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BLOOMS

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# Management Strategies for Harmful Algal Blooms in Worcester

Working with the Worcester Department of Public Works to develop a management strategy for cyanobacteria blooms in Worcester and to identify the implications of a potential mandate regarding these blooms

An Interactive Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

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## **Abstract**

The City of Worcester has multiple different bodies of water accessible to the community for recreational purposes. Every summer, residents from all over the city like to visit the different recreational areas to make the most out of the hot summer weather. However, most people are not aware of the implications of Harmful Algal Bloom (HABs) formation. This kind of HAB can cause many adverse health effects in both humans and animals including vomiting, diarrhea and flu-like symptoms. HAB formation has been an issue identified from a local to an international level. Many places and organizations have established a set of guidelines to manage the potential effects that HABs could cause. In order to manage recreational water quality and avoid closing beaches, a management strategy that covers prevention, monitoring, treatment and response strategies should be established.

We collaborated with Worcester's Department of Public Works (DPW) to recommend management strategies for prevention, monitoring, treatment and response for HABs in Worcester. Worcester's current strategies are more developed when compared to other locations. After compiling our research, we came to the conclusion that Worcester is ahead of the curve judging on their implementation of methods for each category under prevention, monitoring & testing, treatment, and response. However, after conducting extensive research, interviews and literature reviews, we found several methods that can be augmented or implemented to Worcester's current efforts to manage HABs. For example, for prevention, we determined that Barley straw is a new method that can effectively be implemented in Worcester. In terms of monitoring and testing, we found many methods such as a biovolume count, establishing nitrogen and phosphorus thresholds and using probes and fluorometers can improve Worcester's current efforts to monitor cyanobacteria. In the other hand, we believe that Worcester's current treatment methods are working fine for the city and preventing HAB formation is only another way we can keep the lakes safe. Therefore, besides from Aluminum sulfate, prevention is the second best treatment. Lastly, for the response, we determined that most locations perform the same basic actions when it comes to public notification of harmful algal blooms; the three main methods to do this are posting of signs at the affected waterbody, posts on websites, and posts on social media.

Currently, Worcester is proactive in finding a way to make the HABs less of a detriment on the city's public recreation. The research done on this project gave an insight on how the methods being currently used to combat HABs can be implemented in Worcester. In spite of all the methods we identified that could be augmented or newly implemented, it is clear that Worcester's efforts to manage HABs are already far more advanced than the many other locations and organizations we looked into.

## **Executive Summary**

The City of Worcester has more than ten different bodies of water accessible to the community for recreational purposes. One of the most popular is Indian Lake, the largest local lake that lies entirely within the City of Worcester. Every summer, residents from all over the city like to visit the different bathing beaches and recreational areas to make the most out of sunny days and the hot summer weather. However, most people are not aware of the implications of Harmful Algal Bloom (HABs) formation, a common summer issue most water bodies in Worcester face every year. HABs, also known as blue-green algae or cyanobacteria, have been a constant issue through different bodies of water in Worcester, that has forced the Department of Public Works (DPW) of Worcester to close several public beaches and bathing areas for safety purposes. This kind of HAB can cause many adverse health effects in both humans and animals. Symptoms such as fever, vomiting, diarrhea, and more have been observed in those who have been exposed to cyanobacteria. Furthermore, these blooms can negatively affect neighboring ecosystems and aquatic life. Fishes have been killed as quickly as overnight due to the oxygen deplete caused by cyanobacteria. HAB formation is not an issue exclusive to Worcester's bodies of water. Many places and organizations from local to an international level have established a set of guidelines or mandates to manage the potential effects that HABs could cause in many different ways. However, a good amount of places remain severely under-regulated, so a strategy must be put in place to limit adverse public effects. In order to manage recreational water quality and avoid closing beaches, a management strategy that covers prevention, monitoring, treatment and response strategies should be established.

For this project, we collaborated with Jacquelyn Burmeister, Senior Environmental Analyst for Worcester's DPW to recommend management strategies for monitoring, prevention, treatment and response for HABs in Worcester by evaluating and augmenting current strategies. We focused on the three main objectives outlined below:

- **Objective 1:** Evaluate the current management strategies for Worcester and other locations
- **Objective 2:** Research methods for prevention, monitoring, and treatment for HABs
- **Objective 3:** Research and recommend a public notification and response plan

In order to achieve these objectives, we conducted interviews as well as research and literature reviews. After collecting this information, we determined:

1. Finding what other locations are doing for cyanobacteria management is difficult. Due to the lack of method diversity within each locations guideline on cyanobacteria strategies, figuring out exactly what each area did to manage cyanobacteria was hard.
2. Most places establish guidelines or recommendations instead of mandates. Every location we researched decided to make a document regarding recommendations on

how to tackle cyanobacteria blooms. The only exceptions for this were China, as they are another country with limited regulations on what to try, and Ohio as they released laws that were focused on cyanobacteria problems in drinking water specifically.

3. Worcester's strategy is more developed when compared to other locations. After compiling our research, we came to the conclusion that Worcester is ahead of the curve judging on their implementation of methods for each category under prevention, monitoring & testing, treatment, and response. Along with their activity in this aspect, they also reached out to be proactive in order to manage this problem even better.
4. The EPA will most likely not create any regulations regarding cyanobacteria. After interviews from people in the Massachusetts Department of Public Health and other locations in Massachusetts working on this problem, a conclusion was made that the EPA will be focusing their efforts on implementing a mandate on drinking water aspects and not recreational water regulations.
5. There are many methods employed elsewhere that the city of Worcester has not tried. Although they are ahead of other locations with management methods, there are still many methods found in other locations that Worcester has not implemented, and could eventually benefit from.
6. Implementing the use of a Biovolume Count would be a change in Worcester's own advisory levels, not a change in monitoring methods.
7. Probes and Fluorometers may be beneficial to use when monitoring for cyanobacteria in lakes.
8. According to Massachusetts DEP in 2018, water temperatures above 25°C contribute to an increase of cell division, and likely cyanobacteria.
9. For a shallow body of water (like Indian Lake and other bodies of water in Worcester), a safety range of Phosphorus and Nitrogen levels should be established to control cyanobacteria bloom formation.
10. Zooplankton and Phytoplankton are important factors in cyanobacteria community dynamics that the city of Worcester should examine further.
11. Satellite imaging may be used in Worcester.
12. Barley straw is a new method that could be used in Worcester.
13. Most locations perform the same basic actions when it comes to public notification of harmful algal blooms. The three main methods to do this are posting of signs at the affected waterbody, posts on websites, and posts on social media.

Each method plays a specific role in combating cyanobacteria, but there is no one set way to manage this issue due to the wide diversity of cases. In order to effectively manage HABs, multiple strategies may be implemented in order to ensure a long-standing management process. As a result of this, we recommend that:

1. Improvements on certain aspects of Worcester's public response strategy, as well as some additional methods being added is optimal. Adding new ways to alert the public about cyanobacteria blooms would make dealing with the public easier. With

improvements and new strategies to the plan they have now, the rest of the public's awareness on the problem would help the future of recreational beach health.

2. The Worcester DPW should look for a specialist in biology to help with research within the methods that include heavy biological detail. If a member with this area of expertise is included, then a more in depth understand of how the cyanobacteria dynamics work would benefit. Knowing more about these dynamics would give a better comprehension on the most effective way to combat the cyanobacteria growth.
3. The DPW should find a way to communicate and collaborate with members in other locations that have found similar success with managing cyanobacteria. If an act of collaboration is reached, then having more experience between the few shared methods could bring a whole new strategy to tackle cyanobacteria blooms in recreational water.

Presently, Worcester is proactive in finding a way to make the HABs less of a detriment on the city's public recreation. Anyone should be able to enjoy their time during the warm summer months on a beach without the need to worry. The research done on this project gave an insight on how the methods being currently used to combat HABs can be implemented in Worcester. In spite of all the methods we identified that could be augmented or newly implemented, it is clear that Worcester's efforts to manage HABs are already far more advanced than the many other locations and organizations we looked into.

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## **Chapter 1 – Introduction**

Blue-green algae blooms, one type of Harmful Algal Bloom (HAB), occur in many places around the world when certain conditions are met. Despite common belief, blue-green algae, also known as cyanobacteria, are in fact not algae, but prokaryotic bacteria that harvest energy through photosynthesis. They prefer specific water conditions such as warm temperatures and high nutrient inputs (Environmental Protection Agency, 2019). These conditions often occur in urban shallow bodies of water, such as our very own Indian Lake here in Worcester, Massachusetts. Anyone exposed to these cyanobacteria can experience adverse health effects. (Environmental Protection Agency, 2019). In the summer of 2018, a cyanobacteria outbreak forced the Department of Public Works and Parks of Worcester (DPW) to close all the public beaches and bathing areas in Indian lake. The warmer months of the year cause a spike in both cyanobacteria blooms as well as social activity at local beaches. This combination present a serious health and safety concern that many people might not be aware of. The United States Environmental Protection Agency (EPA) provides guidance for closing lakes and ponds due to high concentrations of cyanobacteria and cyanotoxins present in the water. However, there are currently no existing regulations or mandates regarding cyanobacteria in public bathing beaches.

Indian Lake was closed near the end of the summer of 2018 after high cyanobacteria densities were observed on August 28th (Moir, 2018). This surprised the DPW, as a previous cyanobacteria outbreak had already been successfully neutralized earlier that summer (Edward M. Augustus Jr, 2018). Cyanobacteria blooms not only prevent residents from enjoying Worcester's beaches during the hot summer months, but the necessary closing of these beaches can impact lifeguard and staff jobs. These blooms also cause many adverse health effects in both humans and animals. Symptoms such as fever, vomiting, diarrhea, and more are observed in those who have been exposed to cyanobacteria while swimming (Pilotto et al., 1997). Animals and pets who ingest the cyanobacteria blooms can suffer sickness and even death if not treated properly. Furthermore, aquatic life such as fish can suffer death as quickly as overnight due to cyanobacteria that deplete the oxygen in the water (Chorus et al., 2000). In order to control these cyanobacteria, a management strategy that covers prevention, monitoring and testing, treatment, and response methods should be established.

Many other places around the world are plagued by the same cyanobacteria issues as Worcester. In order to aid in dealing with cyanobacteria blooms, the World Health Organization (WHO) provides information on several cases of outbreaks around the world, and how they were dealt with. For example, the Ohio EPA developed a guideline document that focused on cyanobacteria in drinking water in order to prevent future outbreaks (Ohio EPA, 2015). They were able to implement various methods to suppress the toxic nature of the blue-green algae. For the past few years, the DPW has been working on multiple ways to improve the quality of local recreational bodies of water. Their goal is to find an effective way to prevent and manage cyanobacteria blooms at public beaches. The DPW organized a group of science volunteers called the Worcester Cyanobacteria Monitoring Collaborative (WCMC) that focuses on monitoring and testing for blue-green algae in local water bodies, as

well as researching different prevention methods. Much of the focus of their research is on external sources that pass nutrients into water bodies. A previous WPI IQP project examined the effects that road salt runoff has on drinking water (Nicholas Gigliotti et al., 2015), which led to our research on road salt's impact on lakes and cyanobacteria. Additional salt and chloride have potential negative effect on lakes and could lead to a harmful algae bloom (Parnapy, 2017); prevention of this runoff could be another way to manage cyanobacteria blooms. These cases can all be useful when developing a policy or mandate that aims to make the harmful algal blooms issue more manageable.

There are other water quality issues for which the EPA has established testing and response mandates, such as the levels of fecal matter in the water (Environmental Protection Agency, 2015). However, because there are no regulations regarding cyanobacteria in lakes and ponds, the burden falls to local government to create a management plan regarding cyanobacteria outbreaks in public bathing sites. For this reason, the DPW introduced the WCMC to regularly test and monitor local water bodies. According to data collected last summer, there was a second significant cyanobacteria outbreak just after the water had been treated with aluminum to prevent another outbreak (Appendix A). The DPW has no explanation as to why this happened.

The fundamental goal of this project was to recommend management strategies for monitoring, prevention, treatment, and response for Harmful Algal Blooms in Worcester by evaluating and augmenting current strategies. Current mandates and response strategies for similar issues were used as guidance to make a response recommendation for future cyanobacteria outbreaks in Worcester. The objectives of the project were to evaluate the effectiveness of current algal bloom management strategies, to research methods for monitoring and testing of blooms and to research and recommend a public relations response plan.

## **Chapter 2 – Background**

Blue-green Algae, also known as Cyanobacteria, are bacteria-like prokaryotes often found in bodies of water with high nutrient inputs in warm environments. Due to their toxins, this specific type of algal bloom is considered to be harmful to humans, pets and neighboring living ecosystems. The occurrence of harmful algal blooms seem to be increasing worldwide, and has caused local ponds and lakes to be closed to the public in recent years. Despite current testing methods being lengthy and expensive, the DPW periodically performs tests for cyanobacteria density in of Indian Lake during the summer. There are currently no complete mandates for testing and closure of bathing beaches for cyanobacteria in Worcester. This section will discuss factors taken into account by other places in the world to manage harmful algal blooms, and other details with research regarding cyanobacteria.

### **2.1 Health effects of Cyanobacteria**

Human exposure to cyanotoxins usually occurs via three methods: Direct contact with openings of the body such as the ears, eyes, mouth, and throat; swallowing of water; and uptake of water through inhalation (Chorus et al., 2000). Exposure can lead to many adverse health effects in both humans and animals. Diarrhea, vomiting, flu-like symptoms, skin rash, mouth ulcers, fevers, and eye/ear irritations are all examples of these health effects (Pilotto et al., 1997). These symptoms do not always appear immediately after exposure. In one study conducted in 1995, at two days after exposure, no significant difference was observed between exposed and unexposed individuals. After seven days however, a significant trend of increasing symptoms was observed in those exposed (Pilotto et al., 1997). Furthermore, health effects vary based upon the length of exposure to, concentration of, and area of algal blooms. The symptoms of the previously mentioned study showed correlation to cyanobacterial cell density and duration of exposure. Specifically, “participants exposed to more than 5000 cells per mL for more than one hour had a significantly higher symptom occurrence rate than the unexposed,” (Pilotto et al., 1997, p 563).

### **2.2 Environmental Factors that Facilitate Cyanobacteria Growth and Development**

Cyanobacteria occur naturally, but various environmental factors can facilitate their growth. There are several conditions in the environment that have a direct relationship with cyanobacteria growth and reproduction as well as their activity and tendencies in the water. For example, water temperature, weather conditions, season of the year, phosphorus and oxygen levels in the water can all contribute to cyanobacteria growth. Additionally, external factors such as road salt runoff from nearby roads, influx of nutrients from agriculture, and domestic wastewater runoff can lead to increased chances of algal bloom cases (Chorus et al., 2000).

### **2.2.1 Worcester Cyanobacteria Monitoring Collaborative Reports**

The Worcester Cyanobacteria Monitoring Collaborative (WCMC) is a group of volunteers that investigate and study the presence and diversity of blue-green algae in Worcester's bodies of water. A report from September 2017 shows that the concentration and presence of different types of cyanobacteria varies depending on the weather conditions and the seasons of the year (EPA, 2018). In one particular month, the weather conditions were described as "damp and chilly" with temperatures in the low 50's (WCMC, 2017). Under these conditions, a significant reduction in concentration of cyanobacteria was observed in multiple bodies of water in Worcester such as Lake Quinsigamond and Indian Lake. These changes in concentration suggest that there is a decline of cyanobacteria presence in bodies of water as the temperatures falls and vice versa. These observations suggest that there are multiple types of cyanobacteria that have seasonality trends throughout the year.

There are multiple sources that can cause an elevation of phosphorus and other excess nutrients in the water, which feed and facilitate cyanobacteria growth and reproduction. This means that if the phosphorus levels in the water peak, there will most likely be a stronger presence of cyanobacteria (WCMC, 2017). Similarly, the oxygen levels in the water are a good indicator to identify the presence of photosynthetic organisms like cyanobacteria. High oxygen levels during the day and low oxygen levels during the night suggests that at night-time, cyanobacteria utilize most of the oxygen in the water for cellular respiration. As a result, the levels of oxygen are depleted enough to kill fish and other organisms in the water. As mentioned previously, cyanobacteria prefer warmer weather in shallow areas with high nutrient inputs. Therefore, the temperature of the water is also key for cyanobacteria growth and reproduction. Warmer water temperatures will present higher levels of cyanobacteria compared to colder water temperatures. This is why we see a trend of faster growth and development on cyanobacteria during the months of summer season (WCMC, 2017).

### **2.3 Basics of Prevention and Treatment**

Despite the fact that cyanobacteria is a bacteria and not an algae, it compares similarly with the properties of algae blooms in lakes. In other words, these blooms are still a part of the algae community. It is also not uncommon to see algae blooms that are harmless; in fact, less than one percent of algae blooms produce harmful toxins (NOAA, 2018). As a result, eliminating HABs entirely from the environment is not necessary. Though there are many environmental factors for cyanobacteria growth, not all of them can be easily controlled, such as temperature. Because of this, one of the most basic prevention methods is to reduce the amount of nutrients, such as phosphorus and nitrogen, entering the water. The best way to do this is to identify and reduce the nutrient sources, such as runoff from things like fertilizers and soil erosion (D'Anglada, 2018). Nutrient input, however, is only one of many factors regarding HAB growth. Effective management strategies should employ a variety of methods to biologically, physically, and chemically control cyanobacteria blooms.

### 2.3.1 Biological Methods

Many algae blooms can be controlled through methods that are not foreign to the established ecosystem, which is known as a Biological Control (D'Anglada, 2018). This can be beneficial because some biological controls have a low price relative to the value they bring. For example, a possible simple solution could be to increase riparian vegetation surrounding the lake itself. With the increase in vegetation around the lake, the roots will be able to hold the soil together and keep it from eroding into the water. In addition, the roots can filter stormwater from entering the lake, as well as provide shade for some areas of the lake (D'Anglada, 2018). This is considered a biological control for cyanobacteria, as it does not involve introducing an artificial component into the environment. Biological control methods, while they can be effective in many cases, lack in regards to the range of scenarios in which they can work. Some biological methods may have limitations in their effectiveness due to the geographic characteristics, as some lakes may be too large for biological solutions (D'Anglada, 2018). Despite this, biological methods still have potential as a solution to cyanobacteria blooms.

### 2.3.2 Physical Methods

Physical control methods are often used to help alter the environment in order to make survival difficult for cyanobacteria. One example of a physical control method is lake mixing. The idea is to limit the nutrients that reach the surface, as well as maintain healthy levels of dissolved oxygen in order to reduce the competition these added nutrients have caused. This will cause a disruption in the cyanobacteria's natural environment and stunt cyanobacteria growth. However, if a body of water is too large, physical controls can become expensive and more difficult to implement.

### 2.3.3 Chemical Methods

Methods that utilize chemicals to prevent and control cyanobacteria, also known as chemical controls, present the opportunity for a quick and practical solution to algal blooms. For example, hydrogen peroxide could be a solution to clear out algae blooms when they become a problem. Tests run over the summer of 2018 used hydrogen peroxide to wipe out a strain of golden algae known as *Prymnesium parvum*. Hydrogen peroxide also demonstrated the ability to wipe out harmful blooms of cyanobacteria in follow up lab tests. Dr. Ben Wagstaff said, "The adoption of H<sub>2</sub>O<sub>2</sub> in smaller lakes and watercourses popular for sailing and water pursuits means they would no longer have to close for long periods when blooms occur," (Field, 2018). The amount of hydrogen peroxide used in this article was enough to wipe out the algae, yet was harmless to the existing fish and microorganisms in the lakes. Through tests they ran, the team from the article also showed that any effects of hydrogen peroxide used on existing waterways faded after two days (Field, 2018).

## **2.4 Factors Regarding the Development of a Policy to Combat HABs**

When developing policy to combat algal blooms, there are many factors one must consider. Policy on this topic can be broken down into four major categories: Monitoring/Surveillance, Treatment, Response, and Prevention. Not only does each category present its own unique challenges, but each also has both societal and biological factors that shape the policy that surrounds them. Although not all of these factors were not applicable in our in depth method research, each of these factors are and should be considered when a strategy to combat HABs is being developed.

### **2.4.1 Societal Factors**

Understanding the public's reaction to these recreational water toxins is crucial when considering a plan of control. As shown, cyanotoxins are a big problem with human and wildlife safety. However, the public knowledge on this topic could vary from people seeing nothing wrong with the water to people who have genuine concerns based on what they experienced. Despite how people feel about it, knowing the extent of the problem in the area is key to creating a way to confront it. "Knowledge of the characteristics of a hazard, the local occurrence of the hazardous conditions and an assessment of the seriousness of the outcomes of exposure, provides the basis for development of policy" (WHO, 1999). Cases from around the globe will help in comparing ideas that have been implemented by others.

### **2.4.2 Biological Factors**

There are many biological factors that make the development of management of the cyanobacteria problem difficult. Despite the numerous symptoms of exposure to cyanotoxins, the observation of these symptoms is not an efficient way to detect cyanobacterial blooms due to the time it takes for these symptoms to manifest. In addition, there is still much we do not know about cyanobacteria. Many more types of cyanotoxins are likely to be discovered, and it is difficult to tell if the observed health effects of cyanobacteria are due to substances other than the currently discovered cyanotoxins (Chorus et al., 2000). It can also be difficult to determine whether a bloom is toxic or not. As previously stated, not all types of cyanobacteria are toxic, and even toxic blooms can be harmless in low concentrations, especially if the bloom is spread out over a large area (Chorus, Falconer, Salas, & Bartram, 2000). One common factor of a toxic bloom, however, is that hazardous conditions usually result from buildup of cyanobacterial cells themselves. While toxins within cyanobacteria cells can leak directly into the water, they are rapidly diluted and usually do not pose a threat. Therefore, "measures for recreational safety should chiefly address cyanobacterial cells containing toxins," (Chorus et al., 2000, p. 327) as opposed to the monitoring of specific strains of cyanobacteria and their toxins. .

## 2.5 Current EPA and WHO Guidelines

A variation of guidelines for monitoring are implemented to give an idea on what to monitor within the water body. The World Health Organization (WHO) guidelines use a three tiered system to have a base for their monitoring of cyanobacteria:

Low risk of health effects occur around a density of less than 20,000 cyanobacterial cells per mL. Medium risk health effects occur around a density of less than 100,000 cells per mL. While there are theoretical levels of cyanobacteria concentration that could prove lethal, no deaths have ever been reported. Therefore, there is no official guideline for high risk situation. Instead, this level of hazard calls for strict observation of bathing sites and flexible responses (Chorus et al., 2000).

The Environmental Protection Agency (EPA) provides guidance for the closing of lakes and ponds due to high concentrations of cyanobacteria present in the water. However, there are currently no existing regulations or mandates for cyanobacteria testing in public bathing beaches established by this organization. The EPA guidelines for monitoring and responding to cyanobacteria in recreational waters state the following:

Common visual signs of cyanobacteria include water discoloration, reduced transparency and accumulations of scum-like substance in the surface. Additionally, the water may have an unfavorable smell and taste (EPA, 2019). In order to reduce the occurrence of cyanobacteria blooms, nitrogen and phosphorus pollution must be addressed. For long term and short term management options refer to the *World Health Organization: Guidelines for Safe Recreational Water Environments* (EPA, 2019).

## **Chapter 3 - Methodology**

The fundamental goal of this project was to recommend management strategies for monitoring, prevention, treatment, and response for Harmful Algal Blooms in Worcester by evaluating and augmenting current strategies. The team worked on this project for a total of 7 weeks from March 11th, 2019 to April 30th, 2019, with another 7 weeks of preparation from January to March. The objectives of the project were as follows:

- Evaluate the current management strategies of Worcester and other locations
- Research methods for prevention and monitoring/testing of blooms
- Research and recommend a public communication response plan

Our approach to the project was formed in collaboration with our sponsor, Jacquelyn Burmeister, Senior Environmental Analyst with the DPW. Most of our focus went into the first two objectives, partly because most of the info needed for the third objective was obtained during the first one. Prevention and Treatment were areas the DPW felt comfortable with, so they were not our focus.

The three objectives relied heavily on literature research and interviews. Additional documents were also created to house the information researched in order to provide easy access when needed. Most of these documents will be covered in further chapters, and placed in our appendices.

### **3.1 Evaluate the current management strategies of Worcester and other locations**

This objective aimed to evaluate the current strategies that have been used in Worcester and other places. By first examining what Worcester has done, we found what was important to look at when comparing to other locations. This allowed us to examine what was missing from Worcester's current mandates and strategies, as well as how other mandates and strategies could be applied in Worcester.

Research into locations that have struggled with cyanobacteria blooms provided valuable information on methods that have been used around the world. First, the team, working with Jacquelyn, conducted thorough research into strategies that the DPW employs to combat cyanobacteria. Once this was complete, a list of other locations to research was drafted, which included governing bodies representing many different levels of management, ranging from international to local. After, the team researched the locations and organized their management strategies into four main sections: Prevention, Monitoring and Testing, Treatment, and Response. Finally, we constructed a comparison document containing all of the management strategies researched (refer to <https://wp.wpi.edu/wroc/algae/>). With this document, we compared the types of methods used by each location to form an understanding of what Worcester has not yet explored. In addition to this document, we created summaries of the two interviews performed for this objective, the details of which can be found in Section 3.4.



### **3.2 Research Methods for Monitoring and Testing Blooms**

The final goal of this objective was to determine which methods discovered in Objective One could be most helpful to Worcester. After determining all of the methods that were used by locations other than Worcester, we presented them to our sponsor Together with Jacquelyn, the team chose which methods we believed to be the most promising. We then began research on these methods, focusing on both how the method works in other places, and on how it could work in Worcester.

### **3.3 Research and Recommend a Public Communications Response Plan**

The goal of this objective was to determine how the DPW could more efficiently communicate to the public when a bloom is detected. Since the team had already researched Response strategies used in other locations in Objective One, we first collected these results and reviewed them in terms of applicability to Worcester. Specifically, we gathered information not only from our summary tables, but from our interview with Karen Malkus-Benjamin. This was the shortest of the three objectives due to the vast similarities each of these locations had with one another in terms of response.

### **3.4 Data Collection Methods**

We collected data for our objectives using the following methods:

- Literature review
- Field data collection and observation
- Interviews

Literature review was used for all three objectives, but most research was done in the first two. Field data collection and observation was performed for the first objective in the form of a trip to Indian Lake in order to gain a first-hand picture of the problem we were dealing with. This allowed us to examine the warning signs posted and lake characteristics. Two interviews were performed in Objective One, one with Mike Celona in the Massachusetts DPH, and the other with Karen Malkus-Benjamin of Barnstable. The summaries were used to give us insights on what other locations may be doing, and how the government is managing this problem. Through interviews with these experts, we were able to attain vital feedback.

## **Chapter 4 - Research Results and Data**

This section will summarize the data collected throughout this project. All of our research topics gave certain findings and recommendations to solve the problem. However, the research done on these methods covered more than what is shown in our outcomes chapter. More in depth detail about the results and data are presented in the following chapter.

### **4.1 Current Cyanobacteria Management Strategies (Objective One)**

Different locations have different ways of managing cyanobacteria outbreaks. The team selected ten locations/governing bodies at various levels of scope and researched their strategies regarding cyanobacteria. Most locations surveyed had guidelines implemented, but not mandates. Only two locations surveyed (Ohio and China) did create mandates that must be followed. All of the following strategies released are ways to combat cyanobacteria blooms in recreational waters, other than Ohio. The only difference with Ohio's strategy is that they have released it to focus on drinking water safety, not public recreational use. This information is still useful because we can base what we take from their mandate and compare it to Worcester's potential use of the method and whether it can be viable to implement.

#### **4.1.1 Worcester Cyanobacteria Response**

The WCMC, managed by Department of Public Works, employs multiple strategies to manage cyanobacteria. In order to keep the public safe from hazards of the water, they work as a volunteer group to control blooms. Their main prevention method is the application of aluminum sulfate, a coagulant that removes phosphorus from the water, preventing cyanobacteria proliferation. The compound is administered once near the beginning of the summer, and costs \$25,000 per use on Indian Lake. While preventative measures are one of the best ways to manage an algal bloom, they are not always effective. Therefore, it is important to monitor lakes during the summer months when blooms are most likely to occur.

The DPWs main monitoring method is cyanobacteria cell count. Due to regulations from the Massachusetts Department of Public Health, the city must close the lake if the cell count surpasses 70,000 cells/mL. This count is administered every other week in the summer months, costs \$500 per count of Indian Lake, and the test takes 7 days. The city also monitors levels of phosphorus, nitrogen, oxygen, total suspended solids, pH, temperature, chlorophyll, phycocyanin, visibility, and toxins. Through monitoring, levels of ...and then treatment may be necessary

For treatment, the city administers copper sulfate as an algaecide when a harmful algal bloom is spotted. This costs \$3000 per use on Indian lake, and takes effect after half a day. However, treatment cannot be administered once the cell count rises above 70,000 cells/mL due to depletion of oxygen in the lake, which can disrupt the ecosystem.

The DPW has an established system for public response and public notification, the city posts signs at closed water bodies, places a health advisory on the city website, and posts on Twitter and Facebook. Various media outlets also sometimes cover the closing of lakes.

#### 4.1.2 Strategies from Other Places

Different places and organizations from a global to local level were investigated to specific cases in order to gather the best and most efficient strategies that can be applied to Worcester's efforts to deal with cyanobacteria. It is important to gather information from other states and countries with different climates and environments in order to explore other solutions to the same issue. After having gathered a broad variety of information from different locations and organizations, evaluations can be made regarding which new strategies could be applied to optimize Worcester's current response plan for cyanobacteria outbreaks.

The table below (Table 1) shows an overview of this information, showing what types of management each location or organization does. Only Worcester and the EPA have information available for all four categories. The Massachusetts DEP contains a [/] because it contains a prevention strategy of referring to the EPA government website.

Table 1: Overall management summary

Locations / Organizations	Prevention	Monitoring and Testing	Treatment	Response
<b>Worcester</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>
Mass DEP	/	X	X	
WHO	X	X		
<b>EPA</b>	X	X	X	X
Lake Erie (PA)		X		X
New Jersey		X		X
Maine		X		X
California		X		X
New Zealand		X		X
Ohio		X	X	X
China	X	X	X	

Every location examined performs at least some monitoring action, which is to be expected since it would be a public health hazard to not close lakes affected by cyanobacteria blooms. For this reason, most locations also have some sort of response plan. The larger the scope of the organization, however, the less likely it is to make effective policy about public notification. The only locations examined to have policy in all four categories were Worcester and the EPA. It is noteworthy that the team had access to in-depth information regarding Worcester's management strategy through our sponsor.

The table below represents the different prevention methods and strategies used in each place and organization. The highlighted categories represent new methods not being used in Worcester.

Table 2: Prevention Summary

Locations / Organizations	Phosphorus Sources	Nitrogen Sources	Light Reduction	Aluminum Sulfate	Coagulants	Barley Straw	Ecological Remediation	Lake Mixing	Watershed Protection Program
<b>Worcester</b>	X	X		X	X		X		X
Mass DEP	X	X			X			X	
WHO	X	X	X						
EPA	X	X			X	X	X	X	
Lake Erie (PA)									
New Jersey									
Maine	X		X	X	X				
California									
New Zealand									
Ohio					X				X
China	X	X	X	X	X	X	X	X	X

**Phosphorus Sources:** Cyanobacteria need phosphorus to grow, so reducing phosphorus levels can limit algae growth

**Nitrogen Sources:** Cyanobacteria need nitrogen to grow, so reducing nitrogen levels can limit algae growth

**Light Reduction:** Cyanobacteria need light to photosynthesize and grow, so limiting light can limit algae growth

**Aluminum Sulfate:** Can reduce phosphorus levels in the water body. It can also be used for treatment (see below)

**Coagulates:** Some coagulates, such as alum, remove phosphorus from the water. Coagulates can also be used for treatment (see below)

**Barley Straw:** Produces a chemical that inhibits algae growth. May cause deoxygenation of water.

**Ecological Remediation:** removal of pollutants from environmental media such as muds, groundwater and soil; build environmental-friendly constructions such as wetland.

**Lake Mixing:** Cyanobacteria need oxygen to grow, so mixing or otherwise disrupting a lake can limit the ability of algae to rise to the water's surface and grow

**Watershed Protection Program:** A program focused on a specific water bodies to reduce the nutrient load there.

Worcester employs many of the methods in this table, but some are only implemented at a basic level. Limiting of nutrient input from phosphorus and nitrogen sources can always be improved, both through public notification and increased monitoring. As can be seen, China has devoted a great amount of effort to the prevention of cyanobacteria blooms. However, this effort cost millions of dollars, which Worcester does not have. The most

important factor that should be taken away from this is that even though there are some more direct ways of prevention than others, it is likely that more than one should be taken into account to effectively prevent blooms.

The table below represents the different monitoring and testing methods and strategies used in each place and organization. The highlighted categories represent new methods not being used in Worcester.

Table 3: Testing and Monitoring Summary

Locations / Organizations	Satellite Imaging	Toxin Testing	Cell Count	Bio-volume Count	Danger Levels	Phosphorus Level	Nitrogen Levels
<b>Worcester</b>		<b>X</b>	<b>X</b>		<b>X</b>		
Mass DEP		X				X	X
WHO			X		X	X	X
EPA		X			X	X	X
Lake Erie (PA)		X	X				
New Jersey		X	X		X		
Maine	X	X	X		X	X	
California	X	X	X		X		
New Zealand		X		X	X		
Ohio		X	X				
China	X	X	X		X	X	X

Table 3 cont.: Testing and Monitoring Summary

Locations / Organizations	Citizen Monitoring	Secchi Disk/ Transparency	Chlorophyll levels	Phycocyanin Probes	Phytoplankton levels	Water Temp/Thermal Stratification
<b>Worcester</b>	<b>X</b>	<b>X</b>	<b>X</b>			
Mass DEP		X	X	X	X	X
WHO		X				
EPA		X				
Lake Erie (PA)	X				X	
New Jersey	X	X	X			
Maine	X	X	X			
California	X	X				
New Zealand						
Ohio						
China		X	X		X	

**Satellite Imaging:** Satellite Imagery provides a synoptic view of the development, and temporal and spatial distribution of cyano-HABs by distinguishing between chlorophyll and phycocyanin.

**Toxin Testing:** Even if cyanobacteria is present, if no toxins are detected, the water is theoretically safe. However, it is likely that there are types of cyanotoxins not yet discovered.

**Cell Count:** The amount to cyanobacteria cells is a good general measure of how severe a bloom is due to the many different types of cyanobacteria and cyanotoxins

**Biovolume Count:** While cell count does not account for the size and geometry of cells, biovolume count does.

**Danger Levels:** A level system of warnings and actions, usually based on cyanobacteria cell count

**Phosphorus Levels:** Phosphorus levels are an indicator of the cyanobacteria growth potential

**Nitrogen Levels:** Nitrogen levels are an indicator of the cyanobacteria growth potential

**Citizen Monitoring:** Volunteer groups that go to the water bodies to conduct sampling and relay monitoring information to officials.

**Secchi Disk/ Transparency:** The more severe an algal bloom, the lower the transparency will be.

**Chlorophyll Levels:** Examination of the chlorophyll concentrations in tandem with cell counts can be used to determine the amount of phytoplankton in the water.

**Phycocyanin Probes:** Used to measure a pigment that is found specifically in cyanobacteria. Generally used to determine abundance and concentration of the cyanobacteria.

**Phytoplankton Levels:** Organisms that are an indicator of the cyanobacteria growth potential.

**Water Temp:** The warmer layer up top is more susceptible to cyanobacteria blooms. This is something that can be monitored as this is where most cyanobacteria blooms.

Though Worcester does technically monitor most of the factors in the above table, there are no advisory levels or procedures in place for many of them, which is why they are highlighted. Phosphorus and nitrogen in particular are two factors that many researchers sight as the main indicators of cyanobacteria growth potential. Of the strategies that Worcester does not employ, these two are also by far the more widely used in other locations, meaning they might be helpful in Worcester. The other methods highlighted are more niche methods, but still could have merit and use in Worcester.

The table below represents the different treatment methods and strategies used in each place and organization. The highlighted categories represent new methods not being used in Worcester.

Table 4: Treatment Summary

Locations / Organizations	Copper Sulfate	Hydrogen Peroxide	Coagulants	Ultrasound Waves
Worcester	X		X	
Mass DEP	X		X	
WHO				
EPA	X		X	X
Lake Erie (PA)				
New Jersey				
Maine	X	X	X	

California	X			
New Zealand				
Ohio	X	X	X	
China	X	X	X	

**Copper Sulfate:** An algaecide.

**Hydrogen Peroxide:** An algaecide. Only mentioned by the Ohio EPA, but more in-depth information can be found.

**Coagulates:** Cause cyanobacteria to settle below the surface of the water, losing their oxygen supply. Some coagulates, such as alum, also have preventative effects (see above).

**Ultrasound Waves:** Used to rupture the internals of a cyanobacterial cell. Further research required.

For treatment, we are interested in methods that treat the issue in a more efficient way than what is being done today in Worcester. The current treatment methods the DPW is using here are effective and straight to the point, and don't need further research. The only restriction due to specific regulations is that treatment is not allowed after the cyanotoxin levels have reached the advisory levels for Worcester because further treatment will compromise the ecosystem. In the end, we only found two methods that we are interested in exploring further. There is not much variety when it comes to treatment for cyanobacteria, as there are similarities between many methods. The treatment methods being used in Worcester are also being used in many other locations.

The table below represents the different response methods and strategies used for cyanobacteria management in each place and organization. The highlighted categories represent new methods not being used in Worcester.

Table 5: Response Summary

Locations / Organizations	Posting Signs	PR Guidelines	HAB Notification	Review, Reporting and Revision
<b>Worcester</b>	<b>X</b>		<b>X</b>	
Mass DEP				
WHO				
EPA	X	X		
Lake Erie (PA)			X	X
New Jersey	X	X	X	X
Maine	X	X	X	
California	X	X	X	X
New Zealand				
Ohio		X	X	X
China			X	X

**Posting Signs:** Warning signs posted at affected water bodies

**PR Guidelines:** Plans and guides on how to communicate the health hazards to the public.

**HAB Notification:** Notification sent out to the public about the what has caused the closing of the certain waterbody.

**Review, Reporting and Revision:** Steps taken after knowledge of cyanobacteria in the water body to spread awareness.

For response, it was observed that most places are sticking to basic public notification and awareness methods. There is not a wide variety of methods to inform the public about the issue. Worcester is already doing two of the four common methods other locations are using. To go beyond current efforts for public notifications, Worcester should consider developing and publishing PR guidelines to educate and guide the public about harmful algal blooms management. Additionally, another method that seems to be working efficiently in other places is establishing a citizen based monitoring and reporting and revising system to spread awareness.

## 4.2 Road Salt Pollution

Road salt, also known as sodium chloride, is often applied to road in order to lower the freezing point of ice in order to prevent icy roads. However, road salt will also increase the chlorine level in water bodies due to runoff from the roads. A previous IQP from 2015 titled “A Framework for Assessing Impacts of Road Salt on Groundwater Supplies in Massachusetts” explained what road salt pollution is, how bad it is, and how to control it in Massachusetts (Nicholas Gigliotti, 2015). The report mentioned that road salt pollution impacts waterways, which leads to a question: Can road salt pollution cause harmful algae blooms?

Chlorine level could affect the growth of normal algae, which leads to a shift from algae dominance to cyanobacteria dominance of the algae community (Parnapy, 2017). Different water bodies also respond differently to additional chlorine: low nutrient water bodies, specifically those low in phosphorus and nitrogen, can experience an impact on algae ecosystem at chlorine levels of about 2-10 mg/L. For high nutrient water bodies, however, the impact is not observed until about 70 mg/L (Parnapy, 2017).

In addition to chloride level, road salt also contributes to the increasing of salinity level into water bodies. These two aspects potentially affect algae community in different ways. Salinity, according to the effect of osmosis, could kill cells and microscopic plants that has a low salt tolerance, such as green algae, while cyanobacteria have a high salt tolerance that could still adapt high salinity environment. Road salt is usually applied during winter, though it can be used as late as March or April. Cyanobacteria growth becomes a concern as water temperatures rise around May. Due to this, road salt can still affect algae growth in the summer. As a result, controlling use of road salt could be a prevention method on algal bloom problems (more information can be found in Appendix B).



### **4.3 Prevention, Monitoring, and Testing Method Research (Objective 2)**

With input from our sponsor, we determined that there were methods from Objective One that should be researched further. All topics explored are shown below, and the locations they are used can be found in the tables in Section 4.1.2.

#### **4.3.1 Barley Straw**

Although the exact reason of why barley straw controls the cyanobacteria remains uncertain, there are different hypothesizes about how it works. One article wrote specifically about the procedure of the use of barley straw (Newman, 2012). Newman stated that when barley straw first get into the water, soluble components (likely to be mix of carbohydrates and hemicelluloses) also get into the water. The water body is now in a Bacteria dominant. After 2-8 weeks, which is depend on the water temperature, barley straw starts its decomposition process. At this moment, the dominance was changed from a micro-flora dominance to a fungi dominance. During the decomposition, products of lignin are transformed by bacterial and fungal enzyme activity. The mixture of compounds now transformed into Fulvic and Humic Acids, or Dissolved Organic Carbon (DOC). As the decomposition continuous supply of the right form of DOC, it creates conditions for continuously producing of Hydrogen Peroxide and other oxidising agents (Newman, 2012).

Since the main reason using barley straw is to control the growth of cyanobacteria, it can be applied twice a year and only use it during summer, when cyanobacteria is most active because of the high water temperature.

#### **4.3.2 Phosphorus Levels**

Strategies for the monitoring and surveillance of cyanobacteria growth have been developed by the World Health Organization. These methods aim to narrow down which areas are in need of surveillance, as well as provide a baseline of procedures to follow that can be augmented based on the characteristics of the body of water. Quantitatively, they also aim to restore bathing quality to the point where a visibility of >2m is observed using a Secchi disk (Chorus et al., 2000).

Due to its aforementioned effects on cyanobacterial growth, control of phosphorus concentration is one recommended long term treatment for bodies of water plagued by algal blooms (Chorus at al., 2000). The concentration of phosphorus in a body of water can be an indicator of whether algae growth is possible. According to Chorus at al., "In most bodies of water, [restoration of bathing water quality] can be achieved by keeping total phosphorus concentrations below 0.01mg/L. Cyanobacterial densities rarely reach hazardous levels even in water bodies containing 0.02-0.03 mL/g total P," (2000, p. 342). While phosphorus is far from the only factor of proliferation of algae, factors are often limnological and predictable, and therefore can be observed in bodies of water over time, as stated by Carmichael in 1995. This information can help in the targeting and prediction of algal blooms (Chorus at al., 2000).

Analysis of the chlorophyll present in water samples can also help in monitoring of cyanobacteria growth. Cyanobacteria development is often monitored through the counting of cyano-cells with a microscope. This process is long and tedious, though it can be circumvented if phytoplankton biomass can be quantified through chlorophyll analysis. In this case, analysis with a microscope can be limited to the dominant cyanobacteria species (Chorus et al., 2000). Additionally, if chlorophyll-a concentrations of 40 ug/L or more are present with cyanobacteria dominance, scum can form. Severe scums can form from chlorophyll concentrations of more than 100-150 ug/L when measured in open water (Chorus et al., 2000). There are also methods to analyze the level of toxicity of the different types of different cyanobacteria, but they are expensive and would be difficult to use effectively since there are so many types of cyanobacteria.

Since Ohio's management was state-level, the scope was small enough to create an effective mandate. In addition, this mandate was in regards to drinking water, which is much more of a health concern to the public, and therefore must be regulated. Through the comparison, we found that only two of the ten locations (including Worcester) had data for each of the subsections. The only other place with info on all four was the EPA. We found that because of this, all of the areas we considered had at least somewhat based their strategies off the the EPA guidelines, with the exception of New Zealand and China.

#### 4.3.3 Phytoplankton Levels

A study conducted at Lake Blaarmeersen in Belgium by Gremberghe et al. in 2007 examined the relationships between the levels of Phytoplankton, Zooplankton, and Cyanobacteria in the lake. Specific data regarding these levels and the characteristics of Lake Blaarmeersen can be found in Appendix C.

The Zooplankton present in Lake Blaarmeersen could be broken into three major groups: copepods, cladocerans and rotifers. The study concluded that the composition of Zooplankton influenced the amount of cyanobacteria, but the amount of zooplankton did not influence the composition of cyanobacteria (Gremberghe et al., 2007, p. 230). In addition, the ratios of the three major groups to each other had no significant correlation to cyanobacteria community composition. However, the specific species of zooplankton present within these three groups had a significant effect on cyanoabcteria community composition (Gremberghe et al., 2007, p. 230). This means that it matters not how much of each major group there is. It only matters what species of zooplankton make up each group, as there are many species within the group.

The study went on further to say that in this particular case, only the cladoceran group has a significant correlation to cyanoabcteria community composition. *Bosmina* and *Daphnia* were the main cladocerans, and their biomass had a significant correlation to both cyanobacterial community composition and biomass. However, only *Bosmina* seemed to influence the cyanobacterial community dynamics independently (Gremberghe et al., 2007, p. 230). A positive correlation was observed between biomass of *Bosmina* and biomass of cyanobacteria, while a negative correlation was observed between biomass of *daphnia* and biomass of cyanobacteria. According to Gremberghe et al., "*Bosmina* is a selective grazer

that sometimes consumes predators of cyanobacteria, allowing cyanobacteria to flourish” (2007, p. 233). *Bosmina* does not directly boost or help cyanobacteria, but due to its selective grazing nature it is less likely to prey on cyanobacteria, or the things that cyanobacteria need to survive. Researchers are not sure whether *Daphnia* is bad for cyanobacteria, or the other way around. (Gremberghe et al., 2007, p. 233).

Finally, the study commented that unicellular cyanobacteria are most likely more easily grazed by Zooplankton. However, if the nutrient levels in a lake become too high, the cyanobacteria community will begin to proliferate, resulting in a cyanobacteria dominance. In this case, zooplankton will have trouble proliferating, and therefore will have a limited impact on cyanobacteria (Gremberghe et al., 2007, p. 233).

#### **4.3.4 Satellite Imaging**

The Cyanobacteria Assessment Network (CyAN) is a multi-agency project among the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and EPA to develop an early warning indicator system using historical and current satellite data to detect algal blooms in U.S. freshwater systems (EPA, 2018). It was also mentioned in a article about satellite imaging given by NASA as a option for accessing satellite imaging data (Rocchio, 2018).

This research supports federal, state, and local partners in their monitoring efforts to assess water quality to protect aquatic and human health. The CyAN project started October 1st, 2015, and had been providing satellite imaging using MERIS archive in FY12. Weekly composites of the European Space Agency Copernicus Sentinel-3 OLCI sensor data are now available to collaborators for initial review and validation, with a Full resolution at 300m on ground and a Reduced Resolution at 1.2km on ground (ESA, 2019). Landsat surface water temperature product is now publicly available through USGS EROS (EPA, 2018).

#### **4.3.5 Ohio EPA Public Notification Data**

The Ohio EPA released a plan to combat the cyanobacteria blooms in their water systems, and had a section based on public notification. Before a notification goes out, they state that there are a few things to look at to determine how public it should go. These are:

- What is the type of cyanobacteria present?
- When was the last non-cyanobacteria detection sample?
- What is the severity of the cyanotoxin level sampled?
- Where are the cyanobacteria blooms being found?

Next, they state that a procedure should be followed to bring awareness to the problem. After getting results for positive cyanobacteria, access to the body of water contaminated should be restricted to monitoring use. The general public should then be brought to attention on the case with a clear and concise message. Some ways of notifying could be done through;

- Set up a warning page that could be released on the Worcester City website to be accessed by the public.

- Send an alert, email, or possible messages out to the Worcester Residents
- Post on any available social media outlet.
  - For example, most school systems have a twitter account to notify the students the schools status after a storm.
- Display warning signs and notices at major points of public access to affected water bodies is vital.
  - These signs should be prominent and simple, with symbols or minimum text while still indicating all exposure risks.

## **Chapter 5: Findings and Recommendations**

During researches for background and different methods, a lot of findings were emerging. This chapter meant to collect all major findings extracted from all the documents we had written, in order to compress the best ideas, as well as making recommendations from them. Findings were arranged in order of the three objectives:

- **Objective 1:** Evaluate the effectiveness of current management strategies
- **Objective 2:** Research method for monitoring and testing of blooms
- **Objective 3:** Research and recommend a public relations response plan

### **5.1 Current Management Strategies of Worcester and Other Locations - Findings and Recommendations:**

#### **5.1.1 Worcester's strategy is more developed than most**

Our primary finding was that Worcester's strategies to combat cyanobacteria blooms is more developed compared to others. Management plans developed in other locations lack the depth and complexity that Worcester's has. The main advantage Worcester has is that they use many different testing, monitoring, and treatment methods to manage their cyanobacteria problem. Other locations, such as Barnstable, often focus on only basic prevention methods, like nutrient levels and runoff (Karen). Worcester is also actively researching new and better ways to manage the problem. The Department of Public Works have a dedicated staff member, Jacquelyn Burmeister, who is assigned to the cyanobacteria management for the city. Management in other Massachusetts towns is often carried out by a volunteer group, and not by a person in a hired position. As most locations focus on specific areas, like prevention or treatment. Worcester has focused in on all aspects of the problem. Management strategies through prevention, monitoring & testing, treatment, and response are all covered by the DPW. Most other locations examined had at least one of these strategy sections missing in their guideline proposal.

#### **5.1.2 EPA Regulations for Recreational Beaches are Unlikely**

Though algae bloom is an issue in many places, the EPA will most likely not create any regulations regarding cyanobacteria. Instead, a final set of recommendations will most likely be created. Mike Celona from DPH and Karen Malkus-Benjamin who worked with Barnstable both expressed to us that the EPA's focus is not on recreational waters, but on finalizing their legislation regarding drinking water. Mike, in addition, mentioned to us that the EPA will soon release their final set of recommendations regarding cyanobacteria management. With this on the horizon, it is unlikely that cyanobacteria legislation will be created anytime soon. However, recommendations seem to be a standard way to address cyanobacteria issues, as they were present in most of the places that we researched. Due to the unlikelihood of official legislation, we recommend that Worcester simply focuses on perfecting its own cyanobacteria recommendations. If legislation were to be passed, it would

most likely come from the state. Based on our research into other places, if the Mass DPH were to make legislation, they would most likely observe what towns and cities are doing to combat the problem, and model their mandate after that. Since Worcester has the most advanced management strategy in MA, they most likely have nothing to worry about regarding conflicting legislation from the state.

### **5.1.3 Scarce Data Exists in Other Locations**

Access to detailed in-depth information about cyanobacteria management in other locations is very scarce and limited. Due to our partnership with the Worcester DPW, we were able to get useful insight about the current strategies being used for prevention, monitoring and testing, treatment and response for cyanobacteria blooms formation. Additionally, the EPA also had detailed and extensive information for all the management categories previously mentioned. On the other hand, the guidelines and management plans for other locations and organization had information about monitoring and testing methods, but lacked information about at least one of the other categories. This might be due to the fact that the published management strategies for the other locations and organizations are meant to be used by the general public. Furthermore, most cities and towns have either a very small department working on cyanobacteria management or no one at all.

### **5.1.4 Most Locations Implemented Recommendations**

After conducting extensive research on the different management strategies used in Worcester and other places, it became clear that most places establish guidelines or recommendations to manage HABs formation instead of mandates. Each HAB outbreak behaves differently depending on the levels of nutrient input, the season of the year, or even the size, depth and temperature of the body of water in question. There are in fact many different factors that can alter the conditions of a lake as well as many different types of cyanobacteria and cyanotoxins that could be present in the water. Therefore, it is hard to enforce a set of rules and laws that will be effective for all the many different cases and places.

### **5.1.5 Worcester can Implement Methods used Elsewhere**

Finally, there are multiple methods employed elsewhere that the city of Worcester does not currently utilize. These methods will be the subject focused on in objective 2.

## **5.2 Objective Two Findings and Recommendations:**

Through conversation with our sponsor, we were able to determine which methods identified in Objective One were most likely to be helpful to Worcester. Light Reduction and Lake Mixing did not appear feasible due to Indian Lake's size, and Hydrogen Peroxide and Ultrasonic Waves are both treatment methods, whereas our sponsor was more interested in prevention methods. These methods still show potential when dealing with cyanobacteria, but were not applicable in our specific case. Public Response Guidelines, and Review Report and

Revision are both addressed in Objective 3. In depth research into the remaining methods was conducted to further understand how these methods could be applied in Worcester.

### 5.2.1 Barley Straw

Barley straw has been used in some places as an alternative method to manage cyanobacteria blooms (PondScape), the exact mechanism of how it controls the growth of cyanobacteria remains uncertain for scientists due to chemical components that cannot be determined (PondScape). However, barley straw has been proven in use that it does help the control of harmful algae blooms (Swistock, 2013).

It is surprising that the result of decomposition turns out to be similar to hydrogen peroxide. It is known that hydrogen peroxide is a kind of antiseptic that could be used to control cyanobacteria growth; continuously input small amount of “hydrogen peroxide” seems to be able to control cyanobacteria growth without much side effects, which makes barley straw an alternative solution to treat the harmful algal bloom.

In still waters such as lakes, ponds, and reservoirs, the minimum quantity of straw needed to control algae is about 10g straw m<sup>-2</sup> of water surface (PondScape). Treated lakes will need a higher dose (25 g/m<sup>2</sup>) and quantities up to 100 g/m<sup>2</sup> (PondScape). The efficiency of barley straw is related to temperature, it may take 2-8 weeks for the straw to become active when water temperatures are below 10°C but only 1-2 weeks when the water is above 20°C (PondScape).

*Worcester can look into barley straw as a preventative measure, as it is possible to apply barley straw right after a preventative treatment with aluminum sulfate.*

### 5.2.3 Biovolume Count

Some locations, such as New Zealand, use a measurement known as biovolume counts in place of traditional cell counts. Biovolume counts takes into account cell size and shape, which provides a more accurate estimate of toxin concentration (Wood, 2009). A biovolume count is determined by multiplying a cell count by the predetermined cell volume of the specific type of cyanobacteria. A biovolume count is not a change in the way one samples or measures cyanobacteria, but rather is a change in the advisory levels one uses.

New Zealand has a 3-tier warning system that utilizes biovolume count levels. This system outlines biovolume levels for both toxic and general cyanobacteria, and states the following (Wood, 2009):

- Total cyanobacteria < 500 cells/mL OR total cyanobacteria biovolume count < 0.5 mm<sup>3</sup>/L: Bi-weekly sampling and inspection
- Biovolume equivalent of 0.5 to < 1.8 mm<sup>3</sup>/L of potentially toxic cyanobacteria OR 0.5 to < 10 mm<sup>3</sup>/L total biovolume of all cyanobacterial material: Weekly sampling, notify the public health unit
- ≥ 12 µg/L total microcystins; **OR** biovolume equivalent of ≥ 1.8 mm<sup>3</sup>/L of potentially toxic cyanobacteria OR 10 mm<sup>3</sup>/L total biovolume of all cyanobacterial material: Test for toxins, notify the public

*The team recommends that the city of Worcester examine the types of cyanobacteria present in Indian Lake, and see if a biovolume count yields a different hazard level than a regular cell count.*

### **5.2.3 Fluorometers/Probes**

Probes and fluorometers are beneficial to use when monitoring for cyanobacteria in a water body. Both of these tools help with determining the amount of phycocyanin in the water, or even chlorophyll-a for some of the probes. Phycocyanin probes are a more direct and specific way to measure the presence and concentration of cyanobacteria (MassDEP, 2018). The phycocyanin levels in water are considered to be the most specific analysis to find the abundance and concentrations of cyanobacteria. These are important also because they are a part of a biomass only found in cyanobacteria (Ankita Shrivastava et al., 2018). Korea has taken part in a study with phycocyanin levels in a water body, and came up with these recommendation levels(Ankita Shrivastava et al., 2018):

- Levels of 0.1  $\mu\text{g/L}$ : caution
- 30  $\mu\text{g/L}$ : warning
- 700  $\mu\text{g/L}$ : outbreak

These levels can be used as a guideline to determine if a harmful algal bloom is about to occur.

The handheld fluorometer Worcester currently owns would make monitoring blooms less daunting in the future. This may be a more useful way to study the cyanobacteria growth potential in water, especially when compared to the time consuming cell count technique. According to tests run by the Dutch, the phycocyanin fluorometer was a more robust way to study the biovolume compared to cell count ([van der Oost et al., 2010](#); [Ibelings et al., 2014](#)). This is also more beneficial because due to in between laboratory counting, findings can be varied through this time, which the fluorometer does not have the same problem with direct results. After listening to Jacquelyn and researching more on these monitoring pieces, Worcester may benefit by utilizing the fluorometer they have rather than looking for another.

Probes and fluorometers have many options on how to monitor cyanobacteria. According to the WHO, fluorometers have successfully monitored the variability in phytoplankton biomass and species composition, as well as surface temperature, salinity, and nutrient concentrations, in the Baltic Sea. They used passenger ferries, three of them, in which they attached the fully automated analyzers for high-frequency sampling. Another way to use probes is through a submersible automated cyanobacteria probe. There are some probes that can be used for long term monitoring trends by deploying them on water intake structures.

*Using the fluorometer that is already in Worcester's hands is recommended, as this will make monitoring for blooms easier and more efficient. The introduction to a submersible probe for long term monitoring may not be possible now, but could prove helpful in the future when this plan develops more.*



### 5.2.4 Water Temperature

Water temperature plays a significant role in cyanobacteria growth. According to the document written by the Massachusetts Department of Environmental Protection in 2018, water temperatures above 25°C contribute to an increase of cell division, and likely cyanobacteria (pg. 14). Water qualities like temperature give an indicator to when a potential growth of cyanobacteria may occur, due to the friendly environment this presents for the organisms. This shows how important monitoring the lakes water temperature is, as these trends along with the water quality will help predict possible blooms.

External nutrient inputs are also a major factor on cyanobacteria growth, especially in relation to the water temperature. A series of controlled experiments, done by the Aquatic Ecology and Water Quality Management Group, Department of Environmental Sciences, and Wageningen University & Research, gave an indication that chlorophyll-a levels were affected much more in warmer waters. In an experiment of monitoring samples of water from a chosen water body, they found that chlorophyll-a levels increased under warmer water temperatures. Even more interesting, for one of the experiments had a nutrient injection, which ended up increasing the chlorophyll levels by nine times. This leads to the assumption that even at temperatures a bit below 25°C, blooms can still greatly occur with the problem of external nutrient input.

The lakes in Worcester most likely do not have thermal stratification within their water bodies. Thermal stratification occurs in deep lakes, where the nutrients and temperature fluctuates at specific levels in the water. The Massachusetts DEP states that, thermal stratification typically occurs in deeper water bodies, greater than 5 meters deep for small water bodies and 10 meters for larger water bodies (MassDEP, 2018). Since all of the lakes in Worcester, with the exception of Lake Quinsigamond which is also a part of three other towns, are less than 5 meters deep, thermal stratification qualities will not show. Although knowing the body of waters characteristics is important, this is one area of monitoring that needs much less attention to.

*Water temperature should continue to be monitored, and compared side by side to the nutrient levels entering the water.*

### 5.2.5 Phosphorus and Nitrogen Levels

Nutrients like Phosphorus and Nitrogen play a significant role in the growth and development of Harmful Algal Blooms. As mentioned before, high nutrient inputs in shallow bodies of water combined with several other factors can facilitate and promote HAB formation. Therefore, we can control the presence and formation of cyanobacteria by controlling the concentration of Phosphorus and Nitrogen in the water (Xu, et al., 2014). For a shallow body of water like Indian Lake and other bodies of water in Worcester, a safety range of Phosphorus and Nitrogen concentration levels should be established to control cyanobacteria booms and outbreaks. This range might slightly vary from case to case depending on different factors specific to the water body and the surrounding environment. Some of these factors are:

- Water body dimensions
- Water temperature
- Different seasons of the year / seasonality of cyanobacteria present
- Dominant cyanobacteria species

Lake Taihu in China shares similar conditions with Indian Lake in Worcester, including an average depth of about 6 to 8 feet (Quin, 2015). For Lake Taihu, a maximum concentration threshold for Phosphorus and Nitrogen was established to aid in the control of HAB formation (Xu, et al., 2014). Due to the similarities between the lakes, these thresholds can be used as a guide or starting point for developing Phosphorus and Nitrogen thresholds for Indian Lake and other water bodies in Worcester. These thresholds are shown below (Xu, et al., 2014):

- Total Phosphorus Concentration = below 0.05 mg per L
- Total Nitrogen Concentration - below 0.80 mg per L

A study shows that cyanobacteria blooms can potentially facilitate the transition from low-nutrient to high-nutrient concentration levels in bodies of water, thus creating a Phosphorus and Nitrogen cycling process (Cottingham, Ewing, Greer, Carey, & Weathers, 2015). This could be a possible explanation to a Phosphorus spike reported at Indian Lake in the summer of 2018 after what seemed to be a successful treatment. Therefore, a minimum concentration threshold for Phosphorus and Nitrogen should be established for Indian Lake and other bodies of water in Worcester to prevent nutrient cycling. These minimum concentration thresholds would also depend on different factors specific to the water body and the surrounding environment.

*Further research and studies should be conducted to determine what these thresholds could be for the different bodies of water in Worcester. By establishing minimum and maximum Phosphorus and Nitrogen concentration thresholds, a safety range of these nutrients can be determined to successfully control and prevent further Harmful Algal Bloom formation.*

### **5.2.6 Lake Community Dynamics (Phytoplankton Levels)**

A critical factor of cyanobacteria growth that many fail to account for is the effect that other organisms, mainly zooplankton and phytoplankton, have on cyanobacteria community dynamics. Zooplankton is the general name for any microscopic animal, whereas phytoplankton is the general name for any microscopic plant, which includes cyanobacteria. Different types and species of zooplankton and phytoplankton can affect the community dynamics of various cyanobacteria in different ways. A study conducted at Lake Blaarmeersen in Belgium by Gremberghe et al. in 2007 concluded that cyanobacteria community composition is affected not only by dissolved nutrients and physical conditions of the lake, but also by the zooplankton and phytoplankton composition in the lake (p. 229). The factors with the highest impact on cyanobacteria growth were dissolved nutrients, physical

variables, and zooplankton community composition. A slightly lower correlation was found with the phytoplankton community composition (Gremberghe et al., 2007, p. 229).

The factors identified in this study not only affect cyanobacteria, but they each affect each other as well (Gremberghe et al., 2007). *We recommend that the DPW examine the phytoplankton and zooplankton present in Indian Lake and their potential effects on cyanobacteria and lake conditions, possibly with the aid of professionals and experts in this area of study.* Use of the data in Section 4.3.2 and in Appendix C may help, as it provides an example of one lake environment where phytoplankton and zooplankton contributed greatly to cyanobacteria growth.

### 5.2.7 Satellite Imaging

Satellite imaging is a modern monitoring method used in many fields, including cyanobacteria monitoring. A project called Cyanobacteria Assessment Network can be an accessible resource to any organizations as they approve (EPA, 2018). Satellite imaging provides remote sensing data which is an important reference in developing an early warning indicator system using historical and current satellite data to detect algal blooms in U.S. freshwater systems (EPA, 2018).

Worcester had been very well developed in collecting data by hand for predicting cyanobacteria, which is also a needed procedure for a satellite predicting system. Worcester can use satellite imaging as a reference in monitoring cyanobacteria, which could save a lot of time for not sending people to monitor the lake until there is an emergency noticed by the satellite.

*We recommend getting in touch with the company that runs these satellite imaging programs may help Worcester setup a connection with them for the future.* Contact information for CyAN project: [CyAn@epa.gov](mailto:CyAn@epa.gov). After trying to get in touch with them, we did not get direct communication after emailing/calling. This could be due to the fact that an authorized organization is needed if one wants to get their attention.

## 5.3 Objective Three Findings and Recommendations:

Most locations perform the same basic actions when it comes to public notification of harmful algal blooms. The three main methods to do this are posting of signs at the affected waterbody, posts on websites, and posts on social media. However, there are a few new method the City of Worcester could implement. Karen Malthus-Benjamin of Barnstable has found success with an email alert system dedicated to cyanobacteria. She asks anyone who calls regarding cyanobacteria if they would like to be added to the system, as well as posts about it on websites and signs. Karen also alerts local veterinarians in the area of harmful algal blooms, and urges them to alert their patients, as cyanobacteria can be toxic to animals as well. The Ohio EPA has section on public notification within their guidelines on cyanobacteria blooms. The data found goes into deeper detail on chapter 4 section 3.3. Finally, the EPA has a multitude of examples on their website of warning signs to be posted

at affected water bodies. These signs focus on clearly communicating several things to the public including lake status, safe and unsafe activities, duration, and how to get more information.

*The City of Worcester should examine these signs and make sure that they are communicating all the information the EPA recommends in a clear and concise way. They must also reach out to local vets to create an awareness of the problem through these facilities.*

## **Chapter 6 - Conclusion**

Presently, Worcester is proactive in finding a way to make the harmful algae blooms less of a detriment on public recreation. Anyone should be able to enjoy their time during the warm summer months on a beach without the need to worry. If Worcester wishes to effectively combat HABs, they must continue their efforts to make their management strategy more effective. By basing their efforts on prevention, monitoring, treatment, and response they can develop a well thought out effort to manage this problem.

Prevention techniques should be implemented to reduce the amount of external nutrient inputs into the water from runoff. Low salt zones should be implemented over winter months, in order to limit the salt runoff impacts on the water bodies. Barley straw, also a method of prevention, should be used to limit harmful algae growth. Further research is required to find ways Worcester can use Barley straw in their lakes and is worth the investment. By limiting salt and using Barley Straw Worcester can utilize the safe months as prevention months in hopes to avoid further complications during the summer or high risk months. Once prevention techniques are executed, monitoring and testing must be used effectively to predict when a bloom may occur.

Monitoring and testing methods are the most important to avoid an outbreak and keep the beaches available to community members.. During summer months these methods will be used during peak cyanobacteria growth weather. In order to have a positive strategy, nutrients such as phosphorus should be monitored regularly along with the water temperature. Fluorometers and probes must be utilized, as these can be used to predict when a future bloom may occur. Satellite imaging is another technique that can be implemented to predict blooms, and where they may happen. However, it is recommended that the DPW gets in contact with the CyAN project organizers to run it in Worcester. Once testing runs are done, the harmful blooms must be reduced to a safe level with the use of treatment.

The city of Worcester is treating the HABs at an optimal level right now, with the use of copper sulfate. Remembering that prevention is key this may help to avoid larger outbreaks and limit the need of copper sulfate. Effective treatment is helpful if used in collaboration with known prevention techniques like lowering salt use, using barley straw and reducing nutrient inputs. Once treatment is administered, public notification is key when the lake is past safety levels.

Worcester currently has a strategy in regards to notifying the public of unsafe swimming conditions. We do recommend that a few extra methods be used to make notification more effective. Worcester will be able to successfully notify the general public if they are sure to include visits and notifications directly to veterinarians and animal owners, updating signs on lakes, use of social media and updating information on their website.

Lastly, the DPW should find a way to communicate and collaborate with members in other locations that have found similar success with managing cyanobacteria. Multiple locations continue to face the same problems faced here in Worcester, and could provide valuable information with one another. If an act of collaboration is reached, then having more

experience between the few shared methods could bring a whole new strategy to tackle cyanobacteria blooms in recreational water. HABs can be managed effectively if preventions are set up, water is monitored on a consistent basis, treatment is applied when necessary, updated public notification and collaboration is reached with other impacted communities. The hope is that through these methods the recreational beaches will no longer be closed due to cyanobacteria blooms and will continue to be used for years to come.

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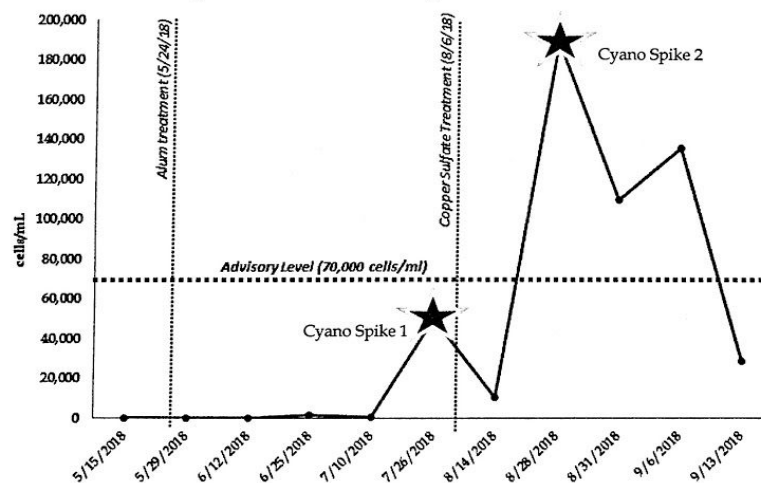
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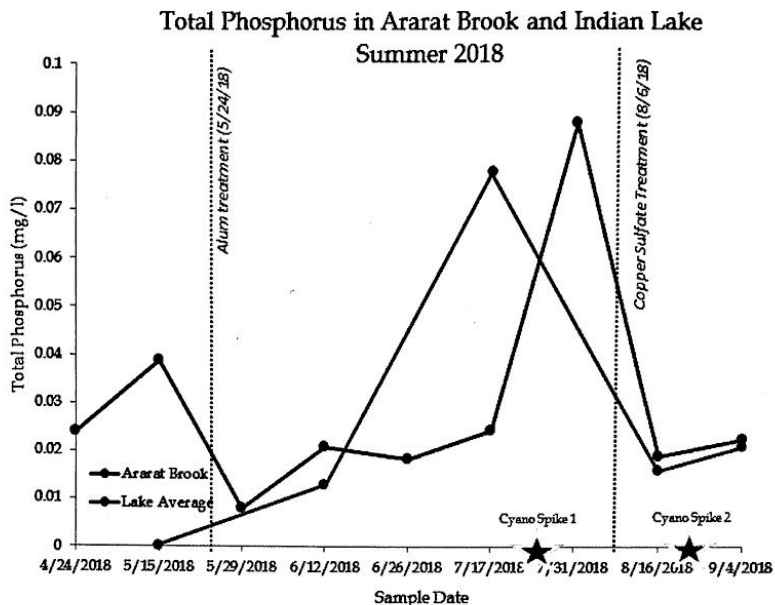
# Appendix A: Summary of Cyanobacteria Activity at Indian Lake (summer 2018)

## Summary of Cyanobacteria Activity at Indian Lake Summer 2018

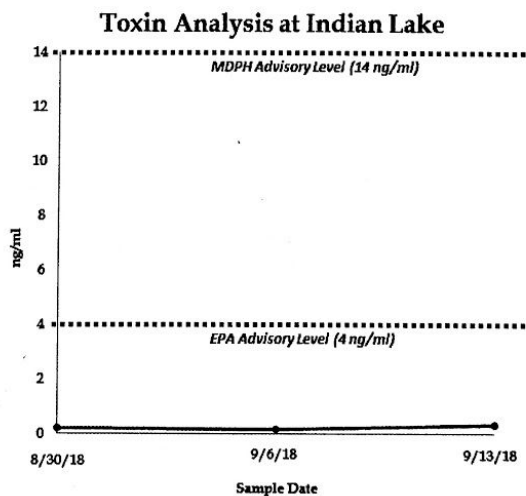
- DPW&P began collecting semimonthly cyanobacteria density samples from Indian Lake in May. Between May and mid-July results remained far below action levels.
- A preventative treatment of aluminum sulfate was applied on May 24th to reduce the likelihood of bloom development. This may have been responsible in-part for continued low densities. Other parameters pointed to a relatively healthy lake: *Secchi clarity*, a measure of lake water transparency, was as high as 8 feet in June, and average around 4 feet during this time. However, experience had told us that a copper sulfate (algicide) treatment would probably be necessary later in the season.
- Early July was hot and rainy. Over a short period of time, *Secchi clarity* decreased to an average of 3 feet. On July 31<sup>st</sup>, daytime oxygen levels were reported very high and overnight fish-kills suggested high rates of respiration by photosynthetic organisms, such as cyanobacteria. Residents complained of the lake smelling "funky". On August 2<sup>nd</sup>, DPW&P received the cyanobacteria density results taken on July 28<sup>th</sup> to be 50,000 cells/ml. DPW&P called in a contractor to treat the lake with copper sulfate on August 6<sup>th</sup> so as to prevent the density to reach advisory levels.
- Post-treatment sampling suggested success, with *Secchi clarity* reading at an average of 4 feet again, and normal oxygen levels. Cyanobacteria density was reported to be 10,500 cells/ml on August 14<sup>th</sup>.
- Since the 14<sup>th</sup>, there was continued hot weather and rain, however, clarity remained the same and there were no other visual or olfactory indicators of bloom formation. All parties were surprised to receive the result of 188,000 cells/ml on sample date August 28th, indicating a 177,500 cell/ml spike in density over just 14 days.
- Because the density result was above advisory level, DPW&P had no option to treat the lake, but collected a sample for overnight toxin analysis to determine if the cyanobacteria were harmful to human health. Additionally a sample was collected for a repeat density analysis to confirm the spike. The repeat sample confirmed the bloom with a result of 101,000 cells/ml. However, toxin levels were almost undetectable.
- DPW&P will continue to take samples until two consecutive samples read below the 70,000 cells/ml threshold and toxin levels are still below the MDPH's guidance advisory threshold. The latest sample, collected on 9/13, had a result of 29,000. We sampled again on 9/17, and await results with the hope of reopening the lake.

**Cyanobacteria Density at Indian Lake 2018**





- A high concentration of total phosphorus (TP) is considered one of the factors that may promote an algal or cyanobacteria bloom. DPW&P regularly tests TP in Ararat Brook and in Indian Lake. Increases in lake TP throughout the summer seemed to be halted by chemical treatments, but concentrations were still very high prior to the July 26<sup>th</sup> cyanobacteria population spike. Noteworthy is the relatively low TP concentration prior to the late August spike.



- Following the second spike in cyanobacteria density, DPW&P began to track toxin production in the lake. Throughout the bloom, there has been little toxin production by the cyanobacteria. All three samples collect have read for microcystin levels below 0.4 ng/ml. This level is well below the Environmental Protection Agency (EPA) and Massachusetts Department of Public Health's (MDPH) guidelines for an advisory.

## **Appendix B: Road Salt Impact**

### Road Salt's Impact to Cyanobacteria

Written and edited by Algae Bloom team, Worcester Polytechnic Institute, 2019

#### **Introduction:**

As part of our research regarding cyanobacteria blooms in Worcester's Indian Lake, the team conducted research into the effects that road salt runoff into a lake has on algae growth. Through our research, we came to the conclusion that both the salinity and chlorine levels of the lake can affect algae growth. Since cyanobacteria have a higher salinity and chlorine tolerance than most typical algae, high level of either could cause a cyanobacteria dominance.

#### **Road salt and its disadvantages**

Road salt is mostly composed of NaCl; it differs from table salt in that it is not purified. It is already known that road salt could be corrosive to concrete, vehicles and other structures (1). A project conducted by Worcester Polytechnic Institute in Massachusetts also mentioned that road salt could impact local water bodies through stormwater runoff (2).

After further research about road salt and its impact on waterways, we came to the conclusion that road salt greatly contributes to the salinity and chlorine input into streams, and as a result, into lakes (3). This was then further investigated to see road salts impact on cyanobacteria blooms.

#### **Sodium Chloride and Magnesium Chloride**

Facts:

1. NaCl is more corrosive than MgCl<sub>2</sub>. (10)(11)
2. MgCl<sub>2</sub> is more expensive than NaCl.
3. MgCl<sub>2</sub> works faster than NaCl and can be effective in lower temperature. (12)
4. MgCl<sub>2</sub> needs more in application because it has higher water content. (13)

According to all above, NaCl has been a cheap deicer for many years, although Magnesium Chloride is more environmentally friendly. However, thinking of Chloride

contribution to lake water, since Magnesium chloride literally needs a larger amount and contains higher chloride in its component, it contributes more chloride than NaCl does.

### **Salt and Lakes:**

A study published in 2017 speaks on road salt inputs into lakes (8). They investigated and tested the long-term chlorine trends in 371 freshwater lakes in North America, where the road salt has been used for many years (8). It turns out that many of these 371 lakes have suffered noteworthy salinization over the last 10 to 70 years (7). One of the 15 researchers in this study, Dugan, mentioned that in the 1900s the chlorine levels in Madison lakes were about 2 mg/L, but now the level had risen to 50 mg/L in Lake Mendota (7).

There are strategies made in order to reduce salt's impact on the environment. For example, the low salt zone is a strategy regarding areas that are sensitive to contamination by road salt; less or even no salt should be applied in these areas in order to protect the environment(9).

### **Chlorine level and Cyanobacteria:**

The increasing level of chlorine in the water can affect fish, aquatic plants, and the algae community (6). An increase in chlorine levels can cause a shift from Chlorophyte( green algae) dominance to a Cyanobacteria (blue-green algae) dominance, which can lead to a harmful algal bloom (3). Different water bodies also respond differently to additional chlorine: low nutrient water bodies, specifically those low in phosphorus and nitrogen, can experience an impact on algae ecosystem at chlorine levels of about 2-10 mg/L. For high nutrient water bodies, however, the impact is not observed until about 70 mg/L (3).

### **Salinity and Cyanobacteria:**

Salinity is another important aspect of how road salt contributes to algal blooms. Research shows that salinity tolerance of cyanobacteria is much higher than that of normal algae such as green algae (4). An article written about the impact of salinity on cyanobacteria mentioned that a salinity change of 1 practical salinity unit (1 PSU = 1g salt /kg of water) would cause the death of most green algae in a waterbody, and let cyanobacteria take the dominance since cyanobacteria can tolerate with a PSU of up to 16 (5).

Because of cyanobacteria's high tolerance to salinity, researchers, in addition to focusing on freshwater lakes, focused a lot on estuaries where freshwater and seawater mix (4). As the control of phosphorus input into lakes and streams became successful, dormant cyanobacteria did not have a chance to grow until it reached the estuaries, where water is less treated and higher salinity causes cyanobacteria to dominant the algae community (4).

**Conclusion:**

According to the chlorine level impact, we can tell an increase in chlorine level affect more to low nutrient water bodies, which are the treated/non-polluted water bodies; this emphasizes the need for reducing road salt in-use.

In order to reduce the use of road salt, restrictions like low salt zone, even the no-salt zone has been used in many states. Determining where to set a low/no salt zone is not a simple work that can be done by doing research, but we expected more studies and works can be done on this topic.

Road salt has saved us from icy roads for many years, however, it also brought undeniable damage to environment and constructions. We hope this document helps to understand road salt's effect on cyanobacteria, but more importantly, to encourage more study on road salt and maybe, find a better solution that won't hurt the planet we live on.

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## Appendix C: Phytoplankton Levels Data

### Background info (Results Section):

**Phytoplankton-** General name for any types of algae and water microplants. Cyanobacteria is one type of these. All Cyanobacteria is Phytoplankton, but not all Phytoplankton is cyanobacteria

### Lake Characteristics:

- Thermal stratification occurs in the summer and results in low oxygen levels in some layers.
- In summer months (see Fig. 2 on right):
  - At depth of 0.5 m, max phosphorus was 15 µg/L
  - At depth of 7.5 m, max phosphorus was 7 µg/L
  - At depth of 0.5 m, max nitrogen was µg/L
  - At depth of 7.5 m, max nitrogen was µg/L
  - At depth of 0.5 m, max ammonium was 50 µg/L
  - At depth of 7.5 m, Max ammonium was 125 µg/L
- pH was higher in the summer as phytoplankton were more active

### Zooplankton History: pg 226 and 227.

- To compare the grazing capacity of different zooplankton, biomass is more appropriate than numbers
- Zooplankton community Mostly dominated by rotifers
  - Encountered in both years in early summer just after the ‘clear water phase’ (more than 2000 indiv/L ).
  - Became scarce in late summer (August and September), but then came back in October, November and December.
  - Most abundant: *Polyarthra sp.*, *Keratella cochlearis*, *Keratella quadrata*, *Asplanchna priodonta*, *Synchaeta sp.*, *Kellicottia longispina* and *Pompholyx complanata*.
- Cladocerans:
  - Herbivorous cladoceran *Daphnia*
    - Mostly in spring “clear water” phase when secchi depth was high (max of 50 Indiv/L).
  - *Bosmina*
    - Very abundant in summer and autumn 2003 (max of 170 Indiv/L).
  - Other cladocerans were detected in low densities, like *Ceriodaphnia* and *Leptodora*.
- Copepods
  - Present both years in the winter and spring (max of 180 indiv/L).

- Calanoid copepods were present in spring 2003, after which they were replaced by cyclopoid copepods.

### Phytoplankton History:

- Similar values obtained for the total biomass of phytoplankton at a depth of 0.5 m (epilimnion) and 7.5 m (hypolimnion),
- High biomass of phytoplankton (up to 1300 mgCL1 ) was especially seen in summer and autumn (see Fig. 1).
- Mostly cryptophytes
  - Dinophytes, chlorophytes, cyanobacteria and diatoms also reached high numbers in particular periods.
- Early spring both years a bloom of small centricate diatoms (*Stephanodiscus sp.*) was detected
- Bloom just before the ‘clear water phase’ of cryptophytes (*Cryptomonas sp.*).
- June and July, high numbers of dinophytes (*Ceratium furcoides*, *Peridinium sp.*) were encountered
- In late summer filamentous phytoplankton (chlorophytes: *Mougeotia sp.* and cyanobacteria: *Anabaena sp.*, *Aphanizomenon flos-aquae* and *Limnothrix redekei*) was present in the lake.
- In autumn, there was again a bloom of cryptophytes.

### Cyanobacteria History:

- In general, cyanobacteria had a rather low contribution to the total phytoplankton biomass and reached a maximal contribution during summer and autumn (see Fig. 1).
- During the sampling period, the biomass of cyanobacteria was similar or lower in the hypolimnion compared with the epilimnion, except in late summer and early autumn of 2004.
- Cyanobacteria was identified using DGGE Profiles to examine their DNA.
- *Synechococcus* was the most dominant cyanobacterium, followed by *Limnothrix redekei* and *Anabaena/ Aphanizomenon* (nitrogen fixer)

## Appendix D: Case Studies

In this section you will find more detailed information about current management strategies being used in other places and organizations at the global, national, and state level, as well as sources of the information. The strategies discussed below are *guidelines* established by the appropriate authority in each case.

### Current Management Strategies - WORCESTER

1. Prevention
  - a. Aluminum sulfate
    - i. Coagulant, not an algaecide.
    - ii. Removes phosphorus and other particles from water, preventing the algae from eating it, thus preventing its growth and proliferation
    - iii. \$25,000 per use on Indian Lake
2. Monitoring and Testing
  - a. Cell count [Enzyme Linked Immunosorbent Assay (ELISA)]
    - i. Shows cyanobacteria concentration
    - ii. Advisory level of 70,000 cells/mL from Mass DPH
    - iii. Administered every other week
    - iv. \$500 per count of Indian Lake sample, takes 7 days for test to come back
    - v. ESS Group collects sample, ships overnight on ice to lab in Florida for testing
  - b. Phosphorus/Nitrogen Concentration
    - i. Indicator of cyanobacteria growth potential
    - ii. No formal advisory level
    - iii. Done in house
  - c. Oxygen Concentration
    - i. High oxygen levels during the day indicate respiration of photosynthetic organisms such as cyanobacteria
    - ii. Low levels of oxygen during the night caused by photosynthetic respiration results in overnight fish-kills
    - iii. Done in house
  - d. Total suspended solids, pH, temperature
    - i. Done in house
  - e. Chlorophyll and phycocyanin
    - i. These levels tell the biomass of phytoplankton in the water body
    - ii. Also can be used to indirectly detect phosphorus and nitrogen
    - iii. Done in house

- f. Secchi disc
  - i. Used to check visibility of lake
  - ii. Pre-cursor to cyanobacteria testing? What is good visibility?
- g. Toxin testing
  - i. Occurs once cell advisory level is hit
- 3. Treatment
  - a. No treatment is permitted above advisory level of 70,000 cells/ml
    - i. It will deplete the oxygen in the lake
  - b. Algaecide: Copper Sulfate
    - i. Administered only if cyanobacteria cells are below advisory level:
      - If too much is used to kill the high levels of cyanobacteria present, it can lead to depletion of oxygen and kill aquatic life in the water body.
    - ii. \$3,000 per use on Indian Lake, takes half a day
- 4. Response
  - a. Public notification:
    - i. Jacquelyn Burmeister
    - ii. Signs at public water bodies:
      - Used to tell the oncomers that the water is dangerous
      - The information could be more clear on these signs, even to direct the viewer to a link to find more detail
    - iii. Health advisory on the City of Worcester Website:
      - A very clear and concise way to provide what to avoid, and the risks it can bring if contacted
      - A great example of an outline to the problem that could be copied onto social media accounts or other media notification outlets

<http://www.worcesterma.gov/announcements/health-advisory:-indian-lake-closed>
    - iv. Overview of closure on news websites:
      - Websites such as Telegram posted an article on the closure of Indian Lake due to cyanobacteria, which is good exposure for those who may view that site.

<https://www.telegram.com/news/20180901/indian-lake-in-worcester-closed-by-blue-green-algae-pollution>
    - v. Social Media Outlets
      - Twitter (@WorcesterDPW) and Facebook cover the warning posted on the Worcester City website.

Worcester's water bodies:

1. Indian Lake
2. Lake Quinsigamond

3. Blackstone River
4. Sinepuxent Bay
5. Isle of Wight Bay
6. Chincoteague Bay
7. Wachusett Reservoir
8. Newport Bay
9. Wallum Lake
10. Nashua River
11. Sugden Reservoir
12. Thompson Pond
13. Hickory Hills Lake
14. St. Martin River

## **Current Management Strategies - MASSACHUSETTS DEP**

1. Prevention
  - a. Refer to article on EPA website, *What are some measures to prevent cyanobacterial blooms in surface waters?*
2. Monitoring and Testing
  - a. Dual-nutrient reduction strategy
    - i. Done by local PWS or monitoring group**
    - ii. Collect and analyze total nitrogen as well as total phosphorus samples throughout the reservoir.
    - iii. Document the data and evaluate patterns over time focusing on increased nutrient levels in relation to target area land use.
    - iv. Cyanobacteria is affected by the amount of nutrients entering the water, for example a moderate risk of cyanobacteria growth is a total phosphorus level of 10-25 micrograms per liter ( $\mu\text{g/L}$ ).
  - b. Water Temperature
    - i. PWS monitors water temperature**
    - ii. Collect water temperature readings throughout the reservoir at the same sampling locations identified for nutrients.
    - iii. Document the data and evaluate patterns over time.
    - iv. Water temperatures over  $25^{\circ}\text{C}$  contribute to increase cell division, leading to increased cyanobacteria blooms.
  - c. Thermal Stratification (Thermocline)
    - i. This is a layer in the waterbody that separates the densities of the warmer-lighter/surface layer from its cooler-denser/deep layer due to surface water heating.
    - ii. Identify reservoir characteristics and identify general timeframe of thermocline development, if applicable.
    - iii. Document and evaluate patterns over time

- iv. The warmer-lighter top layer is more prone to cyanobacteria growth warmer months
- d. pH Changes
  - i. Record pH changes, particularly at the raw water or filter influent.
  - ii. Evaluate any patterns of pH changes and use for comparison against any increased turbidity and taste and odor problems.
  - iii. An increase in pH means an increase in Cyanobacteria blooms
- e. Chlorophyll-a Probes
  - i. **To be measured in a laboratory or in the field**
    - **Breaking up or rupturing cells to extract the chlorophyll**
    - **Using a probe to measure chlorophyll in vivo**
  - ii. Used as a method to determine when a cyanobacterial bloom is underway, or increasing to a level that requires action by the water supplier.
  - iii. \*There is potential to overstate the impact of a bloom by pooling toxic and non-toxic chlorophyll a types into a single reading.\*
- f. Phycocyanin Probes
  - i. Phycocyanin probe measures the pigment found specifically in all cyanobacteria.
  - ii. Most specific analysis for estimating the abundance and concentration of cyanobacteria.
- g. Fluorometers
  - i. Handheld fluorometers can be used to obtain chlorophyll or phycocyanin readings. <http://beaglebioproducts.com/>
  - ii. Function similar to probes but are less expensive
- h. Secchi Disk Depth Monitoring
  - i. Lowered into the lake to test the visibility
- 3. Treatment
  - a. Algaecides (Copper Sulfate)
    - i. **Released by the Public Water Systems**
    - ii. Used with caution, as killing the cyanobacteria cells may potentially release intracellular toxins.
    - iii. Should only occur when cell counts are low enough to avoid potentially releasing high concentrations of cyanotoxins.
  - b. Nutrient Treatment (Ferric Salts)
    - i. **Released into the water body by the PWS**
    - ii. After entering the water, they act as a coagulant causing the cyanobacteria to settle away from the top layer of the water.
    - iii. \*More about how the process works is here:  
<https://www.epa.gov/nutrient-policy-data/control-and-treatment>\*
- 4. Response
  - a. N/A

Sources:

<https://www.mass.gov/files/documents/2018/09/27/pws-cyano-guidance-0918.pdf>

## Current Management Strategies - WORLD HEALTH ORGANIZATION

1. Prevention
  - a. Stop P and N from entering the water
    - i. Soil erosion, chemical runoff, animal feedlots, etc.
  - b. Limit the light that the cyano-cells can absorb
    - i.  $I_Z = I_0 e^{-Z\epsilon}$  where  $I_Z$  = intensity at depth Z,  $I_0$  = Intensity at the surface, and  $\epsilon$  is the vertical extinction coefficient
2. Monitoring and Testing
  - a. Cyanobacteria Cells
    - i. Monitor every two weeks
    - ii. Use chlorophyll-a concentration to measure cyanobacteria density.
      - If concentrations of chlorophyll-a remain below 0.01 mg/L hazardous densities of cyanobacteria are unlikely.
    - iii. Guideline of 20,000 cells/mL to minimize adverse health effects
    - iv. Guideline of 100,000 cells/mL for beach closings
  - b. Phosphorus
    - i. Guideline of 0.01 mg/L to 0.02 mg/L
    - ii. Monitor twice a year
  - c. Nitrogen
    - i. Keep nitrogen concentrations lower than a 7:1 N to P ratio
  - d. Procedure:
    - i. Begin with visual inspection of the bathing site. Assess the most likely areas to be affected first, i.e., downwind shorelines.
    - ii. Note any changes in wind direction or strength in the preceding 24 h as conditions can vary within hours.
    - iii. Determine if: (a) the bottom of the lake can be seen at 30 cm depth along the shore line, or—if a Secchi disc is available—whether the Secchi transparency is >2 m; (b) cyanobacteria are visible at the water edge or as green or blue-green streaks on the water surface; and/or (c) a green or blue- green scum is on the water surface in any area.
    - iv. If cyanobacteria are suspected, decide whether or not to (a) buoy off affected areas and prohibit access to them by water users; (b) prohibit access to the water edge affected by scum or reduced visibility, except for launching boats; and/or (c) prohibit access by all recreational users where cyanobacterial blooms cover a large part of the water surface.

- v. If cyanobacteria are suspected, immediately take a grab sample (100 ml) for microscopic analysis. 6. If cyanobacteria are present, initiate the structured monitoring program given in Table 4.

### 3. Treatment

### 4. Response

## Current Management Strategies - ENVIRONMENTAL PROTECTION AGENCY

### 1. Prevention

- a. Reducing P and N input from both point and nonpoint sources
  - i. Water treatment discharges
  - ii. Agricultural runoff
  - iii. Stormwater runoff.
- b. Utilize devices that result in the mixing of lakes (for example, by air bubbling) to minimize the formation of surface blooms of buoyant cyanobacteria.
  - i. Better for small bodies of water
- c. Increase the water flow through lakes or estuaries in order to reduce water residence time small affected water bodies.
  - i. Better for small bodies of water

### 2. Monitoring and Testing

- a. Cyanotoxin tests
  - i. Enzyme–linked immunosorbent assays (ELISA)
  - ii. Protein phosphatase inhibition assay (PPIA)
  - iii. Reversed-phase high performance liquid chromatographic methods (HPLC) combined with mass spectrometric (MS, MS/MS) or ultraviolet/photodiode array detectors (UV/PDA).
  - iv. Liquid chromatography/mass spectrometry (LC/MS)
  - v. Conventional polymerase chain reaction (PCR), quantitative real–time PCR (qPCR) and microarrays/DNA chips
- b. Provides danger level/concentration guidelines from WHO and various States

### 3. Treatment

- a. A Summary of Waterbody Management Methods for Cyanobacterial Blooms  
<https://www.epa.gov/nutrient-policy-data/control-and-treatment>

### 4. Response

- a. Communication Toolbox:  
<https://www.epa.gov/nutrient-policy-data/recreational-water-communication-toolbox-cyanobacterial-blooms>

Sources:

<https://www.epa.gov/nutrient-policy-data/cyanobacterial-harmful-algal-blooms-water>



Additional links:

<https://www.epa.gov/nutrient-policy-data/monitoring-and-responding-cyanobacteria-and-cyanotoxins-recreational-waters>

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## Current Management Strategies - LAKE ERIE

### 1. Prevention

#### a. N/A

### 2. Monitoring and Testing

#### a. Citizen Volunteer Monitoring

i. Train private beach and marina managers on HAB identification, advisory protocols, and hazards.

**ii. Citizen scientists conduct sampling, relay monitoring information to PADEP**

#### b. Lake Erie Sampling Plan

**i. Regional Science Consortium conducts routine monitoring.**

ii. Focused on the production of cyanobacteria and cyanotoxin levels

#### c. Microcystins-ADDA ELISA Standard Operating Procedure

i. Samples analyzed for cell count should follow the PA DEP's BOL7018 Plankton Identification and Enumeration protocol.

**ii. PA DEP runs tests.**

#### d. Phytoplankton Sample Collection

i. Identify organisms to determine if the bloom consists of cyanobacteria.

ii. Collections to be preserved with Lugol's iodine solution at a ratio of 1:100, although Lugol's can be added to a sample anytime within eight hours.

**iii. Deliver samples to the PADEP at TREC for shipment to the PADEP main laboratory in Harrisburg.**

#### e. Jar Float Test

i. Fill the jar with water affected by the blooms, then let it sit.

ii. Helps to show cyanobacteria, as they can regulate their buoyancy and will float to the top of the water when it is calm.

**iii. Anyone can do this.**

### 3. Treatment

#### a. N/A

### 4. Response

#### a. Review, Reporting and Revision

**i. Strategy implementation is evaluated by the participating agencies and community partners.**

- ii. Includes at least: “outreach activities completed, sample collection locations and results, water resource areas of potential concern, confirmed HABs, advisory postings, public response to advisories, and reports of human or pet illness.”
- iii. After action report is then created and used in the revision of the original monitoring strategy.
- b. HAB Notification
  - i. **The RSC and/or the DEP** releases these alerts
  - ii. Email is the main method used to alert agencies and organizations of a HAB event.
    - RSC send the sample results, location, and threshold comparison
    - DEP sends information on the cyanobacteria scum found that leads to an advisory determination and contact the resource manager.
  - iii. Lake’s responsible agency will send out a local news release.
  - iv. Recreational Use Advisories
    - Informational Notice
    - Recreational Use Advisory
    - Avoid Contact Advisory
  - v. Informational Notice
    - How to identify HABs
    - The associated risks
    - Safety precautions
    - Reporting information
    - Where to get more information

Sources:

[https://seagrant.psu.edu/sites/default/files/PA%20Lake%20Erie%20HAB%20Response%20Strategy%207-24-2017\\_0.pdf](https://seagrant.psu.edu/sites/default/files/PA%20Lake%20Erie%20HAB%20Response%20Strategy%207-24-2017_0.pdf)

## Current Management Strategies - NEW JERSEY

### 1. Prevention

a. N/A

### 2. Monitoring and Testing

#### a. Cyanobacterial Cell Count

- i. Advisory level of 20,000 cells/ml
  - Equivalent to 10µg/L of chlorophyll-a
  - Enough to post advisory signs
  - Above this level, monitor for cyanotoxins is initiated
  - Advisory level based on WHO(2003a) guidance

- ii. Individual advisory levels for each most common cyanotoxin
  - Microcystin-LR = 3 µg/L
    - a. Test method: Microcystins/Nodularins (ADDA), ELISA kit #520011 (Abraix, Inc.)
    - b. Positive results requiring regulatory action should be confirmed by alternative method
  - Cylindrospermopsin = 8 µg/L
    - a. Test method: Cylindrospermopsin ELISA kit #522011 (Abraix, Inc.)
    - b. Positive results requiring regulatory action should be confirmed by alternative method
  - Anatoxin-a = 27 µg/L
    - a. Test method: Anatoxin-a ELISA kit #520060 (Abraix, Inc.)
    - b. Positive results requiring regulatory action should be confirmed by alternative method
- b. Citizen-based reports of suspected cases
  - i. Department of Environmental Protection (DEP) hotline
    - 1-877-WARNDEP
  - ii. DEP Division of Water Monitoring and Standards (DWMS)/DEP Bureau of Freshwater and Biological Monitoring (BFBM) online reporting form
    - <http://www.state.nj.us/dep/wms/bfbm/CyanoHABHome.html>
    - for reporting both public and private affected water bodies
- c. Visual Assessment
  - i. visual assessment form modified from an USEPA method
  - ii. performed by trained personnel after every report of suspected affected area
- d. Initial screening
  - i. to confirm cyanobacteria presence
    - In-Field confirmation
      - a. by handheld device called field fluorometer
    - In-Laboratory confirmation
      - a. Phytoplankton Sampling
      - b. collected in amber glass bottles
      - c. refrigerated
      - d. analyzed within 24 hrs
      - e. broad identification of taxa performed using microscopic equipment
  - ii. to confirm toxin presence
    - ABRAXIS microcystins test strip readings for microcystin toxins

- tests available for the cylindrospermopsin and anatoxin-a but their feasibility are under investigation

e. Toxin analysis

- microtiter plate Enzyme-Linked Immunosorbent Assay (ELISA)
- EPA method 546
- ABRAXIS kits

3. Treatment

a. N/A

4. Response

a. Notification of appropriate parties

- DEP DWSG will be alerted for HABs in water bodies that are a direct source of drinking water
- If it's a State Park bathing beach, the State Park Superintendent and DOH will be notified
- IF it's a public recreational bathing facility (not a state park), local health department and DOH will be notified
- If reported at a Wildlife Management Area, Fish and Wildlife will be contacted
- If the report concerns a private water body, guidance will be provided to the owning entity regarding the proper response

b. Advisories

- Warning - Avoid Contact and Ingestion (Humans and Animals):** A Harmful Algal Bloom is suspected which can be harmful to humans and animals. People, pets, and livestock should avoid contact and drinking the water. Avoid swimming, wading, and watersports. Fish caught in this waterbody should not be eaten.
- Danger/ High Risk - No Contact and Ingestion (Humans and Animals):** A confirmed Harmful Algal Bloom is present with levels quantified at or above the NJ Health Advisory Guidance. Do not drink or have contact with the water including, but not limited to, swimming, wading, and watersports. Fish caught in this waterbody should not be eaten. Pets and livestock should not contact or drink the water.



c. Outreach

- i. Enhance DEP website information on HABs
- ii. outreach material available at  
<http://www.state.nj.us/dep/wms/bfbm/CyanoHABHome.html>
- iii. Continue communication/ coordination on HABs with the New Jersey Water Monitoring Council (NJWMC)
- iv. Communication/coordination with County and local health departments through avenues such as the Environmental Health Act (CEHA) program and the Coastal Cooperative Monitoring Program (CCMP).
- v. Training and information exchange for Departmental programs, partners and the public, such as in-person training, webinars and web-based training.
- vi. Development and/or use of existing Smart phone apps, , for identifying, reporting, and communicating potential HAB concerns.
- vii. Partnering with other state agencies in the region to adapt existing communication efforts for New Jersey.

5. Notes

- a. most common types of cyanobacterial toxins found in this area
  - i. Microcystin-LR
  - ii. Cylindrospermopsin
  - iii. Anatoxin-a

Sources:

Cyanobacterial Harmful Algal Blooms (HABs) Freshwater Recreational Response Strategy -  
<https://www.state.nj.us/dep/wms/bfbm/download/NJHABResponseStrategy.pdf>

Questions

1. Response plan doesn't discuss treatment or prevention methods

## Current Management Strategies - MAINE

1. Prevention

- a. N/A

2. Monitoring and Testing

- a. [https://www.maine.gov/dep/water/nutrient-criteria/chapter583\\_10-17-2011.pdf](https://www.maine.gov/dep/water/nutrient-criteria/chapter583_10-17-2011.pdf)

This contains a whole guideline used in Maine in nutrient in the water body, including a table for phosphorus criteria, which is related with Secchi disk depth, Chl a, oxygen level, PH and aqua-life.

- b. <https://www.maine.gov/dep/water/lakes/bloomrisk.html> This is a table with all the lakes in Maine and their risk of encountering a HAB. It would be helpful if we also have a table like this to show the public the situation and how we were doing.
- c. Secchi disk guideline: Lakes are considered to be experiencing an algal bloom when Secchi Disk Transparency is observed to be less than 2 meters by DEP staff or a trained volunteer.
- d. <https://umaine.edu/coastalsat/chlorophyll/>  
Satellite monitoring for chlorophyll

### 3. Treatment

- a. N/A

### 4. Response

- a. Maine has a guideline for the public to follow if they would like to report a algae bloom problem:(Guideline)

<https://www.maine.gov/dep/water/lakes/reportbloom.htm>

Call (207) 287-3901 or (800) 452-1942 in-state. Ask to speak to the "on-call" person in the Division of Environmental Assessment.

When reporting a potential algal bloom, try to get on the lake and look around in several places, including the deeper areas. Try to answer the following questions. It is not necessary to have answers to all these questions in order to report a bloom.

- i. Name of the lake and town.
- ii. Name, address, phone number of person reporting.
- iii. When did this start? How long has the condition persisted?
- iv. Is the bloom mixed in the water or is it attached to plants, rocks or other structures? If it is attached, describe the size and color of the growths. Are they stringy or jelly-like or like cotton candy?
- v. If mixed in the water, what were the color(s) of the water and how intense were they?
- vi. Is the water turbid (cloudy) or is it full of particles you can see with the eye?
- vii. Was the bloom concentrated in certain areas (especially in downwind coves) or was it throughout the lake?
- viii. Is there an obvious odor? (describe)
- ix. Is there a surface scum?
- x. Have you seen anything like this (or heard similar reports in this or another year?)

- xi. If you are a volunteer monitor, what was your most recent Secchi reading for the lake (and the date)?

Sources:

A guideline for the public to report cyanobacteria in Maine

<https://www.maine.gov/dep/water/lakes/reportbloom.htm>

Lakes are considered to be experiencing an algal bloom when Secchi Disk Transparency is observed to be less than 2 meters by DEP staff or a trained volunteer.

<https://www.maine.gov/dep/water/lakes/algalbloom.html>

## Current Management Strategies - CALIFORNIA

### 1. Prevention

#### a. N/A

### 2. Monitoring and Testing

#### a. Cell count, Advisory levels

- i. advisory levels not specified
- ii. based on EPA guidelines

#### b. Satellite imagery

- i. Identifies and tracks cyanobacteria blooms
- ii. done biweekly during season

#### c. Centralized website and reporting system

- i. data management and visuals
- ii. centralized information exchange

- Reporting
- Notifying (advisories)

#### d. Routinely monitoring

- i. Frequency, magnitude, and duration of HABs and toxins associated with a waterbody, watershed, or region
- ii. Seasonality of blooms and toxin production
- iii. Underlying drivers of HAB development

#### e. Sampling and Analysis

- i. If a bloom is suspected, water samples should be collected and analyzed for species composition.
- ii. If a HAB species is identified, toxin analysis should be conducted.

#### f. Citizen science and volunteer monitoring programs

- i. Eel River Recovery Project
  - citizen-based watershed monitoring and education group focused on the Eel River in Northern California

#### g. Laboratory Analysis

- i. identification of blooms
    - h. In-person training
      - i. comprehensive training program
        - HAB general information, including taxonomy and identification, and types of toxins
        - Water quality and public health issues caused by HABs
        - Programs and resources within CA
      - ii. bloom management and remediation workshop
3. Treatment
  - a. waterbody treatments with algaecides
4. Response
  - a. Outreach and education program
    - i. not funded at the time of publication
    - ii. developed and geared toward citizens, policymakers, health care professionals, veterinarians, and public agencies
    - iii. adaptation of training materials (from the Training component of the infrastructure), including guidance documents and HAB background materials, to educate the general public and policymakers
  - b. Guidance documents
    - i. sampling
    - ii. health and safety
    - iii. performance based quality assurance criteria
  - c. Public awareness
    - i. aimed at citizens, policymakers, health care providers, public agencies and veterinarians
    - ii. recognition of issue
    - iii. timely reporting of HABs
  - d. Fact sheets
  - e. Social media
5. Notes:
  - a. Document lacks details and description. Seems to be directed towards the general public.
  - b. References the EPA guidelines frequently

Sources:

California Freshwater Harmful Algal Blooms Assessment and Support Strategy

[https://www.waterboards.ca.gov/sanfranciscobay/water\\_issues/programs/SWAMP/HABstrategy\\_phase%201.pdf](https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/SWAMP/HABstrategy_phase%201.pdf)

## **Current Management Strategies - NEW ZEALAND**



## 1. Prevention

### a. N/A

## 2. Monitoring and Testing

### a. Cyanobacteria Biovolume Count

- i. Used instead of cell count because it takes into account the size and geometry of different cyanobacteria
- ii. Sample was taken at many different places in a large lake

### b. Three different scenarios:

- i. Surveillance, Green mode: biovolume count less  $0.5 \text{ mm}^3/\text{L}$  (500 cells/mL):
  - Weekly or fortnightly testing
- ii. Alert, Amber Mode: Biovolume count of toxic cyanobacteria between  $0.5$  to  $1.8 \text{ mm}^3/\text{L}$ , or biovolume count of all cyanobacteria between  $0.5$  to  $10 \text{ mm}^3/\text{L}$ 
  - Notification and consultation with local health units and ongoing assessment of bloom statuses.
  - Testing up to twice a week
- iii. Action, Red Mode: Biovolume count of toxic cyanobacteria above  $1.8 \text{ mm}^3/\text{L}$ , or biovolume count of all cyanobacteria above  $10 \text{ mm}^3/\text{L}$ 
  - Public warned and signs posted

### c. Modes can only be lowered after two consecutive tests, which must be at least a week apart

### d. Toxin testing may be warranted, as some cyanotoxins can last up to 21 days after cell death, resulting in high toxicity paired with low cell count

## 3. Treatment

### a. N/A

## 4. Response

### a. Hamilton City (drinking water)

- i. Sampling raw and treated water for cyanobacteria and toxins
- ii. Undertaking a risk assessment
- iii. Preparation of a contingency plan
- iv. The establishment of communication pathways between the territorial authorities contact person,

Sources:

<http://www.mfe.govt.nz/publications/fresh-water/guidelines-cyanobacteria/section-3-guidelines>

<https://onlinelibrary.wiley.com/doi/full/10.1111/j.1467-842X.2007.00061.x>

## Case Studies - Mandates

In this section you will find detailed information about current management strategies being used in other places and organizations in the form of case studies. The strategies discussed below are *mandates* established by the appropriate authority in each case.

## Current Management Strategies - OHIO (Drinking Water)

1. Prevention
  - a. N/A
2. Monitoring and Testing
  - a. Cylindrospermopsin and Saxitoxins Sampling (ELISA)
    - i. Tests run to look for cylindrospermopsin
    - ii. Will conduct additional analysis (LC/MS/MS) if the samples are greater than 50% of the cylindrospermopsin threshold.
    - iii. \*As more information becomes available on the relationship between gene detection and cyanotoxin detection, Ohio EPA may be able to establish cyanotoxin sampling triggers\*
    - iv. More than 24 hours are usually required to complete the process and obtain the analytical results.
    - v. **Ohio EPA does sampling. Ohio EPA's Division of Environmental Services (DES) tests the samples.**
  - b. Microcystins Monitoring and Cyanobacteria Screening (quantitative polymerase chain reaction (qPCR))
    - i. Shows microcystins- mcyE gene, cylindrospermopsin- cyrA gene, and saxitoxin- sxtA gene concentrations.
    - ii. Screening distinguishes toxic and non-toxic cyanobacteria cells.
    - iii. More than 24 hours are usually required to complete the process and obtain the analytical results.
    - iv. **Done by any Public Water System under Ohio Administrative Code (OAC) Rule 3745-90-03.**
  - c. Anatoxin-a Sampling and Analytical Method (LC-MS/MS)
    - i. Molecular screening tools for this are **unavailable** so:
      - If **requested by** the public or Ohio Department of Health they will do tests based on phytoplankton identification and enumeration.
    - ii. LC/ESI-MS/MS developed by the US EPA is used for quantitation of anatoxin-a in finished water when requested.
    - iii. The RfD is 0.0005 mg/kg-day, adults were assumed to have a body weight of 60 kg, adults were assumed to drink 2 liters of water per day
    - iv. **Ohio EPA**
  - d. Jar Float Test
    - i. Fill the jar with water affected by the blooms, then let it sit.

- ii. Helps to show cyanobacteria, as they can regulate their buoyancy and will float to the top of the water when it is calm.
  - iii. **Anyone can do this.**
- e. Toxin Threshold

The basic calculation used in developing the saxitoxins and anatoxin-a thresholds is:

$$\text{Threshold} = \frac{\text{BW} \times \text{TDI or RfD}}{\text{IR}} * \text{CF}$$

**Where:**

BW = Body weight in kg  
 TDI = Tolerable Daily Intake in mg/kg-day  
 RfD = Reference Dose in mg/kg-day  
 IR = Ingestion Rate in L/day  
 CF = Conversion Factor, 1000 µg/mg  
 Threshold unit is µg/L

3. Treatment

- a. Created a HAB Treatment Optimization Protocol
  - i. ([http://epa.ohio.gov/Portals/28/documents/habs/Treatment%20Procotol%20May2016%20Draft\\_Protected.docx](http://epa.ohio.gov/Portals/28/documents/habs/Treatment%20Procotol%20May2016%20Draft_Protected.docx))
- b. Conventional Treatment
  - i. Use of coagulation, flocculation, sedimentation, filtration, and disinfection (normally with chlorine) in drinking water treatment is common.
  - ii. Depending on cell life stage and health, cyanotoxin release could occur from cell wall damage or natural decay.
    - Therefor, guidelines are outlined to reduce these chances.
- c. Copper sulfate and **Hydrogen peroxide**
  - i. Applied to the drinking water sources under controlled conditions
    - Required to submit a Notice of Intent (NOI) to Ohio EPA Division of Surface Water and obtain coverage under the pesticide general permit prior.
  - ii. Treatment should be applied at the early stages of a bloom when cyanobacteria cell counts are low (<10,000 cells/ml)
  - iii. The pesticide general permit prohibits algaecide application to severe blooms (>100,000 cells/ml).

4. Response

- a. Resampling
  - i. Done by Ohio EPA, results transported to Ohio EPA's Division of Environmental Services
  - ii. Raw Water Analysis
    - To view intracellular and extracellular cyanotoxins
  - iii. Treatment Train Sampling
    - How to best optimize for cyanotoxin destruction/removal

- b. Public notification:
  - i. **Public Water System**
  - ii. Ohio Administrative Code rule 3745-81-32
    - <http://codes.ohio.gov/oac/3745-81-32>
  - iii. Drinking Water Warnings after Cyanotoxins found
    - To be posted on the official websites

Sources: [https://epa.ohio.gov/Portals/28/documents/habs/PWS\\_HAB\\_Response\\_Strategy.pdf](https://epa.ohio.gov/Portals/28/documents/habs/PWS_HAB_Response_Strategy.pdf)

## Current Management Strategies - CHINA

1. Prevention
  - a. Alum
  - b. clean muds at bottom of the Tai lake <http://cdmd.cnki.com.cn/Article/CDMD-10284-1016004390.htm>
    - i. According to years of monitoring of the Tai Lake, scientists were able to determine the muds distribution at the bottom of the lake; based on the priority(drinking water, shores, and estuaries), use boats to collect excessive muds.
    - ii. It affects the ecosystem in only a little and is able to recover by itself in 1-2 years.
    - iii. This method is a little expensive, especially for big lakes; it is also not very effective because muds keep going into the lake through stormwater and other streams.
    - iv. However, periodically doing this is going to eventually improve the water quality
2. Monitoring and Testing
  - a. ELISA and other, same as what we do
  - b. Secchi Plate in use. It provides a result in a minute and is easy to use
3. Treatment
  - a. salvage algae bloom
    - i. It is not randomly salvaging algae, but first, collect a large number of algae into a blocked space, then salvage with the machine.
    - ii. Not a cheap way to “kill” cyanobacteria, but to protect aqua-life and drinking water.
    - iii. Salvaging algae bloom avoid dead zone effect
    - iv. People reuse the salvaged algae as fertilizer, this avoids cyanobacteria from polluting soil and plants around.

Summary: This method is costly, outdated, and inefficient. However, when algae bloom is really out of control, this method reduces the floating cyanobacteria, and creates better conditions for chemical treatments. <http://blog.sciencenet.cn/blog-475-4629.html>

b. Alum and Copper sulfate

- i. Chemical treatment has been applied in China for many years; it was until recently, the Chinese government restricted the use of algacide because they believe chemical treatment is not a sustainable solution. <http://blog.sciencenet.cn/blog-475-4629.html>

**methods and techniques table**

(Translated from

<http://www.mee.gov.cn/gkml/hbb/bgth/201709/W020170913513471757250.pdf>)

Test	Method	Mandates
Temperature	Thermometer	GB13195
PH	Glass Electrode	GB6920
Oxygen Level	Electrochemical probe method	HJ506
Ammonia	Nessler's reagent spectrophotometry	HJ535
Nitrogen	UV spectrophotometry	HJ636
Phosphorous	Ammonium aluminum Spectrophotometric	GB11893
Permanganate index	Acidic potassium permanganate method	GB11892
Transparency	Secchi Disk	/
Turbidity	Spectrophotometric	GB13200
Conductivity	Conductivity Meter	/
Cyanotoxins	high-performance liquid chromatography(HPLC)/Enzyme-linked immunosorbent assay(ELISA)	GB/T20466
chlorophyll	Spectrophotometric	/

Methods of controlling algae

<http://www.leadingtec.cn/algae-control-method.html>

Testing methods and mandates

<http://www.mee.gov.cn/gkml/hbb/bgth/201709/W020170913513471757250.pdf>