STATUS AND TRENDS OF THE WATER QUALITY OF THE MUSKINGUM WATERSHED CONSERVANCY DISTRICT RESERVOIRS, 2016-2020

Prepared for
Ohio Lake Management Society

Funded by
Muskingum Watershed Conservancy District

EXECUTIVE SUMMARY

Since 1991, the Muskingum Watershed Conservancy District (MWCD) has enlisted the aid of volunteers to monitor the water quality of their reservoirs, in collaboration with the Ohio Lake Management Society's (OLMS) Citizen Lake Awareness and Monitoring (CLAM) program. The purpose of monitoring the MWCD's various waters is to track the effects of nutrient deposition within those waters over time. The primary goal of this project was to compile various sets of water quality data (including water temperature, oxygen profile, total phosphorous, total nitrogen, chlorophyll, and standard level 1 Secchi data), at nine MWCD lakes. The purpose of this report is to summarize lake transparency, chlorophyll, nutrients, and algal toxins over a five-year period (2016-2020) in attempt to understand water quality trends compared to the previous five years as documented by Carlson (2015).

CLAM volunteers began water sampling and data collection from the MWCD Lakes throughout the summer months during the collection period on a set schedule. Volunteers recorded pertinent field data: temperature, water depth, Dissolved Oxygen, Secchi depth, and water color. Volunteers also collected water samples that were put on ice and sent to a laboratory within the same week for analysis for nutrients, algal toxins (microcystin), and algal counts. Chlorophyll samples were frozen immediately and stored at the volunteers' residence and sent to the lab end of the season. All laboratory analyses (chlorophyll a [Chl a], Total Phosphorus [TP], Total Nitrogen [TN], Nitrate-Nitrite as Nitrogen [NO2-NO3], Kjeldahl Nitrogen [TKN], microcystin analysis, and algal identifications) were performed by a Level 3 OEPA-certified laboratory. For this report, data for each labelled site (inflow, outflow, beaches, etc.) were pooled and analyzed as one site for each lake. A value of half the detection limit was used in calculations where nutrient results were non-detect. The Trophic State Index (TSI) for Secchi depth, Chl a, TP, and TN was calculated using those equations excerpted from Carlson and Simpson (1996).

An algal bloom occurred in 2016-2017, which was evidenced by the rise in cyanobacterial cell densities in several of MWCD Lakes, most notably at Clendening, Seneca, and Tappan, and may reflect generally lower phosphorus concentrations in the 2016-2020 period. Charles Mill also saw a rise in cyanobacteria densities, though phosphorus concentrations did not appear to affect algal growth as evidenced by a higher TSI TP. By comparison, low phosphorus levels coincided with limited algal growth at Leesville and Piedmont. Average rainfall was also the lowest at the lakes during 2016, ranging from 36-43 inches for the 2016-2020 time period, and likely influenced increased levels of cyanobacteria and microcystin observed in 2016. Exceedances of the 8 ug/L recreational use threshold of microcystin at Tappan occurred during the bloom in 2016. Increased levels of microcystin did not appear to track with any specific cyanobacterial genera.

Between the two time periods (2010-2015 and 2016-2020), the relationship between TSI values at Pleasant Hill and Charles Mill suggest no change since 2015. Atwood TSI values suggest suspended sediment explains more of the transparency since 2015. Clendening, Leesville, Seneca, and Tappan have shifted to a condition where algae may be responsible for lower TSI TP values seen in the 2016-2020 time period.

Since 2015, Atwood, Charles Mill, and Leesville increased in average transparency; Clendening Seneca, and Tappan decreased in average transparency. For the current 5-year period, Leesville experienced the greatest gain in transparency, and Tappan the greatest loss.

MWCD lakes score "poor" in TP and TN in roughly half the samples when compared to levels set by the NLA. USEPA has since developed nutrient-chlorophyll models in August of 2021 (USEPA, 2021c), which are available in an online tool that computes varying TP and TN criteria based on targeted lake chl a concentration and lake characteristics (USEPA, 2020).

Compared to other lakes, NO2-NO3 levels were elevated at Charles Mill and Wills Creek, though these levels were below the water quality criterion for safe drinking water. Both these lakes also have higher water color scores, and notably high sediment (Carlson, 2015). These lakes may be receiving more non-point source loading compared to other lakes. Wills Creek also has more agricultural surrounding land use (11.24%) compared to other lakes.

ACKNOWLEDGMENTS

The Ohio Lake Management Society appreciates the commitment of the Citizen Lake Awareness and Monitoring (CLAM) Lake Keepers to gather valuable water quality information on the lakes in the Muskingum River Watershed: Rich Bassetti (2008-2015), Connie Beckett (2017), Mike Bennett (2011-2016), Maureen Coleman (2010-2016), Don Dieffenbaugher (2010-present), Don Driver (2010), Nancy Felean (2016-2017), Hayley Glaze (2015), Steve James (2011-present), Donna Kontul (2017), David and June Krause (2017-present), Ed Lee (2014-present), Rick and Elaine Novak (2018-present), Gary Sterrett (2018-2019), Mark Tondra (2010-present), and Dick Zimmerman (2010-2016). These dedicated volunteers have offered their time and expertise over the years to collecting data during the monitoring seasons. Their contribution is highly valued! This report would not be possible without significant effort by the Lake Keepers in gathering data when on the lakes and collecting water samples for laboratory analysis. Thank you!

This annual project provides for valuable oversight on water quality changes over time and assists lake managers in maintaining the integrity of the water systems. A special thank you is offered to the Muskingum Watershed Conservancy District (MWCD) for providing the necessary funding to produce this report. Also, Mark Swiger from MWCD has been a most valued partner on the CLAM project for many, many years. We send a message of appreciation to him as he moves on to other adventures leaving a legacy in the Muskingum River Watershed as a strong collaboration between MWCD, Ohio Lake Management Society, and area residents as the Lake Keepers.

We also appreciate the contributions of BSA Environmental Services, Inc. towards analyzing the many samples each year. Thank you to Susan James as the CLAM Program Manager for offering support to the Lake Keepers in performance of their monitoring duties, and also to Melissa Vaccarino for her time in compiling this useful document. Finally, appreciation is sent to the Board of Directors of the Ohio Lake Management Society for the continued support of the Citizen Lake Awareness and Monitoring program. We look forward to the next five years in documenting the water quality of the Muskingum River Watershed.

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1.0 INTRODUCTION

Since 1991, the Muskingum Watershed Conservancy District (MWCD) has enlisted the aid of volunteers to monitor the water quality of their reservoirs, in collaboration with the Ohio Lake Management Society's (OLMS) Citizen Lake Awareness and Monitoring (CLAM) program. The purpose of monitoring the MWCD's various waters is to track the effects of nutrient deposition within those waters over time. Key nutrients such as nitrogen and phosphorus serve as a food source for microscopic plants (algae) which are at the bottom of the food chain. Sources of excess nitrogen and phosphorus include fertilizer runoff from farm fields, athletic fields and golf courses, and residential/commercial lawns through various tributaries and sewer discharge channels. When these nutrients are deposited in excess, toxic algal blooms can occur, which adversely affect the quality and safety of the water, as well as the homeostasis of the aquatic biome. Adverse effects of eutrophication events include the loss of water transparency, blocked sunlight, a decrease in dissolved oxygen levels, noxious algal scums, dense plant growth, and decreased abundance of sport fish due to clogged gills. Eutrophication also results in the shifting of the algal population from beneficial algae to cyanobacteria (bluegreen algae). This is particularly problematic due to various deadly toxic chemicals that cyanobacteria produce, such as microcystin. In addition to harming aquatic life, cyanotoxins can be toxic to humans if they are ingested, inhaled, or dermally contacted. Watersheds can also be adversely affected by various sources of pollution, including acid rain, fish stocking, pesticide poisoning, invasive species, soil erosion, road salt, and climate change. All of these factors negatively impact the health of a watershed, which is why watershed monitoring is so critical.

MWCD adheres to the Ohio Environmental Protection Agency (Ohio EPA) harmful algal bloom (HAB) public signs notification protocol at beaches and access points (Figure 1-1, Ohio EPA, 2020). Data are also posted on the BeachGuard website (ODOH, 2022).

Figure 1-1. HAB Public Signs from Ohio EPA, 2020

The primary goal of this project was to compile various sets of water quality data (including water temperature, oxygen profile, total phosphorous, total nitrogen, chlorophyll, and standard level 1 Secchi data), at nine MWCD lakes. The purpose of this report is to summarize lake transparency, chlorophyll, nutrients, and algal toxins over a five-year period (2016-2020) in attempt to understand water quality trends compared to the previous five years as documented by Carlson (2015).

2.0 BACKGROUND

2.1 WEATHER AND CLIMATE

The Muskingum Watershed lies within the Northern and Southern Appalachian Ecoregions as categorized by Omernik (1987) and as used by the US Environmental Protection Agency (USEPA) National Aquatic Resource Surveys (NARS). The Appalachian regions are described as generally hilly, with intermixed plains and some mountain ranges. In the northern region, the climate is classified as cold to temperate, with a mean annual temperature of 39-48° Fahrenheit (°F) and total annual precipitation of 35-60 inches (in) (USEPA, 2021a). In the southern region, the climate is classified as temperate wet, with a mean annual temperature of 55-65°F and total annual precipitation of 40-80 in (USEPA, 2021b).

2.1.1 Air Temperature

Air temperature has been recorded at MWCD Lakes from 1991-2020, during the months of April-September (Figure 2-1). In general, air temperatures at MWCD Lakes for these months have ranged from a low of 16.1°C (61.0°F) to a high of 30.3°C (86.5°F). One exception occurred during a particularly hot July, 1999, where the highest average air temperature was recorded at Seneca (35.6°C [96.8°F]).

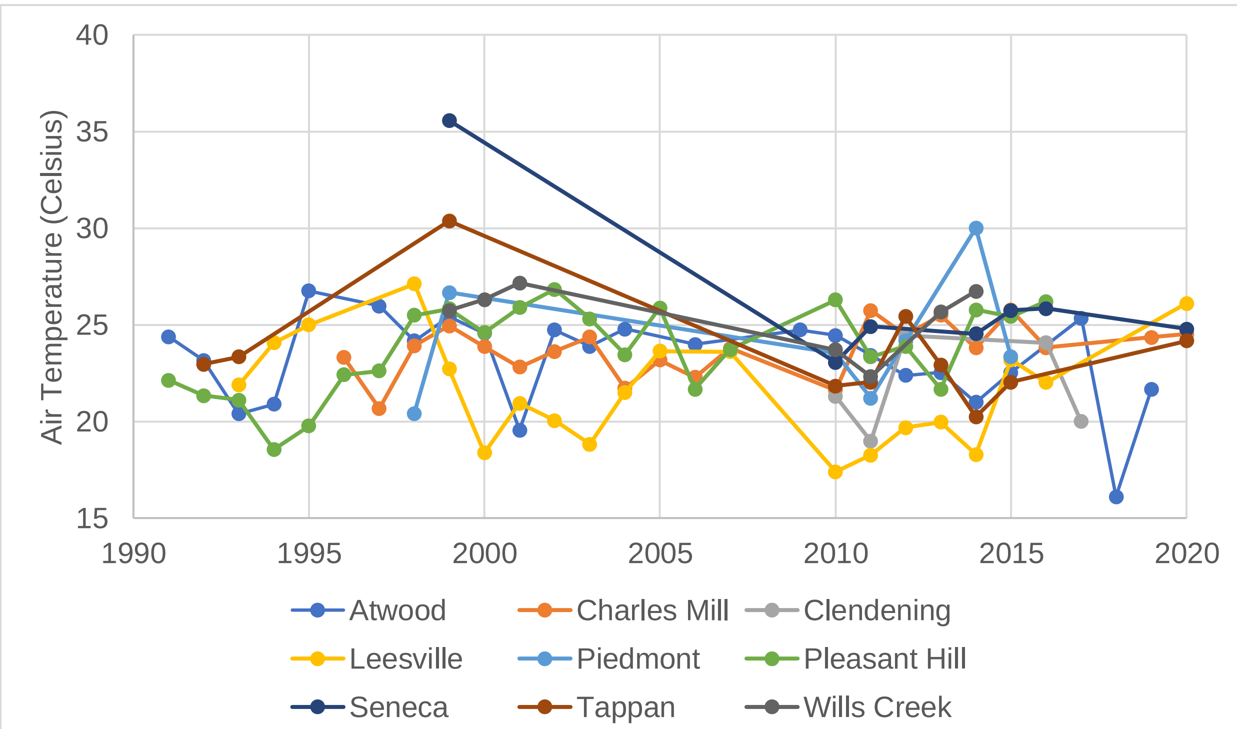


Figure 2-1. Average Ambient Air Temperatures Recorded from MWCD Lakes between 1991 and 2019

2.1.2 Rainfall

Daily rainfall amounts were collected and tabulated for six different rain gauges: Atwood Lake, Clendening Lake, Leesville Lake, Piedmont Lake, Tappan Lake, and Wills Creek. For all six locations, the monthly total, yearly total, yearly average, and standard deviation were calculated.

There is approximately 60 miles between the two farthest locations (Atwood Lake and Wills Creek).

Annual rainfall for 2018 was the highest total amount of rainfall at all six locations. Average rainfall was 60 inches, over 10 inches higher than all other years. The least average annual rainfall occurred in 2016, with an average of 40 inches of rain. Annual rainfall totals for each rain gauge are presented in Table 2-1. Average monthly rainfall ranged from 2 to 6 inches. Maximum monthly rainfall occurred throughout different months of the year for each lake. July 2017 was an unusually wet month. All rain gauge locations recorded about twice as much rainfall than average. There was approximately 300 inches of rainfall across the region during the five-year monitoring period.

Table 2-1. Annual Rainfall (inches) Recorded for six MWCD Lakes from 2016-2020

Year	Atwood	Clendening	Leesville	Piedmont	Tappan	Wills Creek	Average	Standard Deviation
2016	43	43	38	39	39	36	40	3
2017	54	52	48	51	50	33	48	8
2018	62	64	60	62	60	53	60	4
2019	51	47	56	42	52	46	49	5
2020	42	43	48	48	41	41	44	3
Average	50	50	50	48	48	42		
Standard Deviation	8	9	8	9	9	8		

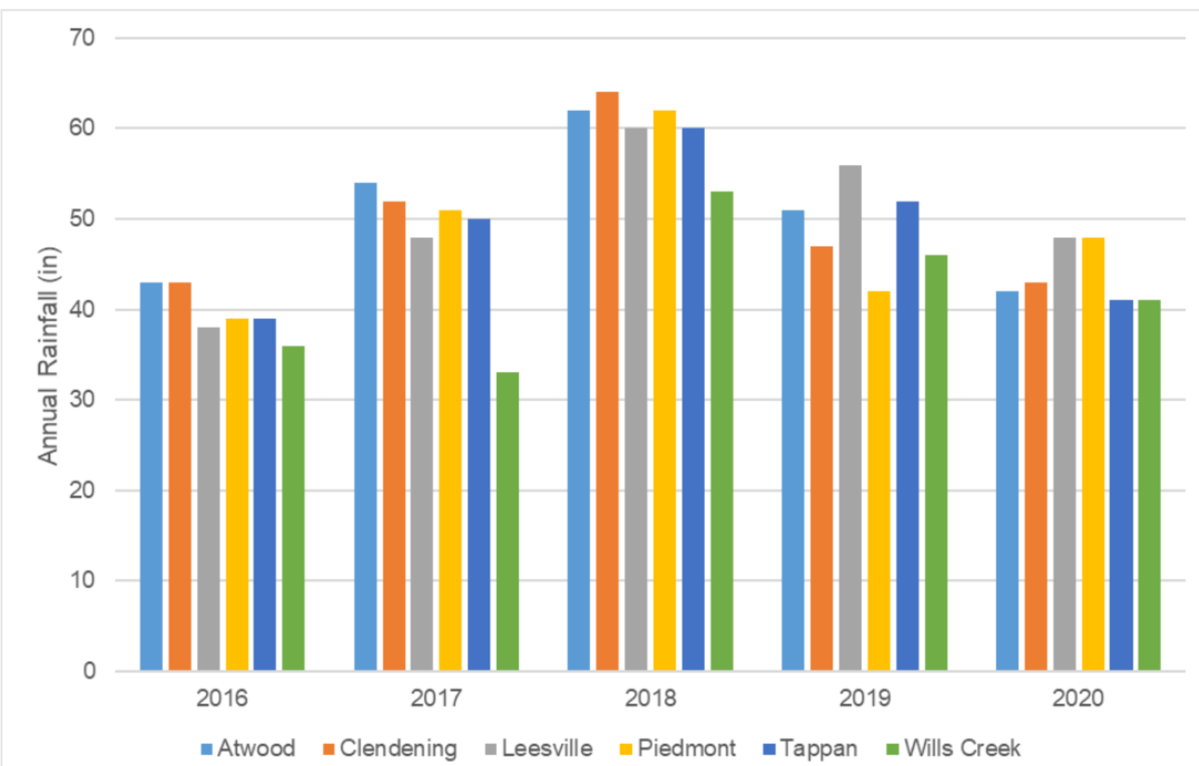


Figure 2-2. Average Rainfall per year at MWCD Lakes, 2016-2020

2.2 WATERSHED LAND USE

Surrounding land use for each of the MWCD Lakes is presented in Table 2-2. Forested areas comprise a majority of surrounding land use for MWCD lakes, with the lowest percentage at Pleasant Hill and Seneca (45.79%) and the highest percentage at Clendening (70.89%). For all lakes, developed areas comprise less than 10% (2.77-9.70%). Compared to the other lakes, Wills Creek has greater than three-times the amount of both agricultural (11.24%) and wetland (8.65%) areas. Wills Creek also has the lowest percentage of open water (9.98%) by comparison. For all other lakes, agricultural use ranges from 0.4% (Clendening) to 2.81% (Tappan), wetland comprises between 0.47% (Tappan) and 2.72% (Charles Mill), and open water comprises between 25.74% (Clendening) to 46.52% (Pleasant Hill and Seneca).

Table 2-2. Percent Surrounding Land Use for MWCD Lakes

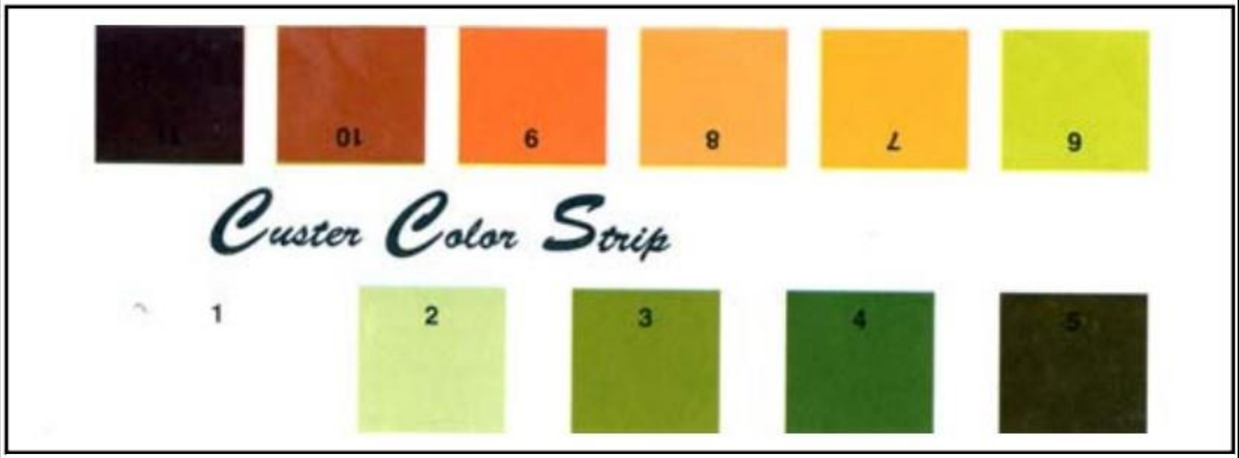
	Percent Land Use						
Lake	**Agriculture**	**Barren Land**	**Developed**	**Forested**	**Grassland**	**Open Water**	**Wetland**
Atwood	1.70	0.04	9.70	52.10	1.30	33.50	1.30
Charles Mill	0.58	0.00	8.49	45.30	0.51	42.40	2.72
Clendening	0.04	0.00	3.09	70.89	0.09	25.74	0.14
Leesville	0.62	0.00	3.18	70.01	0.04	25.99	0.17
Piedmont	1.61	0.00	2.77	61.72	0.20	33.07	0.63
Pleasant Hill	0.52	0.00	6.13	45.79	0.19	46.52	0.84
Seneca	0.52	0.00	6.13	45.79	0.19	46.52	0.84
Tappan	2.81	0.00	7.52	61.21	0.59	27.39	0.47
Wills Creek	11.24	0.03	5.05	64.81	0.26	9.98	8.65

3.0 METHODS

OLMS has developed a pilot program that teaches volunteers to take water quality samples in various lakes in the Muskingum watershed. OLMS began training volunteers for CLAM in spring of 2010. Volunteers began water sampling and data collection from the MWCD Lakes throughout the summer months during the collection period on a set schedule. Over the years, the data has been analyzed and shared with the MWCD and Ohio EPA.

3.1 SAMPLE COLLECTION AND HANDLING

Volunteers recorded pertinent field data (temperature [Celsius], water depth [meters; m] Dissolved Oxygen [DO; mg/L], and temperature via a Yellow Springs Instruments (YSI) ProSolo DO meter®. Measurements were taken at the water surface, and additional measurements for temperature and DO were taken at incremental one-meter depths. To measure transparency, volunteers recorded the average of two Secchi depth measurements. Watercolor was estimated by comparing the color of the lake water against the white portion of the Secchi Disk at half depth to a Custer Color Strip (Figure . Data collection goals were twice monthly, ideally two weeks apart, at a minimum of 10 days apart, from May through October, and within ideal weather conditions and in consideration of volunteer schedules. Volunteers also collected water samples that were put on ice and sent to a laboratory within the same week for analysis for nutrients, and algal toxins (microcystin), and algal counts. Chlorophyll samples were frozen immediately and stored at the volunteers' residence and sent to the lab end of the season. All laboratory analyses (chlorophyll a [Chl a], Total Phosphorus [TP], Total Nitrogen [TN], Nitrate-Nitrite as Nitrogen [NO_2-NO_3], Kjeldahl Nitrogen [TKN], microcystin analysis, and algal identifications) were performed by a Level 3 OEPA-certified laboratory.



The Custer Color Strip was developed by Claude Custer with the Northeast Ohio Four County Regional Planning and Development Organization (NEFCO) as a visual tool in documenting water color indicating algae (green) or sediment (brown) in the water column. A reading is taken by determining the best water color match against the white quadrant of a Secchi disk at a depth one half of the Secchi depth measurement.

Figure 3-1. Custer Color Strip

3.2 DATA

The CLAM program receives and collates field and laboratory data in way that retains files in multiple places for redundancy and as a backup system. For Secchi disk information, paper copies of data submitted by Lake Keepers are archived in a physical storage unit in Columbus. Data are entered into a master Excel file that is updated each monitoring season. This file is stored both on a shared Google drive with project staff and on an external drive. Archived data through 2019 has also been uploaded to the Water Quality Portal housed with the National Water Quality Monitoring Council (www.waterqualitydata.us). Extended protocols such as cyanotoxins, nutrients, cyanobacteria cell counts, and Chlorophyll a are stored in individual files organized by season and saved both in the Google shared drive and on the external drive located in the OLMS office.

For this report, data for each labelled site (inflow, outflow, beaches, etc.) were pooled and analyzed as one site for each lake. A value of half the detection limit was used in calculations where nutrient results were non-detect. The Trophic State Index (TSI) for Secchi depth, Chl a, TP, and TN was calculated using those equations excerpted from Carlson and Simpson (1996).

4.0 RESULTS AND DISCUSSION

4.1 SUMMARY OF SECCHI DEPTH, CHLOROPHYLL A, TOTAL P, AND TOTAL N RESULTS AND TSI VALUES

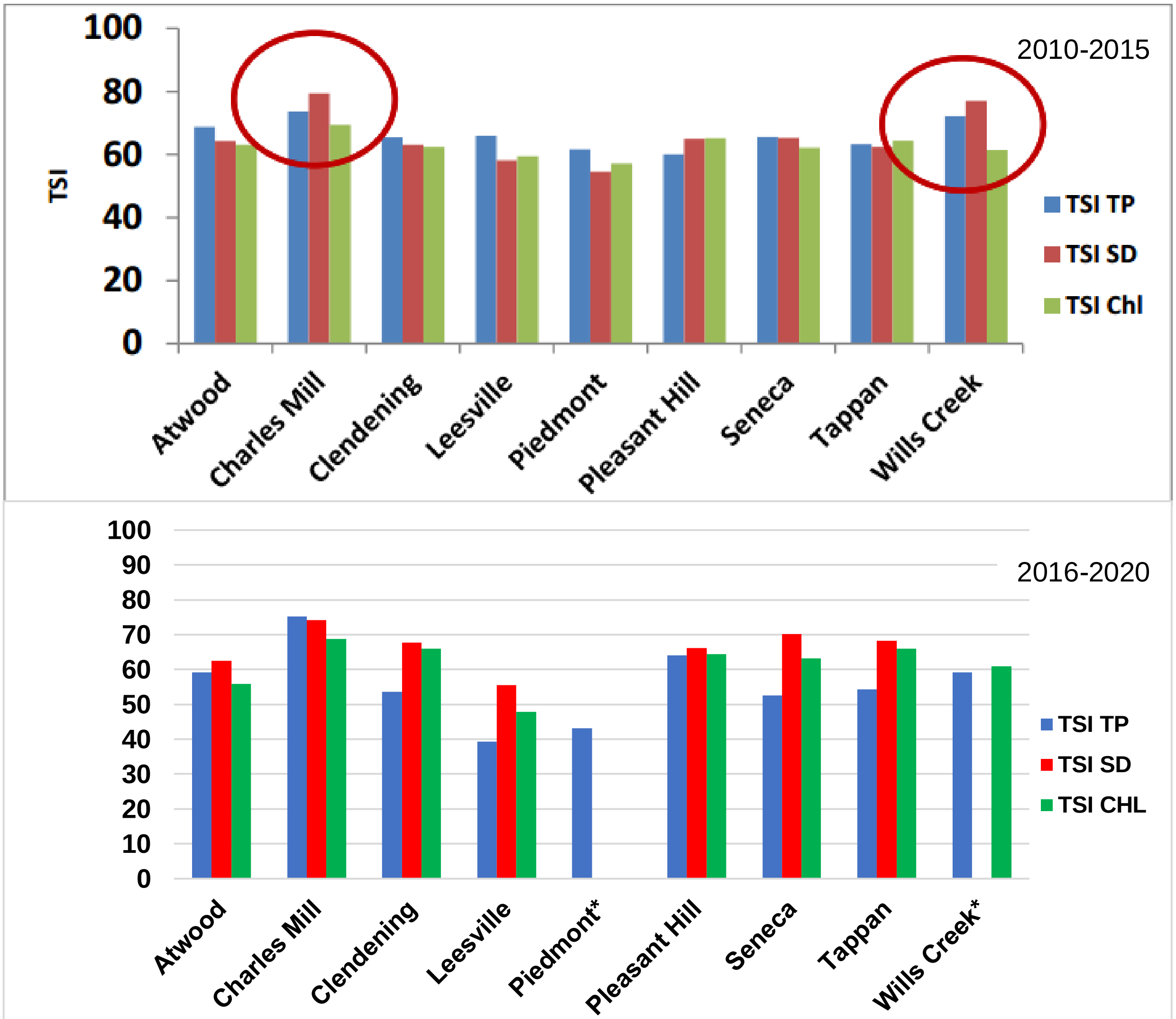
The comparison of average Secchi depth transparency, chlorophyll a, TP, TN, and their calculated Trophic State Index (TSI) values for MWCD Lakes is displayed in Table 4-1, and compares the results of the first report (2010-2015) to the next 5-year period (2016-2020). Secchi depths were recorded between April-October. Chlorophyll a, TP, and TN were sampled between June-October.

The relationship between TSI variables in MWCD Lakes from 2010-2015 (Figure 4 from Carlson, 2015; top) is compared to the the current time period (2016-2020, bottom) in Figure 4-1. Piedmont (SD and CHL) and Wills Creek (SD) were not sampled in the 2016-2020 time period. Conditions at sampled lakes were interpreted following guidance from the TSI relationship table from Carlson and Simpson (1996). Pleasant Hill 2016-2020 TSI values are relatively comparable to each other and to the 2010-2015 time period, which continues to imply that the nutrient–chlorophyll-transparency is probable at this lake (Carlson, 2015). At Charles Mill, TSI TP and TSI SD values track and are higher than TSI CL, which continues to suggest that the lake has suspended sediment. Atwood also appears to have more transparency explained by sedimentation compared to the previous 5-year period. Clendening, Leesville, Seneca, and Tappan have shifted to a condition where TSI SD and TSI CL are both greater than TSI TP, which suggests that algae growth may have contributed to lower levels of phosphorus observed in these lakes. Average TP was particularly low in 2016-2020, (Table 4-1) with the average at or just above the detection limit of 0.01 mg/L (up to 0.03 mg/L). It is likely that these results are reflective of the algal blooms that occurred in 2016-2017 (see Section 4.5.2).

Table 4-1. Comparison of Average Secchi Depth Transparency, Chlorophyll a, Total Phosphorus, Total Nitrogen, and TSI values for MWCD Lakes between 2010-2015 and 2016-2020

	Average SD (m)		Chlorophyll a (mg/m^3)		Total Phosporus (mg/L)		Total Nitrogen (mg/L)	
Lake	2010-2015	2016-2020	2010-2015	2016-2020	2010-2015*	2016-2020	2010-2015*	2016-2020
Atwood	0.74	0.85	27.5	13.09	0.09	0.05	0.73	0.57
Charles Mill	0.26	0.37	52.3	48.95	0.12	0.14	1.82	1.65
Clendening	0.81	0.59	25.6	36.82	0.07	0.03	0.03	0.90
Leesville	1.14	1.37	19.1	5.83	0.07	0.01	0.63	0.42
Piedmont	1.46	NM	15.0	NM	0.05	0.01	0.86	0.39
Pleasant Hill	0.71	0.65	33.7	31.69	0.05	0.06	1.05	1.16
Seneca	0.70	0.49	24.9	27.53	0.07	0.03	0.42	0.62
Tappan	0.85	0.56	31.4	36.56	0.06	0.03	0.52	0.87
Wills Creek	0.31	NM	23.2	21.96	0.11	0.05	0.34	0.75
_	TSI SD		TSI CHL		TSI TP		TSI TN	
Lake	2010-2015	2016-2020	2010-2015	2016-2020	2010-2015	2016-2020	2010-2015	2016-2020
Atwood	64.3	62.4	63.1	55.8	68.7	59.2	49.9	46.4
Charles Mill	79.5	74.2	69.4	68.8	73.7	75.2	63.1	61.7
Clendening	63.1	67.7	62.4	66.0	65.5	53.7	54.6	52.9
Leesville	58.1	55.5	59.5	47.9	66.1	39.3	47.8	41.9
Piedmont	54.5	NM	57.2	NM	61.7	43.1	52.3	40.8
Pleasant Hill	64.9	66.2	65.1	64.5	60.0	64.1	55.1	56.6
Seneca	65.2	70.3	62.1	63.1	65.6	52.6	41.8	47.6
Tappan	62.4	68.3	64.4	65.9	63.3	54.3	45.1	52.4
Wills Creek	76.9	NM	61.4	60.9	72.2	59.2	39.1	50.3

NM = Not Measured
*Data corrected to mg/L compared to Carlson, 2015



*SD and CHL not sampled at Piedmont, SD not sampled at Wills Creek, in 2016-2020.

Figure 4-1. Comparison of the relationship of TSI index values in the MWCD lakes from 2010-2015 (top) to 2016-2020 (bottom).

4.2 TRANSPARENCY (SECCHI DEPTH)

A comparison of average transparencies of the MWCD lakes between the 2010-2015 and 2016-2020 time periods is listed in Table 4-1 and illustrated in Figure 4-2. Atwood, Charles Mill, and Leesville increased in average transparency (became clearer) since 2010-2015 by 0.11 to 0.23 meters (m). Clendening, Seneca, and Tappan decreased in average transparency (became less clear) by 0.21-0.29 m. Piedmont and Wills Creek were not measured in the 2016-2020 time period. Of those lakes measured, Leesville was the most transparent lake (1.37 m) and Charles Mill the least transparent (0.33 m). Leesville experienced the greatest gain in transparency (0.23 m increase), and Tappan the greatest loss in transparency (0.29 m decrease) between the two time periods.

Figure 4-3 compares the Secchi depth rankings of MWCD Lakes to other lakes in Ohio based on Clam-monitored data from 1989-2020. Lakes maintained by MWCD and monitored by CLAM Lake Keepers under contract with OLMS are indicated in red. MWCD Lakes rankings have not changed drastically compared to other Ohio lakes since 2015 (Figure 4-3 has been stretched to include all lake names compared to figure 3 in Carlson, 2015). While Atwood, Clendening, Pleasant Hill, and Tappan have changed ranks relative to each other, the range of difference between these lakes is within 0.2 m (or roughly 8 inches).

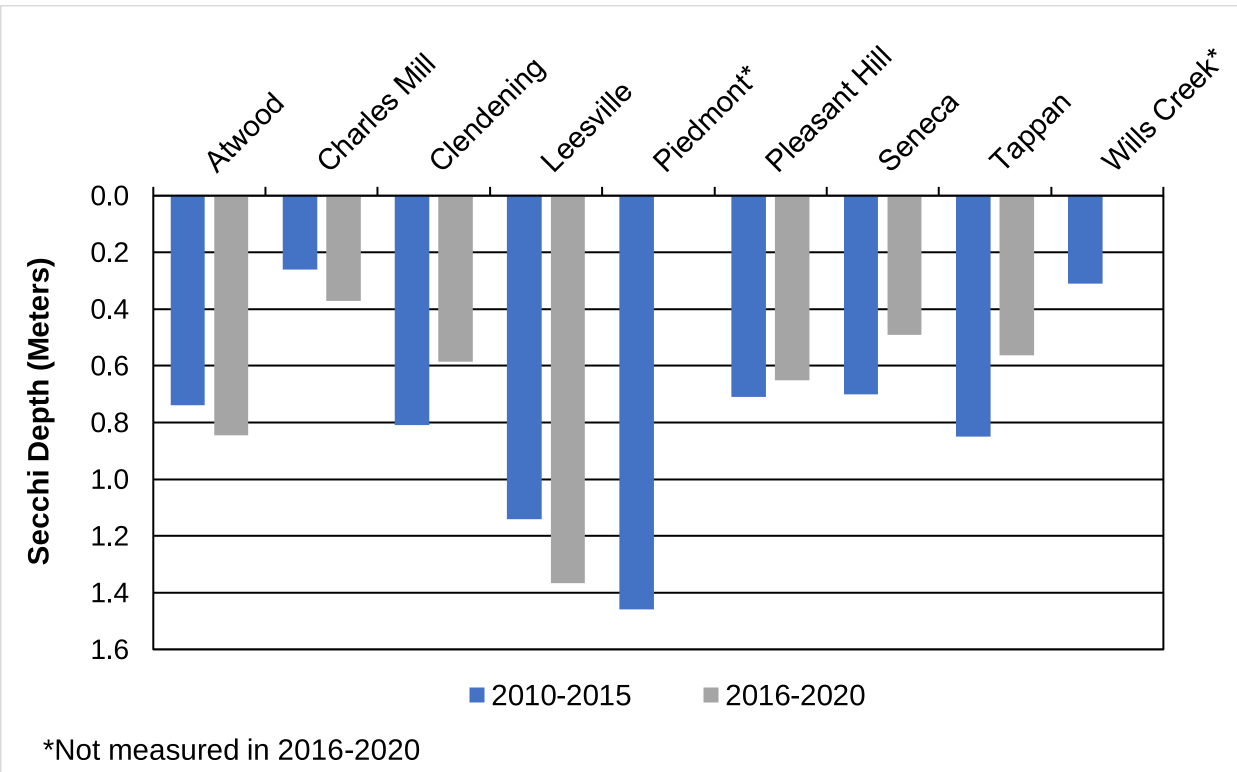


Figure 4-2. Comparison of Average Transparencies of MWCD Lakes between 2010-2015 and 2016-2020.

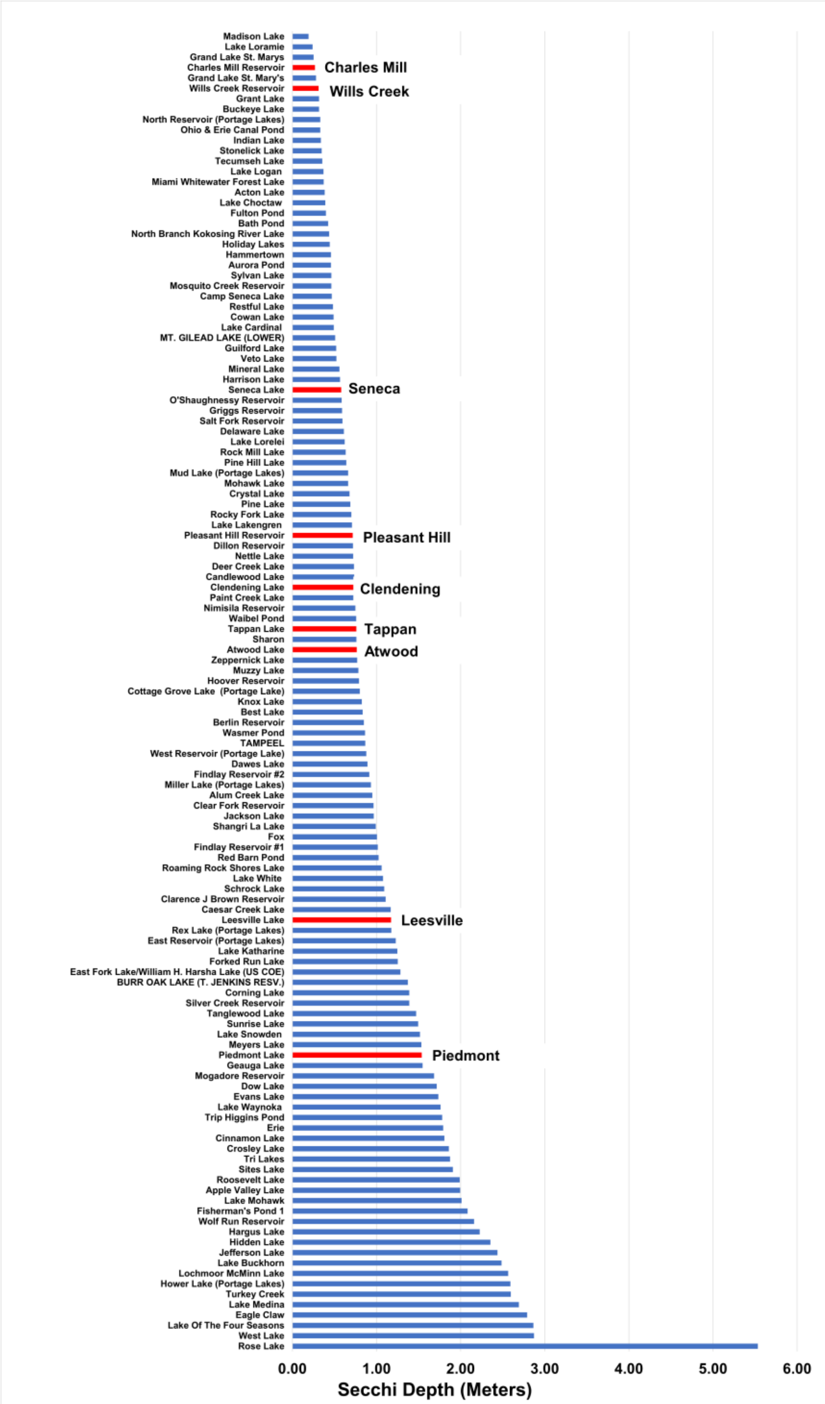


Figure 4-3. Average Transparencies of Ohio lakes (1989-2020) based on CLAM-monitored Data.

4.2.1 Trends in Transparency

The transparency trends for each of the MWCD Lakes are illustrated in Figure 4-4 as the average for each year, from 1991-2020. Sample months ranged from April to October. The solid blue line represents the average transparency from 1991-2015, and the solid red line represents new measurements since the previous report (2016-2020). The dashed blue line represents the previously reported average transparency from 1991-2015 (Carlson, 2015), and the dashed yellow line represents the new average transparency. The black line is the linear regression trend line. Compared to figure 5 of Carlson (2015), Clendening has been newly plotted. Piedmont and Wills Creek were not sampled in 2016-2020, therefore their graphs have not changed.

Of all the MWCD Lakes, only Charles Mill trends towards an increase in transparency, and in recent years having increased from 0.27 m in 2015 to 0.39 m in 2019, and with an increase in overall average transparency from 0.29 m (dashed blue line) to 0.30 m (dashed yellow line). Atwood and Pleasant Hill have relatively stable transparencies since the 90s compared to Leesville, Seneca, and Tappan, which are more strongly trending towards a decrease in transparency. Although Leesville continues to trend towards less transparency over time since 1993, measurements since 2016 were high enough to raise the average transparency over time from 1.27 m (dashed blue line) to 1.29 (dashed yellow line), indicating that the rate of increase is slightly less severe compared to the previous report. Average transparencies at Seneca and Tappan have decreased by 0.09 m and 0.05 m respectively since 2015. While Clendening only has data averages from five years, the recent trend appears to be strongly decreasing in transparency, having decreased from 0.69 m in 2012 to 0.43 m in 2017.

*Secchi Depth not sampled at Piedmont, Wills Creek, from 2016-2020.

Figure 4-4. Transparency Trends in MWCD Lakes from 1991-2020 Yearly Averages.

4.3 FIELD PARAMETERS

4.3.1 Water Color

Water color at MWCD Lakes has been measured between 1991 and 2020, during the months of April-October. Table 4-2 displays the average water color for each lake for the given year and approximates the color on the Custer Color Strip from 1-11. Since 2015, the average water color for MWCD lakes has been recorded from between 1.47-3.69 except for four instances. Charles Mill (5.13 in 2019 and 5.75 in 2020), while darker than the other lakes by comparison, is not outside its typical range since 1995 (2.45-5.85). Leesville had two years of high average water color compared to its historical range (5.33 in 2016 and 5.10 in 2020). These values corresponded with rainfall, flooding, and higher lake levels (2-6 feet higher) seen at the lake; damaging weather events and early season flooding are likely affecting recent high water color at Leesville (Susan James, personal communication). In general, Atwood, Leesville (except for 2019-2020), and Pleasant Hill appear to have improved water color (more transparent) since the 90s. Clendening, Piedmont, Seneca, and Tappan measurements since 2010 indicate an average water color range of 2-4. Wills Creek has the highest water color values of all MWCD lakes (5.42-7.42) since 2010.

Table 4-2 Average Watercolor of MWCD Lakes from 1991-2019.

Lake	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Atwood	4.60	4.85	4.80	4.60	2.00	4.80	5.25	2.67	3.69	4.00	2.90	2.63	2.83	2.00		2.17		2.00	3.50	3.42	2.32	2.44	2.00	2.11		1.95	3.00	3.69	
Charles Mill					4.89	5.16	5.57	4.89	4.84	5.34	4.60	5.77	5.85	4.58	3.78	5.50	4.88		3.75	4.94	4.72	5.00	4.63	3.08	2.45			5.13	5.75
Clendening																			2.00	2.67	2.13				2.00	2.00			
Leesville			2.00	2.00	2.00	2.00	2.00	2.00	3.34	3.37	2.93	2.33	2.40	2.40	3.45		2.80		2.81	2.21	1.54	1.33	1.46	1.83	1.47	2.38	2.00	5.33	5.10
Piedmont								3.25	3.20										2.00	2.00	2.63		2.00	2.00					
Pleasant Hill	6.00	4.00	4.42	3.43	6.67	3.77	4.19	4.55	4.34	4.59	3.97	4.28	4.70	4.36	4.09	3.50	4.42		2.00	2.00	2.00	2.00	2.00	2.25	2.00	2.40	2.00	2.43	2.00
Seneca									1.33										2.00	4.00			2.17	2.00	2.17			3.83	2.00
Tappan		7.00	6.00						2.67										2.12	2.00	3.00	3.00	2.00	2.00				2.00	2.50
Wills Creek									2.50	3.33	3.44								5.42	5.83		7.42	5.89						

4.4 NUTRIENTS

Trend analyses from CLAM data averages for total phosphorous, total nitrogen, TKN, and NO_2-NO_3 are displayed for each MWCD Lake (Figure 4-5). Non-detect values were included in trend analysis as half the detection limit.

4.4.1 Total Phosphorus

Total phosphorus was measured from MWCD Lakes during the months of June-October between 2014-2020. Concentrations of average TP ranged from 0.0015 mg/L to 0.159 mg/L in all MWCD Lakes. Leesville and Piedmont had the lowest recorded TP (0.02 mg/L or less), which remained low across all years. By comparison, average concentrations from Clendening, Seneca, and Tappan fluctuated around 2-3 times higher, and averaging below 0.06 mg/L since 2014. Atwood, Charles Mill, Pleasant Hill, and Wills Creek have had TP fluctuations nearly 5-8 times as high, with maximums between 0.11 mg/L (Wills Creek 2014) and 0.159 mg/L (Charles Mill 2014) since 2014.

According to the Ohio Water Quality Standards (Ohio EPA, 2022) OAC Chapter 3745-1-37 Water quality criteria for recreation use designations and aesthetic conditions, TP:

"…shall be limited to the extent necessary to prevent nuisance growths of algae, weeds, and slimes that result in a violation of the water quality criteria set forth in paragraph (E) of rule 3745-1-04 of the Administrative Code or, for public water supplies, that result in taste or odor problems. In areas where such nuisance growths exist, phosphorus discharges from point sources determined significant by the director shall not exceed a daily average of one milligram per liter as total P, or such stricter requirements as may be imposed by the director in accordance with the international joint commission (United States-Canada agreement)."

According to Table 6-3 of the NLA 2017 Technical Support Document (USEPA, 2022a), which has been provided in Appendix A, TP 75^{th} (good-fair) and 95^{th} (fair-poor) percentiles for the NAP Ecoregion benchmarks are 16 ug/L (0.016 mg/L) and 27.9 ug/L (0.0279 mg/L) respectively. For the SAP Ecoregion, benchmarks are 18 ug/L (0.018/L) and 33 ug/L (0.033 mg/L) respectively. Compared to these criteria, roughly half of all CLAM measurements since 2014 score in the "poor" range (Appendix B). The comparison is not surprising; in the SAP region, the NLA reports 77% of lakes scored "poor" compared to reference sites (USEPA, 2022b). Notably, Leesville and Piedmont typically scored in the "good" range.

4.4.2 Total Nitrogen

Total nitrogen was measured from MWCD Lakes during the months of June-October between 2014-2020. Concentrations of average TN ranged from 0.05 mg/L to 2.075 mg/L across all lakes. In general, average concentrations from Atwood, Leesville, Piedmont, Seneca, and Tappan remain below 0.97 mg/L since 2014. Average concentrations at Charles Mill, Clendening, Pleasant Hill, and Wills Creek have fluctuations roughly 1.5 to 2 times higher, with maximums between 1.3 mg/L (Clendening 2018) and 2.075 mg/L (Charles Mill 2018) since 2014. All lakes experienced an upward trend in TN between 2016 and 2017. Pleasant Hill and Wills Creek trended downward by 2018 and continued this trend through 2020 by 70% and 64% respectively. Charles Mill and Clendening average concentrations peaked in 2018 and then trended downward through 2020 by 35% and 40% respectively. By comparison, average TP concentrations at Atwood, Leesville, Piedmont, Seneca, and Tappan experienced slight variations since 2017. Of these, only Tappan TN concentrations remained elevated compared to 2016 and earlier.

The Ohio WQS (Ohio EPA, 2022) does not address TN, but does have standards for NO_2-NO_3, Nitrite-N, and ammonia-nitrogen. Typically, phosphorus is considered to be the more "limiting nutrient" in lakes (USEPA, 2022c).

According to Table 6-3 of the NLA 2017 Technical Support Document (USEPA, 2022a), which has been provided in Appendix A, TN 75^{th} (good-fair) and 95^{th} (fair-poor) percentiles for the NAP Ecoregion benchmarks are 428 ug/L (0.428 mg/L) and 655 ug/L (0.655 mg/L) respectively. For the SAP Ecoregion, benchmarks are 266 ug/L (0.266 mg/L) and 409 ug/L (0.409 mg/L) respectively. Compared to these criteria, roughly over half of all CLAM measurements since 2014 score in the "poor" range (Appendix B). The comparison is not surprising; in the SAP region, 89% of lakes scored "poor" compared to reference sites (USEPA, 2022d).

4.4.3 Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (organic nitrogen + ammonia nitrogen) was measured from MWCD Lakes during the months of June-October between 2017-2020. Average concentrations of TKN ranged from 0.303 mg/L to 2.03 mg/L at all lakes. TKN closely followed TN measurements in all lakes except for Charles Mill and Wills Creek. The total nitrogen is calculated by summing ammonia, organic nitrogen, nitrate, and nitrite (Gibson et al., 2000). At Charles Mill and Wills Creek, the deviation of TKN from TN in those lakes is explained by the higher concentrations of NO_2-NO_3 compared to the other lakes.

4.4.4 NO_2-NO_3

Nitrate-Nitrite (NO_2-NO_3) was measured from MWCD Lakes during the months of June-October between 2017-2020. Average concentrations of NO_2-NO_3 ranged from 0.002 mg/L to 0.04 mg/L at Atwood, Clendening, Leesville, Piedmont, Pleasant Hill, Seneca, and Tappan, with a single exception at Pleasant Hill in 2019 (0.1 mg/L). Average concentrations at Charles Mill ranged from 0.01 mg/L (2020) to 0.52 mg/L (2018), with the maximum average being 12.5 times higher than typically seen at the other MWCD Lakes. At Wills Creek, averages ranged from 0.175 mg/L (2020) to 0.95 mg/L (2017), with the maximum average being more than 20 times higher than other MWCD Lakes.

Nitrate, nitrite, and ammonia are typically found at very low levels in lakes or reservoirs (Gibson et al., 2000); therefore, the higher incidence of NO_2-NO_3 at Charles Mill and Wills Creek suggests these lakes may be experiencing more non-point source loading (such as fertilizer or wastewater) compared to the other MWCD Lakes. The Ohio WQS water quality criterion for NO_2-NO_3 is 10 mg/L (10,000 ug/L), which is the "maximum contaminant level (MCL) developed under the "Safe Drinking Water Act."" (Ohio WQS). The highest recorded instance of NO_2-NO_3 in MWCD Lakes occurred in Charles Mill, June 2018, at 2.6 mg/L (data not shown), which is still below the water quality criterion for safe drinking water.

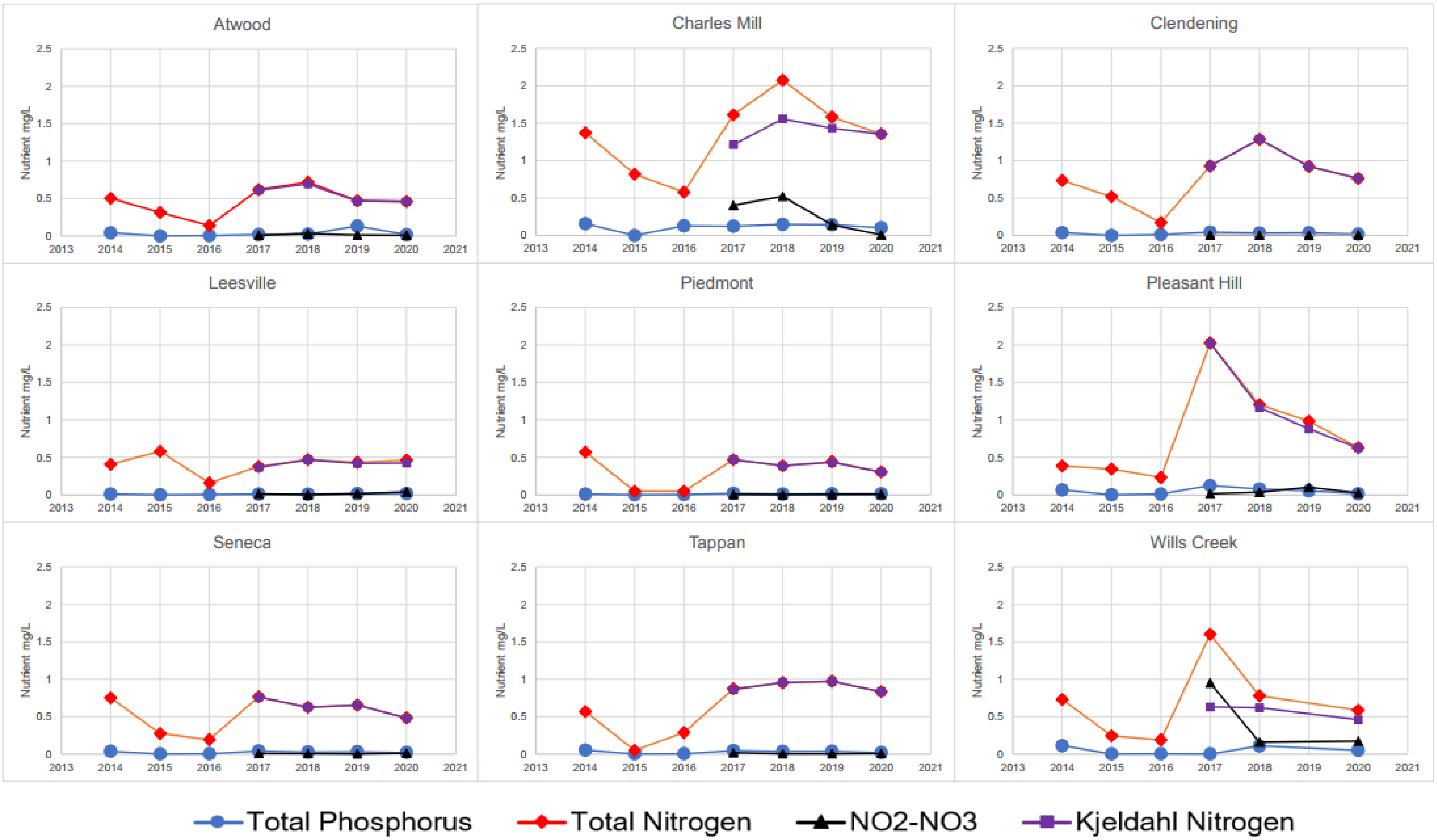


Figure 4-5. Yearly Average Trends in Total Phosphorus, Total Nitrogen, NO_2-NO_3, and Kjeldahl Nitrogen for MWCD Lakes. All measurements are in mg/L.

4.5 CYANOBACTERIA

This section describes the elements of harmful algal blooms ("HABs"), microcystin levels and cyanobacterial community composition, from MWCD Lakes. Figure 4-6 compares monthly maximum microcystin concentrations between the first report (Carlson, 2015) and from 2016-2020, Table 4-3 details the incidence of microcystin detection from 2016-2020, and Table 4-4 lists the maximum concentration of microcystin for each year from 2016-2020. Figure 4-7 displays the monthly maximum cyanobacterial density in each lake between 2014-2020. The relative abundance of cyanobacteria is displayed in Figure 4-8, cyanobacterial species richness (or number of species identified) in Table 4-5, and trends of dominant cyanobacterial taxa from each lake in Figure 4-9. Table 4-6 compares the percentage of cyanobacteria to other groups of algae seen in HAB samples in 2018.

4.5.1 Microcystin

From 2016-2020, microcystin was measured from MWCD Lakes during the months of June through October. Figure 4-6 compares the maximum concentrations of microcystin reported from Carlson (2015; left) to the maximum concentrations during 2016-2020 (right). In general, the maximum concentrations of microcystin have remained low at Atwood, Clendening, Leesville, and Pleasant Hill. Of these lakes, the highest incidence occurred at Pleasant Hill in June of 2018 (0.29 ug/L). At Piedmont, a single higher concentration of microcystin was recorded in July of 2014 compared to other months (1.25 ug/L). Since this time, the concentration of microcystin at Piedmont has been recorded at levels roughly 10 times lower or less, with the second highest incidence seen during September of 2020 (0.15 ug/L). At Wills Creek, higher incidence of microcystin was recorded during the months of July (0.47 ug/L, 2019) and August (0.97 ug/L, 2016) compared to prior years (0.19 ug/L or less). Tappan had the highest concentration of microcystin compared to all lakes in 2014-2015, with the maximum concentration recorded from July of 2014 (5.12 ug/L). Tappan continued to have elevated microcystin concentrations in the 2016-2020 period compared to other lakes, with a record high of 12.8 ug/L in June of 2016. Of note, June and July of 2016 had elevated levels of microcystin at Tappan compared to other years, with records ranging from 3.1-12.8 ug/L. From 2017-2020, June and July concentrations have ranged from 0.11 ug/L to 2.65 ug/L (range data not shown, maximums per year listed in Table 4-4).

From 2010-2014, there have been no incidences of microcystin exceeding the recreational public health advisory of 6.0 ug/L in any of the MWCD Lakes (Table 2 from Carlson, 2015). Tappan was the only lake that had concentrations between 1-6 ug/L (drinking water advisory), which occurred in 28% of samples. According to the State of Ohio Harmful Algal Bloom Response Strategy for Recreational Waters (2020), the current threshold for microcystin in recreational water is 8 ug/L. From 2016-2020, microcystin concentrations at Tappan were recorded over the 8 ug/L recreational use threshold in 7% of samples and were recorded above the drinking water threshold (1-8 ug/L) in 49% of samples (Table 4-3). All incidences over 8 ug/L occurred in 2016 only, and exceedance of the drinking water threshold occurred in all years since 2016 (Table 4-4). No other MWCD Lakes had microcystin levels that exceeded the drinking water threshold.

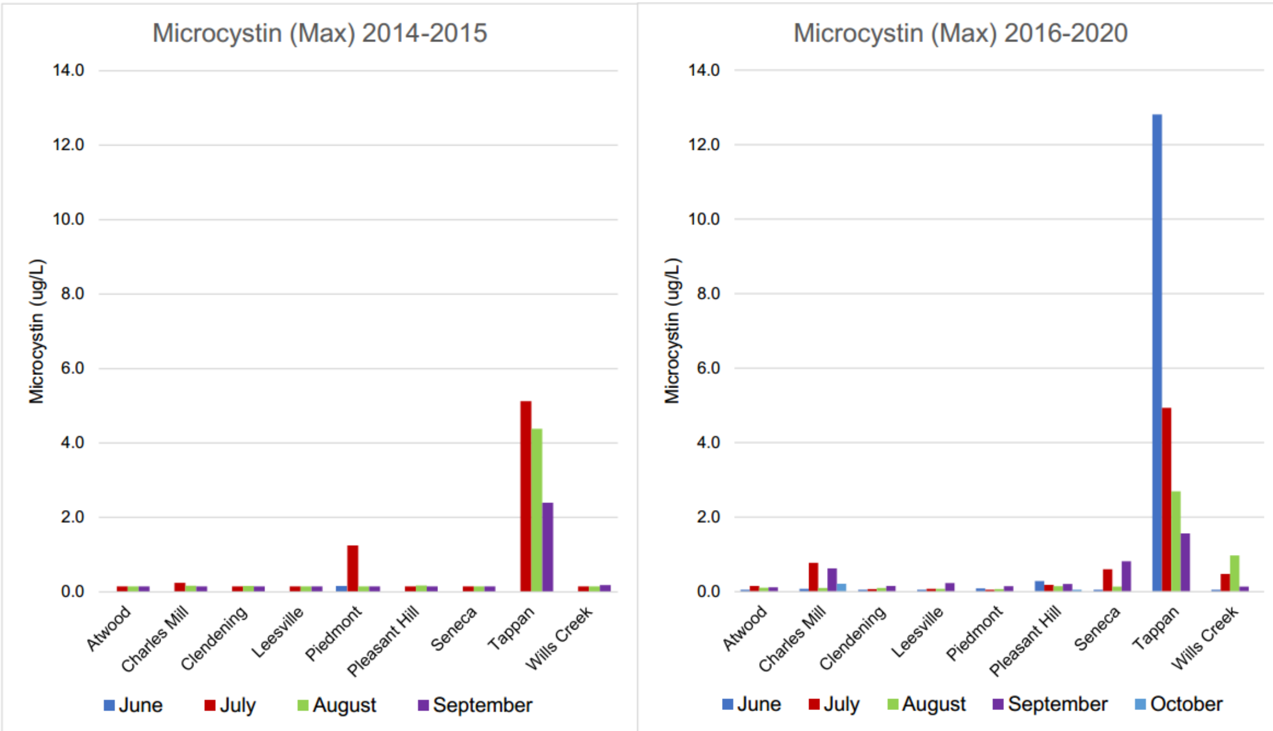


Figure 4-6. Monthly Maximum Concentrations of Microcystin in MWCD reservoirs.

Table 4-3. Incidence of Microcystin found in MWCD Lakes (2016-2020).

				Drinking Water - Do Not Drink 1.0 ug/L	**Recreational Public Health Advisory 8.0 ug/L**
Lake	**Number of Samples**	**<0.15 ug/L**	**<1 ug/L**	**1-8 ug/L**	**>8 ug/L**
Atwood	30	97%	3%	0%	0%
Charles Mill	33	79%	21%	0%	0%
Clendening	29	97%	3%	0%	0%
Leesville	31	90%	10%	0%	0%
Piedmont	23	100%	0%	0%	0%
Pleasant Hill	32	81%	19%	0%	0%
Seneca	34	94%	6%	0%	0%
Tappan	41	7%	37%	**49%**	**7%**
Wills Creek	9	56%	44%	0%	0%

Table 4-4. Maximum concentrations (ug/L) of Microcystin found in the MWCD Lakes (2016-2020).

Lake	2016	2017	2018	2019	2020
Atwood	0.103	0.152	0.050	0.050	0.104
Charles Mill	0.097	0.179	0.100	0.456	0.774
Clendening	0.103	0.050	0.054	0.050	0.153
Leesville	0.068	0.077	0.204	0.066	0.229
Piedmont	0.088	0.050	0.050	0.127	0.147
Pleasant Hill	0.148	0.186	0.287	0.206	0.127
Seneca	0.078	0.104	0.603	0.050	0.821
Tappan	12.809	2.654	1.574	1.082	2.509
Wills Creek	0.970	0.050	0.050	0.477	0.572

4.5.2 Cyanobacterial Community

HAB samples were collected from MWCD Lakes from 2014-2020, during the months of June through September. It should be noted that HAB samples were not collected evenly; therefore, cell densities are difficult to compare fairly considering there may be variation due to the difference in the timing and number of samples collected. For example, at Tappan, only the month of August was sampled from 2017-2019, whereas in 2016 the lake was sampled July, August, and September. While more cyanobacteria were tallied in 2016 due to more sampling, they were captured at a much greater density in 2017. To account for this discrepancy and still visualize a general idea of cyanobacterial activity in the lakes, the sum of the observed monthly densities for each lake was calculated and the maximum total monthly density observed for the year is displayed in Figure 4-7.

A comparatively large algal bloom, in all lakes and to varying degrees, began in 2016 and recurred in 2017, tapering back to near pre-2016 levels from 2018-2020. Clendening, Seneca, Charles Mill, and Tappan saw the highest monthly maximum densities compared to other lakes (from 3 to 7 times those monthly cell densities observed in 2015). This is consistent with results from Figure 4-1 that suggested Clendening, Seneca, and Tappan may reflect generally lower phosphorus concentration in the 2016-2020 period. The timing of the algal bloom also corresponds with the highest microcystin levels seen at Tappan, which occurred in 2016. Charles Mill has comparatively more TP than the other MWCD Lakes. In addition, Charles Mill had more available NO_2-NO_3 (Figure 4-5) compared to the other lakes except Wills Creek. These factors likely contributed to Charles Mill also having high observed densities in 2016-2017. The TSI condition at Leesville also suggested that algal growth at the lake may reflect generally lower phosphorus concentration in the 2016-2020 period (Figure 4-1). Both Leesville and Piedmont had the lowest TP available during the 2016-2020 period, with an average of 0.01 mg/L (Table 4-1), which was about the detection limit. Algal blooms at these lakes were also comparatively the lowest. This result is also consistent with Leesville and Piedmont having the highest transparencies of the MWCD Lakes.

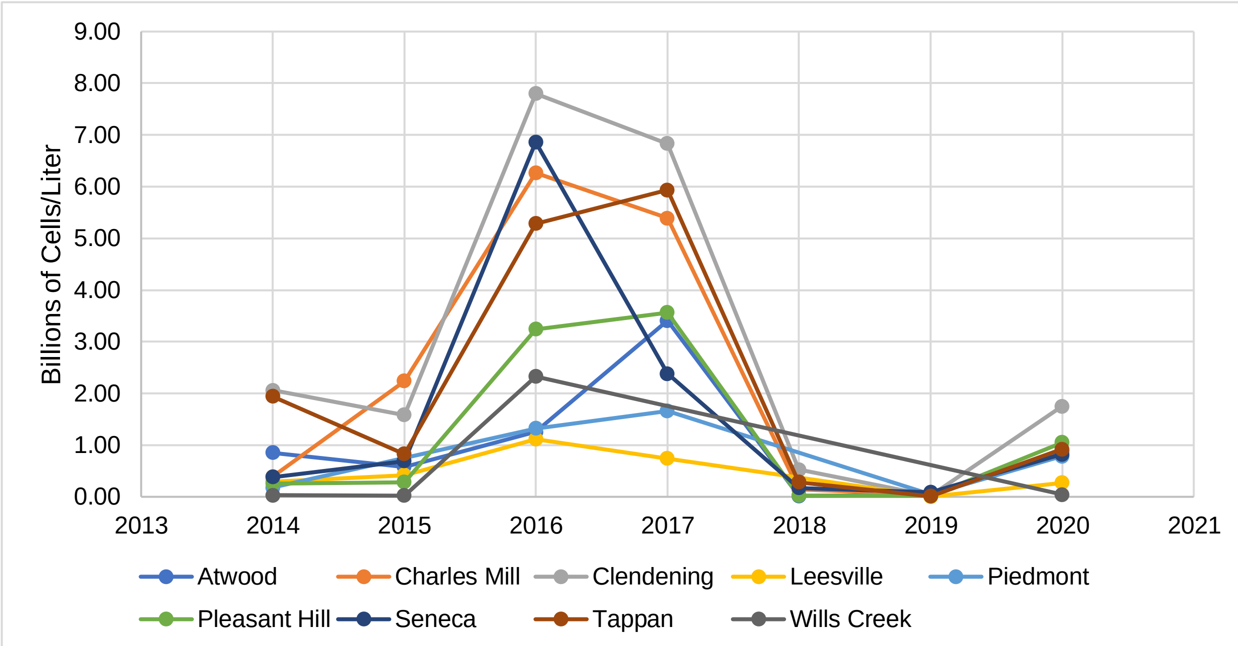
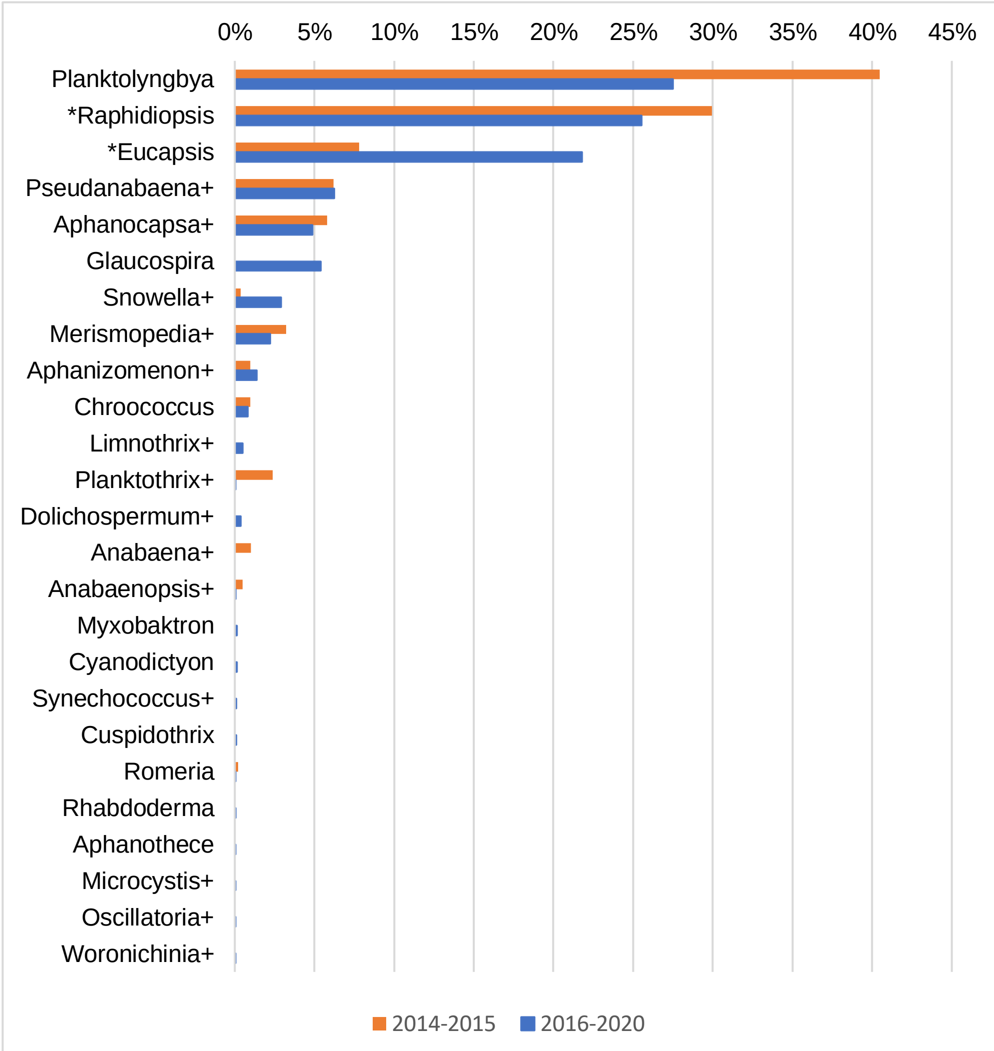


Figure 4-7. Maximum Monthly Density of Cyanobacteria in Billions of Cells/L at MWCD Lakes from 2014-2020

The aggregated percentages (relative abundance) of cyanobacterial genera found in MWCD Lakes is illustrated in Figure 4-8, with results from 2014-2015 in red, and from 2016-2020 in blue. Of note, the genus *Cylindrospermum* has been subsumed into *Raphidiopsis* (Aguilera et al., 2018), and the species *Chroococcus microscopicus* has been moved into the genus *Eucapsis* (Guiry, 2019), since the previous status report. Between the two time periods, *Planktolyngbya* and *Raphidiopsis* remain the dominant genera, although at lower relative abundance compared to the previous time period, at 27.5% and 25.5% respectively. Relative abundance of *Eucapsis* increased to comprise more of the cyanobacterial population, from 7.8% to 21.8%. All other genera comprised less than 10% of the overall population.



***Cylindospermum* subsumed into *Raphidiopsis* (Aguilera et al., 2018), current accepted name of *Chroococcus microscopicus* is *Eucapsis microscopica* (Guiry, 2019).
+ Microcystin production has been documented for these genera (Ohio HAB Response, 2020).

Figure 4-8. Comparison of Relative Abundance of Cyanobacterial Genera Between 2014-2015 and 2016-2020 at all MWCD Lakes.

The number of different cyanobacterial species (specifically, each unique name, or "bench name", used by algal taxonomists) at each lake peaked during the 2016 algal bloom except for Atwood and Charles Mill. Similar to density, species diversity dropped through 2017-2019, to no more than 4 unique species across all sampled lakes by 2019, and trended toward pre-2016 diversity levels by 2020.

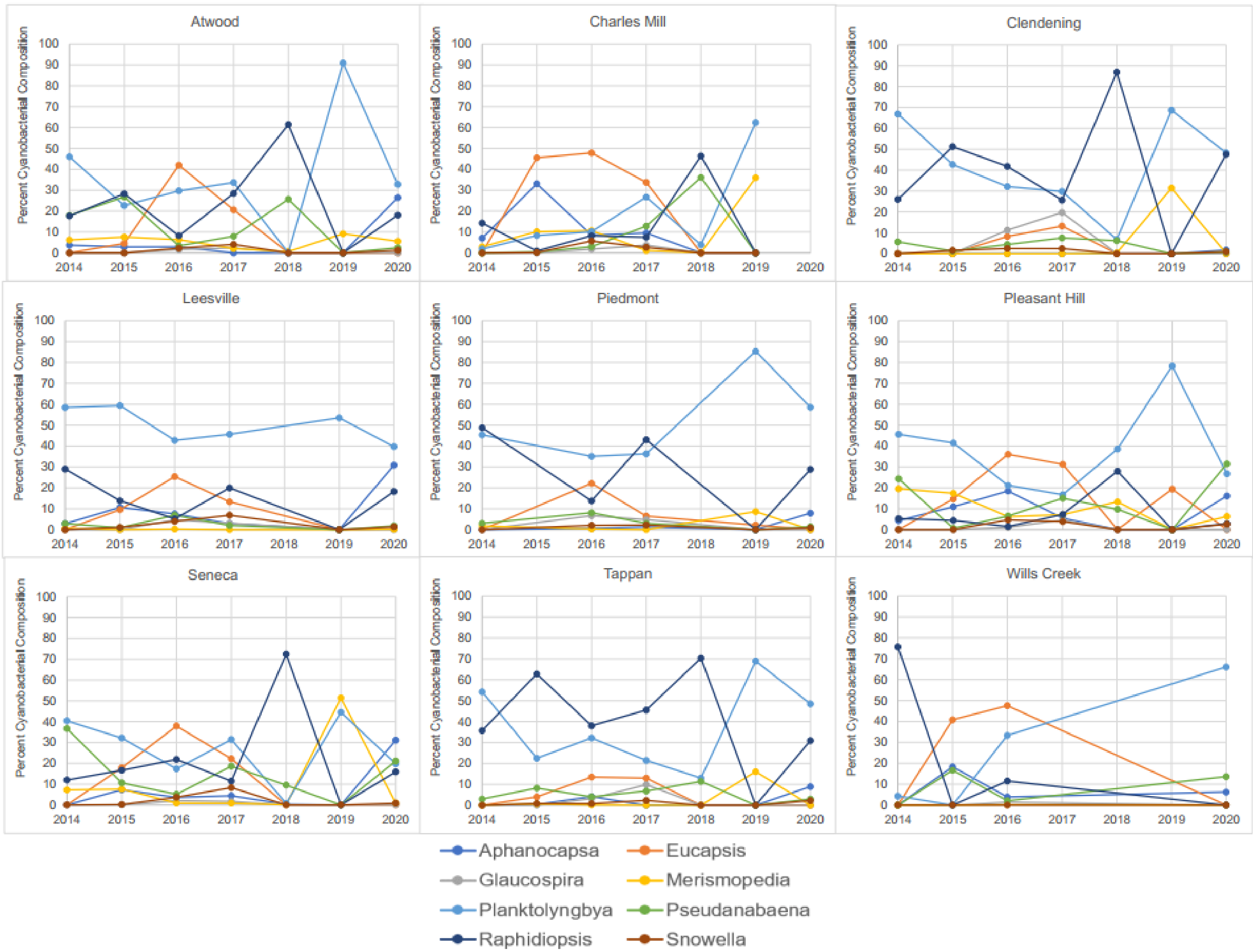
Table 4-5. Number of Different Species (Bench Names) Identified from HAB samples at MWCD Lakes from 2014-2020.

Lake	2014	2015	2016	2017	2018	2019	2020
Atwood	15	16	15	10	5	2	13
Charles Mill	13	12	13	12	8	4	
Clendening	10	11	13	10	7	2	12
Leesville	16	10	24	12	3	2	12
Piedmont	10		16	12		4	11
Pleasant Hill	10	10	27	14	9	3	12
Seneca	12	21	22	11	12	3	14
Tappan	17	13	22	8	11	4	10
Wills Creek	6	4	9				5

Relative abundance of the top eight cyanobacterial genera identified from MWCD Lakes were plotted over time to see if any trends or patterns corresponded with their dominance (Figure 4-9). In general, the top three genera (*Planktolyngbya, Raphidiopsis,* and *Eucapsis*) alternately dominated the lakes over time except in Leesville, where *Planktolyngbya* was dominant in all years. *Eucapsis* tended to peak in either 2016 or 2017. Lakes that were sampled in 2019 saw a drop-off of *Raphidiopsis* and increase in *Planktolyngbya*.

The genera marked with "+" in Figure 4-8 have been documented as capable of producing microcystin, according to Table B1 in the Ohio 2020 HAB Response Strategy (Ohio EPA, 2020), and has been provided in Appendix C. Of these, *Pseudanabaena*, *Aphanocapsa*, *Snowella*, and *Merismopedia* were in the top eight genera across the lakes. Their relative abundances do not appear to correspond to elevated levels of microcystin (nor those of other genera), particularly at Tappan in 2016; however, it should be noted that HABs at Tappan were not sampled until July of 2016 at Tappan, whereas the highest levels of micocystin were detected in the earlier half of June.

In August of 2018, all groups of algae were identified from HAB samples (Table 4-6). Cyanobacteria comprised upwards of 80% of HAB samples at all MWCD Lakes, followed by cryptophytes at Atwood and Seneca (11.8% and 9.4% respectively) and by diatoms at Charles Mill (10.4%).



Charles Mill not sampled in 2019, 2020; Leesville and Piedmont not sampled 2015, 2018; Wills Creek not in sampled 2017, 2018, 2019.

Figure 4-9. Relative Abundance of Dominant Cyanobacterial Genera in MWCD Lakes from 2014-2020.

Table 4-6. Percent Algal Group Community in Near-shore Samples in MWCD Lakes, August 2018.

Lake	Cyanobacteria	Cryptophytes	Diatom	Dinoflagellates	Euglenoids	Green Algae	Yellow-Green Algae
Atwood	84.9%	11.8%	1.4%	0.0%	0.5%	1.2%	0.1%
Charles Mill	82.2%	0.6%	10.4%	0.0%	2.4%	4.1%	0.3%
Clendening	95.5%	2.9%	0.0%	0.1%	0.0%	1.5%	0.0%
Leesville	92.2%	0.0%	3.7%	1.3%	2.0%	0.7%	0.0%
Pleasant Hill	97.1%	0.0%	1.8%	0.0%	0.2%	0.9%	0.0%
Seneca	86.7%	9.4%	2.3%	0.0%	0.4%	1.1%	0.1%
Tappan	95.5%	3.6%	0.0%	0.0%	0.0%	0.8%	0.0%

5.0 SUMMARY AND RECOMMENDATIONS

5.1 TSI VALUES

Between the two time periods (2010-2015 and 2016-2020), the relationship between TSI values at Pleasant Hill are relatively comparable, suggesting no overall change in lake condition since 2015. TSI values at Charles Mill also suggest no change (has suspended sediment) since 2015. Atwood TSI values suggest suspended sediment explains more of the transparency since 2015. Clendening, Leesville, Seneca, and Tappan have shifted to a condition where algae may be responsible for lower TSI TP values seen in the 2016-2020 time period. The shift corresponds with algal blooms that occurred in 2016-2017.

5.2 TRANSPARENCY

Since 2015, Atwood, Charles Mill, and Leesville increased in average transparency and Clendening Seneca, and Tappan decreased in average transparency. Of lakes measured, Leesville remains the most transparent lake and Charles Mill the least transparent. For the current 5-year period, Leesville experienced the greatest gain in transparency, and Tappan the greatest loss. Based on measurements since 1991, the only lake trending towards an increase in transparency is Charles Mill. Atwood and Pleasant Hill have had relatively stable transparencies. Leesville, Seneca, Tappan, and Clendening are more strongly trending toward decreasing transparency.

5.3 WATER COLOR

Since the 1990s, Leesville, Atwood, and Pleasant Hill appear to have improved water color, except for 2019-2020 at Leesville due to damaging weather events. Clendening, Piedmont, Seneca, and Tappan measurements since 2010 indicate an average water color range of 2-4. Charles Mill continues to be darker than the other lakes by comparison, and recent measurements were not outside its typical range since 1995. Wills Creek has the highest water color values since 2010.

5.4 NUTRIENTS

Since 2014, TP concentrations have remained the lowest at Leesville and Piedmont (0.02 mg/L or less). By comparison, Clendening, Seneca, and Tappan had TP concentrations the fluctuated around 2-3 times higher; Atwood, Charles Mill, Pleasant Hill, and Wills Creek had TP fluctuations nearly 5-8 times higher. For TN, average concentrations from Atwood, Leesville, Piedmont, Seneca, and Tappan remained below 0.97 mg/L since 2014. By comparison, average concentrations at Charles Mill, Clendening, Pleasant Hill, and Wills Creek have fluctuations roughly 1.5 to 2 times higher. TKN closely followed TN measurements in all lakes except Charles Mill and Wills Creek, the deviation of which is explained by higher concentrations of NO_2-NO_3 in these lakes, with maximum concentrations at 12.5 times and 20 times higher respectively.

While specific TP and TN criterion are not addressed in the Ohio WQS, MWCD lakes score "poor" in roughly half the samples when compared to levels set by the NLA. USEPA has since developed nutrient-chlorophyll models in August of 2021 (USEPA, 2021c), which are available in an online tool that computes varying TP and TN criteria based on targeted lake chl a concentration and lake characteristics (USEPA, 2020). Adding dissolved organic carbon to the data collection would allow for the use of this tool.

Compared to other lakes, NO2-NO3 levels were elevated at Charles Mill and Wills Creek, though these levels were below the water quality criterion for safe drinking water. Both these lakes also have higher water color scores, and notably high sediment (Carlson, 2015). These lakes may be receiving more non-point source loading compared to other lakes. Wills Creek also has more agricultural surrounding land use (11.24%) compared to other lakes.

5.5 MICROCYSTIN

Exceedances of the 8 ug/L recreational use threshold of microcystin at Tappan occurred during the bloom in 2016. Increased levels of microcystin did not appear to track with any specific cyanobacterial genera. This could be due to the presence of specific cyanobacterial strains containing the gene for producing microcystin being more present at Tappan, or an outlying environmental factor affecting the cyanobacteria that could induce microcystin production at Tappan compared to the other lakes.

5.6 CYANOBACTERIA

An algal bloom occurred in 2016-2017, which was evidenced by the rise in cyanobacterial cell densities and phosphorus-limiting lake conditions in several of MWCD Lakes, most notably at Clendening, Seneca, and Tappan and Charles Mill also saw a rise in cyanobacteria densities, and except for Charles Mill, may reflect generally lower phosphorus concentrations in the 2016-2020 period. By comparison, low phosphorus levels coincided with limited algal growth at Leesville and Piedmont. Species diversity increased with an increase of cyanobacterial density. Average rainfall was also the lowest at the lakes during 2016, ranging from 36-43 inches for the 2016-2020 time period, and likely influenced increased levels of cyanobacteria and microcystin observed in 2016.

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Appendix A

Table 6-3 from the NLA 2017 Technical Support Document

Table 6-3. NLA 2017 good, fair, and poor benchmarks (75th/95th percentiles) for TP, TN, CHLA, and turbidity condition classes.

Ecoregion	TP (µg/L) 75th Good-fair	TP (µg/L) 95th Fair-poor	TN (µg/L) 75th Good-fair	TN (µg/L) 95th Fair-poor
CPL	43.0	59.5	659	923
NAP	16.0	27.9	428	655
NPL	63.0	82.0	849	1,620
SAP	18.0	33.0	266	409
SPL-manmade	30.0	43.0	650	830
SPL-natural	486	839	7,840	11,100
TPL	38.4	57.5	865	1,350
UMW	24.8	40.0	766	926
WMT	23.4	43.0	253	429
XER	44.0	84.8	605	954

Ecoregion	CHLA (µg/L) 75th Good-fair	CHLA (µg/L) 95th Fair-poor	Turbidity (NTU) 75th Good-fair	Turbidity (NTU) 95th Fair-poor
CPL	12.7	28.0	3.42	4.15
NAP	4.52	8.43	1.30	2.52
NPL	10.9	19.3	3.08	4.46
SAP	5.54	13.1	2.83	4.21
SPL-manmade	8.97	12.6	3.32	4.67
SPL-natural	118	219	71.3	86.4
TPL	13.9	19.8	3.64	4.23
UMW	7.43	14.6	2.18	3.32
WMT	1.86	3.86	0.910	1.60
XER	5.92	9.00	2.97	4.84

Appendix B

Total Number of TP and TN MWCD Samples Categorized by SAP NLA Benchmark

Total Number of TP and TN MWCD Samples Categorized by SAP NLA Benchmark.

	TP			TN		
	Good	**Fair**	**Poor**	**Good**	**Fair**	**Poor**
	<18ug/L	18-33ug/L	>33ug/L	<266ug/L	266-409ug/L	>409ug/L
Year	**Atwood**					
2014	0	0	3	1	0	2
2015	2	0	0	1	0	1
2016	2	1	0	1	0	0
2017	2	3	2	0	1	6
2018	2	1	3	0	3	3
2019	2	1	2	0	0	5
2020	0	2	0	0	1	1
	Charles Mill					
2014	0	0	3	0	0	3
2015	2	0	0	0	0	2
2016	0	0	5	0	0	1
2017	0	0	6	0	0	6
2018	0	0	6	0	0	6
2019	0	0	6	0	0	6
2020	0	0	3	0	0	3
	Clendening					
2014	0	0	3	0	0	3
2015	2	0	0	1	0	1
2016	3	3	0	2	0	1
2017	0	2	4	0	0	6
2018	0	3	3	0	0	6
2019	0	0	4	0	0	4
2020	1	2	0	0	0	3
	Leesville					
2014	3	0	0	1	0	2
2015	2	0	0	0	0	2
2016	7	0	0	1	0	0
2017	5	1	0	0	4	2
2018	6	0	0	2	1	3
2019	3	3	0	0	2	4
2020	0	2	0	0	1	1
	Piedmont					
2014	2	0	0	0	0	2
2015	1	0	0	1	0	0
2016	4	0	0	1	0	0
2017	2	1	1	0	1	3

	TP			TN		
	Good	**Fair**	**Poor**	**Good**	**Fair**	**Poor**
	<18ug/L	18-33ug/L	>33ug/L	<266ug/L	266-409ug/L	>409ug/L
2018	2	1	0	0	2	1
2019	3	2	0	0	1	4
2020	1	2	0	1	1	1
	Pleasant Hill					
2014	0	0	2	1	0	1
2015	3	0	0	1	0	2
2016	3	1	2	2	1	0
2017	0	0	6	0	0	6
2018	0	0	6	0	0	6
2019	0	0	6	0	0	6
2020	2	1	0	0	0	3
	Seneca					
2014	1	0	2	0	0	3
2015	2	0	0	1	0	1
2016	4	0	2	2	0	0
2017	1	1	4	0	0	6
2018	2	1	3	0	2	4
2019	0	3	3	0	0	6
2020	0	2	0	0	1	1
	Tappan					
2014	0	1	2	1	0	2
2015	2	0	0	2	0	0
2016	4	2	0	1	1	0
2017	0	1	6	0	0	7
2018	0	2	4	0	0	6
2019	0	2	4	0	0	6
2020	0	2	0	0	0	2
	Wills Creek					
2014	0	0	2	1	0	1
2015	2	0	0	1	0	1
2016	1	0	1	1	0	0
2017	1	0	0	0	0	1
2018	0	0	1	0	0	1
2020	0	1	1	0	1	1
Grand Total	87	50	112	27	24	168

Appendix C

Table B1 from the Ohio Harmful Algal Bloom Response Strategy for Recreational Waters

Table B1. Cyanobacteria and Their Associated Cyanotoxins

Cyanobacterial Genera	Hepatotoxins		Neurotoxins	
	CYLINDROSPERMOPSIN	MICROCYSTINS	ANATOXIN	SAXITOXINS
Anabaena (Dolichospermum)	x	x	x	x
Anabaenopsis		x		
Aphanizomenon (Cuspidothrix)	x	x	x	x
Aphanocapsa		x		
Arthrospira		x	x	
Chrysosporum	x			
Cylindrospermum	x		x	x
Fischerella		x		
Gloeotrichia		x		
Leptolyngbya (Plectonema)		x		
Limnothirix		x		
Lyngbya (Microseira)	x	x		x
Merismopedia		x		
Microcystis		x		
Nostoc		x		x
Oscillatoria (Planktothrix)	x	x	x	x
Phormidium (Anagnostidinema, Geitlerinema, Microcoleus)		x	x	x
Pseudanabaena		x		
Raphidiopsis (Cylindrospermopsis)	x		x	x
Scytonema		x		
Snowella		x		
Synechococcus		x		
Synechocystis		x		
Umezakia	x			
Woronichinia		x	x	

Information adapted from Jennifer Graham (USGS) with cyanotoxin production documented by Bernard et al., 2017; Chapman and Foss, 2019; Huang and Zimba, 2019.