A Report on the Status and Trends of the Water Quality of The Muskingum Watershed Conservancy District Reservoirs

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CONCLUSIONS

1. To the extent possible, databases pertaining to water quality in the MWCD lakes were combined and their data analyzed and summarized.
2. The average transparencies were similar for many of the lakes; Piedmont was the clearest lake, Charles Mill and Wills Creek were the least transparent.
3. An indirect analysis suggests that the transparency in Wills Creek is largely affected by non-algal particles.
4. Most of the lakes have not exhibited much change in transparency since the early 1990's. However, Leesville Lake has had its transparency halved in that time.
5. All the lakes have detectable levels of blue-green algal toxins, microcystin and cylindrospermopsin. Piedmont and Tappan exhibited levels that should be of concern.
6. Only a few blue-green algal genera dominate the community in the nine lakes, differing only slightly in relative abundance.

RECOMMENDATIONS

Data Management

To date, data management has been centered on aggregating existing data and transforming into compatible formats.

- Do further work on linking the databases in a format that allows ease of data entry and analysis.
- Effort should to be made to locate and standardize the naming of sampling site locations within the reservoirs.

Monitoring

Two types of monitoring are recommended

The first type of monitoring involves keeping track of the general water quality of the reservoirs in a manner complementary to past information gathering.

- Transparency should be monitored by the Lake Keepers on the present schedule.
- Chlorophyll, total nitrogen, and total phosphorus should be monitored at least once a year at the primary site in every lake.
- The possibility of adding analysis of nitrogen forms should be explored.

The second type of monitoring includes two methods of monitoring toxic blue-green algae manners that (1) provide a qualitative early warning of potential algal densities and (2) provide quantitative information for the confirmation of early warning information and discovery of other toxins.

- An early warning protocol would involve Lake Keepers document any surface scums at the swimming beaches

- Explore the use of toxin test strips, which are easier to use and far less expensive than laboratory analysis.

  Laboratory analysis should involve:

- Adding the toxins, anatoxin and saxitoxin to the already-measured microcystin and cylindrospermopsin at least once a year and preferably more often.

  In addition,

- Emphasis should be made on finding the location of high toxin levels within the lakes.
- Omit the identification of the blue-green algae (cyanobacteria).

INTRODUCTION

The Muskingum Watershed Conservancy District (MWCD) has a long history of monitoring the water quality of its reservoirs. Since 1991, a portion of that program has involved volunteers monitoring on behalf of the Ohio Lake Management Society's CLAM (Citizen Lake Awareness and Monitoring) program. This report is an attempt to summarize and analyze the data gathered by these volunteers.

Management of a reservoir that is used for multiple uses is not an easy task. The Ohio Lake Management Society's (OLMS) contribution to the management of the MWCD reservoir system has been to focus on monitoring the effect of nutrients on the growth of microscopic plants (algae) that are the base of the food chain.

The study of the nature and function of lakes is based on a concept that links the surrounding watershed to aspects of water quality in the lake itself.

> The land surrounding a lake (watershed) contributes water, eroded soils, and chemicals to the lake.
>
> Some of the chemicals are plant nutrients, either dissolved in the incoming water or attached to eroded soils.
>
> These nutrients, specifically nitrogen and phosphorus, stimulate the growth of aquatic plants, both algae (mostly microscopic plants suspended in the water) and larger, rooted plants. This plant life, especially the algae, serves as the basis of a food chain ultimately supporting the production of fish.

Figure 1. Toxic blue-green algae, the cyanobacteria, can be a serious public health problem. http://epa.ohio.gov/habalgae.aspx

Excessive nutrients from watersheds dominated by agriculture and urban housing can trigger a number of adverse water quality changes as the abundance of algae and rooted plants increase. Some adverse effects of increased algal growth include the loss of water transparency, noxious algal scums on the water surface, dense growths of larger plants, and decreased abundance of sport fish.

These changes are often accompanied by a shift from beneficial, edible, species of algae to those of the group, Cyanophyta, the blue-green algae (Wikipedia, 2016). Blue-greens are actually a chlorophyll-containing form of bacteria (more correctly termed cyanobacteria). This group of organisms is commonly included in the term algae, because cyanophytes are similar in size and ecology to other forms of freshwater algae. The animals in the lake generally cannot eat cyanobacteria. An abundance of non-edible cyanophytes can short circuit the food chain, decreasing the food supply for fish. Cyanobacteria can also form smelly scums on the surface of the water, decreasing the recreational appeal of the waterbody. Of considerable concern is that these cyanophyte scums can be comprised of species that can produce deadly toxic chemicals. These toxins have been reported to be fatal to dogs, cows, and even humans (Fig. 1). These blue-green algae can be toxic if ingested, if inhaled, or in some instances, can cause skin irritations if touched.

METHODS

OLMS developed a volunteer-based monitoring program for the MWCD reservoirs. The volunteers, called "Lake Keepers," monitor the lakes on a set schedule throughout the open-water season. These data have been entered into Microsoft Excel and Access. At present the resulting data are kept in a number of files, often comprising a single year's data.

Three sources of data were used for this part of the study. Secchi disk transparency was available on an Access database collected since 1994 by CLAM volunteers. Information in the MWCD, gathered by CLAM's Lake Keepers program since 2011, was available on Excel files. Information collected by the Ohio Department of Natural Resources (DNR) was made available by Joseph Conroy of the Ohio DNR.

These various files were edited and merged into four databases. The first database is the CLAM volunteer database, which was downloaded from the CLAM database, and then made into a MWCD-specific Excel file. The other databases contain nutrient data, toxic blue-green algal information, and cyanobacterial species in the lakes. The ultimate goal is to have a minimum of databases that can be (1) easily updated as new information is found or gathered and (2) easily accessible to any researcher desiring the information.

It was found that there were considerable variations in naming of sampling sites; there were over 81 named sites in the DNR database alone. Data for labeled sites, such as "inflow," "outflow," and beaches, have been pooled and analyzed as one site. The analysis presented here has been conducted solely on data aggregated by lake name. The goal of future work should include unification of the data using a uniform site naming procedure.

RESULTS

Transparency

Secchi disk transparency is an inexpensive method to estimate the clarity of the water using the depth of disappearance of a black and white disk when lowered into the water. Transparency is affected by the amount of algal particles as well as particles of clay and other non-algal materials. A considerable amount of transparency data has been gathered by the CLAM volunteers since 1994.

The Secchi transparencies gathered from 2010 to 2015 provided sufficient information to be able to make statements as to the transparency in the MWCD lakes. The results indicate that there is a wide range of transparency in the MWCD lakes (Fig. 2). Piedmont Lake is the most transparent, having the least number of particles in the water. The least transparent were Charles Mill Lake and Wills Creek Lake.

Using transparency information of all the monitored Ohio lakes in the CLAM database, we estimated where the Secchi transparency in the MWCD lakes rank in relation to other monitored lakes in Ohio (Fig. 3). The transparency of the MWCD lakes was distributed throughout the transparency spectrum.

Disturbingly, Charles Mill and Wills Creek are among the least transparent lakes that have been measured in Ohio. They are in the transparency range of lakes such as Grand Lake St. Marys and Buckeye Lake, lakes that have excessive cyanotoxins in their waters.

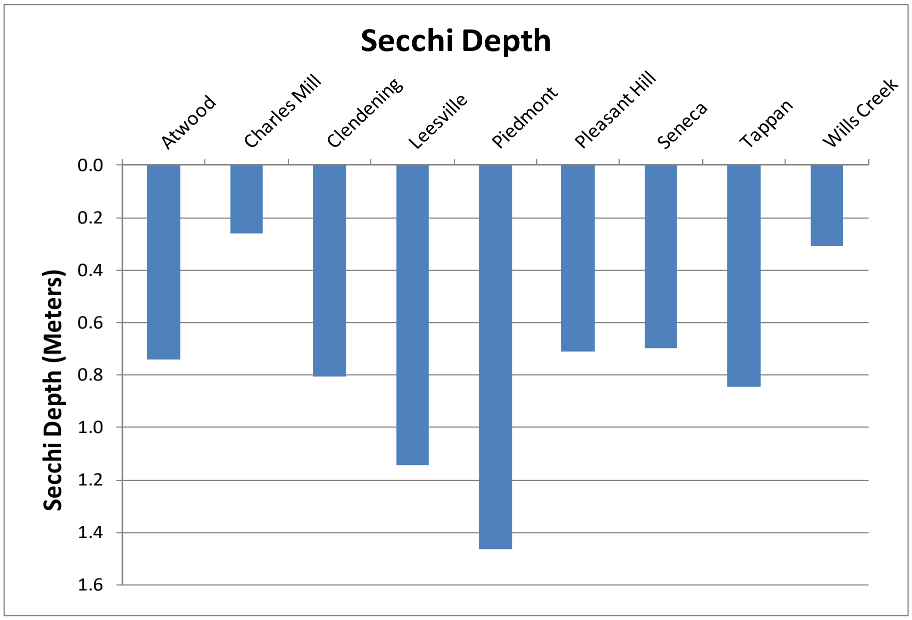


Figure 2. The average Secchi disk transparency in the MWCD lakes from 2010 to 2015.

A disadvantage of Secchi disk transparency is that it cannot differentiate between algal particles and non-algal particles such as clays or suspended bottom sediments. Thus, lakes that are receiving considerable amount of non-algal mineral turbidity from clays and other erosional materials from the watershed or from stirring up of the lake bottom can show exactly the same transparency as would a lake with only algal attenuating light. For example, the two least transparent lakes, Charles Mill and Wills Creek, may both have similar low Secchi transparency values, but the cause for the low transparency could be different.

It is possible to make some statement about the nature of the particles contributing to the transparency in the reservoirs by adding information on algal pigments (chlorophyll) and on total phosphorus, the major nutrient that limits algal growth in many lakes. If phosphorus is the nutrient stimulating algal (chlorophyll) growth, and transparency (Secchi Depth) is largely determined by all species of algae, there should be a relationship between all three variables. Predictive formulas have been devised that transform transparency, chlorophyll, and phosphorus values into a Trophic State Index (TSI) (Carlson, 1977). If most of the transparency in a lake is the result of algal density and the growth of algae is limited by phosphorus, then the three indices will be similar. If the transparency is dominated by non-algal particles, such as clay particles, the chlorophyll index will be much lower than indices based on phosphorus or transparency since both variables are found in typical clay particles as well as in algae. The resulting graph (Fig. 4, Table 1) suggests that Charles Mill and Wills Creek are dominated by non-algal particles rather than algae. The indices for all the other reservoirs tend to be similar, indicating that algae dominate transparency.

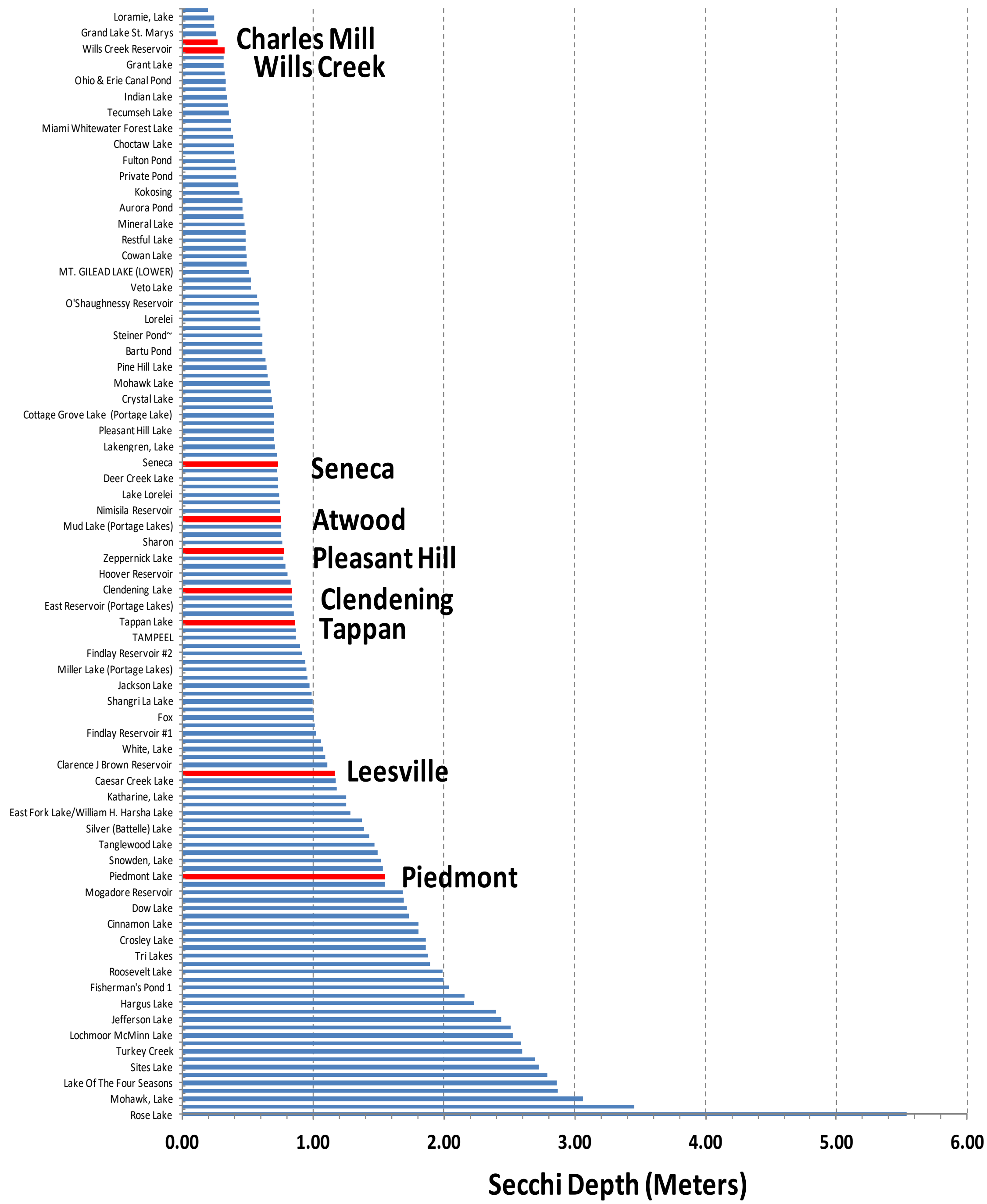


Figure 3. As a comparison throughout Ohio, the average transparencies of Ohio lakes (1989-2015) based on CLAM-monitored data. Lakes maintained by MWCD and monitored by CLAM Lake Keepers under contract with OLMS are indicated in red.

Table 1. The average concentrations of algal chlorophyll, phosphorus, and Secchi transparency in MWCD lakes, 2010-2015.

	SD (m)	Chlorophyll (mg/m^3)	Total P (mg/L)	Total N (mg/L)	TSI SD	TSI Chl	TSI TP	TSI TN
Atwood	0.74	27.5	88.1	728	64.3	63.1	68.7	49.9
Charles Mill	0.26	52.3	124.2	1815	79.5	69.4	73.7	63.1
Clendening	0.81	25.6	70.3	1011	63.1	62.4	65.5	54.6
Leesville	1.14	19.1	73.2	631	58.1	59.5	66.1	47.8
Piedmont	1.46	15.0	54.0	860	54.5	57.2	61.7	52.3
Pleasant Hill	0.71	33.7	48.1	1045	64.9	65.1	60.0	55.1
Seneca	0.70	24.9	70.7	417	65.2	62.1	65.6	41.8
Tappan	0.85	31.4	60.4	523	62.4	64.4	63.3	45.1
Wills Creek	0.31	23.2	112.1	344	76.9	61.4	72.2	39.1

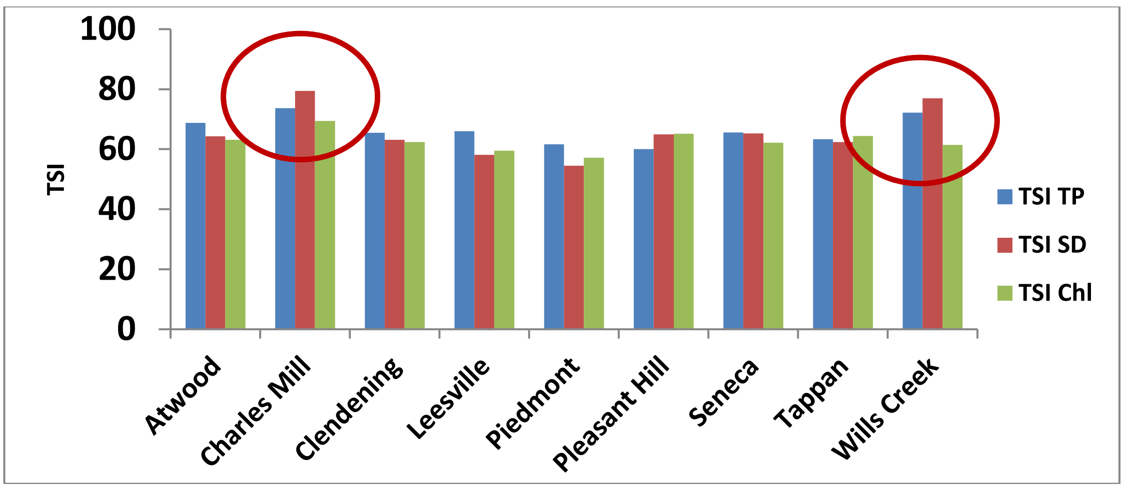


Figure 4. Comparison of the relationship of TSI index values in the MWCD lakes. If TSI indices are similar for a nutrient (TSI TP), Secchi depth (TSI SD), and Chlorophyll (TSI Chl), then it implies that the nutrient–chlorophyll-transparency is probable. The red circles on Charles Mill and Wills Creek indicate that chlorophyll is not strongly related to either the nutrient or to transparency, suggesting that there is a great deal of suspended sediment in the water.

Trends in Transparency

Thanks to the wealth of data collected in previous years, it is possible to examine if there are yearly trends in transparency in the MWCD lakes. Such trends could indicate changes in the land use within their watersheds or changes in the structure or biota of the lakes themselves.

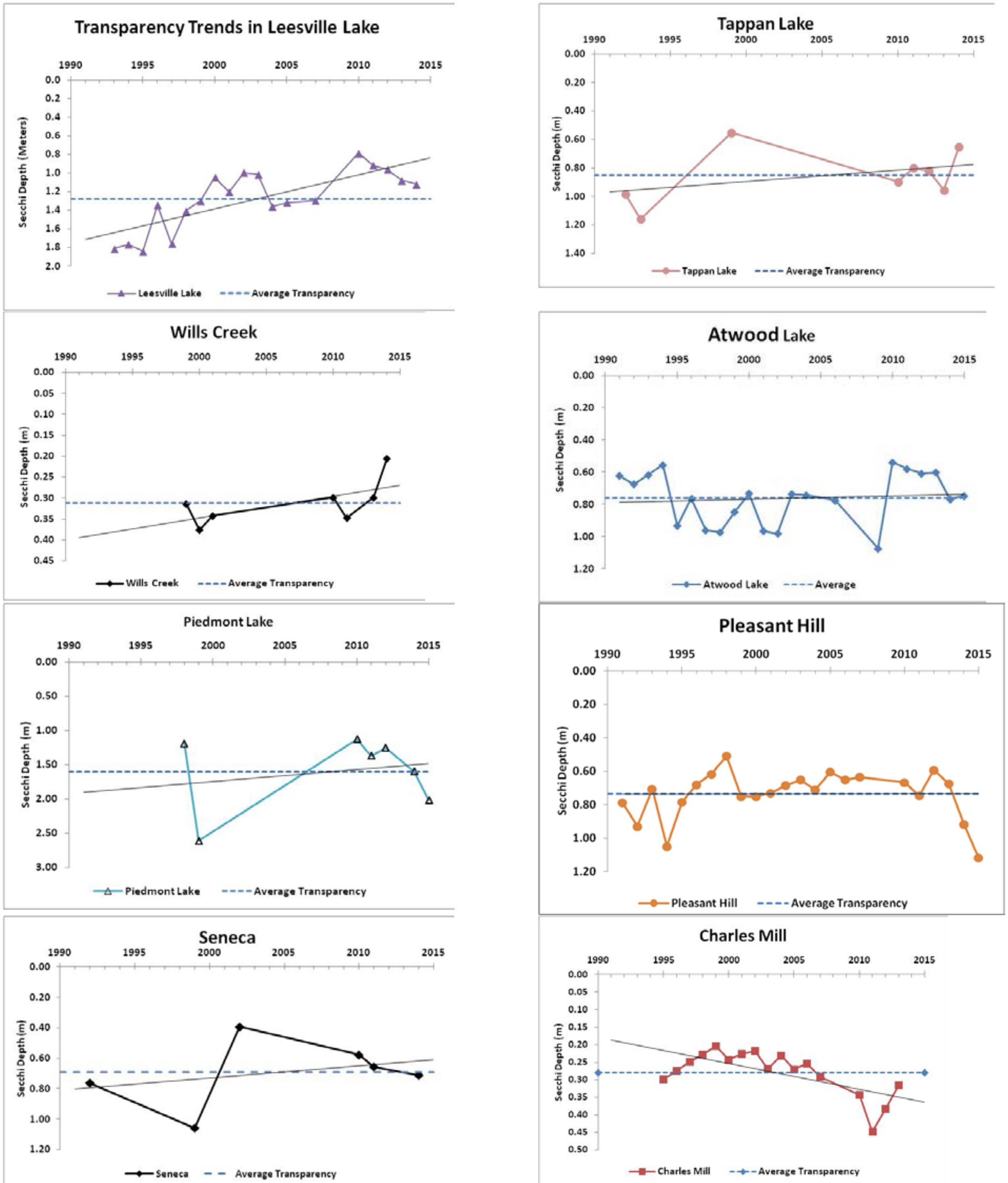


Figure 5. Transparency trends in MWCD lakes. The dashed line indicates the average transparency in each lake from 1991-2015. The solid black line (no symbols) is the trend line as derived by linear regression.

Fig. 5 illustrates the long-term trends in transparency in the individual MWCD lakes. Most lakes show little evidence of change. Some were not sampled every year, making statements about change difficult. Clendening was not plotted at all because data were available for only three years. Only Charles Mill indicates a trend towards clearer waters, although its transparency has been decreasing for the past two years. On the other hand, Leesville exhibits a considerable long-term decrease in transparency, changing from approximately 1.8 m in the early 1990s to approximately 1.0 m in 2013. This change of a near halving of transparency represents a doubling in the amount of particles in the water of this lake. Despite this long-term decrease in transparency, it is encouraging that Leesville's transparency has been improving for the past five years. Pleasant Hill Lake indicates no change from early 1990s to the last few years, when there has been an increase in transparency.

The data do not allow us to speculate on why changes are occurring in some lakes but not others. Examination of possible changes in land use in the watershed may be illuminating if prediction of future conditions and management potentials are to be considered.

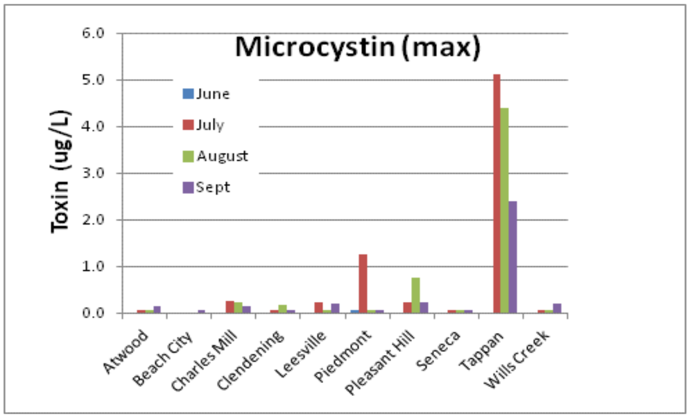
Toxic Blue-green Algae

Since 2011, the Lake Keepers have monitored two cyanophyte toxins, microcystin and cylindrospermopsin, in the MWCD lakes at sites in the middle of the lake and at the swimming beaches (Fig. 6).

There are two designations that are used in this data reporting that designate the very lowest concentrations. If the levels of a toxin are below the level that can be detected by the analytical procedure the sample is considered to be "non-detectable." Toxin concentrations that lie between non-detect and quantifiable amounts are designated as less than (<) the minimum reliable detectable concentration. At higher concentrations, the toxin can be detected, quantified, and expressed as numeric values. Concentrations detectable but below the minimum quantifiable concentration are common in the MWCD reservoirs. The Ohio EPA has also set levels of toxins that can be considered detrimental to human health in drinking water and in recreational activities (State of Ohio, 2016). In this study the reported analytical values do not necessarily correspond exactly with the warning levels, but indicate when the reservoir water toxin levels reach or exceed values that should be of concern.

Levels of the cyanophyte toxin, microcystin, were detected in all the lakes, but were highest in Tappan. Surprisingly it also reached serious levels several times in Piedmont Reservoir, the clearest of the MWCD lakes. In all the other lakes, microcystin was detected but at levels below threshold values of 1 μg/L (micrograms per Liter). In Tappan, the concentrations tended to be highest in July.

Cylindrospermopsin was also found in all reservoirs, but the highest concentration was in Piedmont. In Piedmont, the highest concentration was found in September. Although cylindrospermopsin is produced by several species of cyanobacteria, it is commonly associated with the filamentous cyanobacterium, *Cylindrospermopsis*, which was found to increase in late September.



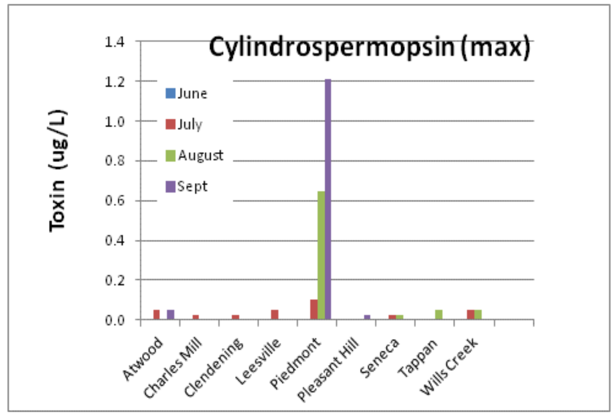


Figure 6. The monthly maximum concentrations of the cyanophyte toxins, microcystin and cylindrospermopsin, in the MWCD reservoirs (2012-2015).

There are published toxin concentrations that could be harmful to human health (State of Ohio, 2016). Rather than comparing the average concentration of toxins found in the lakes, we computed the frequency with which the toxin considerations exceeded various levels in the lake (Table 2 & 3). For comparison, microcystin levels in some non-MWCD lakes were added to the table.

Microcystin was non-detectable or very low in most of the MWCD lakes. The notable exception is Tappan, where 28% of the samples exceeded 1.0 µg/L. Although microcystin levels were still well below the recreational advisory level of 6.0 µg/L, it does stand out in comparison to the other MWCD lakes. In the non-MWCD lakes microcystin levels can be much higher. In Grand Lake St. Marys, they reached levels that would prohibit swimming in 100% of the samples. Other lakes known to have high levels of microcystin, Buckeye Lake and western Lake Erie, also exhibited high percentages at levels that would prohibit drinking or swimming.

Cylindrospermopsin was undetectable or very low in all the MWCD lakes, with Piedmont being the exception.

Table 2. Incidence of the cyanotoxin, microcystin, found in MWCD lakes (2010-2014) and some non-MWCD lakes.

					Drinking Water- Do Not Drink 1.0 µg/L	Recreational Public Health Advisory 6.0 µg/L
Lake	**Number of Samples**	**Non-Detect**	**<0.15 µg/L**	**<1 µg/L**	**1 – 6 µg/L**	**>6 µg/L**
Atwood	32	9%	88%	3%	0%	0%
Beach City	2	50%	50%	0%	0%	0%
Charles Mill	32	9%	75%	16%	0%	0%
Clendening	29	14%	83%	3%	0%	0%
Leesville	30	10%	83%	7%	0%	0%
Piedmont	27	4%	89%	4%	4%	0%
Pleasant Hill	30	10%	60%	30%	0%	0%
Seneca	30	13%	87%	0%	0%	0%
Tappan	32	0%	0%	72%	**28%**	0%
Wills Creek	10	20%	70%	10%	0%	0%
Non-MWCD Lakes						
Buckeye	6	0%	17%	0%	**17%**	**67%**
Choctaw Lake	9	0%	0%	0%	**44%**	**56%**
Erie, Western Basin	6	0%	17%	17%	**67%**	0%
Grand Lake St. Marys	6	0%	0%	0%	0%	100%
Indian Lake	7	0%	29%	43%	**14%**	**14%**
Krzys Mantua Pond	1	100%	0%	0%	0%	0%
Portage Lakes	6	0%	0%	100%	0%	0%
Roaming Rock	14	0%	29%	64%	**7%**	0%
Sunrise Lake	6	0%	50%	33%	**17%**	0%
Sylvan	6	17%	17%	67%	0%	0%
Waibel Pond	6	50%	50%	0%	0%	0%

Table 3. Incidences of the cyanotoxin, Cylindrospermopsin, found in MWCD lakes.					
				Recreational Public Health Advisory (5.0 µg/L)	**Recreational No Contact Advisory (20.0 µg/L)**
Lake	**Total Number of Samples**	**ND**	**<0.10**	**<1.0**	**>1**
Atwood	18	78%	22%	0%	0%
Charles Mill	20	95%	5%	0%	0%
Clendening	18	94%	6%	0%	0%
Leesville	18	94%	6%	0%	0%
Piedmont	17	6%	29%	53%	12%
Pleasant Hill	18	94%	6%	0%	0%
Seneca	18	89%	11%	0%	0%
Tappan	19	95%	5%	0%	0%
Wills Creek	17	76%	24%	0%	0%

Trends in Toxin Concentrations

Two lakes, Tappan and Piedmont, deserve some emphasis regarding their concentrations of cyanophyte toxins, although neither has reached levels that require public notices or further drinking water treatment. The question does arise whether any of the lakes are trending towards higher toxin levels. To address this possibility, the maximum toxins for each lake and reservoir were aggregated and compared by month and year (Table 4).

Tappan does show evidence of an increasing microcystin concentration, the others do not. Only three years of data have been gathered of cylindrospermopsin, and indications of trends are premature.

Table 4. The maximum concentrations (µg/L) of microcystin found in the MWCD lakes (2011-2015).

Lake	2011	2012	2013	2014	2015
Atwood	0.075	0.075	0.151	0.075	0.075
Charles Mill	0.225	0.193	0.075	0.152	0.247
Clendening	0.075	0.075	0.075	0.162	0.075
Leesville	0.239	0.075	0.075	0.075	0.075
Piedmont	0.075	0.075	0.075	1.247	0.075
Pleasant Hill	0.748	0.075	0.181	0.174	0.075
Seneca	0.075	0.075	0.075	0.075	0.075
Tappan	0.991	1.446	0.642	5.125	2.687
Wills Creek				0.187	0.0750

Cyanobacteria in the MWCD Lakes

Throughout the study, water samples were taken and the cyanophytes in the sample were identified down to at least the genus level (Fig. 7). Three or four genera accounted for approximately 80 to 90 percent of the cells found. Only minor differences in the relative abundance or species composition were found between reservoirs.

Differences in relative species composition also failed to be clearly associated with concentrations of toxins. There were ample densities of potentially toxic genera for toxins to be present in all the reservoirs. Of the 25 genera identified in the MWCD lakes, 20 of the genera were known to include toxins.

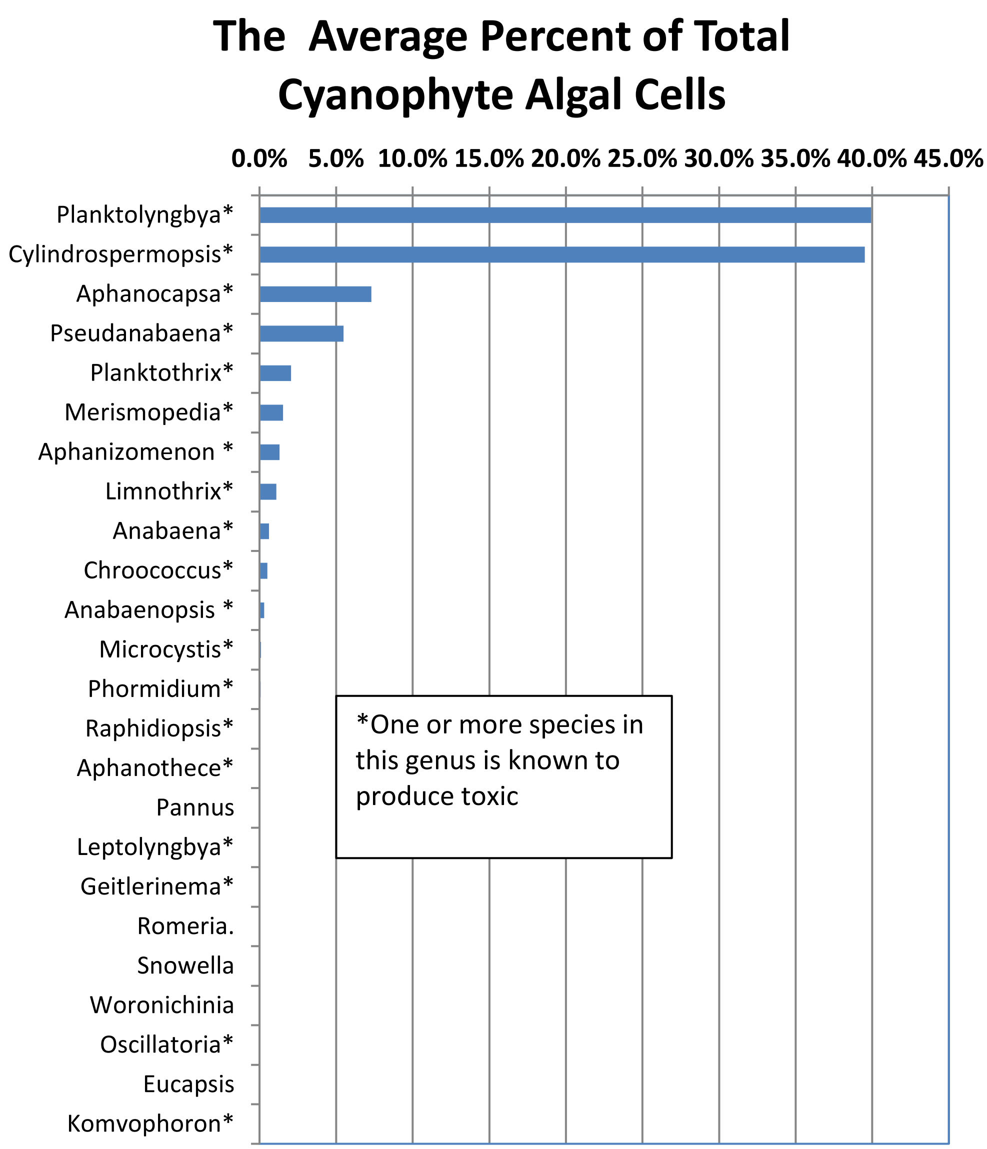


Figure 7. The aggregated percentages of the genera found in the MWCD lakes. The asterisk denotes that one or more species in the genus is known to produce toxins.

DISCUSSION

This report is a compilation of the existing data that has been gathered on the MWCD lakes, particularly the data gathered since 2010 by the Lake Keeper volunteers and the CLAM volunteer monitoring program. The tasks undertaken for this report include:

- Construct and compile a database for the existing data that can be updated with future data.
- Identify any trends, concerns, or future sampling needs, by examining existing data relating to nutrients, algal chlorophyll a, HABs, and the algae found in the reservoirs.

Data Management

The database effort began with collecting and merging data from the DNR, the Lake Keeper program, and the CLAM program. These files were merged into a single format that facilitated summarization of the information by date, location, or variable when new data are added. These data are in Microsoft Excel, whose Pivot Table function allows for easy updating and summarization of any variable or algal species.

At present, there are three separate datasets; one for nutrients and chemical data (Secchi depth, chlorophyll, total N, total P, etc.), a second data set containing the HAB data, and a third, the cyanophyte taxonomic data. Data can be updated by entering or pasting new data to the bottom of the appropriate data table.

Data consolidation is still incomplete. Further work on the database should include linking the three databases. For example, it is difficult to examine the effect of phosphorus concentration on the species or HAB concentration because the data are located in three separate datasets. Linking of the datasets may be accomplished by adding matching ID numbers to each record so that any information collected at the same location and the same depth, day, and time can be merged into one database. This can be done relatively easily in Microsoft Access.

At present, there is a daunting number of site designations that have been used, often with little or no information on where the site is located. For these nine lakes, there are 56 site numbers; numerous site IDs exist for a single site within the same lake. For example, a sampling site designation for a site near the dam may be labeled "Dam," "Outflow," "OUTFLO", 1, 101, and perhaps even more designations that have not been identified. This proliferation of site identifications probably results from various studies inventing novel designations appropriate for their needs. Consistency of site IDs would facilitate a closer examination of in-lake variations of the variables.

Data Analysis

Once the datasets were constructed in the same format, some analyses and summarizations were done.

The transparency of the lakes varies widely. Piedmont was the clearest reservoir and can be compared favorably with other clear Ohio lakes. Conversely, Charles Mill and Wills Creek rank near Grand Lake St. Marys and Buckeye among the most turbid in the state. Deviations of the TSI index values of Total Phosphorus and Secchi Depth from the Chlorophyll TSI indicates that the Secchi disk values are affected by non-algal turbidity as well as by algae. Transparency in Charles Mill and Wills Creek appear to contain the most non-algal material. The importance of information of this kind indicates that different management strategies may be appropriate for any specific lake. Charles Mill and Wills Creek might need erosion control more than nutrient control.

Transparency is a stable variable ideal for the examination of trends that might indicate chemical or biological changes in the lakes. Information on long-term and short term changes may be used to focus management on lakes with declining transparency. Most of the MWCD lakes show little evidence of long-term change, with a few notable exceptions. However, Leesville exhibits a long-term decline in transparency, but for the last 5 years the transparency has been increasing. Charles Mill, on the other hand, has a long-term increase in transparency, but the last 3 years' transparency has been declining. The reason for these changes has not been investigated.

There are four of the more than 20 toxins released by blue-green algae that are examined by the Ohio EPA. These are microcystin, cylindrospermopsin, anatoxin-a and saxitoxin. In our study, microcystin and cylindrospermopsin were chosen to be monitored in the MWCD lakes. Only two lakes exhibited HAB toxin levels high enough to be of concern, especially if concentrations or even transparency is changing as well. Tappan has "high" concentrations of microcystin and concentrations appear to be increasing since 2010. However, transparency in Tappan provides no evidence of a similar change. Piedmont, the clearest of the MWCD lakes, has notable levels of cylindrospermopsin. The link between nutrient and toxin production appears not to be straightforward in these lakes.

The cyanophyte genus *Cylindrospermopsis* is known to produce the toxin, cylindrospermopsin. However, in Piedmont, its relative abundance (34%) was not as dominant as the relative abundance of *Cylindrospermopsis* in other lakes. Three of the possible explanations are that the toxic form of *Cylindrospermopsis* was not abundant in the other lakes, the toxin in Piedmont was being produced by other species (*Aphanizomenon* and/or *Anabaena*[1]), or relative abundance based on cell number does not reflect the absolute abundance of this genus in Piedmont. The existence of multiple possible explanations illustrates the difficulty of attaching a toxin to a specific species of blue-green algae.

At present, cyanophyte toxins could be considered a priority "watch." Based on what we see in Tappan and Piedmont, there is no clear indication that variables, such as nutrient or algal chlorophyll, signal a possible rise in toxins. It's unfortunate that the science behind understanding toxic cyanophytes is still incomplete.

[1] *Some species formerly in the genus Anabaena have been moved to the genus Dolichospermum.*

REFERENCES

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography. 22:361-369. http://aslo.net/lo/toc/vol_22/issue_2/0361.pdf.

Carlson, R.E. and J. Simpson. 1996. *A Coordinator's Guide to Volunteer Lake Monitoring Methods*. North American Lake Management Society. 96 pp. https://www.researchgate.net/publication/244954494_A_Co-Ordinator%27s_Guide_to_Volunteer_Lake_Monitoring_Methods.

State of Ohio. 2016. Harmful Algal Bloom Response Strategy for Recreational Waters. https://www.odh.ohio.gov/-/media/ODH/ASSETS/Files/eh/HABs/2016/2016-Revised-HAB-Strategy-5242016.pdf?la=en.

Wikipedia. Cyanobacteria. https://en.wikipedia.org/wiki/Cyanobacteria.