Nathan Usi
Professor Cooney
TSEM 190

Malignant Microscopic Monsters: Future Research Needed Regarding Freshwater Harmful Algal Blooms

On August 2nd, 2014, an urgent message was sent out to the people of Toledo, Ohio from the Collins Park Water Treatment Plant: DO NOT DRINK THE WATER. Chemists had detected higher than normal concentrations of microcystin, a hazardous toxin, in the drinking water supply. Suddenly, 400,000 people no longer had access to safe public drinking water. Local officials panicked as health and safety personnel rushed to fix the problem. People from across the community banded together to help each other as restaurants shut down and businesses closed. The local militia set up a water distribution center for those in need and retail stores ordered express shipments of plastic water bottles. Finally, a few days after the excess microcystin was first detected, Toledo's Mayor declared the water once again safe for consumption.[1] The increased level of microcystin in the drinking water supply was the product of a freshwater harmful algal bloom which had formed on Lake Erie. The toxins produced by the freshwater harmful algal bloom had seeped through the intake for the plant and were not removed by the treatment process. While this was not the first incident caused by freshwater harmful algal blooms, it most certainly will not be the last.[2] The increasing incidence of freshwater harmful algal blooms in reservoirs and recreational lakes necessitates greater federal

[1] Daniel Peckham, "A Study in Cyan," *New England Water Pollution Control Commission Reprint Series,* no. 16-03 (2018): 3.
[2] Pete Spotts, "Toledo water crisis may be over, but toxic algae blooms are in our future," *The Christian Science Monitor,* August 4, 2014.

funding for research into their adverse health effects and effective, eco-friendly ways of controlling them.

Harmful algal blooms (HABs) are the rapid growth and spread of algae (or related cellular organisms) to form large colonies that can produce toxins which are harmful to humans, animals, and the environment. HABs can occur in both saltwater and freshwater, with each type of HAB creating unique problems. Saltwater HABs typically consist of diatoms or dinoflagellates and form in oceans along coastal areas. Most of the concerns regarding saltwater HABs revolve around recreational exposure to them and their negative environmental impact. Freshwater harmful algal blooms (FHABs) typically consist of cyanobacteria and form in stagnant bodies of water, such as reservoirs or recreational lakes. While cyanobacteria are considered bacteria, they are often referred to as "blue-green algae" because of their photosynthetic capabilities. FHABs are of particular concern because they can grow in bodies of water which are used for drinking as well as recreation.[3] Despite this, saltwater HABs have historically been viewed as a greater national concern, thus receiving much greater funding for research as well as greater legislative action.

Figure 1: FHAB covering part of Rock River near Lake Champlain in Vermont. Picture taken during the summer of 2015.

Peckham, "A Study in Cyan," 5.

[3] "Summary Report – One Health Harmful Algal Bloom System (OHHABS), United States, 2019," Center for Disease Control and Prevention (CDC), last modified September 27, 2021, https://www.cdc.gov/habs/data/2019-ohhabs-data-summary.html

The first legislative action taken regarding HABs was the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) of 1998. The HABHRCA was enacted because researchers began to observe the negative human and environmental health effects caused by harmful algae. The National Oceanic and Atmospheric Administration (NOAA) developed a successful national research plan for investigating the risks associated with HABs and established programs for monitoring and responding to HAB events. However, the HABHRCA initially only focused on saltwater HABs. In 2004, the HABHRCA was expanded to include FHABs, but the congressional authority responsible for it did not have jurisdiction over the Environmental Protection Agency (EPA). Since all freshwater in the United States is under the purview of the EPA, no actions were taken to address FHAB concerns.[4] Spurred on by the Toledo Water Crisis and other similar incidents, an amendment was made to the HABHRCA in 2014 that gave the EPA the greenlight to research and monitor FHABs. Even though this amendment led the EPA to develop a few guidelines for FHABs in drinking water, there still has been no other specific legislative action taken regarding FHABs. Currently, Congress has not passed any legislation to establish an extensive research plan or any federal regulations regarding cyanobacteria in recreational lakes or drinking water.[5]

For there to be any change in FHAB policy in the foreseeable future, policymakers must be convinced that FHABs pose a serious threat to our society and that changing the current policy will either please their constituents or make a real difference. Proving this threat to legislators requires sufficient information on the incidence of FHABs in the United States, on the

[4] H. Kenneth Hudnell, “The state of U.S. freshwater harmful algal blooms assessments, policy and legislation.” *Toxicon* 55 (2010): 1024-1030.
[5] “S.1254 - Harmful Algal Bloom and Hypoxia Research and Control Amendments Act of 2014,” Congress.Gov, accessed November 17, 2021, https://www.congress.gov/bill/113th-congress/senate-bill/1254

adverse health effects caused by cyanobacteria and their toxins, and on the strategies that can be used to control them.

First, what do we know about the incidence of FHABs in the United States? The majority of environmental health researchers agree that the frequency and duration of FHAB occurrence in the United States has been increasing for a long time. As more FHABs form every year, the problems caused by FHABs will only continue to get worse. However, there is a great amount of uncertainty about the true number of blooms that form every year and the number of cases of human illness associated with them. Very little data about the occurrence of FHABS exists from the past as harmful algal blooms only began to be perceived as a problem a few decades ago.[6] To help better understand HABs, the CDC created the One Health Harmful Algal Bloom System (OHHABS) in 2016 to track their occurrence across the United States. OHHABS is a collaborative program where local public health agencies can submit recorded HAB events and cases of HAB-associated illness to a national database. In 2019, 242 HAB events were reported with 63 human cases of illness. About 75% of the reported HAB events occurred in freshwater, with 75% of the FHABs taking place in lakes or reservoirs. Around 85% of the human cases of illness transpired at public freshwater recreational areas. While some may argue that 181 FHAB events is not a large enough number to be of great concern, the data reported to the OHHABS is not representative of the United States as a whole. Despite the OHHABS being a national program, participating in the program is completely voluntary and only 14 states shared their data in 2019. As a result, the OHHABS severely underrepresents the yearly total number of HAB events and illnesses in the United States and will continue to do so until almost every state decides to cooperate.[7]

[6] Hudnell, "The state of U.S. freshwater harmful algal blooms," 1024-1030.
[7] CDC, "Summary Report – OHHABS."

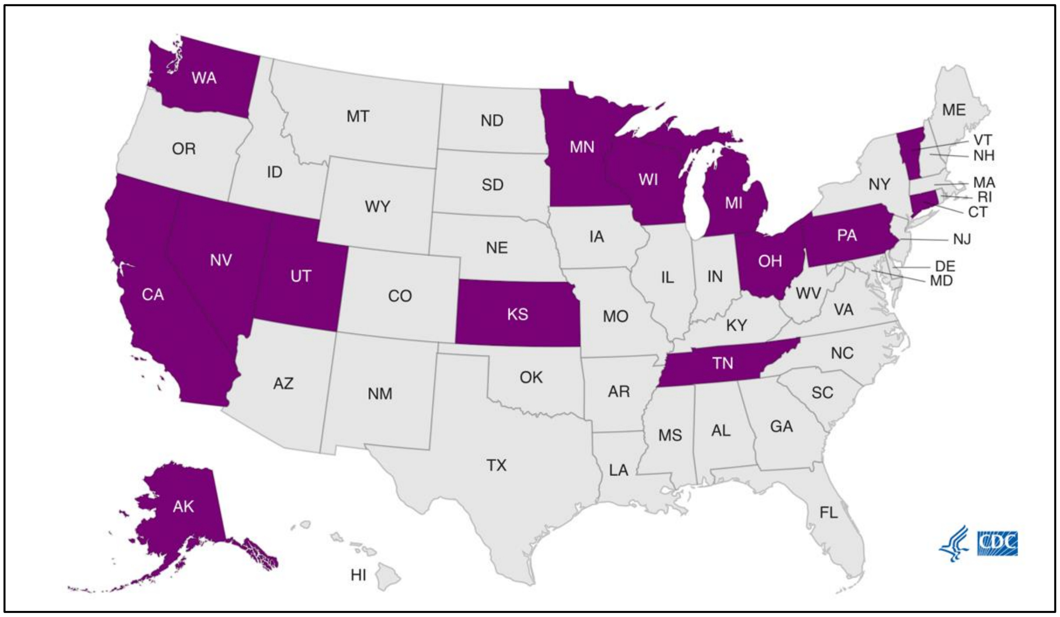


Figure 2: The 14 states in purple are currently the only states that report to the OHHABS. For the OHHABS to represent the whole United States, many other states should be encouraged to join the program.

CDC, "Summary Report – OHHABS."

Even though the OHHABS currently does not monitor national FHAB occurrence very successfully, researchers have found some promise in studying HAB-associated illness through syndromic surveillance of electronic health records. When a patient visits an emergency medical facility, the physician will take a record of the patient's problems and symptoms referred to as the chief complaint. The physician will also document their diagnosis in an online database using diagnostic codes. Recent studies examined multiple electronic health databases for HAB exposure diagnostic codes and chief complaints mentioning HABs and concluded that these databases could be extremely beneficial for tracking HAB incidence.[8] However, this method of surveillance also comes with some limitations. Diagnostic codes associated with HAB exposure

[8] Amy M. Lavery et al., "Evaluation of Syndromic Surveillance Data for Studying Harmful Algal Bloom-Associated Illnesses — United States, 2017–2019," *Morbidity and Mortality Weekly Report* 70, no. 35 (September 2021): 1191-1194.

seem to be underutilized as many more cases were found by examining the chief complaints. Hence, it was once again determined that the number of HAB-associated cases was underrepresented by the available data.[9]

If public health officials are to better understand the threat that FHABs pose to the country's safety, then certainty about the national occurrence of FHABs should be prioritized. All levels of government will be able to properly address FHABs if the degree at which FHABs are a concern is unquestionable. So, what efforts we can take to make our knowledge of the incidence of FHABs indisputable? First, the federal government should incentivize participation in the OHHABS. This incentive could either come from a government mandate or through discussion with local public health agencies about the possible risks posed by FHABs. The more states that participate in the OHHABS, the more representative the data will be for the entire country. Next, public health officials should better educate patients and physicians on FHAB exposure to make electronic health data more accurate to the actual number of HAB-associated cases. Increasing public awareness would help patients know to report any possible exposure and help physicians know to use the appropriate diagnostic code. This would increase the frequency at which the HAB exposure diagnostic codes are used and improve the electronic health database's precision. These two initiatives will make the OHHABS and other databases more reflective of actual FHAB-associated case numbers, enabling researchers to better understand the occurrence of illnesses linked to FHABs and ensuring patients get the proper treatment.

Second, what information is currently available on the adverse health effects caused by freshwater harmful algae blooms? Unfortunately, public health officials' uncertainty around

---

[9] Amy M. Lavery, Lorraine C. Backer, and Johnni Daniel, "Evaluation of Electronic Health Records to Monitor Illness from Harmful Algal Bloom Exposure in the United States," *Journal of Environmental Health* 83, no. 9 (May 2021): 8-13.

FHABs is not restricted to their national incidence. Researchers have identified cyanotoxins as the cause for most of the negative health effects associated with FHAB exposure. Cyanotoxins are a class of toxin harmful to both humans and other animals that is specifically produced by cyanobacteria. While some cyanobacteria may produce multiple different types of cyanotoxins, other species of cyanobacteria may not produce cyanotoxins at all. Humans can be exposed to cyanotoxins through inhalation, ingestion, or skin contact. There are a wide variety of symptoms associated with cyanotoxins that depend on the method in which a person was exposed and the cyanotoxin they were exposed to. In general, symptoms tend to cause respiratory, gastrointestinal, or dermal problems.[10] While the electronic health records indicated that respiratory symptoms, such as coughing and shortness of breath, were more common than others,[11] the OHHABS found that gastrointestinal and generalized symptoms, such as diarrhea and headache, were the most frequently reported symptoms.[12] Even more severe illnesses have been associated with cyanotoxins such as liver damage, seizures, and very rarely death. However, the greatest concern regarding cyanotoxins is that researchers are not aware of their long-term health effects or the consequences of long-term exposure. FHAB exposure has been linked to tumor formation and neurologic diseases, but there has not been sufficient research to prove this.[13] Researchers' lack of knowledge on the adverse health effects of cyanotoxins limits meaningful progress towards updated FHAB legislation and hinders the development of appropriate strategies to address FHAB concerns.

---

[10] United States Environmental Protection Agency (EPA), "Cyanobacteria and Cyanotoxins: Information for Drinking Water Systems," *Office of Water* (June 2019): 1-9.
[11] Amy M. Lavery et al., "Evaluation of Syndromic Surveillance Data," 1191-1194.
[12] CDC, "Summary Report – OHHABS."
[13] EPA, "Cyanobacteria and Cyanotoxins," 1-9.

Despite this lack of knowledge, the EPA has taken a few steps to raise awareness of the potential harm caused by cyanotoxins. Most notably, some cyanotoxins have been placed on the Contaminant Candidate List (CCL). This list contains some troubling contaminants that the EPA reevaluates every five years, but they are not required to be actively monitored. The EPA has also provided some drinking water reference doses for some of the more common cyanotoxins, but they have no power to enforce them.[14] In order for the federal government to gain the power to enforce any cyanotoxin regulations, further research is needed to prove their necessity.

A fully developed research program could help researchers better understand the health risks associated with FHAB exposure. While the toxicological knowledge of a few cyanotoxins has increased in the past decade, there are still many cyanotoxins that do not have established reference doses. Additional research on cyanotoxins will help guarantee FHAB-associated illnesses will always be treated properly in the future. Proper tests should also be completed to confirm or deny the suspected long-term health effects associated with FHABs. All this information should assist in the enforcement of regulations regarding cyanotoxin concentrations in drinking water. As the presence of cyanotoxins in drinking water is not regulated nationwide, some citizens have a chance of being exposed to unsafe levels without knowing it. National standards will help to prevent any future FHAB-associated illness caused by contaminated drinking water.

Lastly, what strategies do public health officials have at their disposal for taking care of freshwater harmful algal bloom formation? There are currently numerous methods which are being utilized to control freshwater harmful algal blooms, despite there being no federal programs for FHAB risk management. While methods of mitigating the adverse health effects of

[14] EPA, "Cyanobacteria and Cyanotoxins," 1-9.

freshwater harmful algal blooms are important, most of the research that has been completed is on different techniques and strategies for prevention, suppression, and termination. Each method varies in its efficiency, effectiveness, cost, and environmental impact.

Out of all the methods used to terminate FHABs, chemical methods have been proven to be the most effective at quickly killing cyanobacteria cells. In the past, algicides have been the most popular methods utilized to suppress the formation of large FHABs. When the algicides are deployed, they will target cyanobacterial cells and destroy their outer membranes, effectively killing them. While this process is quick, the many cyanotoxins stored within the cells are all released at once. This can be extremely harmful to any of the organisms that are around the FHAB when the algicides are used. The algicides can also linger in the water and continue to hurt any other organisms that venture nearby. Chemical methods of FHAB suppression have recently come under scrutiny for their dangerous environmental impact and high cost to use. FHABs have also been growing increasingly resistant to algicides, meaning that they are no longer as effective as they once were. This has motivated researchers to find other ways of FHAB control which are more cost effective and environmentally sustainable.[15]

Ecological methods of FHAB control involve attacking the root cause of freshwater harmful algal bloom formation in an eco-friendly way. Researchers have identified four stimulatory factors which lead to rapid FHAB growth: adequate warmth, sufficient sunlight to allow for photosynthesis, presence of excessive nutrients, and quiescent water. FHABs flourish in warmer water temperatures. This is reflected by FHABs typically occurring during the summer months. Cyanobacteria are also photosynthetic organisms, meaning that, just like many plants, they use the light from the sun to produce their own energy. As such, FHABs can thrive

[15] Hudnell, “The state of U.S. freshwater harmful algal blooms,” 1024-1030.

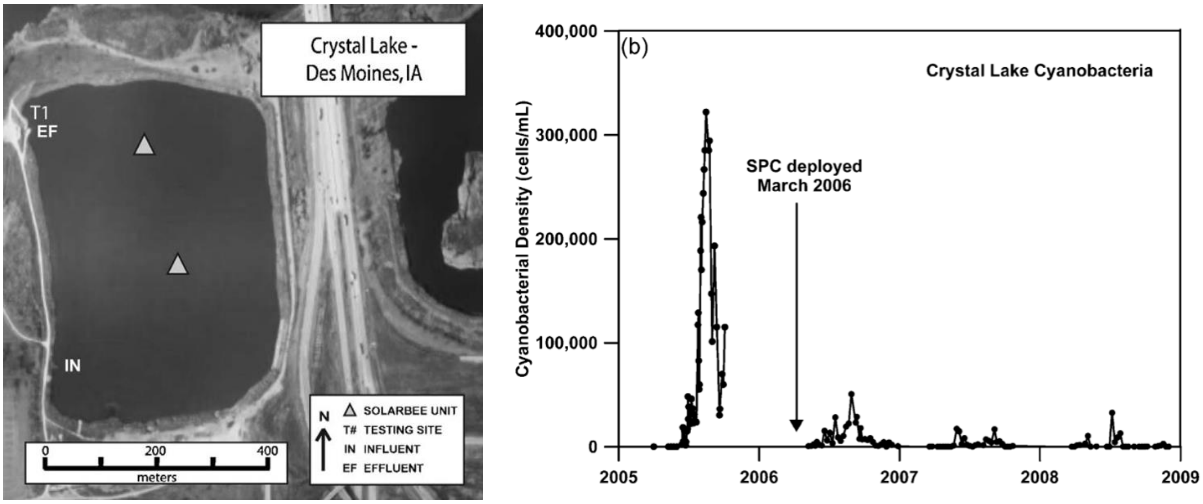
best when they are in direct sunlight and are not under the cover of leafy plants.[16] While both warmth and sunlight are important factors for FHAB growth, they are very difficult to manipulate. Most ecological methods of preventing FHABs try to create artificial water flow or try to limit the availability of resources to FHABs as these factors are much easier to control.

While it is not known for certain why stagnant water is beneficial to the growth of freshwater harmful algal blooms, it is mainly theorized that the stillness of the water allows for cyanobacteria to find the optimal position for growth. A recent study tested the effectiveness of solar powered circulation technology (SPC) to control FHAB growth. The SPC functioned by constantly mixing the surface of the water. This technology was tested on three different reservoirs around the country which had a history of FHAB occurrence year after year. Data was collected before and after the implementation of the SPC which clearly showed the density of cyanobacteria decreasing each year after the SPC was first put in the water. This technology was relatively inexpensive, very eco-friendly, and it increased the biodiversity of algae in each of the reservoirs. However, the researchers acknowledged that this method of controlling FHABs is not one-size-fits-all. Tests completed in very small and shallow ponds were not effective and the SPC technology was not able to suppress FHAB growth effectively in larger bodies of water when only a portion of the surface could be circulated. There were also points during the successful testing of the SPC technology where moderately sized blooms formed for short durations of time. The researchers ultimately concluded that the SPC technology might work best in conjunction with other methods of controlling FHAB growth.[17]

---

[16] EPA, "Cyanobacteria and Cyanotoxins," 1-9.
[17] H. Kenneth Hudnell et al., "Freshwater harmful algal bloom (FHAB) suppression with solar powered circulation (SPC)," *Harmful Algae* 9 (2010): 208-217.

Figure 3: One of the sites used during Hudnell's study to test the effectiveness of the SPC technology (each unit shown with triangle). Every subsequent summer after the SPC was deployed, the cyanobacteria concentration in the reservoir drastically decreased.



Hudnell et al., "Solar Powered Circulation," 210-212.

Other ecological methods of preventing and suppressing FHAB presence try to interrupt the FHABs ability to utilize excessive nutrients. Nutrients are very important to plant growth. However, the presence of excessive nutrients can have many adverse effects on aquatic environments. The difficulty in controlling for excessive nutrients comes from the complexity of quickly reducing the nutrient concentration and the always changing water conditions. Therefore, nutrient regulation can most successfully be completed through long-term watershed management. While point sources are regulated by the Clean Water Act, non-point sources are often uncontrolled and go unnoticed. Some states have regulations to help address these issues, but often these regulations are not enough to make a great difference.[18]

Recently, researchers have been making strides towards quicker solutions for controlling FHABs that work similarly to algicides but are environmentally friendly. Biological methods, a

[18] Hudnell, "The state of U.S. freshwater harmful algal blooms," 1024-1030.

type of ecological method, use other microorganisms to combat the growth of cyanobacteria. Research has been conducted on algicidal bacteria that are capable of outcompeting FHABs for space, nutrients, and light. These algicidal bacteria kill the cyanobacteria cells by attaching to them and lysing them or by releasing toxic allelochemicals. However, just like the chemical algicides, the cyanotoxins inside the cells are all released. A recent review of biological methods for controlling FHABs concluded by proposing the development of the composite biotechnology "flocculation-lysis-degradation-nutrients regulation." This composite biotechnology would compose of a combination of different microorganisms that would all serve a different function in regulating the FHAB growth.[19] While this biotechnology would work very effectively in theory, anything like this is not close to being completed. Many of the microorganisms proposed have only been proven to work effectively in a laboratory setting by themselves. Much more funding and research would be needed for this composite biotechnology to be completed, which may make this solution unreasonable.

So, where do we currently stand? Despite the large quantity of methods available for regulating FHAB growth, there is still no consensus on what approach is the best option. Furthermore, most of these methods have not had sufficient testing outside of a laboratory setting or are not fully developed. Finding a universal method of FHAB control demands even more research. Based on current information, the combination of SPC and algicidal bacteria seems to be the most reasonable way to prevent and suppress FHAB formation in reservoirs and lakes. The SPC would be able to keep FHABs from growing an excessive amount and the algicidal bacteria would be able to maintain a low cyanobacteria concentration if fluctuations start to occur. However, testing would have to be completed first to ensure that the algicidal bacteria can

[19] Rui Sun et al., "Microorganisms-based methods for harmful algal blooms control: A review," *Bioresource Technology* 248 (2018): 12-20.

work in a natural setting and that both techniques can work together. The algicidal bacteria should also be used in conjunction with a different microorganism which can degrade any released cyanotoxins.

As research efforts to determine the best method for controlling FHABs continue, local governments should take steps towards long-term solutions. First, officials should help encourage people to reduce their nutrient input from non-point sources by increasing public awareness of FHABs and other problems caused by excess nutrients. A greater public awareness would help encourage people to make more eco-friendly habits a part of their lives, such as picking up after pets or throwing all trash in the proper location. Second, local and state governments should enact regulations to help reduce nutrient inputs. Limiting the amount of fertilizer farmers can use or mandating that natural waste (leaves, sticks, grass, etc.) is disposed of properly will keep excess nutrients from leaking into watersheds. Lastly, local public health agencies should pressure their governing bodies to take appropriate actions. The more people who speak up, the more likely things will change. While most of these solutions will take years to make a noticeable change, their collective impacts can make a huge difference.

In order to properly address all FHAB concerns nationwide, the United States needs to pass legislation that expands the HABHRCA and increases its focus on cyanobacteria. Instead of proposing a whole new act to Congress, efforts should be made to introduce greater reforms to the HABHRCA. Changing current legislation will likely be more acceptable to Congress than creating new policy. These reforms should primarily increase funding for FHAB related research. Despite the recent increase in FHAB research, environmental health experts believe there is still too much uncertainty regarding the risks posed by FHABs and the proper ways to manage them. More research would help fill the gaps in our knowledge about FHABs and would help legislators make important decisions regarding future policy. However, it is very important that this action is taken as soon as possible. Climate change, population growth, and the ongoing water crisis have only made conditions for FHABs more favorable. Increasing global temperatures are making more bodies of water susceptible to FHABs than there have been in the past. Rising levels of pollution and numbers of large storms are causing already saturated bodies of water to receive more nutrients. FHABs are also benefitting from decreased water flows around the country due to the high demands for water. As FHABs continue to form more frequently, more and more people will be at the risk of becoming sick. If we act now, FHABs may become only a concern of the past.

Bibliography

Center for Disease Control and Prevention (CDC). "Summary Report – One Health Harmful Algal Bloom System (OHHABS), United States, 2019." Last modified September 27, 2021. https://www.cdc.gov/habs/data/2019-ohhabs-data-summary.html

Congress.Gov. "S.1254 - Harmful Algal Bloom and Hypoxia Research and Control Amendments Act of 2014." Accessed November 17, 2021. https://www.congress.gov/bill/113th-congress/senate-bill/1254

Hudnell, H. Kenneth. "The state of U.S. freshwater harmful algal blooms assessments, policy and legislation." *Toxicon* 55 (2010): 1024-1030. http://doi.org/10.1016/j.toxicon.2009.07.021

Hudnell, H. Kenneth, Christopher Jones, Bo Labisi, Vic Lucero, Dennis R. Hill, and Joseph Eilers. "Freshwater harmful algal bloom (FHAB) suppression with solar powered circulation (SPC)." *Harmful Algae* 9 (2010): 208-217. http://doi:10.1016/j.hal.2009.10.003

Lavery, Amy M., Lorraine C. Backer, and Johnni Daniel. "Evaluation of Electronic Health Records to Monitor Illness from Harmful Algal Bloom Exposure in the United States." *Journal of Environmental Health* 83, no. 9 (May 2021): 8-13.

Lavery, Amy M., Lorraine C. Backer, Virginia A. Roberts, Jourdan DeVies, and Johnni Daniel. "Evaluation of Syndromic Surveillance Data for Studying Harmful Algal Bloom-Associated Illnesses — United States, 2017–2019." *Morbidity and Mortality Weekly Report* 70, no. 35 (September 2021): 1191-1194.

Peckham, Daniel. "A Study in Cyan." *New England Water Pollution Control Commission Reprint Series,* no. 16-03 (2018): 2-7.

Spotts, Pete. “Toledo water crisis may be over, but toxic algae blooms are in our future.” *The Christian Science Monitor*, August 4, 2014.

Sun, Rui, Pengfei Suna, Jianhong Zhangb, Sofia Esquivel-Elizondoc, and Yonghong Wua. “Microorganisms-based methods for harmful algal blooms control: A review.” *Bioresource Technology* 248 (2018): 12-20. http://dx.doi.org/10.1016/j.biortech.2017.07.175

United States Environmental Protection Agency (EPA). “Cyanobacteria and Cyanotoxins: Information for Drinking Water Systems.” *Office of Water* (June 2019): 1-9.