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Harmful Algal Bloom Monitoring and Assessment in Michigan Waters

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Introduction

The Michigan Department of Environmental Quality-Water Resources Division (MDEQ-WRD) receives reports each year about nuisance algal conditions from district staff, lake associations, and the broader public. The number of such reports, particularly the occurrence of harmful algal blooms (HABs) and concern over the possible presence of algal toxins such as microcystin, appear to have increased in recent years. As a result, the MDEQ-WRD established an internal work group in March 2013 to develop an approach to monitor, assess, and report on nuisance and harmful algal conditions, to improve our understanding of the nature, extent, and frequency of algal blooms in inland waters and nearshore Great Lakes.

The need to understand and address HABs became more urgent in August 2014. Severe blooms were observed in the western basin of Lake Erie, and access to drinking water for hundreds of thousands of people was temporarily interrupted due to elevated levels of an algal toxin associated with the bloom. This event caused the MDEQ-WRD to reexamine and expedite our efforts related to HABs, including what constitutes a HAB; our monitoring approach; sampling protocols; analytical capabilities and costs; information gaps; and communication with other agencies, stakeholders, and the public on this issue. This document summarizes the current MDEQ-WRD knowledge about HABs, what actions are being taken to respond to the problem, and where the agency needs to gather more information and make improvements. It is not meant to be the “last word” on the subject; rather, will be updated as the agency learns more and enhances the monitoring approach to HABs.

Current Advisory Values

Some strains of cyanobacteria are capable of producing numerous toxins that can affect liver and brain function. Health symptoms commonly associated with cyanotoxin exposure include nausea, skin rashes, gastrointestinal distress, numbness, and fatigue. There have been reports in recent years throughout the U.S. of human illness and dog deaths associated with exposure to HABs.

The various toxins differ in their chemical structure and properties, and are typically classified by the effects they have on organisms: neurotoxins (anatoxins and saxitoxins); hepatoxins (microcystins and nodularins); cytotoxins (cylindrospermopsin); irritants; and compounds that affect the gastrointestinal tract (World Health Organization [WHO], 2003; Codd et al., 2005). Microcystins are the most common and widespread of these. At least 80 different chemical variants of microcystin have been described to date (Humpage, 2008).

Many government agencies use provisional guideline values for microcystin concentrations provided by the WHO for drinking water (1 microgram per liter [µg/l]; WHO, 1998) and recreational water (20 µg/l; WHO, 2003). These guidelines are for microcystin-LR, which is the most studied toxin (WHO, 1998) and is the specific microcystin congener associated with the greatest number of reported cyanotoxin incidents (Fawell et al., 1993).

Of the states that have guidelines for harmful algae, most have concentrated on microcystin-LR (Graham et al., 2009; Hudnell et al., 2012). Some states, such as California and Oregon, have guidelines for other toxins mentioned above (Hudnell et al., 2012). The guidelines used by states in which a contact advisory or closure is issued range from 6-20 µg/l of microcystin (Graham et al., 2009). For example, in Ohio, children, elderly, and immune-compromised individuals are advised to avoid water contact if microcystin concentrations are ≥ 6 µg/l. If microcystin concentrations are ≥ 20 µg/l and a probable case of human illness or pet death has occurred as a result of cyanotoxin contact, then a "no contact" advisory is issued (Ohio Environmental Protection Agency [EPA], 2014b). At this time, federal guidelines have not been established for cyanotoxins (Hudnell, 2010), although the U.S. EPA is working on standards.

The MDEQ-WRD expects to develop a Rule 57 water quality value for microcystin once the U.S. EPA process is completed to ensure consistency and coordination between the two efforts, as well as to take advantage of the information gathered during the process. The U.S. EPA plans to finalize drinking water health standards for microcystin-LR and cyclindrospermopsin in spring 2015. In addition, the MDEQ-WRD will work with the Michigan Department of Community Health and county health departments to establish a process for issuing water body advisories due to the occurrence of HABs and elevated toxin levels. A key component of this process will be to ensure timely and effective public notice. The MDEQ-WRD will evaluate the need for additional Michigan water quality standards for other cyanotoxins in the future.

What Is a Harmful Algal Bloom?

An algal bloom, in its simplest definition, is a large increase in phytoplankton in a given area. Early research referred to phytoplankton accumulations as blooms if they caused a visible discoloration of the water (Fogg, 1969; Reynolds and Walsby, 1975). Paerl (1988) acknowledged that the term "bloom" is subjective and used examples of slight discolorations in oligotrophic waters being termed "blooms," whereas the same occurrence would most likely cause no perceptible change in already eutrophic or hypereutrophic water. As summarized in Graham et al. (2008), the simplest definition of a bloom is "a large population or extremely high cell densities (greater than 20,000 to 100,000 cells per milliliter) of phytoplankton."

The term "harmful algal bloom" generally describes accumulations of cyanobacteria that are aesthetically unappealing and produce algal toxins. Many blooms occur at the water surface, where sunlight is most plentiful. If the water body is stable, algae can reproduce at a high rate and lead to foul odors and taste. In some cases, the bloom can rapidly reduce nutrients and other essential resources, causing the algal population to crash and resulting in large accumulations of decaying matter. The sudden large-scale decomposition process following a bloom crash may also deplete the water column of dissolved oxygen, which can lead to fish kills (Paerl et al., 2001).

HABs with toxin-producing taxa can occur in water bodies of varying nutrient levels and productivity. Cyanobacteria (also known as blue-green algae) are the most widespread and problematic toxin-producing phytoplankton, and therefore are the focus of determining whether a harmful bloom is present. It is impossible to tell visually, by taste, or odor whether a bloom is a HAB. Recently, the Ohio EPA developed quantitative criteria for defining harmful algal blooms as severe, moderate, or mild based on cyanobacteria cell count, biovolume, chlorophyll *a*, the presence of scum or surface accumulations, and the presence of cyanotoxins (Ohio EPA, 2014a).

After reviewing Ohio's and other definitions, the MDEQ-WRD has decided on the following definition for Michigan:

"An algal bloom in recreational waters is harmful if microcystin levels are at or above the 20 ug/L WHO non-drinking water guideline, or other algal toxins are at or above appropriate guidelines that have been reviewed by the MDEQ-WRD." A bloom should be considered *potentially* harmful when "the chlorophyll *a* level is greater than 30 µg/L and visible surface accumulations/scum are present, or cells are visible throughout the water column."

As described in the previous section, the 20 ug/L WHO non-drinking water guideline for microcystin will likely be replaced at a later date by a Rule 57 water quality value being developed by the MDEQ-WRD. Although other states have included cyanobacteria cell counts and biovolume in HAB definitions, the MDEQ-WRD excluded them as indicators at this time because of the expense and time required to generate this information. These indicators may be used in specific cases at sites warranting more detailed investigation, and may be incorporated in the future as this issue is studied further.

A key concept of this HAB definition is that while high chlorophyll *a* concentration and visible surface/water column algal accumulation can indicate potential problems, water samples must be analyzed for the presence of toxins to confirm that a bloom may, in fact, be harmful to humans. Visible appearance of blooms cannot be used as a reliable predictor of toxin content. Even in toxin-producing blooms, there may be great variability as to when the toxin is available for exposure.

Finally, the definitions for actual and potential HABs are not necessarily definitive; there are always exceptions to the general rule. HABs can be present when chlorophyll *a* is lower than 30 ug/L, and HABs may be absent when chlorophyll *a* is greater than 30 ug/L. The topic of toxin synergy needs more research since not much is known about it, specifically whether multiple toxins can be present below each individual advisory level but still be harmful due to synergistic effects.

Lake Types Most Likely To Experience Harmful Algal Blooms

Past studies of microcystin concentrations in inland lakes throughout Michigan and in specific regions of the state have revealed that the majority of lakes do not contain high levels of microcystin (Rediske et al., 2007; Sarnelle et al., 2010; and Bednarz, 2012). Because of the numerous variables that influence the occurrence, frequency, and duration of HABs, it is impossible to predict with certainty whether a specific water body will develop a bloom.

However, based on observations of affected water bodies, HABs often occur in waters with some or all of the following general characteristics (Paerl et al., 2001):

- High phosphorous concentrations (lakes that are eutrophic or hypereutrophic).
- Low nitrogen concentrations.
- Lakes that are shallow and thermally stratify. The ideal temperature for cyanobacteria is around 25° C (77 degrees F).
- Long water residence time, which supports high rates of growth and reproduction.
- Low number of algal grazers (e.g., zooplankton).
- Stable water conditions that support buoyant, surface-dwelling cyanobacteria.
- The presence of zebra/quagga mussels.

An increasing body of literature suggests that even mesotrophic and oligotrophic lakes may experience harmful algal blooms if invasive *Dreissena* (zebra or quagga) mussels are present. Vanderploeg et al. (2001) found that *Dreissena* mussels will selectively exclude the toxin-producing *Microcystis* cyanobacteria while feeding, thus creating disproportionate concentrations of *Microcystis* in water bodies. Raikow et al. (2004) sampled multiple inland lakes throughout Michigan and found that lakes with a combination of low nutrients and the presence of *Dreissena* mussels contained the highest concentrations of *Microcystis.* This dominance of *Microcystis*, created by *Dreissena* mussels, has caused harmful algal blooms in oligotrophic lakes in the northern lower peninsula of Michigan (Woller-Skar, 2009).

In summary, the lakes least likely to develop frequent HABs are those that are oligotrophic or mesotrophic, and are not infested with the invasive zebra/quagga mussels. As the MDEQ-WRD collects more information on this topic, we expect to improve our ability to identify water bodies most susceptible to HABs.

MDEQ Monitoring and Assessment

Between 2003 and 2009, the MDEQ-WRD awarded a number of grants to various organizations to monitor for HABs and associated toxins. The first grants were awarded to the Leelanau Conservancy to monitor six oligotrophic lakes in Leelanau County in the northwest lower peninsula of Michigan. Three of the lakes contained zebra mussels while the other three did not. The lakes with zebra mussels had elevated cyanobacteria levels due to the selective algal feeding of zebra mussels; the lakes without mussels had fewer cyanobacteria (Woller-Skar, 2009). Microcystin concentrations were higher in the lakes with mussels, and the toxin was present in mayfly nymphs and the muscle tissue of walleye.

Another grant was provided to Grand Valley State University (GVSU) to sample seven drowned river mouth lakes in western Michigan in 2006. All but one lake contained low levels of microcystin throughout July and August 2006. Two lakes had instances in which microcystin concentrations were greater than 1 µg/L (the WHO drinking water standard); none of the lakes exhibited concentrations greater than the 20 µg/L WHO guideline for recreational contact (Rediske et al., 2007). GVSU scientists also compared three methods of quantifying microcystins: enzyme-linked immunosorbent assay (ELISA), protein phosphatase inhibition assay (PPIA), and high performance liquid chromatography with mass spectrometry (HPLC/MS). Although the PPIA and ELISA methods are less costly than HPLC/MS, both consistently over-estimated microcystin concentrations. The HPLC/MS method provided more accurate measurements, but requires expensive analytical equipment ($150,000). They recommended using either PPIA or ELISA as initial screening methods, then using HPLC/MS to better quantify the levels if concentrations are greater than 20 µg/L.

A grant was awarded to Michigan State University to use citizen volunteers to collect cyanobacteria toxin samples in lakes throughout Michigan. Of the 77 lakes sampled, only two contained elevated microcystin concentrations (maximum value of 9.4 µg/L in Bills Lake in Newaygo County and 46.4 µg/L in Lakeville Lake in Oakland County). Microcystin concentrations tended to be higher along the shoreline than in the depth-integrated euphotic zone samples (Sarnelle and Wandell, 2008).

Finally, another grant was awarded to GVSU to assess *E. coli* and microcystin in *Cladophora* mats in the nearshore waters of Grand Traverse Bay and Saginaw Bay. They were able to detect microcystins in detached *Cladophora* mats in Saginaw Bay, which could irritate the skin if people walk through the mats (Rediske et al., 2010). Small children playing in the sand and shallow water could also be at risk of microcystin exposure.

Additional monitoring of microcystin concentrations in Michigan inland lakes was conducted as part of the U.S. EPA's National Lake Assessment surveys, which were conducted in 2007 and 2012. In 2007, 50 randomly-selected and 4 reference inland lakes greater than 10 acres in Michigan were sampled for a variety of chemical, physical, and biological indicators. This statewide assessment of Michigan's inland lakes documented detectable levels of microcystin at approximately 30 percent of Michigan's inland lakes. However, microcystin concentrations did not exceed the WHO's thresholds for high (>20 ug/L) or medium (10 ug/L) recreational risk exposure at any of Michigan's inland lakes (Bednarz, 2012).

In 2012, the MDEQ sampled 53 randomly-selected inland lakes (greater than 2.5 acres) in Michigan for a suite of chemical, physical, and biological indicators. Microcyctin samples were collected once again from the deepest portion of each lake and an additional sample was collected from shallow littoral habitat. The results of these efforts are still being reviewed and are considered draft. A preliminary review shows that Michigan's inland lake resource has measurable concentrations of microcystin at many of the lakes but the maximum concentrations at index and littoral sites were well below the WHO threshold of 10 ug/L for medium recreational risk exposure (Walterhouse, 2014; personal communication).

Additionally, microcystin sampling was conducted in 2008 as part of the Lake Water Quality Assessment of Michigan's public access lakes that was conducted by the U.S. Geological Survey and MDEQ from 2001-2010. Mid-lake samples were collected from 41 inland lakes scattered across the upper and lower peninsulas. Microcystin was detected in over 50 percent of the samples, but all samples were less than 1.0 ug/L; well below any levels of concern (Unpublished data; National Water Information System database).

MDEQ HABs Response

In the past, the MDEQ-WRD generally responded to algal bloom reports and complaints on a case-by-case basis and did not have a comprehensive approach to tracking these reports or summarizing the frequency, timing, and spatial extent of nuisance algal conditions. Given the potential effects of nuisance and harmful algae on water quality, aquatic life, wildlife, and recreation, it was recognized that a more systematic monitoring and assessment approach was needed. The MDEQ-WRD district staff record Great Lakes and inland water body algal complaints in the state's Pollution Emergency Alerting System (PEAS) database. From 2004-2012, 77 algal complaints were recorded in the PEAS database at 23 inland lakes, 5 streams or rivers, Lake Erie, Lake St. Clair, Lake Huron, and Lake Michigan. Complaint numbers per year ranged from a low of 2 to a high of 16. Early in 2013 district staff were reminded of the importance of recording complaints and made aware of the renewed interest in tracking algal complaints around the state. Similarly, MDEQ staff in Lansing was instructed in 2013 to begin recording algal bloom complaints on a newly developed "Algal Bloom Survey" form.

In addition, the MDEQ-WRD provides funding to county health departments each year to monitor *E. coli* concentrations at beaches. Personnel that collect samples also record site conditions at the bodies of water that they sample, including algal abundance. Using best professional judgment, algal abundances are recorded as "low," "medium," or "high." The observations by county health departments, MDEQ-WRD staff, and citizens in 2013 were collectively summarized in a recently completed report (MDEQ, 2014). A review of complaints and observations in 2014 is ongoing, and will be summarized in a report in the near future.

The MDEQ also recognized the need to augment our monitoring approach beyond providing the grant awards described above. Since 2012, the MDEQ has been sampling water at seven beaches along the Michigan shoreline of western Lake Erie to investigate possible HAB impacts and other nutrient-related effects (e.g., nearshore attached algae, beach/shoreline 'muck') on Michigan's designated uses. Seven beaches extending from Luna Pier north to Estral Beach have been sampled roughly every other week from June through September each year, for a total of 8 to 10 visits a year. The monitoring includes photos, nutrient sampling (grab sample from approximately 0.5 meters, wading in water 1-1.5 meters deep) and a qualitative assessment of beach and splash-zone debris. Microcystin sampling has primarily focused on bloom conditions, although a few background 'no bloom' samples have been taken. Total microcystin results during bloom conditions were typically less than 10 ug/L, often less than

5 ug/L but with a few around 15 ug/L. Microcystin levels in scum samples (dense surface accumulations of cyanobacteria) ranged from single digits up to 300 ug/L.

In even-numbered years, the MDEQ-WRD monitors four lakes for which total phosphorus Total Maximum Daily Loads (TMDL) have been established, specifically Lake Allegan, Ford and Belleville Lakes, and Lake Macatawa. These lakes are primarily monitored for nutrients. However, water samples were collected at multiple sites in each lake for microcystin analysis in September 2014, and analyzed using the ELISA method. All Lake Allegan samples were below detection limits (0.16 ug/L); however, microcystin was found at relatively low levels in Ford and Belleville Lakes (nondetect-0.66 ug/L) and Lake Macatawa (1.6-2.3 ug/L).

Rather than devising a separate HAB monitoring program, we intend to integrate this work into existing and future monitoring efforts on the Great Lakes, inland lakes, and rivers, in a manner that will allow us to determine the frequency, geographic scope, and intensity of HABs in these water bodies.

Sampling Considerations and Protocols

As described previously, there are several studies indicating the characteristics of lakes most susceptible to HAB occurrence, specifically more productive lakes with high chlorophyll *a* and nutrient concentrations, as well as those infested with invasive zebra/quagga mussels. This knowledge will be used to inform our future monitoring activities and site selection. Sampling protocols will vary depending on the objective of a specific study. Graham et al. (2008) provides helpful guidance on cyanotoxin study design with recommendations on site location, sampling frequency, and sample type across different study objectives. For example, studies focusing on recreational concerns may need to sample differently than those with drinking water supply concerns.

In general, the MDEQ-WRD plans to follow the guidance in Graham (2008) in planning cyanotoxin monitoring. Since human and pet exposure to cyanotoxins is currently a primary concern for the MDEQ-WRD, cyanotoxin monitoring will focus on surface sample collection near shorelines and public access locations. Because surface blooms are often wind-blown and widely distributed throughout lakes, sampling at multiple areas (such as the north, south, east, and west parts of a lake) are recommended. Sampling frequency depends on the question being asked. For example, if the goal is to determine whether cyanotoxins are present, then one sample during or immediately after a bloom is likely sufficient. If a water body is known to contain cyanotoxins and the objective is to determine how concentrations change over time, then weekly, biweekly, or monthly sampling may be necessary.

A cyanotoxin sample should be collected in a sterilized 500 milliliter bottle as a grab sample from about 0.5 meters below the water surface. The bottle should be triple rinsed with lake water prior to collection. If algal accumulations are present on the surface, an additional sample should be taken by submersing the bottle in the scum so that approximately half of the opening is underwater and there is no bubbling as the bottle fills; slowly filling it while moving the bottle around trying to collect as much algae as possible. This type of sample indicates 'worst case' condition for human/pet contact.

If samples are to be collected in shallow water, care should be taken not to disturb bottom sediments. Shallow sample locations should be approached slowly, whether by boat or on foot, to avoid suspending sediments. If the bottom is disturbed, and sediment or detritus is resuspended, move a short distance to avoid sampling this material.

Sample bottles must be properly labeled, placed on ice (no preservative), and taken to the laboratory within one day. If a longer delay is necessary, the samples should be frozen while awaiting delivery. As long as the sample is frozen, holding times are not a concern within a reasonable period of time. If samples are to be frozen, enough water must be discarded so that the sample is just below the shoulder of the bottle to allow for expansion and avoid bottle damage.

Duplicate samples should be collected at a rate of ten percent or a minimum of one duplicate sample per trip if less than ten samples are collected. The results of duplicate analyses are used to calculate a relative percent difference (RPD) between the samples. The target for the RPD should be ≤20 percent, and data falling outside of this RPD should be flagged.

Cyanotoxin Analysis

There are different methods available for measuring toxin levels in water samples, which vary in cost and precision. The ELISA method for counting total microcystins is inexpensive, quick, and conservative. Rediske et al. (2007) found that the ELISA method typically over-estimated microcystin concentrations in several west Michigan drowned rivermouth lakes, thus making it a more conservative approach. However, this method is relatively inexpensive on a per-sample basis. HPLC/MS provides a more accurate assessment of the individual microcystin congeners that are actually toxic. The downside is that this method requires expensive analytical equipment and costs more than the ELISA method on a per-sample basis. Therefore, Rediske et al. (2007) recommended using the ELISA method for initial screenings of large numbers of samples. The HPLC/MS method could then be used to assess samples where microcystin was > 20 µg/L based on the ELISA method.

In addition to ELISA and HPLC/MS methods, more recent products are available that can rapidly test for microcystins in the field *(The link provided was broken and has been removed)*. A kit from Envirologix costs $175 and can process 24 samples ($7.30/sample). This test indicates whether microcystin concentrations are greater than the 1 µg/l drinking water standard, but does not provide reliable, specific concentrations.

Another option is to contract the algal toxin analysis to an external laboratory with existing analytical capabilities. There are several laboratories in Michigan, primarily associated with universities, capable of doing this work. Analytical costs vary depending on the laboratory, method, and specific toxins measured, but generally run about $100-$175 per sample. Sample results can be reported in two to seven days.

Future Issues/Information Gaps

The MDEQ-WRD will address several additional HAB-related issues in the near future, including when to respond to algal bloom reports. Ideally, it would be helpful to follow up on all complaints and conduct additional monitoring to determine whether an algal bloom is harmful. However, staff and financial constraints make that impossible. Therefore, it is important to identify criteria to guide response actions. Bloom intensity, scope (widespread throughout a water body versus a localized bloom), and duration might be important factors to consider. Another potential variable is the importance of the water body to recreation. A bloom in a large lake with many surrounding houses and public access might warrant a response, whereas one in a small, remote lake might not. For the sake of internal planning and public expectations, it is important to have a clear, transparent approach to responding to bloom reports.

There are a number of ongoing and planned monitoring activities on the Great Lakes, inland lakes, and streams/rivers. These include the national aquatic resource surveys (which include Great Lakes coastal, inland lakes, rivers and streams, and wetlands), MDEQ-WRD watershed surveys, sample collection by volunteers, MDNR-Fisheries Division status and trend monitoring, TMDL monitoring support, and aquatic nuisance control program surveys. The challenge to the MDEQ-WRD is to better incorporate HAB assessment into these existing activities, rather than trying to design a separate HAB monitoring program. While some HAB-specific sampling may be necessary, especially in response to complaints, an integrated approach will be more cost-effective. The MDEQ-WRD will consider a balance of complaint response with other site selection techniques while developing a HAB monitoring plan, taking into account management objectives and available resources.

Efforts are underway to improve the MDEQ-WRD internal and external communication on this issue. The first report summarizing 2013 algal bloom observations was recently completed (MDEQ, 2014), and additional annual reports are intended for the foreseeable future. It will be important that these reports be readily accessible to the public, and written in a user-friendly format. There are plans to complete a fact sheet on HABs, modeled on similar products generated by other states. The fact sheet will summarize what a HAB is, why it is important, what factors contribute to HAB development, and recommendations for people affected by water bodies with HABs. The MDEQ-WRD also intends to produce a Web page, which will include pertinent information on HABs. This likely will include our annual summary of bloom observations, the fact sheet, a map showing waters where HABs have been documented in recent years, and links to other important HAB information.

Finally, the MDEQ-WRD will be working with the Michigan Department of Community Health (MDCH) and county health departments to establish a procedure for issuing human health advisories due to HABs. Processes developed by other states (Ohio, Nebraska) will provide guidance for this effort. County health departments in Michigan currently issue advisories due to high bacteria levels at beaches based on comparison to numeric criteria, but the MDEQ-WRD is aware of only a few cases where HAB advisories have been issued based on decisions made at the county level. Improving communication with the MDCH and providing guidance on HAB-related health concerns to local health departments are important future activities for the MDEQ-WRD.

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