MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
WATER RESOURCES DIVISION
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STAFF REPORT

ALGAL TOXIN MONITORING IN MICHIGAN INLAND LAKES: 2015 RESULTS

Introduction

The term “harmful algal bloom” (HAB) generally describes accumulations of cyanobacteria that are aesthetically unappealing and produce algal toxins. In 2015 the Michigan Department of Environmental Quality (MDEQ), Water Resources Division (WRD), developed the following definition of a HAB (Kohlhepp, 2015[a]): “An algal bloom in recreational waters is harmful if microcystin levels are at or above the 20 µg/L World Health Organization (WHO) non-drinking water guideline, or other algal toxins are at or above appropriate guidelines that have been reviewed by MDEQ-WRD.” A bloom should be considered *potentially* harmful when “the chlorophyll *a* level is greater than 30 micrograms per liter (µg/L) and visible surface accumulations/scum are present, or cells are visible throughout the water column.” 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, the WRD’s focus is on the potential harm that toxins represent and so water samples must be analyzed for the presence of toxins to confirm that a bloom may, in fact, be harmful to humans or wildlife. Visible appearance of blooms cannot be used as a reliable predictor of toxin content.

The WRD receives reports each year about nuisance algal conditions, which may or may not be HABs, from district staff, lake associations, and the broader public. These reports can come in as concerns about algae or about suspected pollutants or toxic substances in the water, such as ‘green paint’ spills, which upon investigation, turn out to be algae. The number of such reports, particularly the occurrence of blue-green algal blooms and concern over the possible presence of algal toxins such as microcystin, appear to have increased in recent years, although this is difficult to quantitatively confirm (Parker, 2013 and Parker, 2014). 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. Since 2012, the WRD has been collecting and analyzing samples from 7 Lake Erie beaches, every-other-week from June through September. These data will be presented in separate reports. 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 served by the city of Toledo water treatment facility 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 harmful algal blooms.

Historic monitoring in Michigan has found that microcystin concentrations in Michigan inland lakes are not typically very high across all lakes. Sarnelle et al. (2010) found that only 2 of the 77 inland lakes sampled by volunteers in August and September 2006 had microcystin concentrations greater than 20 µg/L. Recreational use of water with microcystin concentration greater than 20 ug/L is suggested to have high risk levels by the WHO. Rediske et al. (2007) also sampled 7 drowned-river mouth lakes in western Michigan in 2006 and did not find any

microcystin samples above 20 µg/L. During the United States Environmental Protection Agency's (USEPA), National Lake Assessments (NLA), in 2007 and 2012, no samples exceeded 10 µg/L (Kohlhepp, 2015[b]).

In 2015, the WRD expanded algal toxin monitoring to both targeted and randomly selected inland lakes and this report summarizes the results. This study was designed to allow the MDEQ to further understand: (1) the range of algal toxin concentrations across Michigan inland lakes; (2) how algal toxin concentrations change during a growing season in Michigan lakes; (3) if lake water chemistry parameters predictively correlate with algal toxin concentrations; and (4) how microcystin results compare using rapid field test strips and laboratory quantitative analysis.

Study Design

To achieve the study objectives, WRD biologists collected qualitative algal bloom condition and water quality data at both randomly selected lakes and targeted inland lakes. The random sites were selected to represent a geographic range and to provide the ability to broadly understand conditions among Michigan's inland lakes during the summer growing season. The targeted lakes were selected because they are known to have high concentrations of nutrients and historic problems with algae blooms and were expected to represent some of the most productive lakes in Michigan.

Table 1. Michigan Department of Natural Resources (MDNR), Fisheries Division's (FD), randomly selected lakes sampled twice during summer 2015.

Lake Name	County	Lake Name	County
Ninth Street Pond	Alpena	Indian Lake (South)	Livingston
Carter Lake	Barry	Brucker Lake	Luce
Gun Lake	Barry	Panther Lake	Alger
Burt Lake	Cheboygan	Teal Lake	Marquette
Gut Lake	Clare	Sanford Lake	Midland
Shamrock Lake	Clare	Grebe Lake	Ogemaw
Buell Lake	Genesee	Long Lake	Ogemaw
Trout Lake	Gladwin	Bridge Lake	Otsego
Lime Lake	Kent	Rush Lake	Montmorency
Indian Lake (North)	Livingston	Argo Pond	Washtenaw
Indian Lake (Central)	Livingston	Round Lake*	Lenawee

*As part of this project, Round Lake was only sampled in August 2015.

The 22 randomly selected inland lakes (Table 1, Figure 1) included in this project were monitored in 2015 utilizing the MDNR-FD's and MDEQ-WRD's Status and Trends Programs. These lakes were sampled for HABs twice during the 2015 summer growing season; in July by MDEQ-WRD staff and in August by MDNR-FD staff. On both dates, field crews visually assessed whether an algal bloom was occurring in any portion of the lake, collected up to 4 surface water samples per lake, and used Abraxis test strips to estimate microcystin concentrations. General lake water chemistry samples were also collected at the center of the lake in July and August.

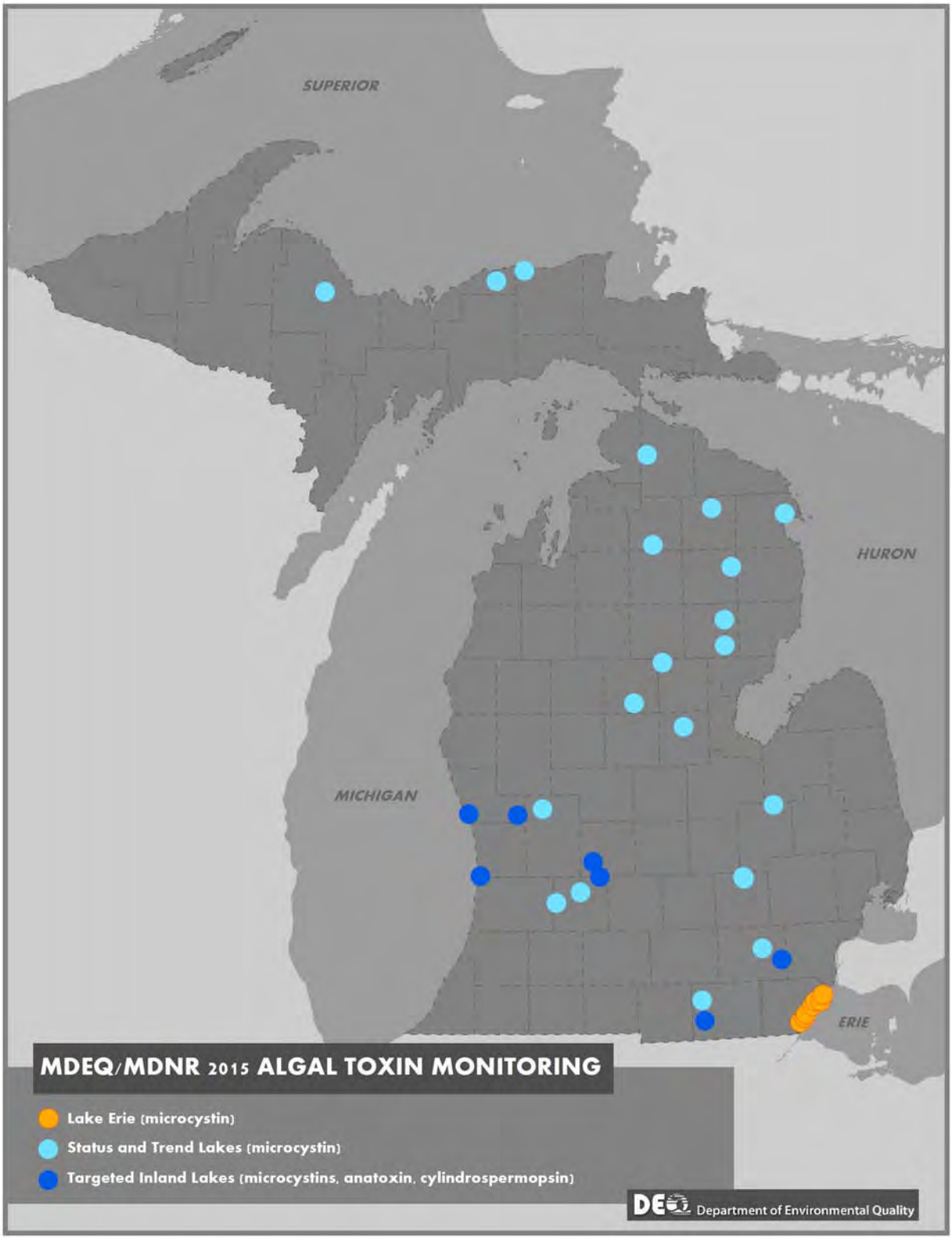

Figure 1. 2015 algal toxin monitoring locations. Lake Erie data are summarized in a separate report.

The targeted portion of this study identified lakes with a known history of cyanobacteria blooms that may produce harmful algal toxins. Ten lakes were identified with high potential for algal blooms and 7 of the lakes were sampled (Table 2, Figure 1). Lakes, with and without herbicide application permits, were intentionally chosen to capture possible relationships between herbicide treatment and microcystin concentrations. The MDEQ-WRD field crews sampled the targeted lakes when there was an algal bloom reported to the MDEQ by an arranged lake contact or when MDEQ staff visited a lake and observed a bloom.

Table 2. Targeted inland lakes with a history of algal blooms. Treated lakes had a current aquatic nuisance control permit with the MDEQ to apply herbicides for aquatic plant and algae management.

Lake	County	Sampled in 2015
Holloway Reservoir (untreated)	Genesee/Lapeer	
Lake Ovid (untreated)	Clinton	
Ford Lake (untreated)	Washtenaw	X
Lake Macatawa (untreated)	Ottawa	X
Lake Hudson (untreated)	Lenawee	X
Morrison Lake (treated)	Ionia	X
Jordan Lake (treated)	Barry	X
Crockery Lake (treated)	Ottawa	X
Mona Lake (treated)	Muskegon	X
Bass Lake (treated)	Mason	

Field Methods

Sampling occurred between late-June and early-September, with most monitoring occurring in July and August. Lakes were sampled repeatedly over varying time scales to assess the changes of algal toxins over the summer. During a monitoring event at a targeted lake, MDEQ-WRD staff took pictures of algal conditions, collected general water chemistry in the center of the lake, and collected water samples for algal toxin analysis from up to 4 locations around the lake. The algal toxin samples were analyzed using both Abraxis test strips to estimate microcystin concentration and High-Performance Liquid Chromatography with Mass Spectrometry (HPLC-MS) for quantitative assessment of a suite of algal toxins including microcystins, cylindrospermopsins, and anatoxins.

Survey Forms

A field sheet was completed during every targeted lake survey to document shoreline algae levels and accumulation.

Water Samples - General Chemistry

Water sample parameters collected at the Status and Trend lakes and the targeted lakes were generally similar, except for quantitative algal toxins. At all lakes, temperature, dissolved oxygen, conductivity, and pH were measured using a YSI sonde at the mid-lake location. At the same location as sonde sampling, water samples were collected for nutrient analyses and a secchi disk reading was taken.

At all lakes, surface water samples were collected at an approximate 1-foot depth using new 250 milliliter (ml) polypropylene sample bottles that were triple-rinsed with site water. At targeted lakes, the following samples were collected: total phosphorus, total Kjeldahl nitrogen, ammonia, nitrate+nitrite, ortho-phosphate, and chlorophyll *a*. The samples were analyzed at the MDEQ Environmental Laboratory (Table 3). At Status and Trend lakes the same nutrient samples were collected, excluding ortho-phosphate.

Following sampling, preservatives were added if required by MDEQ protocols and sample bottles were placed on ice or refrigerated for transport and storage prior to delivery to the laboratory. At targeted lakes, the nutrient samples were not collected at every sampling event if sampling occurred several times over a week. The August Status and Trend water chemistry samples were collected by MDNR-FD staff and analyzed by the Great Lakes Environmental Center.

Water Samples - Algal Toxins

At all lakes, 1 mid-lake sample and 3 shoreline samples were collected in 250 ml polyethylene terephthalate sample bottles. Water was collected in the top foot of water, at locations in the lake approximately 2-to 6-feet deep. Surface algae was neither targeted nor avoided while sampling. The shoreline sampling locations were distributed approximately evenly around the shoreline of the lake. However, downwind locations, bays that may be used for recreation, areas impacted by river outlets, or beaches were preferentially targeted.

Sample bottles were placed on ice or refrigerated for transport and storage. The quantitative cyanotoxin samples were frozen and batch shipped to the Wisconsin State Lab of Hygiene for HPLC-MS analysis of 8 algal toxins: anatoxin-a, homoanatoxin-a, cylindrospermopsin, deoxycylindrospermopsin, microcystin-LR, microcystin-YR, microcystin-RR, and microcystin-LA (Table 3).

Qualitative microcystin samples were held on ice or refrigerated for no more than 5 days prior to analysis. If microcystin samples were held longer than 5 days, they were frozen with care taken to reduce volume to allow for expansion. Qualitative microcystin samples were tested using Abraxis test strips (Product Number #52022) by either MDEQ-WRD or Great Lakes Environmental Center staff following Abraxis protocols. Abraxis microcystin test strips were selected for this project because the procedure includes a cell lysis step, which was more consistent with other MDEQ algal toxin monitoring for total microcystin (both free in the water column and intra-cellular). MDEQ-WRD staff analyzed the July Status and Trend samples and all targeted lake samples using the test strips. The August Status and Trend samples were analyzed by staff of the Great Lakes Environmental Center.

Table 3. Analytical methods and reporting limits.

Parameter	Analytical Method Reference USEPA / SW-846	Reporting Limit (µg/L)
Total Phosphorus	365.4	10
Kjeldahl Nitrogen	351.2	100
Ammonia	350.1	10
Nitrate+Nitrite	353.2	10
Ortho-phosphate	365.1	10
Chlorophyll a	10200H (Standard Methods)	1
Anatoxin-a	OC12703 (HPLC-MS/MS)	1
Cylindrospermopsin	OC12703 (HPLC-MS/MS)	1
Deoxycylindrospermopsin	OC12703 (HPLC-MS/MS)	1
Homoanatoxin-a	OC12703 (HPLC-MS/MS)	1
Microcystin-LR	OC12703 (HPLC-MS/MS)	1
Microcystin-YR	OC12703 (HPLC-MS/MS)	1
Microcystin -RR	OC12703 (HPLC-MS/MS)	1
Microcystin -LA	OC12703 (HPLC-MS/MS)	1
Qualitative Microcystin	Abraxis test strips (PN52022)	1

RESULTS

Status and Trend Lakes

Over the course of the July and August 2015 sampling, 168 Abraxis microcystin test strips were run on discrete samples from the Status and Trend Lakes. All but 4 of the sample results were non-detect (less than 1 µg/L). All 4 samples collected in Rush Lake in July had positive test strip results for total microcystin in the 1 to 10 µg/L range. Although testing only occurred on 2 sampling dates, these results suggest that algal toxins are not routinely present at high levels in most Michigan lakes.

Targeted Lakes

Targeted lake sample dates are presented in Table 4 and Appendix 1, along with herbicide treatment dates. Sampling began in late June to collect data before and after planned herbicide treatments on Jordan and Morrison Lakes. Sampling at each lake was initiated based on reports of blooms, planned herbicide treatments, or MDEQ staff visual assessment of algae blooms. Upon notification of a planned herbicide treatment, sampling was attempted before treatment and generally again after treatment.

Table 4. 2015 sample and permitted chemical treatment dates. Of the targeted lakes, only Crockery, Jordan, and Morrison Lakes were regularly treated with algal herbicides in 2015.

Lake	Sample Dates	Treatment Dates
Crockery	7/15/2015	5/29/2015
	7/17/2015	6/19/2015
	7/20/2015	7/1/2015
	7/23/2015	7/21/2015
	7/28/2015	8/4/2015
	8/3/2015	
	8/11/2015	
	9/2/2015	
Ford	8/24/2015	
Hudson	7/29/2015	
	8/10/2015	
	8/24/2015	
Jordan	6/24/2015	5/6/2015
	7/31/2015	6/9/2015
	8/31/2015	6/24/2015
		7/1/2015
		7/24/2015
		7/31/2015
		9/2/2015
Macatawa	7/28/2015	
	8/13/2015	
	8/21/2015	
	8/26/2015	

Lake	Sample Dates	Treatment Dates
Mona	7/23/2015	6/9/2015
	7/28/2015	
	8/3/2015	
	8/11/2015	
	8/13/2015	
	8/17/2015	
	8/21/2015	
	8/26/2015	
	8/31/2015	
	9/2/2015	
	9/10/2015	
Morrison	6/24/2015	5/6/2015
	7/17/2015	5/27/2005
	7/20/2015	6/5/2015
	7/31/2015	6/16/2015
	8/31/2015	6/24/2015
		7/1/2015
		7/17/2015
		7/31/2015
		9/2/2015

General lake chemistry in the targeted lakes is summarized in Table 5 and Appendix 1. The data collected are indicative of eutrophic to hypereutrophic lakes, as expected. Across all 7 lakes the total phosphorus concentration ranged from 0.019 to 0.220 milligrams per liter (mg/L). Chlorophyll *a* ranged from 7 to 350 µg/L. Total nitrogen ranged from 0.730 to 5.0 mg/L. Secchi depth ranged from 0.9 to 7.8 feet.

Table 5. Targeted lake chemistry data from June to September 2015. Total phosphorus, chlorophyll a, and total nitrogen are presented in µg/L and secchi depth is presented in feet. Total nitrogen was calculated as the sum of kjeldahl nitrogen and ammonia.

	Number of Samples			Total Phosphorus		Chlorophyll *a*		Total Nitrogen		Secchi Depth	
Targeted Lake	Microcystin Test Strips	HPLC-MS	General Water Chemistry	Min	Max	Min	Max	Min	Max	Min	Max
Crockery Lake	33	32	8	0.030	0.062	7.7	30	0.77	1.01	1.7	6.1
Ford Lake	4	4	1	0.051	0.051	24	24	0.92	0.92	3.2	4.8
Jordan Lake	12	12	3	0.019	0.070	7.1	26	0.78	2.76	3.0	7.8
Lake Hudson	12	12	3	0.032	0.043	14	46	1.31	1.62	1.4	5.7
Lake Macatawa	17	17	4	0.092	0.220	41	99	3.80	5.00	1.0	2.0
Mona Lake	43	44	11	0.040	0.100	21	97	0.73	1.25	1.4	4.5
Morrison Lake	24	24	6	0.053	0.100	16	350	1.02	1.61	0.9	4.8

Test Strips

Abraxis field test strip results for the targeted lakes are presented in Table 6. Out of 145 tests, only 10 (all from Mona Lake) had a result greater than 10 µg/L total microcystin. Crockery Lake, Mona Lake, and Lake Macatawa had some test results between 1 and 10 µg/L. Ford Lake, Jordan Lake, Lake Hudson, and Morrison Lake did not have any samples with detectable concentrations of microcystin using the field test strips. Over 20% of Mona Lakes samples exceeded 10 µg/L. Approximately 53% of Mona Lake samples were in the 1-10 µg/L range, while Crockery Lake and Lake Macatawa had approximately 40% and 23% of samples in the 1-10 µg/L range, respectively.

Table 6. 2015 targeted lake information and Abraxis field test results. Abraxis microcystin test strip results are presented as number of tests within ranges (non-detect = 0-1 µg/L range; positive test results = 1-10 µg/L or greater than 10 µg/L.)

							Number of test strips		
Targeted Lakes	**Max Depth (ft)**	**County**	**Storet**	**Lat**	**Lon**	**# Sample Events**	**# Micro ND (<1)**	**# Micro 1-10**	**# Micro 10+**
Crockery Lake	54	Ottawa	700422	43.1658	-85.8564	8	20	13	
Ford Lake	30	Washtenaw /Wayne	810209	42.2163	-83.5847	1	4		
Jordan Lake	60	Barry	80066	42.7686	-85.1422	3	12		
Lake Hudson	30	Lenawee	460247	41.8339	-84.2575	3	12		
Lake Macatawa	40	Ottawa	700238	42.7910	-86.1201	4	13	4	
Mona Lake	40	Muskegon	610226	43.1736	-86.2808	11	10	22	10
Morrison Lake	30	Ionia/Barry	340182	42.8667	-85.2056	6	24		
					Totals:	36	95	39	10

HPLC-MS

Quantitative analysis of 8 algal toxins (Table 3) was conducted using HPLC-MS by the Wisconsin State Laboratory of Hygiene. Total microcystin was calculated as the sum of the concentrations of 4 microcystin congeners (LR, YR, RR, and LA). Minimum and maximum algal toxin concentrations per lake are presented in Table 7. Microsystin LR, microcystin RR, and anatoxin-a were the most commonly quantified toxins. Each of the 8 algal toxins was quantified at least once in the 145 samples.

Seven samples, collected from Hudson, Jordan, and Morrison Lakes, did not have quantifiable concentrations of any toxin. Twenty-eight samples did not have quantifiable levels of any of the 4 microcystin congeners; however, 10 of these had quantifiable levels of deoxycylindrospermopsin, and 13 had quantifiable levels of anatoxin-a.

Table 7. 2015 HPLC-MS algal toxin data summary of 145 inland lake samples. All data are presented in µg/L. The minimum for each parameter is not quantified (NQ); the lowest quantified value is presented in the minimum row in parentheses. Total microcystin (MC) is a sum of the 4 microcystin congeners (LR, YR, RR, and LA). For reference, various health guidelines for drinking water and recreational water use are included in the bottom portion of the table. These data were collected from the following USEPA Web sites: *(The link provided was broken and has been removed)* and https://www.epa.gov/sites/default/files/2017-06/documents/microcystins-report-2015.pdf.

	Total MC (LR, YR, RR, LA)	MC LR	MC YR	MC RR	MC LA	Cylindro-spermopsin	Deoxycylindro-spermopsin	Anatoxin-a	Homo-anatoxin-a
Targeted MI Lakes 2015 Minimum	***NQ (0.025)***	**NQ (0.013)**	**NQ (0.0048)**	**NQ (0.047)**	**NQ (1.78)**	**NQ (0.01)**	**NQ (0.04)**	**NQ (0.003)**	**NQ (0.035)**
Targeted MI Lakes 2015 Maximum	***193.01***	**64.4**	**13.4**	**113**	**2.43**	**0.036**	**0.098**	**3.08**	**0.069**
Number of quantified results	**125**	**89**	**54**	**96**	**3**	**2**	**17**	**75**	**24**
Algal Toxin Health Guidelines									
Drinking Water - Do not drink (OH)	1	na	na	na	na	1	na	20	na
Drinking Water - EPA (age <6, >6)	0.3 \ 1.6	na	na	na	na	na	na	na	na
Drinking Water (MN)	na	0.04	na	na	na	na	na	na	na
Drinking Water - WHO	na	1	na	na	na	na	na	na	na
Recreational Use - WHO	na	20	na	na	na	na	na	na	na
Recreational Use - IL	na	10	na	na	na	na	na	na	na
Recreational Use - OH (Health Advisory\No Contact)	6 \ 20	na	na	na	na	5 \ 20	na	80 \ 300	na
Recreational Use - VT	na	6	na	na	na	na	na	10	na
Recreational Use - OR	10	na	na	na	na	6	na	20	na
Recreational Use - CA	0.8	na	na	na	na	4	na	90	na

The 2 samples with quantifiable concentration of cylindrospermopsin also had higher concentrations of microcystin LR, RR, and LA. All 3 samples with quantifiable concentrations of microcystin LA had higher concentrations of total microcystin (9.4, 29.6, and 193 µg/L). Based on these limited data, it appears that these toxins may only be present when algal toxin production is higher.

The concentrations of the cylindrospermopsins and anatoxins were all low compared to all available drinking and recreational health values (Table 7). Only 3 samples had total microcystin concentrations greater than the WHO provisional recreation microcystin LR guidance value of 20 µg/L. All of these samples were collected in Mona Lake (Figure 2).

The total concentrations of the 4 microcystin toxins are presented in Figure 2. The concentrations in Jordan, Morrison, Macatawa, Ford, and Hudson Lakes were all less than 2 µg/L. Concentrations of total microcystin in Crockery Lake were all less than 4 µg/L. All of the samples collected in Mona Lake had quantifiable concentrations of total microcystin and only 2 samples did not have concentrations of anatoxin-a. Although total microcystin was consistently present in Mona Lake, the concentrations were not consistently high; 14 samples out of 47 (30%) exceeded 4.0 µg/L, 6 samples (13%) exceeded 10 µg/L, and only 3 (6%) exceeded 20 µg/L.

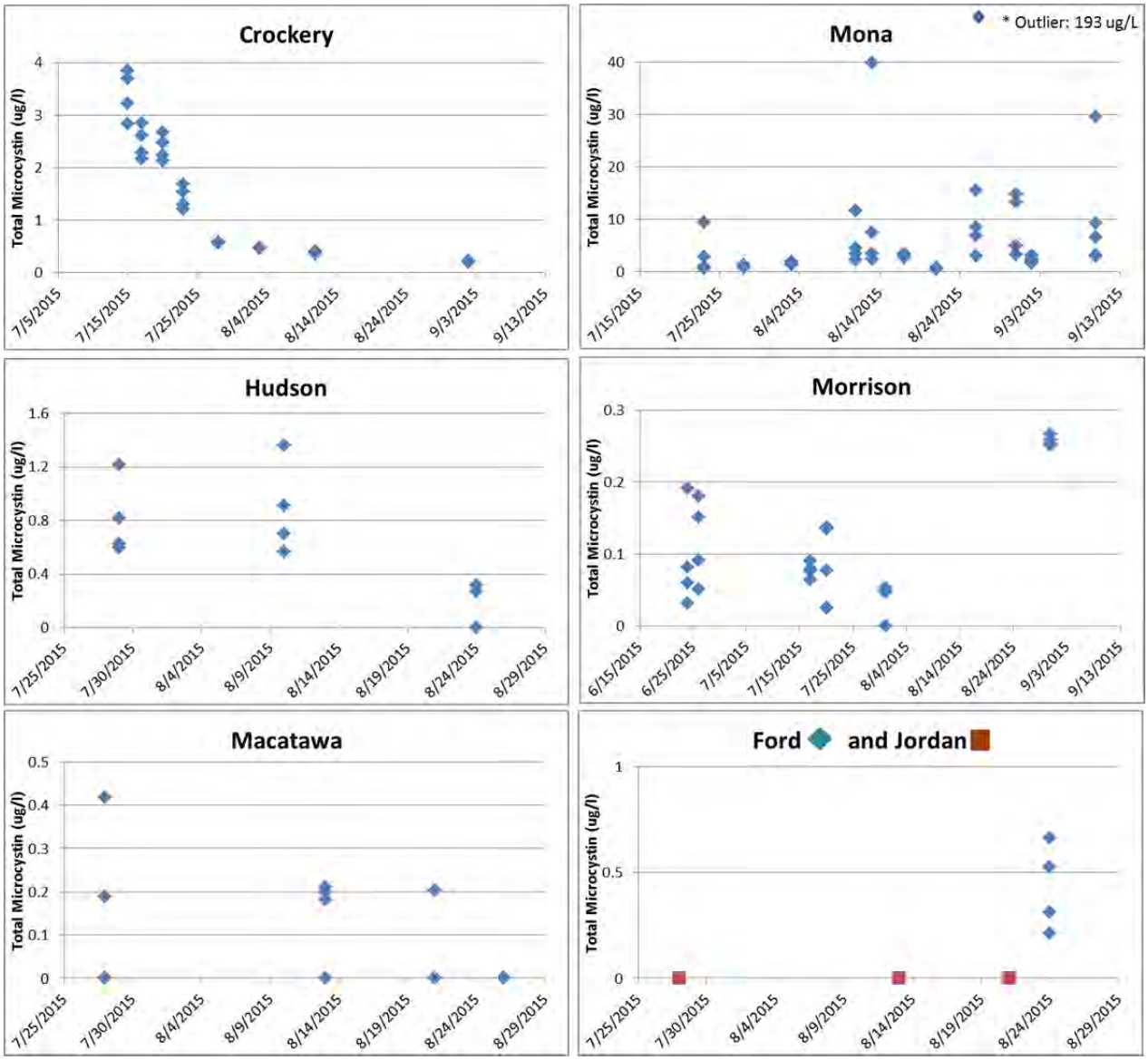

Figure 2. Calculated total microcystin concentrations (total of microcystin LA, LR, RR, and YR concentrations) from 7 targeted lakes. Note: Concentration scale varies on each graph.

Comparisons

HPLC-MS vs Abraxis Test Strips

The test strip data are presented in Table 6 as binned concentrations; non-detect (assumed to be less than 1 µg/L), detectable but less than 10 µg/L, and greater than 10 µg/L. Using the Abraxis test strips, it is possible to estimate a value between 1 and 10, but there is a good amount of user interpretation required. Generally, the MDEQ-WRD will use the categorical data for assessing microcystin concentrations, but we did also estimate a specific value within the 1 to 10 µg/L range and are using those estimates in this comparison analysis.

The total microcystin results using Abraxis test strips and HPLC-MS are moderately correlated (Figure 3) when using the samples with HPLC-MS results less than 10 µg/L (R^2 of 0.6). Because the resolution of the test strip ends at 10 µg/L, including the test results with

microcystin concentrations greater than 10 µg/L, the R^2 value is reduced to 0.45 when the 5 HPLC-MS samples between 11 and 40 µg/L are included.

Overall, the data show that the test strips do not always accurately detect very low concentrations of microcystin, between approximately 4 and 9 µg/L, the test strips appear to overestimate the concentration of microcystin, and the test strips accurately characterized the sites with HPLC-MS concentrations greater than 10 µg/L in 6 of 10 samples. The 10 Abraxis test strips that showed microcystin concentrations of 10 µg/L or greater had corresponding HPLC-MS results ranging from 5 to 193 µg/L, 4 of which were less than 10 µg/L and 6 were greater than 10 µg/L.

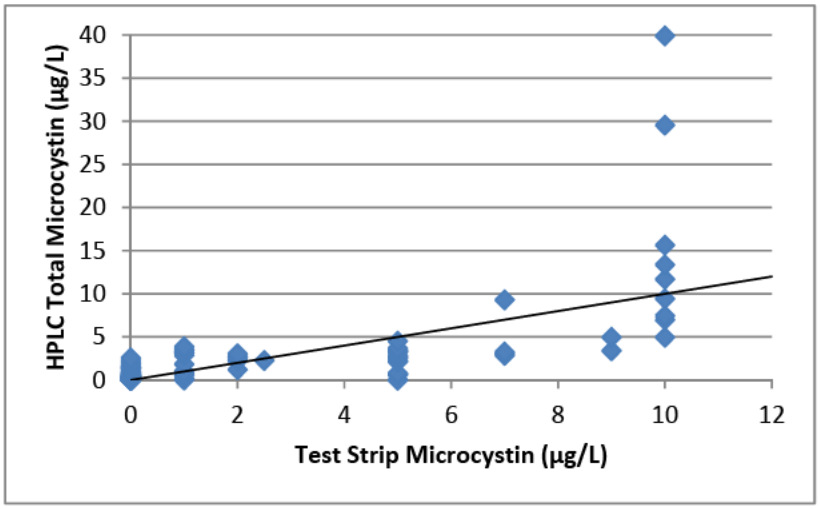

Figure 3. Abraxis test strip microcystin results compared to HPLC-MS microcystin results. Line is the 1:1 line.

HPLC vs water chemistry

A variety of standard water chemistry parameters were collected on most sampling trips, but not all. Generally, these parameters were only collected at 1 station, usually the center of the lake. To examine the relationship between water chemistry components and microcystin concentrations, the average microcystin concentration on a date (across 4 samples) was compared to total phosphorus, ortho-phosphorus, total nitrogen, chlorophyll *a*, and secchi depth.

Table 8. The correlation coefficients (r) of the average total microcystin concentration (across 4 samples) and water chemistry data. Total nitrogen was calculated as the sum of Kjeldahl nitrogen and ammonia.

	All Lakes (n=33)	*Mona Lake (n=11)*	*Crockery Lake (n=6)*
Average of Total Phosphorus	0.07	0.65	0.96
Average of Ortho-Phosphorus	0.007	0.26	0.92
Average of Chlorophyll *a*	0.11	0.74	0.76
Average of Total Nitrogen	-0.14	0.74	0.98
Average of Secchi	-0.14	-0.40	-0.76

When using data from all of the lakes, there are no strong correlations between water chemistry and microcystin levels. Looking at Mona and Crockery Lakes independently, the 2 lakes that had more than 5 sample events and higher concentrations of microcystin, there are some stronger correlations between water chemistry and microcystin concentration (Table 8 and Figure 4). Mona Lake shows some positive correlations with total phosphorus, chlorophyll a,

and total nitrogen. Crockery Lake has strong positive correlations with total phosphorus, ortho-phosphorus, chlorophyll a, total nitrogen, and secchi depth.

The correlations in Mona Lake are driven by the heavy weight of the 1 high microcystin concentration >50 µg/L. The high concentration of microcystin occurred when there were also high concentrations of phosphorus, chlorophyll *a*, and nitrogen and shallow secchi depth, but the overall data are not as strongly correlated absent 1 high data point.

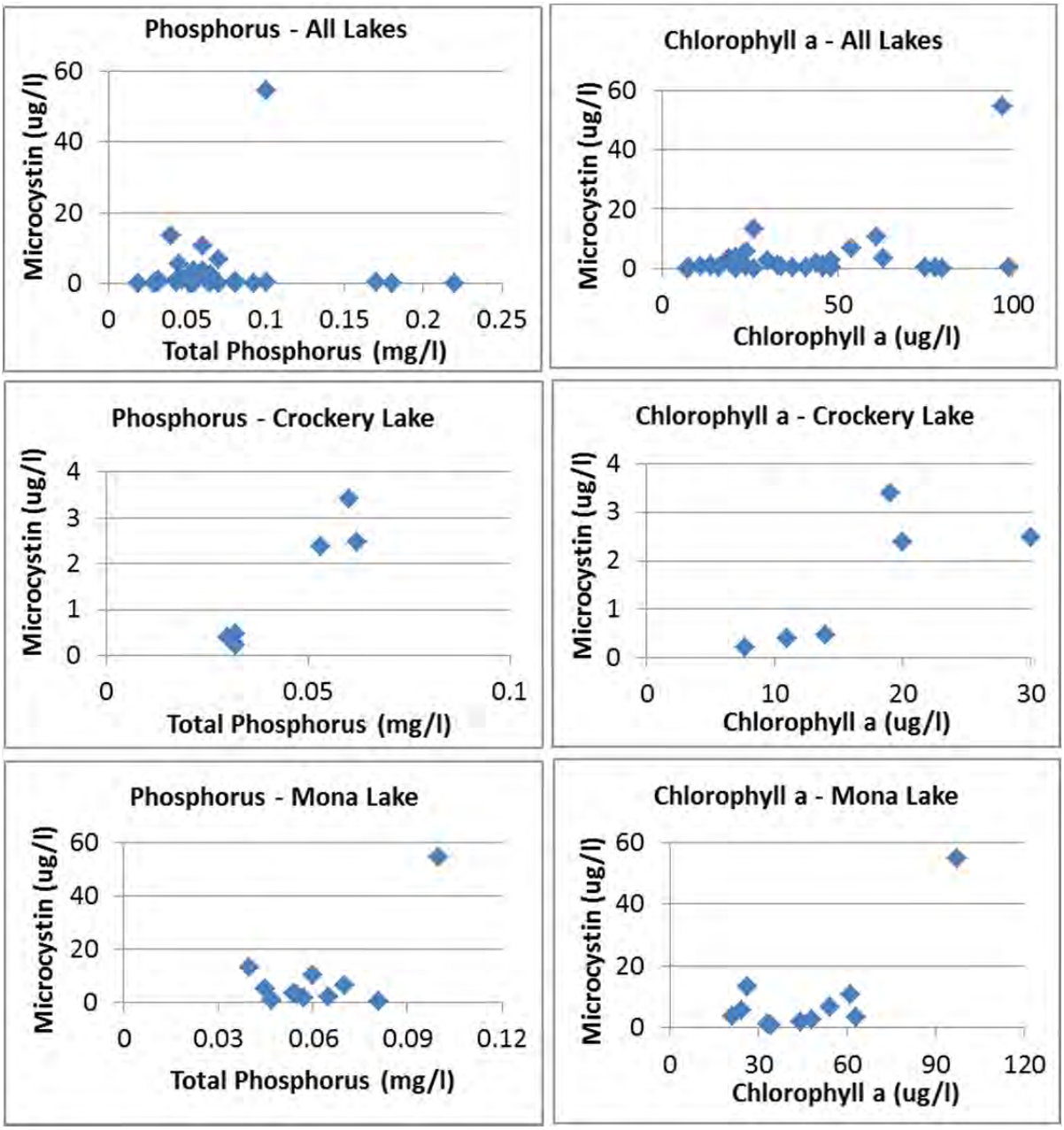

Figure 4(a). Total phosphorus (mg/L) and chlorophyll *a* vs average microcystin (µg/L) concentrations. Each data point is 1 sample date. The top graphs present the data for all lakes, followed by the data for Crockery and Mona Lakes. NOTE: One outlier chlorophyll a data point (Morrison Lake: 350 µg/L chlorophyll *a* and 0.26 µg/L total microcystin) was removed from the all lakes graph.

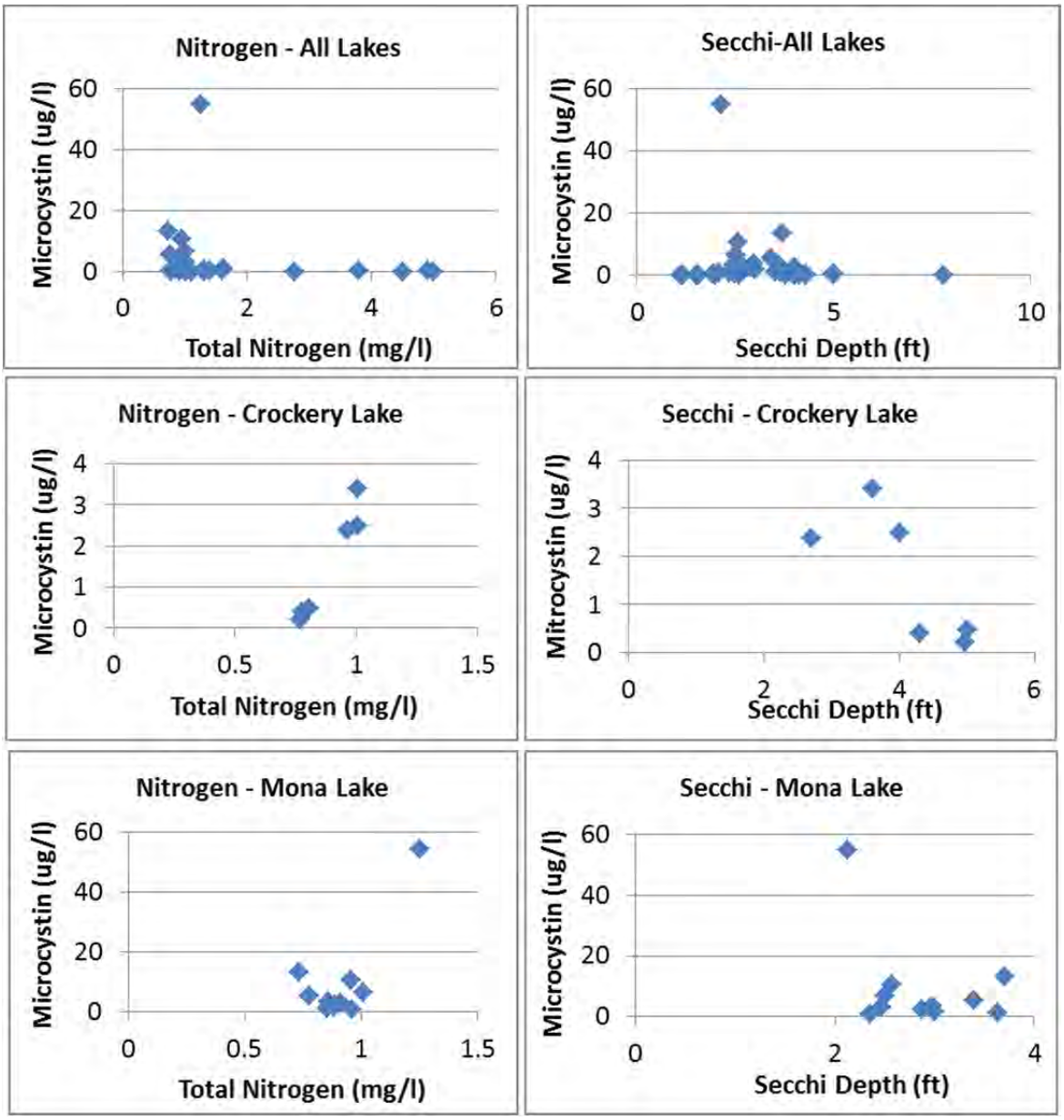

Figure 4(b). Total nitrogen (mg/L) and secchi depth (feet) vs average microcystin (µg/L) concentrations. Each data point is 1 sample date. The top graphs present the data for all lakes, followed by the data for Crockery and Mona Lakes.

Conditions in Crockery Lake changed in late July (Figure 2). In mid-July, the lake had a heavy algal bloom with microcystin concentrations between 2.0 and 4.0 µg/L and associated higher concentrations of phosphorus, nitrogen, and chlorophyll *a*, and shallower Secchi depths. All of the samples collected from late July through early September had microcystin concentrations in the 0 to 1 range, with associated lower concentrations in nutrients, chlorophyll *a*, and greater Secchi depths. The reduction in algae and algal toxins in Crockery Lake may have been caused by weather events or lake management treatments or a combination of several factors. The lake was treated with herbicides on 5 dates, including July 21 and August 4 to reduce algal growth. It is not clear if a single factor caused the apparent reduction in algal biomass from the data collected in the study.

Shoreline versus center toxin samples

Algal toxin concentrations have the potential to be greater along the shoreline than the center of a lake (Sarnelle and Wandell, 2008). Elevated toxin shoreline concentrations may be occur when algal scums accumulate along the shoreline, or in bays or canals, due to wind and lake water movement. The lakes sampled for targeted monitoring in 2015 had higher nutrient concentrations and more algae (as seen through higher chlororphyll *a* concentrations) than the lakes in Sarnelle and Wandell (2008). Although the 8 highest total microcystin samples in 2015 were collected from shoreline samples, there was not a statistically significant difference in the medians of the shoreline versus the lake center microcystin samples (Mann Whitney U test P value 0.39). Because algae was present at higher concentrations and more distributed in the water column in the 2015 targeted lakes, as compared to the Cooperative Lakes Monitoring Program lakes, there may have been more homogeneous toxin concentrations than in less productive lakes. Heiskary et al. (2014) also found that there was no meaningful difference between center and shoreline microcystin concentration in the 2007 and 2012 Minnesota NLA lakes.

DISCUSSION

Monitoring data collected in 2015 from Michigan inland lakes with known histories of algal blooms, found microcystin concentrations (assessed using HPLC-MS) only exceeded the WHO recreation target of 20 µg/L in 3 out of 145 samples. Anatoxin concentrations were all less than 3.1 µg/L and cylindrospermopsin concentrations were all less than 0.1 µg/L, both well below any associated guidelines (Table 7).

Microcystin concentrations, when present in the targeted lakes, did not show consistent patterns over the summer (Figure 2). Several lakes had consistently low or no levels of microcystin, including the Ford, Macatawa, Hudson, and Jordan Lakes. Mona Lake had the highest concentrations of microcystin, but also had high variability at different locations on a given date and across sample dates. Crockery Lake microcystin concentrations were more consistent across sites and showed a decrease over the course of the summer, possibly due to algaecide treatments or weather events.

Across the targeted lakes, there was no broad relationship between water chemistry parameters and microcystin concentrations. However, in Crockery Lake when the microcystin concentrations decreased, there was a corresponding decrease in nutrients and chlorophyll *a* and an increase in Secchi depth. These data indicate there likely was not only a reduction in toxin production within algal cells, but that the amount of algae suspended in the water column decreased.

Using HPLC-MS analysis for algal toxins is advantageous for generating precise quantitative data for many algal toxins. However, the cost and time lag between sample collection and results can be a drawback when you need the results to inform recreation risks in a lake or to make decisions on continued monitoring. The Abraxis test strips used in this study did not consistently detect low concentrations of microsystin and overestimated microcystin in samples at concentrations greater than 4 µg/L of total microcystin, which makes them a conservative screening tool. One potential drawback to using test strips that detect only 1 algal toxin is that it may suggest no health risks for using a body of water after a low or negative result for microcystin, but does not account for other toxins such as anatoxin. In Minnesota, in 2015, there were dog illnesses, dog deaths, and human illness associated with HABs, but follow-up

water chemistry did not always confirm high microcystin concentrations and in 1 dog death anatoxin was found to be the likely cause (Heiskary, 2016).

Michigan, like other states in the upper midwestern United States, has found that algal toxins are produced in inland lakes at variable concentrations (Graham et al., 2004; Graham and Loftin, 2014). In Minnesota, microcystin monitoring in 2004-2007 showed that 80% of the 133 samples were less than 10 µg/L (Linden and Heiskary, 2009), while Wisconsin found that approximately 70% of 43 samples collected from targeted lakes in 2009-2013 were less than 10 µg/L (LaLiberte, 2014). The data collected in 2015, from 22 Status and Trend and 7 targeted lakes, lend support to previous studies (Sarnelle et al., 2010) that found that Michigan inland lakes do not regularly have high concentrations of toxins, although unpredictable and rare occurrences of high concentrations have been, and will be, detected in Michigan lakes.

MDEQ monitoring in 2016 will include sampling lakes with expected, or reported, large algal blooms to further understand the magnitude of toxin levels and how toxins vary throughout and across summers. Microcystin monitoring will continue in randomly selected Status and Trend Program lakes to provide more data on statewide HAB conditions. In 2016, phycocyanin monitoring and dominant algal species identification will provide more information on algae bloom composition. To date, monitoring in Michigan does not indicate that algal toxins are a wide-spread problem in Michigan's inland lakes. However, at any point in time a localized problem can occur and it is warranted to recommend that people limit exposure of themselves, children, pets, livestock, and irrigated crops to water that is very green or very hard to see through because of the risk of algal toxins.

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Appendix 1. 2015 data from targeted lake monitoring of inland lakes. -- indicates no sample was taken. ND indicates the sample result was less than the analytical reporting level.

Lake	Location	Latitued	Longitude	Date	Abraxis Test Strip Estimate of Microcystin (µg/L)	Total Phosphorus (mg/L)	Ortho-phoshporus (mg/L)	Chlorophyll a (µg/L)	Kjehldahl Nitrogen (mg/L)	Nitrite and Nitrate (mg/L)	Total Nitrogen-calculated (mg/L)	Ammonia (mg/L)	Surface Temp (F)	Secchi (ft)	Total Microcystin-calculated (µg/L)	Microcystin-LR (µg/L)	Microcystin-YR (µg/L)	Microcystin-RR (µg/L)	Microcystin-LA (µg/L)	Deoxycylindrosper mopsin (µg/L)	Cylindrospermopsin (µg/L)	Anatoxin (µg/L)	homoana A (µg/L)
Crockery	Center	43.1654	-85.8572	7/15/2015	5	0.06	0 017	19	1	0.007	1.007	0.02	75 6	3.6	2.830	1.100	ND	1.730	ND	ND	ND	0.189	ND
Crockery	Shore	43.1717	-85.8453	7/15/2015	1	--	--	--	--	--	--	--	--	--	3.850	1.540	ND	2.310	ND	ND	ND	0.061	ND
Crockery	Shore	43.1686	-85.8488	7/15/2015	5	--	--	--	--	--	--	--	--	--	3.700	1.600	ND	2.100	ND	ND	ND	0.021	ND
Crockery	Shore	43.1639	-85.8585	7/15/2015	5	--	--	--	--	--	--	--	--	--	3.230	1.320	ND	1.910	ND	ND	ND	0.022	ND
Crockery	Center	43.1656	-85.8576	7/17/2015	2	0.062	0.01	30	1	0.006	1.006	0 009	74.96	4	2.610	1.130	ND	1.480	ND	ND	ND	0.139	ND
Crockery	Shore	43.1719	-85.8451	7/17/2015	5	--	--	--	--	--	--	--	--	--	2.170	0.920	ND	1.250	ND	ND	ND	0.046	ND
Crockery	Shore	43.1699	-85.8475	7/17/2015	0	--	--	--	--	--	--	--	--	--	2.287	0.807	ND	1.480	ND	ND	ND	0.079	ND
Crockery	Shore	43.1637	-85.8583	7/17/2015	1	--	--	--	--	--	--	--	--	--	2.850	1.070	ND	1.780	ND	ND	ND	0.070	ND
Crockery	Center	43.1657	-85.8573	7/20/2015	2	0.053	0.009	20	0.96	0.005	0.965	0.01	77.4	2.7	2.244	0.824	ND	1.420	ND	ND	ND	0.023	ND
Crockery	Shore	43.1719	-85.8450	7/20/2015	5	--	--	--	--	--	--	--	--	--	2.133	0.893	ND	1.240	ND	ND	ND	0.117	ND
Crockery	Shore	43.1686	-85.8488	7/20/2015	5	--	--	--	--	--	--	--	--	--	2.480	1.040	ND	1.440	ND	ND	ND	0.056	ND
Crockery	Shore	43.1638	-85.8583	7/20/2015	5	--	--	--	--	--	--	--	--	--	2.670	1.140	ND	1.530	ND	ND	ND	ND	ND
Crockery	Center	43.1655	-85.8570	7/23/2015	0	na	na	26	na	na	na	na	78.15	2.4	--	--	--	--	--	--	--	--	--
Crockery	Shore	43.1719	-85.8448	7/23/2015	0	--	--	--	--	--	--	--	--	--	1.306	0.520	ND	0.786	ND	ND	ND	ND	ND
Crockery	Shore	43.1719	-85.8458	7/23/2015	0	--	--	--	--	--	--	--	--	--	1.693	0.515	0.194	0.984	ND	ND	ND	ND	ND
Crockery	Shore	43.1677	-85.8488	7/23/2015	0	--	--	--	--	--	--	--	--	--	1.537	0.554	0.271	0.712	ND	ND	ND	ND	ND
Crockery	Shore	43.1639	-85.8585	7/23/2015	2	--	--	--	--	--	--	--	--	--	1.212	0.341	0.286	0.585	ND	ND	ND	ND	ND
Crockery	Center	43.1659	-85.8569	7/28/2015	0	na	na	19	na	na	na	na	81	1.7	0.573	0.262	ND	0.311	ND	ND	ND	ND	ND
Crockery	Shore	43.1716	-85.8450	7/28/2015	0	--	--	--	--	--	--	--	--	--	0.579	0.266	ND	0.313	ND	ND	ND	ND	ND
Crockery	Shore	43.1719	-85.8468	7/28/2015	1	--	--	--	--	--	--	--	--	--	0.577	0.263	ND	0.314	ND	ND	ND	ND	ND
Crockery	Shore	43.1707	-85.8513	7/28/2015	0	--	--	--	--	--	--	--	--	--	0.587	0.290	ND	0.297	ND	ND	ND	ND	ND
Crockery	Center	43.1654	-85.8572	8/3/2015	0	0.032	0 007	14	0 8	ND	0.805	0 005	77	5	0.464	0.209	ND	0.255	ND	ND	ND	ND	ND
Crockery	Shore	43.1719	-85.8450	8/3/2015	0	--	--	--	--	--	--	--	--	--	0.474	0.203	ND	0.271	ND	ND	ND	ND	ND
Crockery	Shore	43.1677	-85.8488	8/3/2015	0	--	--	--	--	--	--	--	--	--	0.488	0.238	ND	0.250	ND	ND	ND	ND	ND
Crockery	Shore	43.1642	-85.8589	8/3/2015	0	--	--	--	--	--	--	--	--	--	0.473	0.227	ND	0.246	ND	ND	ND	ND	ND
Crockery	Center	43.1652	-85.8574	8/11/2015	0	0.03	0.004	11	0.76	0 006	0.78	0.02	76	6	0.402	0.188	ND	0.214	ND	ND	ND	ND	ND
Crockery	Shore	43.1719	-85.8449	8/11/2015	0	--	--	--	--	--	--	--	--	3.5	0.401	0.183	ND	0.218	ND	ND	ND	ND	ND
Crockery	Shore	43.1676	-85.8488	8/11/2015	0	--	--	--	--	--	--	--	--	3.4	0.404	0.189	ND	0.215	ND	ND	ND	ND	0 060
Crockery	Shore	43.1638	-85.8586	8/11/2015	0	--	--	--	--	--	--	--	--	--	0.369	0.177	ND	0.192	ND	ND	ND	ND	0 050
Crockery	Center	43.1650	-85.8576	9/2/2015	0	0.032	0.004	7.7	0.76	0 005	0.769	0 009	74	6.1	0.236	ND	ND	0.236	ND	ND	ND	ND	ND
Crockery	Shore	43.1686	-85.8489	9/2/2015	0	--	--	--	--	--	--	--	--	4.1	0.203	ND	ND	0.203	ND	ND	ND	ND	ND
Crockery	Shore	43.1719	-85.8452	9/2/2015	0	--	--	--	--	--	--	--	--	4.7	0.212	ND	ND	0.212	ND	ND	ND	ND	0 069
Crockery	Shore	43.1638	-85.8585	9/2/2015	0	--	--	--	--	--	--	--	--	--	0.201	ND	ND	0.201	ND	ND	ND	ND	ND
Ford	Center	42.2071	-83.5701	8/24/2015	0	0.051	0.011	24	0.82	0.27	0.92	0.1	77	4.8	0.311	ND	ND	0.311	ND	ND	ND	ND	0 064
Ford	Shore	42.2208	-83.5732	8/24/2015	0	--	--	--	--	--	--	--	--	3.5	0.526	0.082	ND	0.444	ND	ND	ND	ND	0 067
Ford	Shore	42.2237	-83.5977	8/24/2015	0	--	--	--	--	--	--	--	--	3.2	0.212	ND	ND	0.212	ND	ND	ND	ND	ND
Ford	Shore	42.2136	-83.5940	8/24/2015	0	--	--	--	--	--	--	--	--	3.7	0.665	0.230	ND	0.435	ND	ND	ND	ND	ND
Hudson	Center	41.8288	-84.2603	7/29/2015	0	0.032	0.006	14	1 3	0.45	1.31	0.01	83.7	2	0.624	0.323	ND	0.301	ND	ND	ND	ND	ND
Hudson	Shore	41.8326	-84.2504	7/29/2015	0	--	--	--	--	--	--	--	--	2.2	0.598	0.306	ND	0.292	ND	ND	ND	ND	ND
Hudson	Shore	41.8325	-84.2650	7/29/2015	0	--	--	--	--	--	--	--	--	2	1.219	0.449	0.369	0.401	ND	ND	ND	ND	ND
Hudson	Shore	41.8295	-84.2772	7/29/2015	0	--	--	--	--	--	--	--	--	--	0.820	0.329	0.222	0.269	ND	ND	ND	ND	ND
Hudson	Center	41.8283	-84.2582	8/10/2015	0	0.043	0 01	46	1 6	0 003	1.62	0.02	77	2.6	0.914	0.368	0.215	0.331	ND	ND	ND	ND	ND
Hudson	Shore	41.8300	-84.2775	8/10/2015	0	--	--	--	--	--	--	--	--	3.3	1.362	0.598	0.348	0.416	ND	ND	ND	ND	ND
Hudson	Shore	41.8328	-84.2500	8/10/2015	0	--	--	--	--	--	--	--	--	5.7	0.570	0.283	ND	0.287	ND	ND	ND	0.064	ND
Hudson	Shore	41.8315	-84.2562	8/10/2015	0	--	--	--	--	--	--	--	--	2.5	0.701	0.326	ND	0.375	ND	ND	ND	ND	0 043
Hudson	Center	41.8292	-84.2612	8/24/2015	0	0.043	0.01	46	1.4	nd	1.4	0.05	75	2.3	0.272	ND	ND	0.272	ND	ND	ND	0.382	ND
Hudson	Shore	41.8325	-84.2503	8/24/2015	0	--	--	--	--	--	--	--	--	1.9	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hudson	Shore	41.8328	-84.2650	8/24/2015	0	--	--	--	--	--	--	--	--	2.2	0.315	ND	ND	0.315	ND	ND	ND	0.274	ND
Hudson	Shore	41.8277	-84.2698	8/24/2015	0	--	--	--	--	--	--	--	--	1.4	0.316	0.013	ND	0.303	ND	ND	ND	0.312	ND
Jordan	Center	42.7685	-85.1436	6/24/2015	0	0.029	0 003	21	0.76	2	2.76	0.02	74 6	5.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Jordan	Shore	42.7683	-85.1338	6/24/2015	0	--	--	--	--	--	--	--	--	4	ND	ND	ND	ND	ND	ND	ND	0.404	ND
Jordan	Shore	42.7770	-85.1275	6/24/2015	0	--	--	--	--	--	--	--	--	3	ND	ND	ND	ND	ND	ND	ND	0.048	ND
Jordan	Shore	42.7659	-85.1420	6/24/2015	0	--	--	--	--	--	--	--	--	4	ND	ND	ND	ND	ND	ND	ND	0.025	ND
Jordan	Center	42.7687	-85.1418	7/31/2015	0	0.019	0 003	7.1	0.75	1.6	0.78	0.03	79.65	7.8	ND	ND	ND	ND	ND	ND	ND	ND	ND
Jordan	Shore	42.7685	-85.1331	7/31/2015	0	--	--	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND	ND	ND	ND

Appendix 1. 2015 data from targeted lake monitoring of inland lakes. -- indicates no sample was taken. ND indicates the sample result was less than the analytical reporting level.

Lake	Location	Latitued	Longitude	Date	Abraxis Test Strip Estimate of Microcystin (µg/L)	Total Phosphorus (mg/L)	Ortho-phoshporus (mg/L)	Chlorophyll a (µg/L)	Kjehldahl Nitrogen (mg/L)	Nitrite and Nitrate (mg/L)	Total Nitrogen-calculated (mg/L)	Ammonia (mg/L)	Surface Temp (F)	Secchi (ft)	Total Microcystin-calculated (µg/L)	Microcystin-LR (µg/L)	Microcystin-YR (µg/L)	Microcystin-RR (µg/L)	Microcystin-LA (µg/L)	Deoxycylindrosper mopsin (µg/L)	Cylindrospermopsin (µg/L)	Anatoxin (µg/L)	homoana A (µg/L)
Jordan	Shore	42.7757	-85.1262	7/31/2015	0	--	--	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
Jordan	Shore	42.7702	-85.1477	7/31/2015	0	--	--	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
Jordan	Center	42.7689	-85.1423	8/31/2015	0	0.07	0.006	26	1 3	0.73	1.305	0 005	71	4.1	ND	ND	ND	ND	ND	0.060	ND	ND	ND
Jordan	Shore	42.7689	-85.1357	8/31/2015	0	--	--	--	--	--	--	--	--	--	3.2	ND	ND	ND	ND	0.058	ND	ND	ND
Jordan	Shore	42.7760	-85.1333	8/31/2015	0	--	--	--	--	--	--	--	--	3.9	ND	ND	ND	ND	ND	0.064	ND	ND	ND
Jordan	Shore	42.7701	-85.1474	8/31/2015	0	--	--	--	--	--	--	--	--	3.9	ND	ND	ND	ND	ND	0.056	ND	ND	ND
Macatawa	Center	42.7874	-86.1820	7/28/2015	0	0.092	0.009	41	2 6	1.2	3 8	1.1		2	0.419	0.236	ND	0.183	ND	0.071	ND	1.460	ND
Macatawa	Shore	42.7755	-86.1823	7/28/2015	0	--	--	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
Macatawa	Shore	42.7789	-86.1524	7/28/2015	0	--	--	--	--	--	--	--	--	--	0.188	0.188	ND	ND	ND	ND	ND	0.987	ND
Macatawa	Shore	42.7873	-86.1473	7/28/2015	0	--	--	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND	ND	0.518	ND
Macatawa	s4	42.7962	-86.1186	7/28/2015	0	--	--	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND	ND	0.423	ND
Macatawa	Center	42.7915	-86.1190	8/13/2015	0	0.17	0.022	99	3.4	0.71	4 9	1.5	77 5	1.4	0.200	0.200	ND	ND	ND	0.092	ND	ND	0 044
Macatawa	Shore	42.7952	-86.1440	8/13/2015	1	--	--	--	--	--	--	--	--	1.7	ND	ND	ND	ND	ND	ND	ND	0.193	ND
Macatawa	Shore	42.7807	-86.1568	8/13/2015	1	--	--	--	--	--	--	--	--	1.6	0.182	0.182	ND	ND	ND	0.077	ND	0.244	ND
Macatawa	Shore	42.7962	-86.1180	8/13/2015	0	--	--	--	--	--	--	--	--	--	0.211	0.211	ND	ND	ND	0.096	ND	0.120	ND
Macatawa	Center	42.7939	-86.1163	8/21/2015	0	0.18	0.059	48	3.1	0.82	4 5	1.4	76 2	1.2	ND	ND	ND	ND	ND	ND	ND	0.288	ND
Macatawa	Shore	42.7962	-86.1182	8/21/2015	0	--	--	--	--	--	--	--	--	1	0.203	ND	ND	0.203	ND	0.064	ND	0.273	ND
Macatawa	Shore	42.7952	-86.1452	8/21/2015	5	--	--	--	--	--	--	--	--	1	ND	ND	ND	ND	ND	0.058	ND	0.440	ND
Macatawa	Shore	42.7830	-86.1684	8/21/2015	5	--	--	--	--	--	--	--	--	1.2	ND	ND	ND	ND	ND	0.057	ND	0.603	ND
Macatawa	Center	42.7909	-86.1200	8/26/2015	0	0.22	0.049	80	3 6	0.63	5	1.4	71	1.1	ND	ND	ND	ND	ND	0.062	ND	0.419	ND
Macatawa	Shore	42.7954	-86.1264	8/26/2015	0	--	--	--	--	--	--	--	--	1.2	ND	ND	ND	ND	ND	0.080	ND	0.235	ND
Macatawa	Shore	42.7945	-86.1444	8/26/2015	0	--	--	--	--	--	--	--	--	1	ND	ND	ND	ND	ND	0.075	ND	0.406	ND
Macatawa	Shore	42.7827	-86.1683	8/26/2015	0	--	--	--	--	--	--	--	--	1.3	ND	ND	ND	ND	ND	0.075	ND	0.441	ND
Mona	Center	43.1734	-86.2787	7/23/2015	0	0.054	0.007	21	0.85	0.006	0.856	0 007	76 8	3.4	0.683	0.339	ND	0.344	ND	ND	ND	1.220	0 043
Mona	Shore	43.1854	-86.2458	7/23/2015	0	--	--	--	--	--	--	--	--	3	0.955	0.497	ND	0.458	ND	ND	ND	ND	0 041
Mona	Shore	43.1828	-86.2320	7/23/2015	10	--	--	--	--	--	--	--	--	3	9.418	4.430	0.458	2.100	2.430	ND	ND	1.480	ND
Mona	Shore	43.1863	-86.2364	7/23/2015	7	--	--	--	--	--	--	--	--	2.5	2.860	1.680	ND	1.180	ND	ND	ND	1.710	0 044
Mona	Center	43.1790	-86.2602	7/28/2015	0	0.047	0.007	33	0.85	ND	0.854	0 004	81	4	1.479	0.556	0.373	0.550	ND	ND	ND	2.680	0 035
Mona	Shore	43.1760	-86.2474	7/28/2015	0	--	--	--	--	--	--	--	--	--	0.853	0.436	ND	0.417	ND	ND	ND	2.170	0 045
Mona	Shore	43.1848	-86.2477	7/28/2015	0	--	--	--	--	--	--	--	--	4	0.931	0.484	ND	0.447	ND	ND	ND	2.320	0 047
Mona	Shore	43.1809	-86.2478	7/28/2015	1	--	--	--	--	--	--	--	--	2.9	1.015	0.523	ND	0.492	ND	ND	ND	0.824	0 043
Mona	Center	43.1762	-86.2465	8/3/2015	0	0.057	0 01	44	0.88	ND	0.88	0 005	76	3	1.435	0.753	ND	0.682	ND	ND	ND	ND	0 039
Mona	Shore	43.1845	-86.2457	8/3/2015	0	--	--	--	--	--	--	--	--	--	1.472	0.660	ND	0.812	ND	ND	ND	ND	0 046
Mona	Shore	43.1829	-86.2320	8/3/2015	0	--	--	--	--	--	--	--	--	--	2.040	1.030	ND	1.010	ND	ND	ND	ND	0 037
Mona	Shore	43.1864	-86.2364	8/3/2015	0	--	--	--	--	--	--	--	--	--	1.915	0.767	0.279	0.869	ND	ND	ND	ND	0 046
Mona	Center	43.1788	-86.2606	8/11/2015	2	0.045	0.006	24	0.77	0 003	0.775	0 005	75	4.5	2.294	0.937	0.317	1.040	ND	ND	ND	ND	ND
Mona	Shore	43.1846	-86.2455	8/11/2015	5	--	--	--	--	--	--	--	--	3.6	3.457	1.410	0.567	1.480	ND	ND	ND	0.025	ND
Mona	Shore	43.1826	-86.2320	8/11/2015	10	--	--	--	--	--	--	--	--	2.1	11 680	5.490	1.260	4.930	ND	ND	ND	0.005	ND
Mona	Shore	43.1864	-86.2363	8/11/2015	5	--	--	--	--	--	--	--	--	--	4.509	2.020	0.669	1.820	ND	ND	ND	0.003	0 041
Mona	Center	43.1788	-85.2585	8/13/2015	na	0.04	0.008	26	0.73	nd	0.73	0 003	75	4.3	2.409	1.070	0.339	1.000	ND	ND	ND	0.030	0 036
Mona	Shore	43.1851	-86.2456	8/13/2015	10	--	--	--	--	--	--	--	--	3.8	7.454	3.530	0.744	3.180	ND	ND	ND	0.064	ND
Mona	Shore	43.1823	-86.2318	8/13/2015	10	--	--	--	--	--	--	--	--	3	39 900	18.900	3.700	17.300	ND	ND	ND	0.048	ND
Mona	Shore	43.1864	-86.2363	8/13/2015	1	--	--	--	--	--	--	--	--	--	3.443	1.520	0.423	1.500	ND	ND	ND	0.074	ND
Mona	Center	43.1760	-86.2469	8/17/2015	5	0.055	0 01	47	0.91	nd	0.91	nd	80	--	3.337	1.430	0.537	1.370	ND	ND	ND	0.849	ND
Mona	Shore	43.1846	-86.2455	8/17/2015	2									2.6	2.744	1.140	0.374	1.230	ND	ND	ND	0.821	0 042
Mona	Shore	43.1827	-86.2320	8/17/2015	1			79						2.4	3.500	1.690	ND	1.810	ND	ND	ND	0.740	0 046
Mona	Shore	43.1863	-86.2361	8/17/2015	1									2.4	3.193	1.460	0.273	1.460	ND	ND	ND	0.689	ND
Mona	Center	43.1788	-86.2601	8/21/2015	5	0.081	0 024	34	0.89	0.002	0.96	0.07	74	2.5	0.578	ND	0.578	ND	ND	ND	ND	1.110	ND
Mona	Shore	43.1762	-86.2456	8/21/2015	1	--	--	--	--	--	--	--	--	1.6	0.765	ND	0.765	ND	ND	ND	ND	1.110	ND
Mona	Shore	43.1820	-86.2317	8/21/2015	5	--	--	--	--	--	--	--	--	3	0.693	ND	0.693	ND	ND	ND	ND	2.340	ND
Mona	Shore	43.1854	-86.2457	8/21/2015	5	--	--	--	--	--	--	--	--	2.3	0.805	ND	0.805	ND	ND	ND	ND	1.550	ND
Mona	Center	43.1765	-86.2454	8/26/2015	10	0.1	0 016	97	1 2	0.007	1.25	0.05	69	2.4	6.982	3.530	0.482	2.970	ND	ND	ND	0.384	ND
Mona	Shore	43.1845	-86.2454	8/26/2015	7	--	--	--	--	--	--	--	--	2.6	3.060	1.630	ND	1.430	ND	ND	ND	0.377	ND
Mona	Shore	43.1829	-86.2320	8/26/2015	10	--	--	--	--	--	--	--	--	1.4	193.010	64.400	13.400	113.000	2 210	0.098	ND	0.363	ND
Mona	Shore	43.1863	-86.2363	8/26/2015	10	--	--	--	--	--	--	--	--	--	15 630	7.590	0.800	7.240	ND	ND	ND	0.410	ND

Appendix 1. 2015 data from targeted lake monitoring of inland lakes. -- indicates no sample was taken. ND indicates the sample result was less than the analytical reporting level.

Lake	Location	Latitued	Longitude	Date	Abraxis Test Strip Estimate of Microcystin (µg/L)	Total Phosphorus (mg/L)	Ortho-phoshporus (mg/L)	Chlorophyll a (µg/L)	Kjehldahl Nitrogen (mg/L)	Nitrite and Nitrate (mg/L)	Total Nitrogen-calculated (mg/L)	Ammonia (mg/L)	Surface Temp (F)	Secchi (ft)	Total Microcystin-calculated (µg/L)	Microcystin-LR (µg/L)	Microcystin-YR (µg/L)	Microcystin-RR (µg/L)	Microcystin-LA (µg/L)	Deoxycylindrosper mopsin (µg/L)	Cylindrospermopsin (µg/L)	Anatoxin (µg/L)	homoana A (µg/L)
Mona	Center	43.1788	-86.2600	8/31/2015	9	0.07	0.009	54	1	0.002	1.008	0 008	72	2.9	3.390	1.880	ND	1.510	ND	ND	ND	0.395	ND
Mona	Shore	43.1850	-86.2459	8/31/2015	10	--	--	--	--	--	--	--	--	2.4	4.959	2.430	0.269	2.260	ND	ND	ND	0.296	0 058
Mona	Shore	43.1761	-86.2464	8/31/2015	9	--	--	--	--	--	--	--	--	2.7	4.945	2.350	0.005	2.590	ND	ND	ND	0.431	ND
Mona	Shore	43.1826	-86.2319	8/31/2015	10	--	--	--	--	--	--	--	--	2	13 370	7.040	1.000	5.330	ND	ND	ND	0.407	ND
Mona	Center	43.1786	-86.2597	9/2/2015	0	0.065	0 009	48	0.88	0.006	0.886	0 006	73	2.9	2.570	1.030	ND	1.540	ND	ND	ND	0.326	ND
Mona	Shore	43.1851	-86.2460	9/2/2015	1	--	--	--	--	--	--	--	--	3.1	1.837	0.837	ND	1.000	ND	ND	ND	0.299	ND
Mona	Shore	43.1761	-86.2457	9/2/2015	2 5	--	--	--	--	--	--	--	--	2.6	2.256	0.846	ND	1.410	ND	ND	ND	0.286	ND
Mona	Shore	43.1827	-86.2319	9/2/2015	7	--	--	--	--	--	--	--	--	2.9	3.240	1.540	ND	1.700	ND	ND	ND	0.822	ND
Mona	Center	43.1762	-86.2461	9/10/2015	1	0.06	0.009	61	0.95	0.004	0.953	0 003	80	2.8	3.200	1.360	ND	1.840	ND	ND	ND	3.080	ND
Mona	Shore	43.1846	-86.2456	9/10/2015	2	--	--	--	--	--	--	--	--	2.5	3.050	1.240	ND	1.810	ND	ND	ND	2.930	ND
Mona	Shore	43.1829	-86.2321	9/10/2015	10	--	--	--	--	--	--	--	--	2.4	29 550	16.000	ND	11.800	1.750	0.042	0 036	2.300	ND
Mona	Shore	43.1863	-86.2364	9/10/2015	--	--	--	--	--	--	--	--	--	--	6.613	2.940	0.403	3.270	ND	ND	ND	2.050	ND
Morrison	Center	42.8651	-85.2012	6/24/2015	0	0.053	0.004	78	1 3	0 003	1.303	0 008	76.94	1.5	0.061	ND	0.061	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8633	-85.1978	6/24/2015	0	--	--	--	--	--	--	--	--	1.5	0.032	ND	0.032	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8664	-85.2089	6/24/2015	0	--	--	--	--	--	--	--	--	1.5	0.192	ND	0.192	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8566	-85.2140	6/24/2015	0	--	--	--	--	--	--	--	--	1.5	0.082	ND	0.082	ND	ND	ND	ND	ND	ND
Morrison	Center	42.8649	-85.2005	6/26/2015	0	na	na	36	na	na	na	na	74 6	3.3	0.151	ND	0.151	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8626	-85.1984	6/26/2015	0	--	--	--	--	--	--	--	--	3.2	0.181	ND	0.181	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8666	-85.2091	6/26/2015	0	--	--	--	--	--	--	--	--	2.3	0.052	ND	0.052	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8596	-85.2240	6/26/2015	0	--	--	--	--	--	--	--	--	2.2	0.092	ND	0.092	ND	ND	ND	ND	ND	ND
Morrison	Center	42.8653	-85.2009	7/17/2015	0	0.054	0 01	16	1	0 017	1.017	0.02	75.07	4.3	0.065	ND	0.065	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8582	-85.2113	7/17/2015	0	--	--	--	--	--	--	--	--	--	0.091	ND	0.091	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8630	-85.2198	7/17/2015	0	--	--	--	--	--	--	--	--	--	0.080	ND	0.080	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8666	-85.2091	7/17/2015	0	--	--	--	--	--	--	--	--	--	0.076	ND	0.076	ND	ND	ND	ND	ND	ND
Morrison	Center	42.8650	-85.2007	7/20/2015	0	0.081	0 014	75	1 3	0.006	1.306	0 009	78.1	2.5	0.135	ND	0.135	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8630	-85.1978	7/20/2015	0	--	--	--	--	--	--	--	--	2.7	0.137	ND	0.137	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8660	-85.2084	7/20/2015	0	--	--	--	--	--	--	--	--	--	0.025	ND	0.025	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8591	-85.2104	7/20/2015	0	--	--	--	--	--	--	--	--	--	0.078	ND	0.078	ND	ND	ND	ND	ND	ND
Morrison	Center	42.8646	-85.2007	7/31/2015	0	0.064	0 006	37	1.1	0.002	1.108	0 008	80.14	4	0.047	ND	ND	0.047	ND	ND	ND	ND	ND
Morrison	Shore	42.8632	-85.1979	7/31/2015	0	--	--	--	--	--	--	--	--	--	0.050	ND	ND	0.050	ND	ND	ND	ND	ND
Morrison	Shore	42.8662	-85.2089	7/31/2015	0	--	--	--	--	--	--	--	--	--	0.054	ND	ND	0.054	ND	ND	ND	ND	ND
Morrison	Shore	42.8594	-85.2240	7/31/2015	0	--	--	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
Morrison	Center	42.8652	-85.2004	8/31/2015	0	0.1	0.013	350	1 6	0.006	1.61	0.01	72	0.9	0.251	ND	0.251	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8603	-85.2212	8/31/2015	0	--	--	--	--	--	--	--	--	4.8	0.253	ND	0.253	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8625	-85.2016	8/31/2015	0	--	--	--	--	--	--	--	--	1.8	0.259	ND	0.259	ND	ND	ND	ND	ND	ND
Morrison	Shore	42.8660	-85.2090	8/31/2015	0	--	--	--	--	--	--	--	--	2.4	0.267	ND	0.267	ND	ND	ND	ND	ND	ND