional interview.

Objective 2: Identify and compare the cyanobacteria prevention methods recommended by MassDEP and utilized by PWSs

In the Commonwealth, MassDEP has provided recommendations for PWSs in the “MassDEP Guidance: Cyanobacteria and Public Water Systems” (Beaton et al., 2018). This guidance document is intended to assist PWSs in preventing cyanobacteria events in a surface drinking water source. However, MassDEP does not require PWSs with surface drinking water supplies to follow and implement the guidance. We were interested in understanding if methods the Guidance outlines are used, and if any additional methods have been implemented.

We gathered information regarding the existence of an algal monitoring plan, various preventative methods, and watershed management practices. To collect this data, we used both interviews and surveys, which can be found in Appendices B and C. To decide what could be learned

from an interview or survey, we created a flowchart guide, as seen in appendices D & E. The charts outlined the areas of interest we had, what we wanted to know from each area, and who we would get that information from.

While we gathered some information from our standard question set for the regional employee interviews, we conducted one interview at the North Andover PWS. Wanting to draw conclusions on all PWS with surface water supplies, we were advised to send 72 surveys instead of interviewing individual PWS. Interviews of all 72 PWSs with surface water supplies was not feasible due to time limitations.

Objective 3: Identified the response methods developed and utilized by MassDEP and PWSs for cyanobacteria events

For public safety, PWSs are required to have an Emergency Response Plan (ERP). However, MassDEP does not require PWSs to incorporate a cyanobacteria response plan into their ERP (K. Divris & A. Lowery, personal communication, September 6, 2019). With a lack of regulations regarding the content of cyanobacteria in ERPs, PWSs are at various levels of preparedness. For this reason, our third objective was to understand the response methods developed by the MassDEP and individual PWSs, to provide an understanding of response across the Commonwealth.

Data was gathered from the same interviews and surveys utilized in the previous objective. We structured our ERP survey question, so we could review the extent that PWSs implement suggestions from the Guidance document discussed in Objective 2. Presented with a list of response methods to select, we learned if PWS contact MassDEP, the Field Assessment and Support Team (FAST), or utilize a variety of methods to handle the event internally

Objective 4: Developed informational material for MassDEP and PWSs

Our final objective was to provide MassDEP and PWSs with materials regarding the state of cyanobacteria prevention and control throughout the Commonwealth. As a culmination of our interviews and surveys, we identified three strategies which led to our outreach materials: Assess PWS response to cyanobacteria and cyanotoxin concerns, organize preliminary and field data, and analyze data for patterns of prevention/response.

After completing objectives 1-3, we drew conclusions on preventive and response methods most commonly used around the Commonwealth. Providing this information to the MassDEP helps them determine how prepared PWS are for preventing cyanobacteria events, as well as assist MassDEP with determining which prevention methods need to be more heavily promoted.

Although these findings are important for MassDEP's understanding, they are just as valuable for PWSs. Having a document that outlines current practices, while referring PWS to the MassDEP Cyanobacteria Guidance, can help alleviate concern over cyanobacteria. Content can be used to create various cyanobacteria related plans and to understand the permitting process.

With data specifically from objective 1, we created case studies for events post 2015. This allows MassDEP to have a record of which steps were or were not taken leading up to, during, and following an event. A complete narrative of past events can be used as a reference for MassDEP when deciding how to manage a future cyanobacteria event.

Chapter 4 Findings

By completing our first three objectives and analyzing our results, we identified seven findings relevant to cyanobacteria’s presence in the Commonwealth. In this chapter, we introduce our individual findings, and explain how we justified each.

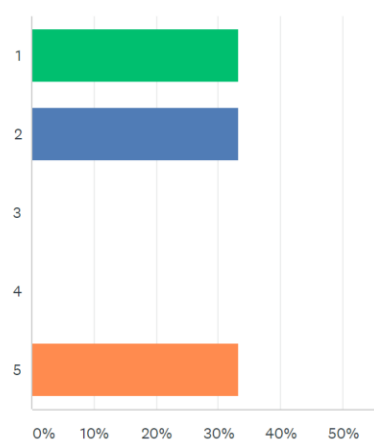
In review, our data came from recorded documentation, 8 MassDEP employee interviews, 1 site visit, and 1 mass survey. For the interviews, our sponsors helped us identify regional cyanobacteria leads as well as those specializing in the Drinking Water Program (DWP) and the permitting process. Unfortunately, we only received four responses to the 72 survey we distributed. While we had successful interviews, we had underrepresentation from the PWS surveys.

Perspectives on Cyanobacteria

Finding 1: Existence of an Algal Monitoring Plan is associated with PWS level of concern

In our first and second survey questions, we asked PWSs how concerned they are with cyanobacteria, and if they have an algal monitoring plan. Even though we only received four responses, we start to see the relationship between concern and monitoring plans by comparing individual responses.

Answered: 3 Skipped: 1



Answered: 4 Skipped: 0

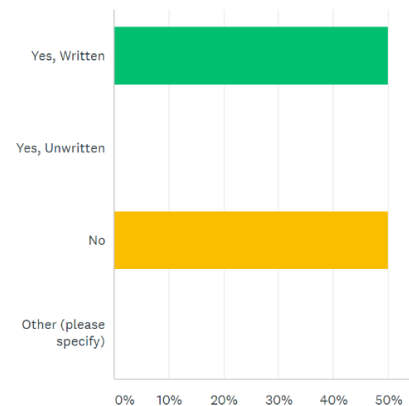


Figure 5. Results from PWS Survey for Questions 1 & 2.

Seen in the left side of Figure 5, only two of the four respondents indicated they are at a level “one” or “two” for concern over cyanobacteria. These two respondents also indicated they have no algal monitoring plan at all. However, PWSs who indicated they are at a “five” for concern, has a written algal monitoring plan in place. Our final respondent preferred not to indicate their concern level but chose to indicate they have a written algal monitoring plan.

From interviews, we learned that not all MassDEP regions struggle with cyanobacteria events in the same way. The point of contact for the DWP in the Western region expressed how she is not aware of any monitoring plans as the region has never experienced a real cyanobacteria event (Anonymous, personal communication, September 20, 2019). From this interview, we expected that PWSs from the same region would share concern levels. However, as three of the four survey responses were from the Northeast, we saw that a PWS’ region is not associated with its concern level and

existence of an algal monitoring plan. The relationship between level of concern and an algal monitoring plan is based on individual PWSs.

Finding 2: There are mixed opinions among MassDEP and PWS employees about whether publicity of cyanobacteria impacts their work

As cyanobacteria becomes a more prevalent issue, there have been many news articles highlighting their health effects to humans and pets (Backet, Landsberg, Miller, Keel, Taylor, 2013). We asked our interviewees, “Has the recent publicity about cyanobacteria events affected the work of MassDEP?”.

The responses suggest that recent publicity increase has not affected any cyanobacteria efforts. Many interviewees stressed that publicity is not a new concept. Two different regions expressed that they have been receiving calls of green paint spills, which are cyanobacteria blooms, for years. More recently, the southeast region dealt with numerous calls regarding cyanobacteria in response to newspaper articles. While all these calls involved recreational waters, the region felt no pressure to alter their drinking water operations.

In contrast, one interviewee mentioned they were involved with a cyanobacteria event that was influenced by the public. In 2018, there was an algal bloom highly publicized due to its odor problems. Even though the regional MassDEP office had identified the bloom as golden brown algae, which do not produce toxins, they still conducted tests for toxins which only result from the blue-green algae cyanobacteria. When asked about this, the interviewees stated this was an overreaction so they could ensure the public they were safe.

Interviewees also mentioned how they use publicity to educate the public about cyanobacteria. According to one member of the Drinking Water Program, PWSs have used the Mass Audubon, gardening clubs, local cable shows, and billing services to distribute informational material. They hope that educating the public will not only help them report blooms but reduce public outcry in cyanobacteria events.

With more cyanobacteria events occurring, our sponsors were interested in knowing if regions felt pressure to alter their normal operations from publicity. In conclusion, we found that recent publicity has not affected operations in drinking water.

Treatment and Monitoring of Surface Water Supplies

Finding 3: There is concern regarding current methods used to treat cyanobacteria events

Through our MassDEP employee interviews, we found that there was concern with how current treatment methods affect the ecosystem and future of a water body. When asked about preventative and response methods used, interviewees supplemented their responses with reservations.

Of the eleven interviewed, six expressed concern of the use of copper sulfate as well as methods which remove aquatic plants. Responses stated that copper sulfate is an accepted treatment method because of its low cost, historical success, and its lack of permitting requirements (Anonymous, personal communication, September 23, 2019). However, most of the six were concerned with copper loading in the water body’s sediment. Interviewees want more research done to conclude that copper loading over

time will not mimic past issues, such as mercury deposits traveling through fish into humans causing illness. Furthermore, a PWS employee we interviewed believes that cyanobacteria may develop a resistance to copper sulfate due to its repeated usage (anonymous, personal communication, September 23, 2019).

Aside from specific consequences of copper sulfate use, interviewees expressed concerns about the way that PWSs and governmental employees treat the water bodies. They are primarily concerned that the water bodies are not being treated as an ecosystem. One MassDEP employee believes the removal of certain plants and moss in the 1980's is partially to blame for West Monponsett Pond's struggle with cyanobacteria (Anonymous, personal communication, September 16, 2019). In addition to absorbing some nutrients, these nuisance plants produce a chemical hindering cyanobacteria growth.

Finding 4: MassDEP and PWS employees believe Phycocyanin (PC) monitoring is an appropriate method to monitor raw water

Without algal monitoring regulations, many PWS use preventative measures accepted as industry standard, such as copper sulfate usage discussed in Finding 7. While many referenced visual inspections and Secchi disks, interviewees often praised the potential of PC Monitoring.

One interviewee expressed that many monitoring methods require expertise to use, and more user-friendly methods are desired. Phycocyanin can be measured using an in-vivo fluorescence (IVF) meter. As a device that can be used without expert training and produces immediate results, PC monitoring through an IVF meter can be effectively implemented into weekly routines as part of an algal monitoring plan. In review of events since 2015, we found that both the North Andover Water Department and the Andover Water Department employed PC measurements as part of their monitoring program.

From our site visit and interview in North Andover, we learned that PWSs take many factors into account to decide if they are experiencing a bloom event. The usability of the IVF meter allows PWS to routinely record PC measurements and track cyanobacteria levels over time, helping them make treatment decisions. By recording PC measurements over time, a PWS can identify bloom growth through deviation in the data. In 2018 the Andover Water Department used PC measurements to determine that sulfate application would be beneficial, as changing PC levels indicated the cyanobacteria population was increasing (Appendix H).

While most interviewees agreed on the potential PC monitoring for the state of surface water, one interviewee was particularly passionate about its implementation. The interviewee stated that PC has the potential to provide more accurate sampling results, when compared to cell counts, as a greater number of measurements can be taken (Anonymous, personal communication, September 26, 2019). PC is a measure of biomass that is irrelevant of cell size, while cell counts are highly dependent on the size of the cells in the sample volume.

Most notably, we found that some interviewees are already using PC measurements. A MassDEP employee has started to include PC measurements in their reports, hoping others start to see its potential. A PWS in the northeast has implemented PC measurements into their unwritten monitoring plan and is using this data to develop a baseline of PC levels.

Finding 5: MassDEP and PWS employees highlighted uncontrolled runoff entering a PWS' watershed and water source as a concern

Four out of the eleven people interviewed identified that stormwater is a primary concern for their water bodies. They recognize that it is the primary method in which chemicals and nutrients are introduced into the raw drinking water. However, none of the four survey respondents indicated they identified points of stormwater discharge into their water body.

During the interviews, MassDEP employees were asked about the influence of stormwater on surface water sources. We learned that although PWSs try to limit certain phosphate-based fertilizers, the nutrients from fertilizers end up in water bodies promoting cyanobacteria growth. Interviewees feel nutrient loading is being exacerbated by "more intense storm and flooding events than in the past" (Anonymous, personal communication, September 24, 2019).

Common methods to manage runoff include:

- Acquisition of land via:
 - Land acquisition applications;
 - Conservation Restrictions and
 - Land Donations.
- Control of stormwater via:
 - Catch basins.

As noted above, one way to control storm water is using catch basins. MassDEP employees suggested an increase in their implementation, as these basins limit localized floodwater flow into water bodies from residential areas, but the MassDEP does not oversee the installation and maintenance of catch basins. Another common way to manage runoff is through permitting programs which involve land acquisition around the PWS. Land can be gathered through land purchases, conservation restrictions, and land donation. According to a representative from the Drinking Water Program, there are about 10-12 applications for the land acquisition grant program per year.

Finding 6: PWSs do not fully utilize the resources provided by the MassDEP for response, such as FAST

When the interviewees from the Northeast were asked, "In your opinion, are the current actions taken by MassDEP and PWSs sufficient for preventing and managing cyanobacteria events?", they stated PWS do not utilize all their resources. Specifically, they felt the FAST program is underutilized.

Housed at the Northeast regional office, there is a mobile lab for the Field Assessment Support Team (FAST). The mobile lab is staffed 24/7, ready to dispatch to any region in the Commonwealth. When asked about logistic concerns, they mentioned that FAST would respond to all regions, regardless of distance. However, to their surprise, the FAST hotline rarely receives calls regarding cyanobacteria. Upon further inquiry, we learned from another interview that when working with the MDPH, regional offices have the resources to produce the same analysis FAST can.

Due to a lack of survey responses, our claims regarding FAST are inconclusive. However, of our four survey responses, no PWS recorded that contacting FAST was part of their Emergency Response Plan (ERP). This is notable because one PWS recorded they were extremely concerned about cyanobacteria, while the others were not concerned. Our case studies found that of the 16 documented bloom events since 2015, only four have contacted FAST for support. These four have all been from locations that service relatively small populations, and they all benefitted from the guidance of FAST.

Chapter 5 Recommendations

In the following chapter, we outline recommendations for both the MassDEP and PWSs with surface water supplies. Through review of literature, in-person interviews, and survey responses, we have identified ways that cyanobacteria are managed to minimize risk to public health. These recommendations are expressed with the understanding that cyanobacteria are becoming more prevalent in water bodies and in the public eye. The purpose of these recommendations is to provide MassDEP with suggestions regarding their cyanobacteria efforts, based on our work.

Recommendation 1: MassDEP should suggest the monitoring of phycocyanin (PC) as part of best watershed management practices

If MassDEP suggests PC monitoring as part of best watershed management practices, the risk of cyanobacteria for drinking water supplies can be further minimized. If PWS implement this suggestion, cyanobacteria blooms can be detected as they start to form. However, one limitation to PC measurements is that not all cyanobacteria blooms produce toxins, and PC measurements do not specify the type of cyanobacteria present.

During an interview with regional staff, the interviewee expressed that PWS would be able to more readily monitor their raw water if more user-friendly devices were available. This interviewee indicated that in-vivo fluorescence (IVF) meters are valuable tools, as they “can be used without requiring expertise” (Anonymous, personal communication, September 16 2019). IVF meters are programmable and can be set to measure phycocyanin, a unique pigment produced by cyanobacteria. We found that two of the 11 interviewees have already implemented IVF monitoring of PC in their reports and routine water body testing.

Discussed in Finding 4, PC monitoring has many benefits over conventional monitoring methods. Most notably, samples taken for identification and enumeration require expert analysis, while IVF measurements for PC produce an immediate reading which can be compared over time. As another statistic to gauge the state of cyanobacteria in a water body, PC measurements provide objective results when compared to cell size influenced samples.

Recommendation 2: MassDEP should develop a standardized, inter-regional database for recording cyanobacteria events specific to surface drinking water supplies

Having complete historical data allows PWSs to use past event details to formulate monitoring plans, ERPs, and gauge the state of their own water body. For example, PWSs in the Western Region have not experienced a bloom event and lack experience, when compared to those who have had blooms, like the Andover Water Department.

Our sponsor, Kristin Divris, informally tracks events that are reported in drinking water, as she is the main contact for cyanobacteria. We found that tracking databases like these often lack vital details, such as cell counts and toxin levels, which make it difficult to determine the event severity. Furthermore, these databases only include events which were reported to MassDEP by PWSs, the public, or other agencies in Massachusetts, such as the MDPH. In our study, we found that there are bloom events that are handled internally by a PWS and therefore never documented.

One way to fix this is by implementing a standardized way to report and document cyanobacteria events. Having a standardized method of reporting, such as a form on a webpage, would prompt PWSs to fill out predefined fields and auto populate a larger database. In doing so, all cyanobacteria would be recorded in a standardized format, allowing for comparison. As part of our

project we developed a cyanobacteria report outline (Appendix G) which could help with recording consistent data from cyanobacteria events. We also applied this outline to past cyanobacteria events (Appendix H). Creating a database that PWS can access would be very beneficial in their efforts to reduce the risk of harmful cyanobacteria events.

Recommendation 3: MassDEP should investigate the effects of treatment methods, such as copper sulfate

An investigation into the long-term effects of current treatment methods can potentially prevent future health implications. We found that copper sulfate is widely used for both regulatory treatment and response. While copper sulfate's benefits are outlined in the third finding, as one interviewee stated, most of its popularity results from its continuous usage and success in past events.

Many of our interviewees were concerned with how treatment methods would affect not only public health, but future ecosystems. The interviewees expressed that the long-term effects of specifically copper sulfate use are not fully known. However, PWS are required to report when they apply copper sulfate, allowing us to know how much and when it has been historically applied. If the MassDEP were to find that copper loading in the water bodies' sediment is a risk, we would know which PWS are most likely to have implications.

Due to popularity, MassDEP should start by researching the effect of copper loading in a water body. If research shows that copper loading will cause health concerns in the future, MassDEP will need to research and identify different treatment methods to be used throughout the regions. Since copper sulfate is widely used, there may be trouble in finding a better alternative. Although there was a pattern of concern through our interviews, nobody suggested an alternative treatment method that could be implemented.

Recommendation 4: MassDEP should assess how FAST can be used in response to cyanobacteria events

While the FAST team normally handles waste and hazardous spills, they have the capability to address cyanobacteria events. Their mobile lab has the equipment to conduct cyanobacteria and cyanotoxin tests onsite, helping to quickly identify the risk to public health.

However, we found that there is a misunderstanding with FAST's purpose and capabilities, between those who run and those who use the program. Interviewees working on the FAST program feel they should be "receiving more requests", with their program's capability. They indicated that especially smaller PWS who lack resources, should contact FAST more often as it is way to receive "free testing". Aside from logistic concerns discussed in Finding 6, we received many reservations regarding FAST's purpose, when presenting these claims made by FAST personnel.

With the ability to provide PWS with additional resources, such as amino acid tests for toxin concentrations, FAST can be an asset if used properly. However, we recommend that MassDEP work with FAST and identify their intent regarding cyanobacteria. If it is determined that PWS should be using FAST more frequently, cyanobacteria events can be identified and managed before there is any concern of treatment plant capabilities, or public health.

To educate PWSs on how FAST can be used for cyanobacteria response, we included a section on our informational trifold (Appendix F) which will be distributed to PWSs. This trifold describes what cyanobacteria are, how they develop, the methods of prevention and response outlined

in the MassDEP guidance document, as well as provide information on resources which MassDEP provides to PWSs.

Recommendation 5: MassDEP should assess challenges preventing PWSs from addressing non-point source runoff

Cyanobacteria is an organism that thrives on nutrients such as nitrogen and phosphorus. These nutrients can be introduced to a water body through non-point source runoff. Addressing runoff is an example of best watershed management and is an effective step for a PWS' nutrient control efforts. Non-point source runoff resulting from rainfall, erosion, and fertilizers are significant contributors to cyanobacteria algal blooms (J. Fitzgerald, personal communication, September 26, 2019).

Mentioned in Finding 5, four out of 11 people interviewed identified that non-point source runoff was a major concern for water bodies. None of the four respondents indicated that they identify points where stormwater is discharged into their water supply. With these results, we see some PWS are not following best watershed management practices which are discussed in the Guidance document. In review, MassDEP employees have concern over non-point source runoff, and some PWS have not addressed recommendations outlined in the Guidance.

To alleviate MassDEP employee concern and understand the extent of Guidance implementation, MassDEP should assess how non-point source runoff is being addressed by PWSs. In doing so, they can determine if the Guidance is helping or if another approach needs to be taken for watershed management. For example, through increased public education, non-point source runoff can start to be managed. PWS can distribute informational material to people living within their watershed, directing them in appropriate ways to manage their footprint (K. Romero, personal communication, September 24, 2019). With an effort to control environmental non-point source storm water and factors contributed by the public, PWS can address a significant detractor of their water quality and contributor to bloom growth.

Recommendation 6: MassDEP should redistribute our survey to draw additional conclusions

In creating our PWS survey, we wanted to gauge concern and preparedness of PWS with surface water supplies around the Commonwealth. We hoped to relate level of concern to the existence and content of monitoring and emergency response plans, how PWS regional location influenced cyanobacteria efforts, and the extend that the MassDEP Guidance had been implemented.

Although we gathered sufficient data through in-person and phone interviews, we relied on the PWS survey for un-biased results. However, with our limited survey responses, our claims are preliminary. Limited by the project's timeline, we were only able to provide the PWSs five days to complete the survey. However, we felt this was an adequate time frame, as the survey took on average two minutes to complete. Our sponsors also sent two additional reminder emails the day of our proposed deadline. Understanding that this survey is distributed by the MassDEP who regulates PWSs, we took consideration to ensure we would avoid concern of intent. We made all questions voluntary, went through many language revisions, and made the survey anonymous. While we had innocent intentions for our fifth survey question, asking how the MassDEP could better help their PWS, we believe this is a place PWS would have intent concerns.

After identifying why the survey lacked results in the first round of distribution, it may be beneficial for the MassDEP to distribute a similar survey once again. While interviews are an excellent means for data collection, having a larger data set would help the MassDEP understand cyanobacteria efforts in a more conclusive manner. While bias is hard to eliminate, drawing conclusions from a large anonymous data set introduces less bias than statements made by MassDEP employees on behalf of the PWSs they overlook.

Chapter 6 Conclusion

Access to potable drinking water is necessary for all life. The consumption of unsafe water can lead to a variety of serious illnesses that have killed many people. While drinking water infrastructure can significantly improve water quality, infrastructure has not eliminated all water contaminants. The blue-green algae known as cyanobacteria poses a threat to all forms of life as it can form into a CyanoHAB and produce dangerous cyanotoxins. This threat has grown in recent years as the effects of climate change and land use promote conditions conducive to CyanoHAB development.

This project cannot singlehandedly reduce the threat of cyanobacteria in surface drinking water supplies in Massachusetts. However, we hope that our work with MassDEP has helped to provide a better understanding of the history of cyanobacteria events in surface water supplies in the commonwealth. As the effects of climate change become more apparent, we hope that our findings and recommendations will continue to assist the MassDEP and the PWSs in the state with preparing for and responding to cyanobacteria.

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Appendices

Appendix A: Interview Questions for Massachusetts Department of Environmental Protection Employees

General Questions

1. What is your role with regards to cyanobacteria events in your region?
2. In what ways were you involved in the cyanobacteria events in your region?

General Preventative Methods

3. In your experience, what prevention protocols does your region most frequently utilize that are intended to manage cyanobacteria prior to an event?
 - a. How were the prevention protocols chosen for your region?
 - b. Have you found any prevention protocols to be ineffective in your region?

General Response Questions

4. Does your region utilize any preset communication protocol when addressing cyanobacteria events?
5. In your experience, what response measures are utilized by your region to address a cyanobacteria event?
 - a. How does your region determine the response measures for a cyanobacteria event?

Specific PWS Site

6. Are there any cyanobacteria events which you have participated in, that were not listed in the email or the list that we brought today?
7. Is there a site that is notably better or worse with preventing and responding to cyanobacteria events in your region?

Final Questions

8. In your opinion, are the current actions taken by MassDEP and PWSs sufficient for preventing and managing cyanobacteria events?
 - a. What sort of changes would you like to see be made by MassDEP with respect to cyanobacteria?
 - b. What sort of changes would you like to see PWS make with respect to cyanobacteria?
9. Has the recent publicity about cyanobacteria events affected the work of MassDEP?

a. In what ways would you expect heightened public awareness to change the actions taken by MassDEP and PWSs?

Appendix B: Interview Questions for PWS Employees

General Preventative Methods

1. What methods of prevention/ algal monitoring does your PWS utilize?
 - a. How were the prevention protocols chosen for your sites?
 - b. Have you found any prevention protocols to be ineffective in your sites?

General Response Questions

2. Does your region utilize any preset communication protocol when addressing cyanobacteria events?
 - a. Is this protocol recorded in your ERP or any prevention plan?
3. What response methods do you most commonly use to respond to cyanobacteria?
 - a. How does your region determine the response measures for a cyanobacteria event?

Specific PWS Site

4. Are there any cyanobacteria events which you have participated in, that were not listed in the email or the list that we brought today?

Final Questions

5. In your opinion, are the current guidelines provided by MassDEP sufficient to communicate effective actions for managing cyanobacteria?
 - a. What sort of changes would you like to see be made by MassDEP with respect to cyanobacteria?
 - b. If you had more resources, how would you more actively address cyanobacteria?
6. Has the recent publicity about cyanobacteria events affected the way you manage cyanobacteria and your sites?
 - a. In what ways?

Appendix C: Survey Questions for Public Water Systems with Surface Water Supplies

Concern:

1. On a scale of 1 to 5 with 1 being not concerned at all and 5 being extremely concerned, how concerned are you with the threat of cyanobacteria in your surface water source(s)?
 - a. Why are you concerned or not concerned?

Prevention:

2. Does your PWS have an algal monitoring plan?
 - a. Yes, Written
 - b. Yes, Unwritten
 - c. No
 - d. Other (please specify)

Response:

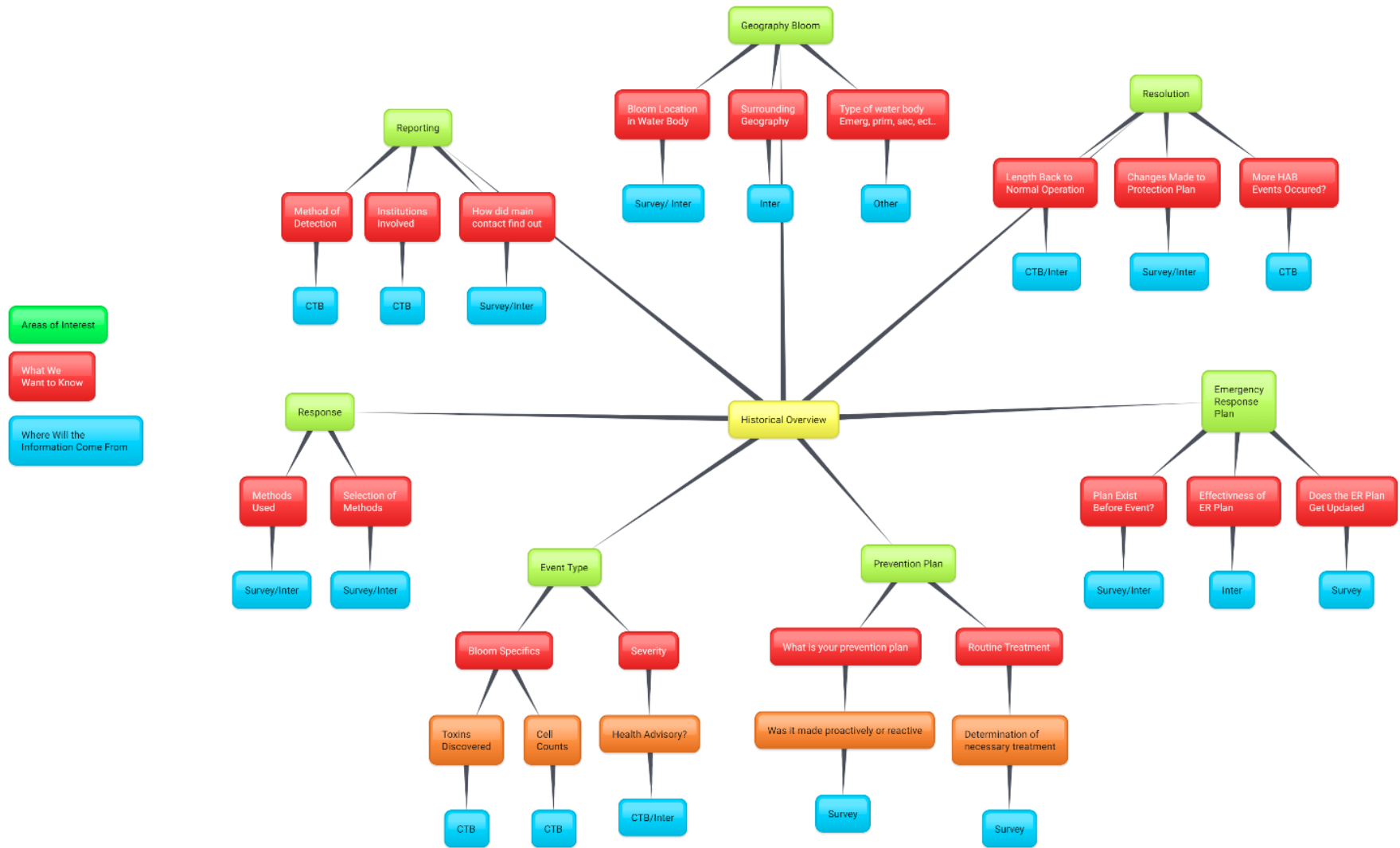
3. How does your Emergency Response Plan (ERP) address response to cyanobacteria? (Check all that apply)
 - a. MassDEP contact information for directive
 - b. As any source contamination event already required within the ERP
 - c. Refers to algal monitoring plan
 - d. Monitoring protocol for cyanobacteria identification/enumeration (counts)
 - e. Monitoring protocol for cyanotoxins analysis
 - f. Criteria for in-source treatment (including copper-containing algaecides or other pesticides)
 - g. Steps to acquire a permit for source treatment if necessary
 - h. Request MassDEP Field Assessment Support Team (FAST) assistance
 - i. Protocol for anticipated treatment changes
 - j. Other (please specify)

Relationship:

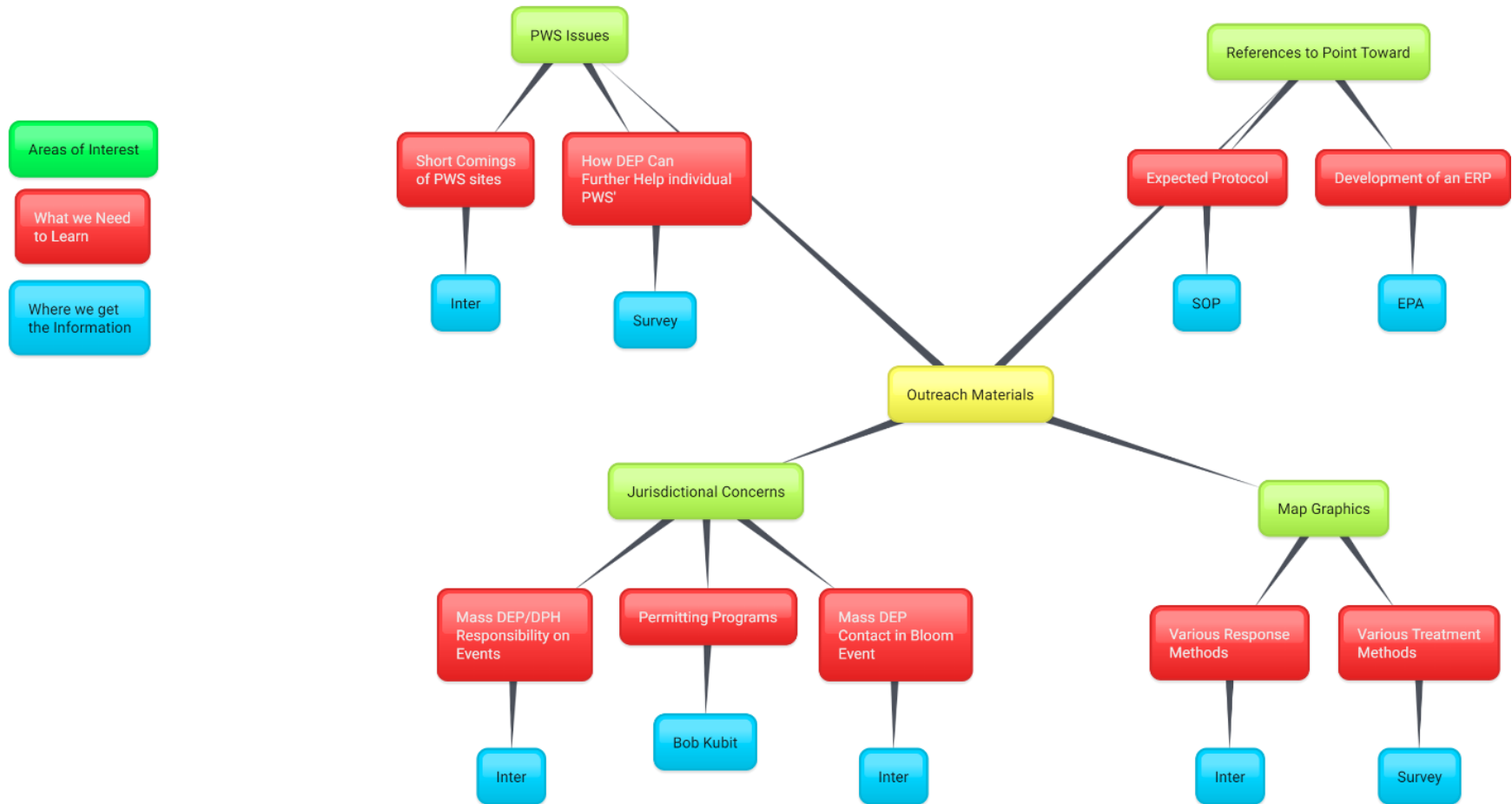
4. Are any measures used to mitigate potential cyanobacteria events? (Check all that apply)
 - a. Routine visual observations of source(s)
 - b. Routine algaecide applications
 - c. Surface Water Supply Protection Plan
 - d. Source water temperature monitoring and evaluation
 - e. Source water nutrient monitoring (i.e., nitrogen or phosphorus sampling) and evaluation
 - f. Source water pH monitoring and evaluation
 - g. Source water phycocyanin (PC) monitoring
 - h. Source water residence time determination
 - i. Stormwater discharge point identification
 - j. Source water perimeter security (e.g., fencing, signage, security cameras)
 - k. Installation of vegetative strips to address storm water
 - l. Work with local DPW or MassDOT to reduce entry of untreated storm water
 - m. Work with local DPW or MassDOT to treat storm water before entry
 - n. Work with local DPW or MassDOT to eliminate entry of untreated storm water
 - o. Public outreach to educate residents (dog waste pickup, fertilizer usage, etc...)
 - p. Other (Please specify)
5. What type of assistance can MassDEP provide to better assist your system regarding:
 - a. Preventive Measures

- b. Emergency Response Measures
- 6. Which MassDEP region are you part of?
 - a. Western Region
 - b. Central Region
 - c. Northeast Region
 - d. Southeast Region

Appendix D: Historical Overview Flowchart Guide



Appendix E: Outreach Materials Flowchart Guide



Appendix F: Informational Trifold for Public Water Systems

Responding to a CyanoHAB

There are a variety of actions and resources for responding to a potentially harmful cyanobacteria bloom. Actions which can be taken by a PWS when responding to a CyanoHAB include:

- Collecting samples for cyanobacteria identification and enumeration.
- Sampling for toxin analysis.
- Using algaecides such as Copper Sulfate (CuSO₄) or Hydrogen Peroxide to kill the cyanobacteria cells.
- Aluminum Sulfate (Al₂(SO₄)₃) which can be used to reduce phosphorus levels in the water body.

Permitting requirements for herbicide and pesticide application to waterbodies can be found at: www.mass.gov/how-to/wm-04-herbicide-application. The CuSO₄ notification form can be found at: www.mass.gov/lists/source-water-protection-forms-and-templates

Additionally, MassDEP provides resources to PWSs for a CyanoHAB response. These resources include:

- Field Assessment and Support Team (FAST) a free, state-wide and state-sponsored program that has equipment used for screening CyanoHAB development.
- PWSs may contact regional MassDEP employees for assistance with CyanoHAB questions

Jurisdiction and Oversight

Jurisdiction over a water body with reports of a CyanoHAB depends on how the body is used. In general, CyanoHABs in water bodies used for drinking water are overseen by the PWS and MassDEP through the Drinking Water Program (DWP). CyanoHABs in water bodies used for recreation are overseen by the local Boards of Health in coordination with Massachusetts Department of Public Health (MDPH) which makes a health-based recommendation for the water-body. MDPH may recommend an advisory in cases where the water body is being used for both drinking water and recreational purposes, the two agencies will coordinate their response.

MassDEP Contact Information

MassDEP contacts who can assist with PWS CyanoHAB response.

FAST	State Wide	888-304-1133 or www.mass.gov/service-details/request-a-fast-vehicle-deployment
Kristin Divris	CERO	Kristin.divris@mass.gov
Amy Lachance	NERO	Amy.lachance@mass.gov
Richard Rondeau	SERO	Richard.rondeau@mass.gov
Cathy Wanat	WERO	Catherine.wanat@mass.gov
MDPH	Recreational & Mixed Usage	617-624-5757

Cyanobacteria & Surface Drinking Water Suppliers



Contact information
Kristin Divris Drinking Water Program (DWP)
kristin.divris@mass.gov

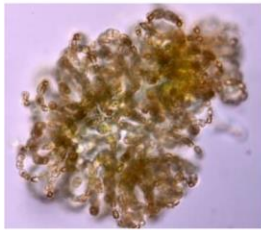
Kathleen Romero Drinking Water Program (DWP)
kathleen.romero@mass.gov



This pamphlet was developed through an Interactive Qualifying Project with Worcester Polytechnic Institute and MassDEP.
Fall 2019

What is Cyanobacteria

Cyanobacteria, also known as blue-green algae, are a photosynthetic bacteria present in all water bodies, normally in low numbers. These bacteria, specifically *Anabaena* and *Microcystis*, produce cyanotoxins such as cylindrospermopsin and microcystins, during regular cell functions. When the bacteria cells lyse, or die, the cyanotoxins are released.



Microscopic image of *Anabaena*, From MassDEP Guidance: Cyanobacteria and Public Water Systems

During a Cyanobacteria Harmful Algal Bloom, or CyanoHAB, the cyanobacteria population is capable of growing from 1,000 cells/ml to over 25,000 cells/ml in 2 weeks. During a bloom, large quantities of cyanotoxins are produced by the individual bacteria.

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

From MassDEP Guidance: Cyanobacteria and Public Water Systems

In 2015, the EPA developed a 10-day health advisory for the toxins Microcystins and Cylindrospermopsin in drinking water. For school age children and adults, ingestion of 1.6 µg/L of microcystins for a 10-day period can cause adverse health effects including gastrointestinal issues, liver failure, and in some cases, death.

Factors Promoting Bloom Growth

The rapid growth of cyanobacteria which can cause a CyanoHAB is encouraged by many factors. As detailed in the "MassDEP Guidance: Cyanobacteria and Public Water Systems" (2018). Factors include:

- Water temperature above 25°C or 77°F
- Long residency times
- Increased runoff from storms
- Excessive nutrient loading (Nitrogen and Phosphorus)
- Compromised function of proximate wetlands
- Non-existent, or compromised wooded buffer zones.

Additional information on Cyanobacteria and its growth factors can be found in the MassDEP Guidance located at: www.mass.gov/doc/massdep-guidance-cyanobacteria-and-public-water-systems



Not all CyanoHABs will have the same appearance. Some will form a blue-green surface scum. Other blooms may not be visible on the surface. Screening for cyanobacteria is important to detect all blooms.

Preventing Cyanobacteria Blooms

While a CyanoHAB can grow rapidly and cause serious health effects, there are actions which can be taken to prevent a CyanoHAB from developing. Prevention methods which can be practiced by a PWS and the public in the watershed to reduce nutrient loading include:

- Maintaining septic systems
- Reducing use of fertilizers
- Picking up and proper disposal of pet waste
- Maintaining a wooded/wetlands buffer

PWSs can implement these actions through:

- community outreach and
- protecting land through the use of conservation restrictions.

Additional information on conservation restrictions can be found at: www.mass.gov/how-to/ws-26-sale-or-acquisition-of-land-for-water-supply-purposes

Additionally, there are source actions a PWS can take for better control of CyanoHAB formation depending upon risk. These actions include:

- Development of an algal monitoring program
- Routine algacide application (Copper Sulfate (CuSO₄))
- Artificial mixing of water source
- Biological Controls (Floating wetlands)

Many activities can be included in an algal monitoring program such as routine inspection of water source, monitoring water temperature, phycocyanin levels, and turbidity levels. Additional details on monitoring techniques can be found in the MassDEP Guidance.

Appendix G: Cyanobacteria Bloom Event Recording Template

Name of PWS

Name of DEP Employee Affiliated with Location

Name of PWS superintendent

Location of Bloom

Town, and water source, location within water source

Reporting

Who reported the event, the person or agency which it was reported to, and how the correct person to handle the report was determined and notified.

Event Type

Whether or not this was an actual bloom, or a prevention measure. If it is an actual bloom, then the location of the bloom in the water source with respect to the inlet for the water treatment facility.

Site's Preventive Maintenance for Cyanobacteria

If applicable, how did the site create their plan and what does it consist of. Does any routine monitoring or chemical application occur? What monitoring methods are employed? If a routine treatment is used, what criteria must be met for a routine treatment to occur?

Method of Response

What algaecides or other chemical methods were used to treat the bloom. What other response methods were utilized?

Site's Emergency Response Plan

Did the site have an Emergency Response Plan (ERP)? If so, what steps were laid out in the plan? Were they all followed? If the site didn't have an ERP or they didn't follow all steps, how did they respond to the situation?

Resolution

How long did it take for the bloom to be resolved? Did the MDPH post a health advisory? If so, how long was the health advisory in place? What led to a return to normal operation? When did they start drawing water from the specific location that the bloom occurred?

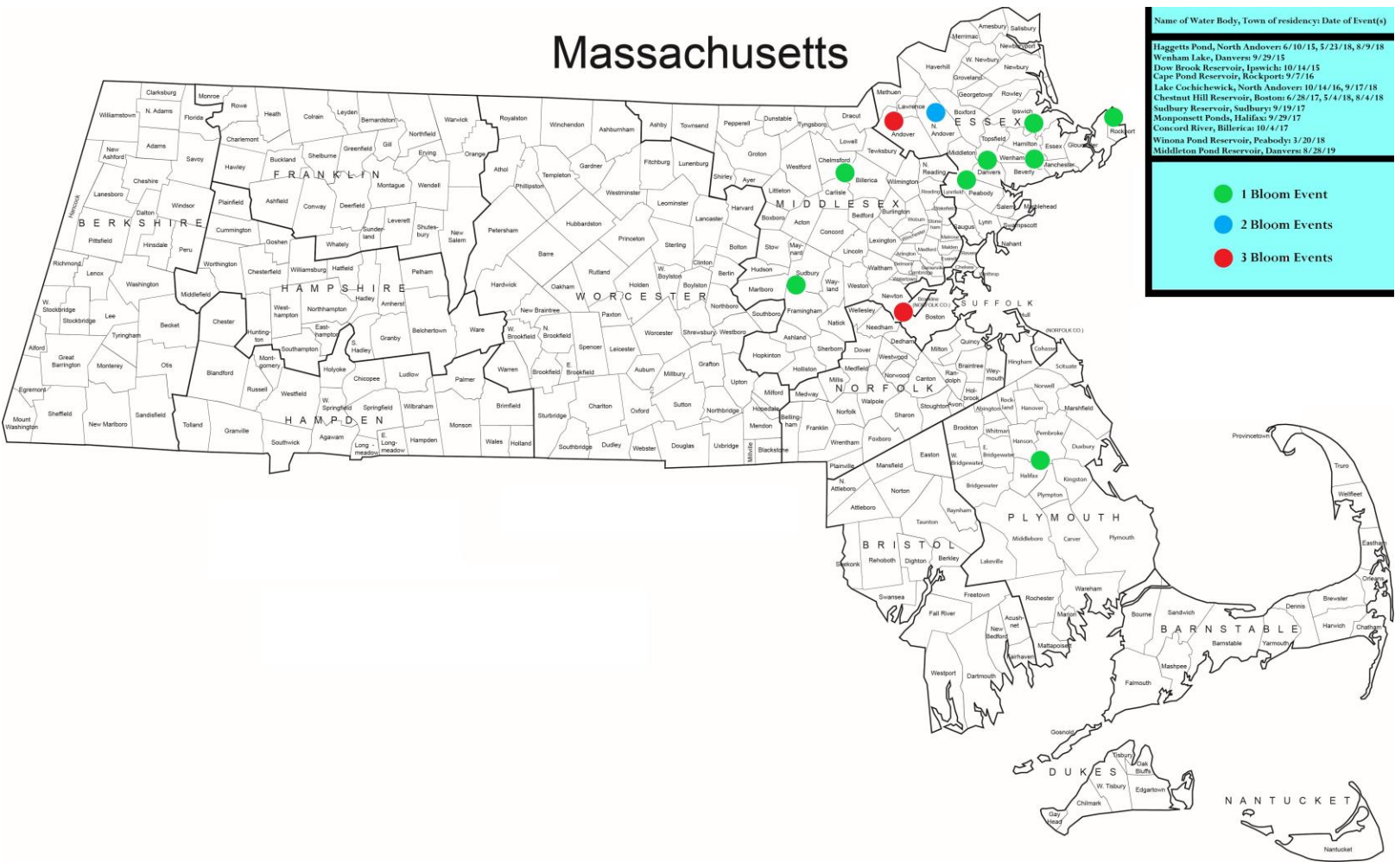
Appendix H: A History of Cyanobacteria Events in Massachusetts

A History of Cyanobacteria Events in Massachusetts

Massachusetts

Name of Water Body, Town of residency	Date of Event(s)
Haggets Pond, North Andover	6/10/15, 5/23/18, 8/9/18
Wenham Lake, Danvers	9/29/15
Dow Brook Reservoir, Ipswich	10/14/15
Cape Pond Reservoir, Rockport	9/7/16
Lake Cochichewick, North Andover	10/14/16, 9/17/18
Chestnut Hill Reservoir, Boston	6/28/17, 5/4/18, 8/4/18
Sudbury Reservoir, Sudbury	9/19/17
Momonsent Ponds, Halifax	9/29/17
Concord River, Billerica	10/4/17
Winona Pond Reservoir, Peabody	3/20/18
Middleton Pond Reservoir, Danvers	8/28/19

- 1 Bloom Event
- 2 Bloom Events
- 3 Bloom Events



Introduction to Bloom Events in Massachusetts

During the 2014 cyanobacteria bloom in Lake Erie, the water supplier for Toledo, Ohio was forced to cut off the city's water supply. This incident left the city's 400,000 citizens without drinking water for the weekend. This event prompted the Environmental Protection Agency (EPA) to include cyanotoxins in its Fourth Unregulated Contaminant Monitoring Rule (UCMR4) which required PWSs in the US to monitor for cyanotoxins from 2018 to 2020 (EPA, 2018). Additionally, the Massachusetts Department of Environmental Protection (MassDEP), and the Massachusetts Department of Public Health (MDPH) developed recommendations and guidance regarding cyanobacteria and the cyanotoxins that they produce. Starting in 2015 in Massachusetts, employees at MassDEP started to track and identify cyanobacteria events in public water suppliers (PWS) surface drinking water sources.

This tracking effort has resulted in a total of 16 recorded bloom events as of 10/2/19. In this overview, a bloom event is classified solely as a bloom response/discovery that was recorded through the MassDEP channels. A full bloom event is qualified as a growth of cyanobacteria that grows to either exceed 70,000 cells/mL or requires cyanotoxin testing due to the visible size. The 70,000 cells/mL qualifier is part of the MDPH guidance, where recreational bodies of water with cyanobacteria concentrations in excess of 70,000 cells/mL must have health advisories posted around the perimeter of the water body (Beaton, et al. 2018). This is independent of any MassDEP regulations or requirements, but for the sake of communicating the severity of blooms this value is a practical tool for this paper.

Cell concentration is a useful indicator for the threat of a bloom as there is a relation between cell count and toxins produced. While there is no direct conversion rate between the two values, the higher the cell concentration in a location the higher the cyanotoxin concentration. The EPA released information about the quantity of cyanotoxins that, if consumed over a 10-day period, can cause adverse health (EPA, 2019). A school-age child or adult will begin to develop illness after consuming water with microcystin levels at or above 1.6 µg/L for a 10-day period. Illness from cyanotoxin ingestion can include abdominal pain, nausea and vomiting, diarrhea, pneumonia, and, in some cases, death (EPA, 2019). The most common measurement for cyanotoxin analysis of water samples involves PPB, which is a roughly 1:1 ratio from PPB to µg/L.

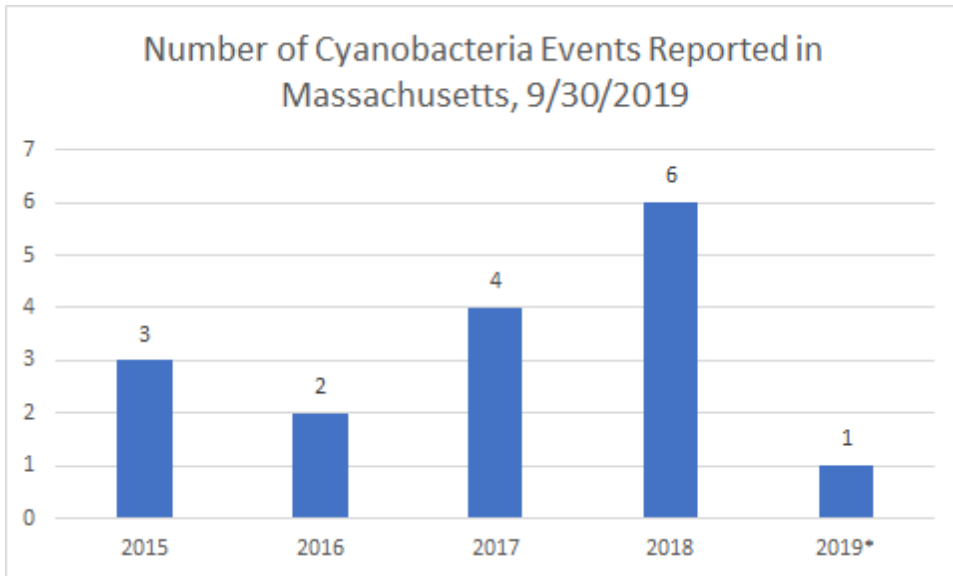


Figure 6. A Chart of Reported Cyanobacteria Events in Massachusetts since 2015

The annual distribution of reported bloom events in drinking water sources in Massachusetts, as seen in Figure 1, does not show any trends that indicate an increase in reports year over year. The statistical variance isn't significant enough, nor are there enough data points to make a claim that they are becoming more frequent in the commonwealth of Massachusetts. This does not support or contrast the common belief that cyanobacteria blooms are becoming more common due to changing environmental factors, as no strong conclusions can be drawn from this data set.

Jurisdiction Overview

Jurisdiction over a water body with reports of a cyanobacteria harmful algal bloom (CyanoHAB) depends on how the body is used. In general, CyanoHABs in water bodies which are used for drinking water are overseen by the PWS and MassDEP through the Drinking Water Program (DWP). Meanwhile, CyanoHABs in water bodies on or within state land which are used for recreation are overseen by the MDPH who will make a health-based recommendation. If the recreational water body is not on or within state property, the MDPH will also coordinate with local Boards of Health and Health Departments to determine if a health-based recommendation is necessary. In the case of the water body being used for both drinking water and recreational purposes, the two agencies will coordinate their response, and will conduct their duties as if the site was only a recreational or drinking water body.

The Story of Bloom Events in Massachusetts

2015: Haggetts Pond, Wenham Lake, Dow Brook Reservoir

The first recorded cyanobacteria incident in the Commonwealth occurred in Haggetts Pond. This event was not a CyanoHAB, but simply an act of prevention. The PWS applied copper sulfate to the water body at the start of the season in order to stymie the cyanobacteria population low throughout the summer.

The first cyanobacteria bloom event occurred in Wenham Lake and was reported on 9/29/15. Although Wenham Lake is a drinking water source, and enumeration is not required, cell counts gathered on site were found to be between 62,000 and 234,000 cells/mL. The cell counts were well above the 70,000 cell/mL level used by the Massachusetts Department of Public Health to determine the posting of health advisories. However, Wenham Lake did not have to comply with this standard as it is not a recreational body of water. While the bloom had elevated cell counts, it was concentrated in a location away from the water intake. Additional testing around the water intake showed no concerning levels of cyanobacteria. The PWS continued to draw water from the site, ensuring it was safe after being treated by the treatment plant by completing toxin analysis tests on the finished water. The PWS choose not to engage in any active response as the cyanobacterial bloom was far enough from the intake to not be a concern, toxin results were below detectable values, and heavy rainfall dispersed the bloom.

The final cyanobacteria even in 2015 was at the Dow Brook Reservoir. This bloom event was the first to feature assistance from the state-sponsored Field Assessment & Support Team (FAST) which is trained to respond to environmental emergencies in Massachusetts, including CyanoHABs. Pictorial data did not suggest that there was cause for concern, as the size of the bloom was very small. A shutdown did not occur as the toxin analysis came back with levels of Microcystis below 0.5 PPB, far below dangerous levels.

2016: Cape Pond Reservoir, Lake Cochichewick

The Rockport Water Department initially discovered the algal bloom problem in the Cape Pond Reservoir due to heightened total suspended solids (TSS) levels. This shutdown lasted for approximately a week before it was reported and responded to by FAST. No cell enumeration was completed for this site, but toxin analyses for Anatoxin-A, Microcystis, and Cylindrospermopsins all resulted in non-detect (ND) results, meaning the concentrations were too low to be detected. During the time span from the initial shutdown to the restoration on 9/20/16, the PWS shifted to another site in its system, Carlson Quarry, and drew water solely from that site. Because they were reliant on one source instead of the normal two, the PWS requested that their request to draw additional water from Carlson quarry be expedited. Additionally, the PWS banned all non-essential water usage in their service region. The practice of relying on a backup site during a cyanobacteria event in the main site is common for water suppliers with multiple locations available. Access to an alternate water source is an important component in a PWS' Emergency Response Plan (ERP).

Lake Cochichewick, on the other hand, is the only supplier of water for the North Andover Water Department. For this reason, North Andover takes a more aggressive approach to monitoring and treating a cyanobacteria event. When Lake Cochichewick experienced a cyanobacteria bloom event in

2016, the PWS was able to prevent a CyanoHAB from developing through the routine testing that they conduct on the water body. The North Andover Water Department (NAWD) routinely measures phycocyanin (PC), a pigment unique to cyanobacteria. Through this measurement, NAWD was able to track the cyanobacteria biomass in their water sources. When they detected an increase in the PC concentration in the water body, they immediately responded by starting the copper sulfate application process and took samples for enumeration, even though no visible bloom was present. Cell count results never exceeded 53,000 cells/mL, and toxin analyses showed levels of toxins below 0.33 PPB, at safe levels during the event. The response and prevention showed in this site is beyond what is legally required. However, it proved essential in stopping a bloom event from becoming a problem while it was not visible.

2017: Chestnut Hill Reservoir, Sudbury Reservoir, Monponsett Ponds, Concord River

The Chestnut Hill Reservoir incident in 2017 highlights the interplay between water bodies where recreational use is not permitted but may still occur. Upon discovery of the bloom event, the Massachusetts Water Resource Authority (MWRA) took samples of the water for enumeration and toxin analysis purposes and informed MDPH of the event due to the stated recreational usage on the site. The results of the enumeration revealed counts between 69,000-128,000 cells/mL, and toxin analysis showed level of Microcystis <1 PPB. This location is not a primary source of water for the MWRA, but instead a backup emergency source. For these reasons, the DEP recommended against active chemical treatment and instead recommended a health advisory along with the MDPH. If active treatment was done and the toxins were exposed to the water body in higher concentrations, any recreational usage at all would become very dangerous, so their choice to both not actively treat it and to post advisories against using the water in any capacity were important in protecting the population. Following over 5 enumerations, including counts well below the 70,000 cells/mL threshold separated by a week in time, the MWRA determined that the CyanoHAB was no longer a credible threat and the health advisory could be withdrawn.

The Sudbury Reservoir bloom was first detected as part of routine monitoring of the drinking water source on 9/14/17. The MWRA directly reported this event to the DEP, going directly to the proper channel of communication. Cell counts and toxin analysis revealed levels that were not concerning. The bloom was declared resolved on 9/20/17 following additional testing of the water source.

The incident in the twin Monponsett Ponds on 9/29/17 was another example of recreational bodies with drinking water applications. The ponds are surrounded by residential areas and has route 58, a state highway, running directly between the two ponds. For this reason, when a bloom was detected, the MDPH responded quickly with a health advisory to not enter the water, as it is highly visible and an easily accessible water body. Meanwhile, the East Monponsett Pond is used as part of Brockton's water supply system as it has a release valve that flows into Silver Lake. Because of the bloom in the West Pond, the Brockton Water Commission (BWC) conducted enumeration in both ponds. The cell counts for West Monponsett pond were at 69,000 cells/mL while East Monponsett pond had cell counts of 42,000 cells/mL, below the MDPH 70,000 cells/mL. Because BWC did not want the cyanobacteria bloom to spread into Silver Lake, they postponed water diversion from East Monponsett, and applied aluminum sulfate to both ponds to treat the blooms. On 10/26/17 samples were taken from

East Monponsett and came back negative for toxins, so the health advisories were withdrawn, and normal activities continued at each pond.

The Concord River bloom was discovered when a resident that lived along the river noticed an accumulation of, what he identified to be, cyanobacteria cells. This resident was an EPA scientist knowledgeable on cyanobacteria, which allowed the individual to better communicate the information to the proper authorities and take his own samples from the water. FAST was then contacted to investigate the bloom event, as well as the MDPH as the Concord River is also a recreational water body. Upon arrival, FAST tested the water using in-vivo fluorometry (IVF) and detected levels of phycocyanin that were not indicative of a cyanobacterial bloom. Later scans of samples taken in the main cluster revealed concentrations of phycocyanin 100x the size of the original sample. FAST conducted Abraxis tests on the samples to test for Microcystis and cylindrospermopsins which came in negative. However, there were concerns pertaining to the accuracy of the tests due to the expiration date having passed on the kits and a known production defect. Later toxin analysis produced results that were not sufficient enough to inform MassDEP of, so these results are not recorded, but usual operations continued following these tests. This case demonstrates how an informed populace can be extremely helpful to any bloom control effort. Due to the fact that he was so knowledgeable, he was able to provide useful information and contact the proper departments to handle the situation.

2018: Winona Pond Reservoir, Chestnut Hill, Haggetts Pond, Chestnut Hill, Haggetts Pond, Lake Cochichewick

The initial reporting of the Winona Pond Reservoir occurred when FAST was informed of “fishy and musty” odors by people in the area. Within two days, samples were submitted for enumeration which revealed cryptophytes, a form of golden-brown algae, not the blue-green cyanobacteria genre. This specific form of algae does not produce cyanotoxins and is not a health hazard for the people drinking the water, but the scent and aesthetic is unpleasant. Despite this knowledge, cyanotoxin assessment was recommended and the PWS complied. This toxin analysis was expected to come up as non-detects, due to the lack of toxin producing bacteria detected, but the test was done more so for the public’s conscience, and so they could be certain the water was safe.

The Chestnut Hill Reservoir’s bloom event in 2018 was first reported to the DEP by MWRA themselves. During routine water monitoring, the MWRA discovered the growing bloom and took samples for enumeration. At certain parts of Chestnut Hill, the cyanobacteria count reached 270,000 cells /mL. Due to the known recreational usage of the region, the MWRA posted signage at five locations around the reservoir. After conducting enumeration, the MWRA conducted toxin analysis which had levels of toxins below dangerous levels. Nevertheless, MWRA responded with an aluminum sulfate application to the water source. This treatment led to an improvement in water quality, but cell counts still showed levels of Oscillatoria in excess of 70,000 cells/mL. Phosphorous levels tested before and after the application of aluminum sulfate also indicated that there were increased levels of Oscillatoria in the lower levels of the reservoir. There is no specified ending event for this case.

The Haggetts pond bloom in May, similar to the Chestnut Hill Reservoir’s bloom, was discovered due to the algal monitoring plan in place on-site. Following the discovery, the Andover Water Department took samples of raw water and of finished water at the entry point of their distribution center. Toxin analysis of these samples revealed levels of Anatoxin A, cylindrospermopsins, and

nodularin's below the 0.3 PPB, well below the threshold of danger. Due to this, the site continued to operate in its full capacity.

In August of 2018, the Chestnut Hill event was continued with further updates, but there was no additional action taken. The MWRA had already identified the situation as under control, so public response and concerns about the topic were responded to with explanations about the state of the MWRA system, and that they could afford to have this site non-operational for the time period. The reservoir, according to email correspondence during the event, appeared to contain more cyanobacteria than the event earlier in the year. However, the status of Chestnut Hill as an emergency backup reservoir was still the same.

The second event at Haggetts Pond in 2018 was first declared when the Andover Water Department informed the DEP that they were hiring an independent contractor to apply copper sulfate to Haggetts pond in order to mitigate a growing anabaena population. This response is outlined as part of the PWS' prevention and response plan. When amounts of cyanobacteria are found as they were in this case, the immediate response of the Andover Water Department is application of sulfate. The cyanobacteria was discovered when doing phycocyanin analysis and finding ratios of PC:Chl-A that were far above normal values (PC:Chl-A ratio of 46:1). Samples taken for toxin analysis yielded levels of toxins that were below detectable levels, and the site was deemed still safe for consumption.

As part of their standard monitoring program where they frequently measure the PC:Chl-A ratio, the North Andover Water Department discovered a growing cyanobacteria population in September of 2018. After this discovery, they informed the DEP of the development, and collected samples for enumeration. The highest recorded cell counts were 11,000, a level that is far below one which would cause concern. Cyanotoxin analysis also yielded values that were far below dangerous levels, so the site was able to safely continue delivering water to its community. As mentioned earlier, Lake Cochichewick is the sole source for this PWS, so ensuring its health is essential for the NAWD. This factor explains why their monitoring is robust enough to detect these slight changes in PC level, which allowed them to find and stop the bloom before it became a credible threat to the quality of the water.

2019: Middleton Pond Reservoir

This bloom was first discovered when a citizen was walking dogs around the water body and noticed a growing bloom on the perimeter of parts of the pond. Upon reporting, the Danvers Water Department took action to increase their monitoring of the bloom event, but the bloom increased in size when the same citizen returned a week later to walk dogs again. Pictorial data suggests this was a full bloom event, but the Danvers Water Department noted that the bloom was far from the intake, so they continued to monitor the situation and draw water. The DWP also has an on-site laboratory, so they were able to test for toxins and enumeration without sending samples away to an outside contractor. The aforementioned citizen continued to express concern and request visible signage be posted to protect people from the bloom event, but due to the fact that the Middleton Pond Reservoir is a private location and recreational use of the surrounding area is not permitted, people should not even be in that location in the first place. For that reason, no public warnings were posted around the water body.

Through the years, there was an increase in bloom event frequency, but the sample size is far too small to assert it is representative of anything other than natural variance. This increase also did not carry into 2019, as so far there has only been one serious bloom event reported to the DEP, which was discovered by a citizen who stumbled upon the site.

Insight from Case Studies

We have found some general trends relating to preparedness of PWS for bloom events. Sites that have never had bloom events (Ipswich, Billerica, Rockport, Peabody) are more likely to contact FAST than sites that have more extensive experience (Monponsett, Chestnut Hill, North Andover, Haggetts pond). This indicates that sites that have experienced blooms are more likely to handle the situation independently and need less guidance from MassDEP. This also indicates that experience matters when presented with a cyanobacteria event as many suppliers do not know their level of preparedness until they experience a bloom event. In our research, we found that certain regions, such as the Western Region (WERO) and Central Region (CERO) have never had any bloom events, but the DEP employees think they are adequately prepared for responding to a bloom event. It is impossible to truly know their level of preparedness without testing their emergency response plans, though.

Another discovery through these case studies is that sites with experience handling bloom events do a better job of discovering the event themselves and reporting it to DEP. This means that there is a more streamlined communication process, making the response efforts clearer and more communicable. This experience contributing positively can be seen in the Massachusetts Water Resource Authority, North Andover Water Department, Brockton Water Commission, and the Andover Water Department.

The MWRA doesn't actively monitor Chestnut Hill, but they were proactive in responding to the Sudbury Reservoir bloom, and the Chestnut Hill blooms in 2017/2018 despite the lack of active monitoring. North Andover might have more experience in managing bloom events solely due to the fact that they are monitoring the water in such a thorough way that they detect small blooms that might just subside naturally if they weren't paying any attention. Their Secchi readings to measure turbidity, phycocyanin counts, and frequent visual monitoring are essential, particularly since Lake Cochichewick is their sole water source. The BWC has experience with blooms in Monponsett, even though only one is officially recorded as a drinking water source bloom in East Monponsett. Their experience in West Monponsett informed their decisions to post health advisories and keep the drain between Silver Lake and East Monponsett closed during the bloom. The Andover Water Department, like the NAWD, also frequently monitors their water body and is very diligent about reporting information to the DEP whenever anything serious arises.

Specific Case Study Insight

Most PWS that have experienced bloom events demonstrated unique characteristics that relate to cyanobacteria management. These experiences can be very beneficial in informing future decision making processes when experiencing blooms, even for other PWS that simply share characteristics with the PWS that experienced the blooms.

The Wenham lake bloom event showed that even if there is a large event in the water, sometimes waiting it out can be sufficient if the proper conditions are present (low toxin count, proximity from intake, incoming strong weather patterns)

The Cape Pond Reservoir event showed that having multiple sources capable of supplying your whole water supply is extremely helpful in ensuring your PWS can deliver safe water. Because they were

able to use Carlson Quarry, they didn't rush the return of Cape Pond Reservoir, and they were able to manage the bloom before returning it to operation

The first Lake Cochichewick event, on the other hand, showed how seriously you have to take a credible bloom threat, especially when it is occurring in your only drinking water source. In this event, they showed proactive response and preventive measures that were above and beyond what was expected of them, a large part of why they were able to handle the bloom

The Chestnut Hill reservoir incidences show how large water suppliers, such as MWRA, may choose to handle a visible bloom event in an area with significant recreational use. Even though it is a drinking water supplier and not a recreational body, they still had the level of awareness to treat it as if it were a recreational source, posting health advisories around the water body telling people not to enter or use the water. The blooms also show the inherent value of having emergency backup sources. Of course, they would like these locations to be usable if an emergency occurs, but they made the value assessment that using their resources on this source would not be necessary for their water supply purposes, and they were right.

The Monponsett ponds highlighted the way that water bodies in close proximity affect each other. First and foremost, the Brockton Water Commission had to be aware of the condition of their water supply's feeder streams, in order to ensure that no derelict water enters their system. They also have to make sure that the West Monponsett Pond isn't negatively impacting the East pond, as the West has historically suffered more extensively from bloom events than the East. Overall, this event shows how complicated the problem becomes when multiple water bodies are being used to provide water to a main source, and the level of care a PWS must take in protecting their water.

The Concord River bloom event showed the importance and value of having an educated populace. Because the citizen who discovered the bloom was knowledgeable, he responded in the appropriate ways, not overreacting or misinterpreting what he saw in the water. This helped the DEP and the PWS work effectively to stop the bloom event, and having an informed populace is a valuable tool in a PWS toolbox.

The Winona Pond Reservoir event showed the importance of ensuring public safety to the public. There was not a real need for the responses taken such as cyanotoxin analysis, but the tests were taken anyway in the interest of the public that the water supplier surfaced.

The Middleton Pond Reservoir event highlights the way that some PWS can choose to handle recreational use around their private water source. Because they don't allow people on their premises, any request for public health postings warning people from entering the raw water body is unnecessary.

Specific Case Study Insight Organized

Specific Finding	Cases that demonstrate this	Justification
Waiting for the bloom to dissipate can be sufficient	Chestnut Hill, Wenham Lake,	When environmental factors align and you have other sources to draw from, it may be most resource efficient to simply allow a bloom to handle itself
Utilizing backup sources is an important part of an ERP	Sudbury Reservoir, Chestnut Hill Reservoir (all 3), Cape Pond Reservoir	The ability to rely on other sources in the event of a serious bloom can be important in saving resources that can be used elsewhere
Strong preventive and proactive measures are important in stopping blooms before they can become threats	Lake Cochichewick (both), Haggetts Pond (both)	The best way to combat a bloom is to make sure it doesn't happen. Sites with strong preventive plans can more adequately manage blooms.
If you only have one water source, ensuring the water quality is paramount	Lake Cochichewick	If you have no backup available, you must ensure the one you can use is always operational
Awareness of recreational use, even if unpermitted, is important in ensuring the public is safe in or around your water body	Chestnut Hill Reservoir (all 3 entries)	Protecting the populace can include things that technically do not have to be done, but it is in the best interest of the public to act in their interest
Understanding and addressing the tributaries into your final water source is important in protecting your water source	Monponsett Ponds	Water source protection involves ensuring the water that feeds into your source is also safe and of good quality.
An informed populace can be extremely helpful in managing cyanobacteria events	Concord River	Informed citizens can discover bloom events and react to them appropriately.
Some PWS may choose to stay firm on their "unpermitted recreational usage is not allowed" policies	Middleton Pond Reservoir	PWS own the land surrounding their sources for a reason. If they choose to enforce their trespassing orders, they do not need to post public signage

Table 2. Main Findings from Each Case Study

Table 2 organizes the main findings from the case studies into the three sections. The first section is the finding, the second section is a list of case studies which support the finding. The final section provides a justification for the finding.

Appendix: Case Studies

Andover Water Department – 6/10/15

MassDEP contact affiliated with event: Melissa Privetera

Andover Water Department contact affiliated with event: Alan Carifio

Location of Bloom

Haggetts pond, Andover, Massachusetts.

Reporting

The Andover Water Department noticed the start of blue-green algae in the water and took samples that were identified as such. As part of their local prevention plan, the PWS applied copper sulfate to the water body. The PWS then reported this application to the DEP directly, and there were no other parties involved in the process.

Event Type

This was not a full CyanoHAB event. The only hint of cyanobacteria was in the blue-green algae that was observed, but the density and count of cells was too small to be considered an issue. The Andover Water Department responded with routing Copper Sulfate treatment. This response was preventative, as there was no significant bloom to mitigate. No public notice was posted

Site's preventive protection plan

On an annual basis, the Andover Water Department applies copper sulfate to Haggetts pond. This annual treatment intends to inhibit the growth of cyanobacteria in large volumes before they can begin.

Method of response

Copper sulfate application

Site's Emergency Response Plan

The Andover Water Department maintains all their necessary permits to apply sulfate and algicide. They also have a discharge plan, which details how Andover will investigate the presence of algae in the pond and measures that will be taken for treatment.

Resolution

Due to the fact that this was an act of prevention, there was no end date to the event.

Salem-Beverly Water Supply Board (SBWSB) – 9/30/15 – 10/19/2015

MassDEP contact affiliated with event: Rebecca Weidman

Salem-Beverly Water Supply Board contact affiliated with event: Peter S. Smyrnios

Location of Bloom

Wenham Lake, Beverly, Massachusetts

Reporting

A citizen emailed pictures of the potential HAB to the DCR who then forwarded the emails to the DPH who notified MassDEP. DEP NERO contacted the PWS which identified the bloom had been present for 1-1.5 weeks at the time of the correspondence.

Event Type

Enumeration revealed values of 62,017 cells/mL and 234,570 cells/mL at varying depths. No public notice was posted for the event.

Site's preventive protection plan

None

Method of response

There was no active response taken by the PWS, aside from active monitoring of the site conditions and the bloom state. Environmental conditions, such as heavy rainfall and wind mixed the water body and dispersed the bloom

Site's Emergency Response Plan

On 9/28, the PWS collected two sources of samples that were sent to Phycotech and on 9/29/15 the PWS sent raw and finished water samples that were sent to Beagle Bioproducts for "Toxin related" analysis. On 9/30/15, NERO performed a site visit to Wenham Lake during heavy rainfall and obtained a sample at the eastern shore. The water there was a "dye green" color and was analyzed via IVF with results indicating approximately 1000 µg/L of PC. Samples taken on 10/5/2015 showed elevated levels of cyanobacteria, but levels of cyanotoxins that were less than MDLs.

Resolution

On 10/6/2015, NERO decided that, due to toxin results, heavy rainfall in the area which would disperse the remaining bloom, and the bloom proximity being distant from the intake, that no further actions need be taken beyond the SBWSB notifying NERO if any further issues arise. On 10/16/2015 another sample from the lake was taken and analyzed, which was identified as still experiencing an intense bloom of Anabaena while having Microcystis in lower amounts. After this point, no further tests with concerning results were conducted.

Ipswich Water Department - 10/14/15-10/19/15

MassDEP contact affiliated with event: Joan Beskenis

Ipswich Water Department contact affiliated with event: Vicki Halmen

Location of Bloom

Dow Brook Reservoir, Ipswich, Massachusetts. This site is surrounded by woodlands, but there is not much woodland separating the body from developed land on the northern side.

Reporting

On 10/16/15 NERO-FAST submitted images of a potential bloom taken on 10/14/15 to WPP-Beskenis requesting identification. NERO-FAST requested microcystin analysis as well, which was delivered to Beskenis on 10/16/15. No identification/enumeration was documented. On 10/19/15 WPP completed microcystin analysis and did not find sufficient information to warrant a health advisory posting.

Event Type

Visual and pictorial data identifies that a cyanobacteria event did occur, but testing did not find that the results were harmful, and no toxin analysis is available. No public notice was posted for the event, nor did a shutdown occur.

Site's preventive protection plan

No preventive plans stipulated aside from visual monitoring of the location.

Method of response

No chemical response occurred.

Site's Emergency Response Plan

The site contacted FAST for guidance on bloom response. FAST arrived on the scene and took control of the situation, advising the PWS on their options as well as taking samples and submitting them for testing.

Resolution

After testing results from 10/19/15 showed that there was no cause for concern, standard activities continued

Rockport Water Department – 9/7/16

MassDEP contact affiliated with event: NERO DWP

Rockport Water Department contact affiliated with event: Joseph P. Parisi Jr.

Location of Bloom

Cape Pond Reservoir, Rockport, Massachusetts

Reporting

On 9/7/2016 the PWS reported to NERO DWP that they shut down one of their two water treatment plants due to high Total suspended solids reading (TSS) which appeared to be the result of algae in the pond reservoir.

Event Type

This event was sufficient for the PWS to stop pulling water from the site. No specific cell counts were recorded, but the bloom was visibly large enough to cause concern. Field tests conducted on 9/7/16 using ABRAXIS strips indicated a “slight difference in control and test strips”. Toxin analysis of samples from 9/8/16, 9/12/16, and 9/20/16 indicated levels of Anatoxin-A, Microcystis, and cylindrospermopsin that were below detection levels in both raw and finished water

Site’s preventive maintenance for cyanobacteria

The site had basic algal monitoring in place.

Method of response

The site did not specify a specific response.

Site’s Emergency Response Plan

At the time of the report and event, the PWS had been safely operating using an alternate water source for approximately a week. The second site available, Carlson’s Quarry, was unaffected by the bloom event. NERO’s FAST reported to the Cape Pond Reservoir and collected samples from the source, raw water, and finished water. Cyanobacteria was detected in both the source and raw water samples, and cyanotoxin ABRAXIS test strips were used on the samples. DEP-NERO directed PWS to collect samples of both raw and finished water of cape pond for microcystin and cylindrospermopsin analysis with their preferred Liquid Chromatography Mass Spectrometry (LC-MS) method. DEP-NERO then requested additional sampling on 9/8/16, 9/10/16, and 9/12/16

Resolution

The PWS submitted samples on 9/8/16, 9/12/16, and 9/16/16. The toxins were all toxin non-detects. During the shut down of the Cape Pond reservoir, the Rockport Water Department was reliant solely on Carlson’s Quarry. Due to this, DEP-NERO directed the PWS to implement a full ban on non-essential outdoor water use to maximize conservation efforts. The DEP also provided the PWS with instructions to petition MassDEP for a Declaration of Water Supply Emergency if necessary. NERO-DEP also identified that it would review and expedite a current permit application to allow increase pumping capacity from Flat Ledge Quarry into Carlson’s Quarry to ensure the town could continue to meet its water demands.

North Andover Water Department - 10/14/16-10/27/16

MassDEP contact affiliated with event: Kristin Divris

North Andover Water Department contact affiliated with event: Glen Alt

Location of Bloom

Lake Cochichewick, North Andover, Massachusetts

Reporting

In late September 2016, phycocyanin (PC) levels started increasing while no visible blooms were present. PWS collected 3 samples each on 9/29/16, 10/12/16, and 10/18/16 for cyanobacteria ID/counts.

Event Type

This event was managed properly and never exceeded the requirements for dangerous levels. At its highest measured cell count, there were 52,170 cells/mL in the raw water samples. Microcystis and Anatoxin-a were both below 0.33 PPB, at safe levels. No public notice was posted for the event

Site's preventive protection plan

The PWS routinely monitors chlorophyll-A and phycocyanin as per the EPA region 1 Cyano Monitoring Collaborative. This allows them to be aware of any sudden changes to the ratio of chlorophyll-A : phycocyanin, an indicator of increased cyanobacteria populations. They also routinely test the turbidity of the water with Secchi disk measurements.

Method of response

Copper sulfate application to the afflicted body.

Site's Emergency Response Plan

Upon the discovery of the heightened PC levels, they immediately began testing for signs of cyanobacteria in the water. Contracted Solitude Lake Management for copper sulfate application

Resolution

On 10/20/16, DEP-WURP collected raw and finished water samples for cyanotoxin analysis by WES prior to treatment; NERO-DEP then approved copper sulfate treatment to the lake. On 10/21/16 DEP-WES provided preliminary toxin results for total MC/Nodularins (Abraxis ELISA method) and Anatoxin-A were all found to be at levels below the mandatory reporting levels. Enumeration counts from samples taken on 10/20/16 were 10,283 cells, and enumeration from samples taken on 10/18/16 had values between 690-2,300 cells/mL, well below any levels that can call for concern. Source was treated with copper sulfate on 10/26/16.

Massachusetts Water Resources Authority (MWRA) - 6/27/2017

MassDEP contact affiliated with event: Kristin Divris

MWRA contacts affiliated with event: Stephen Estes-Smargiassi, Betsy Reilley, Dave Coppes

Location of Bloom

Chestnut Hill Reservoir, Newton/Boston, Massachusetts. This location is an emergency source

Reporting

MWRA responded to a known algal bloom problem by taking samples for identification and microcystin analysis. MWRA initially contacted MDPH due to known (but not permitted) recreational use at the source which is not currently active for drinking water.

Event Type

Full CyanoHAB event that took the reservoir out of use. The cell counts were sufficiently high, 129,000 cells/mL at maximum and 68,000 cells/mL at minimum, that the DEP recommended against treatment of the water, instead suggesting continued monitoring along with a health advisory posting. The microcystin concentration was <1 PPB and never exceeded this value.

Site's preventive protection plan

The MWRA routinely monitors the water bodies using visual inspection.

Method of response

MWRA contacted Solitude to manage the event for them. They completed enumeration 5 times from 6/27-7/10, and the populations declined following results received 6/29. No report of any algaecide application was recorded.

Site's Emergency Response Plan

Contacted the MDPH and MassDEP for advice on resolving the bloom and were told not to treat. Bloom was dense enough that treatment would not have been sufficiently effective to warrant its use. This PWS has extensive water sites and this is an emergency backup source, so the Massachusetts Water Resource Authority simply chose the appropriate response of simply not drawing water from this site during the event. Due to the known recreational use, the MWRA posted a health advisory around the perimeter of Chestnut Hill Reservoir

Resolution

MWRA had concerns that they may require Chestnut Hill Reservoir in case of an emergency, but no active response methods were employed, nevertheless. Instead, they continued monitoring the response from the DEP advising against applications. MWRA took samples to monitor until cell counts fell below 70,000 cells/mL and these samples were taken 6/27, 6/28, 6/29, 7/2, 7/3, 7/5, and 7/6. Once two consecutive measurements, conducted a week apart, showed enumeration below 70,000 cells/mL, MWRA decided to withdraw the health advisory and return the site to use.

Massachusetts Water Resource Authority (MWRA) - 9/15/2017-9/26/2017

MassDEP contact affiliated with event: Dan Davis to Joan Beskenis

MWRA contacts affiliated with event: John Gregoire, Kimberly Lebeau, Todd Earle, Betsy Reilley

Location of Bloom

Sudbury Reservoir, Sudbury, Massachusetts. Sudbury Reservoir is an emergency backup reservoir

Reporting

DEP-WPP (Water Protection Plan) were in the field for routine monitoring beginning on 9/14/17 and observed a potential cyanobacterial bloom and collected a grab sample 6-9" in depth on 9/15/17 for ID and enumeration by Joan Beskenis. Beskenis observed the sample on 9/19/17 and identified microcystis flos-aquae. Davis alerted DCR staff Jamie Carr of the possible bloom on 9/15/17, while Beskenis submitted the results to additional WPP staff on 9/19/17. Beskenis forwarded email information to Kristin Divris on 9/19/17 as well. DEP informed MDPH on 9/20/17 as there is recreational use in the Sudbury reservoir.

Event Type

The detected cyanobacteria were Microcystis flos-aquae which is a potentially dangerous cyanobacteria. No toxin analyses were made available for documentation. No shutdown of the site occurred due to cyanobacteria, but it is unclear whether the MWRA was drawing water from the reservoir anyways, due to the fact that it is a backup reservoir.

Method of response

No method of response was stipulated, copper sulfate application did not occur.

Site's Emergency Response Plan

The site had a strong reporting process, going through all the proper channels. They went directly to the DEP, the correct first step given that it the Sudbury Reservoir is a drinking water source. They received guidance from the DEP to help with managing the bloom.

Resolution

Following the discovery and reporting, the MDPH and DEP had a conference call on 9/21 to discuss the state of the bloom. At this point, DEP-WPP relayed to Department of Conservation and Recreation that no further evidence of a bloom was visible as of 9/20/17. On 9/26/17 DEP-WPP staff went to Sudbury Reservoir to do final sampling where they found significantly reduced bloom visibility. As Dan Davis said, "(we) sampled five separate areas that had cyanobacteria blooms but none of them were really as bad as a week ago".

Brockton Water Commission - 9/29/2017-10/31/2017

MassDEP contact affiliated with event: John Hobill to Rebecca Weidman

Brockton Water Commission contacts affiliated with event: N/A

Location of Bloom

East and West Monponsett Ponds, Halifax, Massachusetts. East Monponsett is a tributary for Silver Lake, which the Brockton Water Commission draws water from

Reporting

On 9/25/17, MassDEP collected water samples from both East and West Monponsett Ponds as part of routine monitoring. East Monponsett had cell counts of 42,938 cells/mL while West Monponsett had counts of 18,828 cells/mL and 69,181 cells/mL at varying locations. There were also reports of visible scum along the surface of the water

Event Type

Although the cell counts were below the 70,000 cells/mL threshold, the visible scum on the surface is one guideline for recommending an advisory. For this reason, the current advisory in place for West Monponsett was recommended to remain by the MDPH. This event is categorized as a CyanoHAB event for that reason. The MDPH posted an advisory due to known recreational usage of the Monponsett Ponds, meaning they fall partially under MDPH jurisdiction.

Site's preventive protection plan

The Monponsett ponds have ongoing monitoring plans to detect algae. This is due to the site's experience with algal blooms in the past, frequently suffering from bloom events. In June of 2017, aluminum sulfate was applied to the site to aid in the prevention of cyanobacteria.

Method of response

Due to the fact that aluminum sulfate had already been applied 3-4 months prior, the Brockton Water Commission chose not to apply any chemical response to the ponds.

Site's Emergency Response Plan

The Brockton Water Commission intended to divert flow from East Monponsett into Silver Lake but postponed this due to the health advisory on West Monponsett. Due to the proximity of the lakes and the geography of the region, it is very easy for the two ponds to exchange water, which could lead to East Monponsett becoming infected with cyanobacteria. Due to cyanobacteria concerns, the Brockton Water Commission opted to not use the potentially contaminated water in the Monponsett ponds as a part of their emergency response plan.

Resolution

SERO requested three water samples to be analyzed for microcystin and cylindrospermopsin. They drew two samples on 10/26/17 from the two sampling locations that were consistent with the routine monitoring locations used by SERO staff. These samples were delivered to WES to be tested for Anatoxin a, Microcystins, and Nodularin by the testing method of Abraxis ELISA (enzyme-linked immunosorbent assay). These tests came back negative; no cyanotoxins were detected.

Billerica Water Works - 10/4/17-11/10/17

MassDEP contact affiliated with event: Joan Beskenis

Billerica Water Works contact affiliated with event: John McGovern

Location of Bloom

Concord River, Billerica, Massachusetts. Concord river is both a PWS and a recreational water body

Reporting

On 10/4/2017, EPA wetlands scientist and resident of Billerica contacted Joan Beskenis of MassDEP's WPP and Michael Celona of MDPH to report a possible cyanobacteria bloom on the Concord River near his riverfront property.

Event Type

This event was never confirmed to be a legitimate cyanobacteria bloom. All toxin counts came in at very safe levels, far below minimum reporting levels (MRLs), the smallest concentration of a substance that can be measured using the tool in question. Hence no public posting was required

Site's preventive protection plan

The site has basic monitoring in place, but a citizen was the entity that contacted FAST and the DEP.

Method of response

No chemical response was taken to handle this event.

Site's Emergency Response Plan

No information relating to their ERP is available. Much of the work on the ground that is available comes from FAST reporting.

Resolution

The PWS collected raw water samples to be tested for microcystins, cylindrospermopsins, anatoxin and saxitoxin for two rounds (1-2 weeks apart). PWS sampled raw water on 10/26/17 and analyzed cyanotoxins noted under UCMR4. No further actions were reported.

Peabody Water Department - 3/20/2018-3/29/2018

MassDEP contact affiliated with event: John J. Fitzgerald to J. Beskenis, A. Clark, T. Mahin, E. Worrall, K. Divris

Peabody Water Department contacts affiliated with event: Davis Scribner

Location of Bloom

Winona Pond Reservoir, Peabody, Massachusetts. This location is a PWS Source.

Reporting

On 3/20/2018 NERO-FAST reported that DEP was receiving complaints about “fishy” or “musty” smells in the drinking water.

Event Type

This event was **NOT** a blue-green algae event, but instead an event with golden-brown algae. These algae do not create cyanotoxins, and is only problematic, as far as human’s are concerned, due to the taste and odor they create. Toxin analysis came back negative.

Site’s preventive protection plan

Because this event did not actually contain cyanobacteria, the information regarding cyanobacteria monitoring was unavailable.

Method of response

No CyanoHAB response occurred because this was not a CyanoHAB.

Site’s Emergency Response Plan

Emergency plan involved informing FAST of the problem and allowing them to handle the sample gathering and testing processes. Further tests and analysis were advised by the DEP and FAST and were completed in order to acquiesce the public’s concerns.

Resolution

On 3/20/18 FAST reported to Peabody and obtained two samples; one source water sample near the intake to the WTP and one on the raw water tap within the WTP. FAST tested both samples on IVF meter, viewed samples on PCM and submitted the images to J. Beskenis for identification. The cells were identified as chrysophytes (golden-brown algae) which often cause odor and taste issues. Field samples from the MWRA’s Kim Lebeau also identified the chrysophytes from samples taken from the raw water tap, finished water tap, middle of the Winona Pond Reservoir, and from the distribution system at Burke school. On 3/23/18, Peabody Water Department collected a finished water sample for cyanotoxin analysis by Eurofins Laboratory. They found that MC, Anatoxin-a, Nodularin, and Cylindrospermopsin were all below the MRLs.

Massachusetts Water Resources Authority (MWRA) - 5/4/2018-5/30/2018

MassDEP contact affiliated with event: Kristin Divris

MWRA contact affiliated with event: Betsy Reilley

Location of Bloom

Chestnut Hill Reservoir, Boston/Newton, Massachusetts. This location is an emergency PWS.

Reporting

MWRA called Kristin Divris to report the bloom event in progress. Samples had been sent out and were awaiting results.

Event Type

Significant CyanoHAB event. Cell counts exceeded 250,000 cells/mL in certain locations.

Site's preventive protection plan

The MWRA routinely monitors this water body. It is in a very public space, so information about the status of the site is easy to come by both through employees that work on Chestnut Hill, and through citizen reporting.

Method of response

Aluminum sulfate treatment that resulted in improved water quality.

Site's Emergency Response Plan

MWRA continued to leave the site as non-operational for water drawing purposes. Used one of the many other locations available to provide water to their PWS consumers.

Resolution

Testing conducted by Northeast Laboratories identified cyanobacteria (*Oscillatoria*) present at levels ~ 270,000 cells/mL. In response, MWRA immediately posted signage at five locations around the reservoir. *Oscillatoria* is a toxin producer, so MWRA sent a sample for toxin analysis to Northeast Laboratories. MWRA also used the Abraxis Microcystins strip test and AbraScan Test Strip Reader that provided results of approximately 1 ppb. Microcystin –LR was non-detect from any results. After these results, they moved to Aluminum sulfate treatment which improved the water quality, but *oscillatoria* cell counts were still in excess of 70,000 cells/mL. Phosphorous tests conducted pre and post application of aluminum sulfate showed increased levels of *oscillatoria* deeper in the reservoir. It is speculated that this is due to cell settling and internal recycling, as DO levels are also very low.

Andover Water Department - 5/23/2018-6/12/2018

MassDEP contact affiliated with event: Tom Mahin

Andover Water Department contact affiliated with event: Alan Carifio

Location of Bloom

Haggetts Pond, Andover, Massachusetts. Haggetts Pond is a primary PWS source

Reporting

The actual reporting of this event is undocumented. Discovery is unknown. Database suggests that through Andover's monitoring program, they studied the algae with fluorometry and that is how it was discovered.

Event Type

Toxins were found in incredibly small amounts, Anatoxin-A <0.03 PPB, Cylindrospermopsin <0.09 PPB, Microcystin & Nodularins <0.3 PPB. These toxin levels are within the safe range, and the study was conducted by Eurofins Eaton Analytical on 6/12/18. No public notice was required.

Site's preventive protection plan

Site conducts active monitoring of the site. This includes visual monitoring as well as phycocyanin measurements, which help them track the trends in cyanobacteria mass in the water in a cost-effective and time-effective way. Andover also routinely applies copper sulfate to the water body at the start of the spring/summer seasons in order to proactively inhibit cyanobacteria growth.

Method of response

No chemical response was applied. Sampling was conducted to track the populations, but toxin concentrations never broached levels of concern.

Site's Emergency Response Plan

This site is well prepared to respond to bloom events, should they occur. They are prepared to respond via chemical treatment, as well as changing their intake.

Resolution

PWS sampled finished water at the entry point to their distribution center for cyanotoxin analysis on 5/22/18. These results were submitted to NERO DWP Tom Mahin on 6/12/18 and forwarded to Kristin Divris on 8/16/18. No further information regarding source treatment was furnished.

Massachusetts Water Resources Authority (MWRA) - 8/4/18

MassDEP contact affiliated with event: Yvette Depeiza to Kristin Divris and Stephen Estes Smargiassi

MWRA contact affiliated with event: Betsy Reilley

Location of Bloom

Chestnut Hill Reservoir, Boston/Newton, Massachusetts. This location is an emergency PWS.

Reporting

On 8/4/18 an email was submitted through the general DWP Program Director email indicating "All fish are dead and many birds! Aug 4, 2018! The water is peach (pitch) black! Is this for drinking?"

Event Type

This is a known bloom event that had been underway for a long time. No extra testing was conducted.

Site's preventive protection plan

This site is not used in any active water program, so it can remain in its state. The MWRA identified that it would be more prudent to leave the site as it is.

Method of response

No response was taken.

Site's Emergency Response Plan

The site is not used actively, so no emergency response plan is in effect. It can remain in its state. This entry is also a continuation of a previous entry, and the policy taken therein is continued in this case.

Resolution

On 8/6/18, the DWP Program Director responded to the email answering that the source was an emergency backup reservoir and not a part of the active water supply system and provided a contact number to the complainant for the MWRA. DWP Program Director also forwarded response to MWRA representative and Kristin Divris. Complainant was nonplussed at the idea of contacting the MWRA, citing it as "extra work" and indicated he should have sent the pictures to the Boston Globe instead.

Andover Water Department - 8/9/18 - 9/5/18

MassDEP contact affiliated with event: Tom Mahin

Andover Water Department contact affiliated with event: Alan Carifio

Location of Bloom

Haggetts Pond, Andover, Massachusetts. Haggetts Pond is a primary PWS source.

Reporting

The PWS informed the DEP that they would be contracting Solitude Lake Management to apply copper sulfate to the lake in order to mitigate a growing Anabaena population.

Event Type

Toxins were found in incredibly small amounts, Anatoxin-A <0.03 PPB, Cylindrospermopsin <0.09 PPB, Microcystin, Nodularin <0.3 PPB. These toxin levels are within the safe range, and the study was conducted by Eurofins Eaton Analytical on 6/12/18. No public notice was required. This bloom event was mild in nature, with only moderate levels of anabaena being discovered.

Site's preventive protection plan

The PWS was monitoring the state of Haggetts pond when they noticed a developing bloom of anabaena. Their prevention plan involves sulfate application to discovered bloom events, so they contracted Solitude Lake Management, as per their recent protocol regarding cyanobacteria bloom management.

Method of response

Copper sulfate application

Site's Emergency Response Plan

Because this was not a legitimate bloom event, and only an act of prevention, the only response plan necessary was their prevention plan, which proved effective for this case.

Resolution

The decision to apply copper sulfate came in response to readings of PC at 65.1 PPB and chlorophyll-a at 1.41 PPB, a ratio of P/A = 46. Due to inclement weather conditions, this was sufficient to arouse concern, leading to a request from the DEP asking what testing should be performed. The DEP directed the PWS to conduct and analyze the same tests that they had used in May of that year for an earlier cyanobacteria concern.

North Andover Water Department - 9/15/18-10/10/18

MassDEP contact affiliated with event: Kristin Divris

North Andover Water Department contact affiliated with event: Glen Alt

Location of Bloom

Lake Cochichewick, North Andover, Massachusetts. This is a Primary PWS source, the only source for the entire PWS.

Reporting

On 9/17/18 the PWS reported to the DEP that a potential bloom was starting, and they were planning to take samples on the same day and requested direction from the DEP.

Event Type

The highest recorded cell counts were 11,000 cells/mL at a depth of 9' at the water intake and the lowest cell counts were 7800 cells/mL at a depth of 3' at the water intake. Analysis for cyanotoxins resulted in Microcystins, anatoxin A, and cylindrospermopsin all reporting **below** detectable levels.

Site's preventive protection plan

The PWS routinely monitors Chlorophyll-A and phycocyanin as per the EPA region 1 Cyanobacteria Monitoring Collaborative (CMC). For this event specifically, they detected the developing bloom through their standard monitoring processes.

Method of response

Copper sulfate application to the afflicted body.

Site's Emergency Response Plan

Upon the discovery of the heightened PC levels, they immediately began testing for signs of cyanobacteria in the water. Contracted Solitude Lake Management for copper sulfate application.

Resolution

The initial grab-samples from 9/17 revealed chlorophyll-A to phycocyanin ratios of 8.56:0.47 (18.21:1) for the laboratory grab sample and 4.76:0.54 (8.85:1) on the boat ramp surface grab. On 10/20/16, DEP-WURP collected raw and finished water samples for cyanotoxin analysis by WES prior to treatment; NERO-DEP then approved copper sulfate treatment to the lake. On 10/21/16 DEP-WES provided preliminary toxin results for total MC/Nodularins (Abraxis ELISA method) and ANA(a) were all found to be at levels below the MRL. Enumeration counts from samples taken on 10/20/16 were 10,283 cells, and enumeration from samples taken on 10/18/16 had values between 690-2,300 cells/mL. Source was treated with copper sulfate on 10/26/16.

Danvers Water Department – 8/28/19

MassDEP contact affiliated with event: Kristin Divris

Danvers Water Department contact affiliated with event: N/A

Location of Bloom

Middleton Pond Reservoir, Middleton/Danvers, Massachusetts. This is a primary drinking water source.

Reporting

This bloom was discovered through citizen reporting. A citizen was walking dogs around the perimeter of the Middleton Pond Reservoir and noticed the start of a bloom on 8/28. He reported to both the MDPH and to DEP. He returned 9/4/19 and noticed the bloom had increased in size.

Event Type

Toxin analysis and enumeration values are not available for this event, but imagery suggests there was a full bloom event in effect. Tracking of the event indicates that it was taken seriously as a credible threat to health. While the initial reporter requested a health advisory, no such posting was made because this is a drinking water source, not a recreational source.

Site's preventive protection plan

This site's preventive protection plan was not detailed.

Method of response

No active chemical application was mentioned, only increased monitoring of the toxin levels and bloom location.

Site's Emergency Response Plan

The Danvers Water Department immediately took action to increase their monitoring of the site when the bloom was reported. This includes "daily visual monitoring of waterbody and overhead drone footage to track bloom movement". As of 9/4, the bloom was not near the water intake, so the PWS did not choose to adjust their water withdrawal from the site. The site also used an internal laboratory to monitor the status of the raw and finished water, to make sure that the water was safe.

Resolution

This event is currently ongoing as of the creation of this case study, and no resolution has occurred.