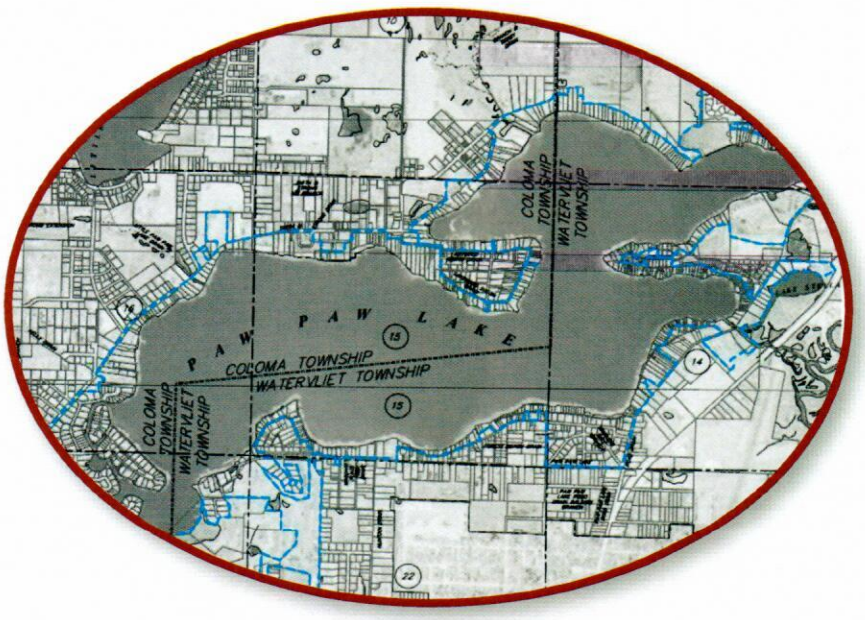
PAW PAW LAKE ANNUAL WATER QUALITY REPORT

2017 FINAL REPORT



PREPARED FOR:

PAW PAW LAKE IMPROVEMENT BOARD

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Spicer Group, Inc (Spicer) and GEI Consultants of Michigan (GEI) were retained to conduct water quality monitoring efforts in 2017. Monitoring data will be leveraged to help inform future lake improvement goals and tasks required to achieve those goals

Twelve sites on Paw Paw Lake were monitored for water quality in 2017. Five monitoring events were conducted, beginning in May and ceasing in October. Six monitoring sites were in the "north lobe", and six sites were in the "middle lake." In years previous, lake improvement treatment methods, including aeration, were employed on the lake in the north lobe. Sonar herbicide was applied on Paw Paw Lake to control nuisance, invasive aquatic plants and did not have any adverse effects on the water quality of Paw Paw Lake. Monitoring in 2017 showed that Paw Paw Lake is a mesotrophic to eutrophic lake; water clarity increased by about 5 feet, nutrient and chlorophyll-a levels decreased in the epilimnion (the upper layer of a stratified lake, approximately 0 – 25 feet), and dissolved oxygen increased in the epilimnion. The hypolimnion (the lower layer of a stratified lake, approximately 25 feet to the lake's bottom), similar to trends in years past, has higher concentrations of nutrients, higher specific conductivity, and little to no dissolved oxygen. pH also tends to be lower in the hypolimnion due to lower dissolved oxygen levels and natural, anoxic organic material decomposition.

One round of algae analysis was performed on Paw Paw Lake during mid-July. Results showed that the dominant species in Paw Paw Lake is blue-green algae. A reduction in the conjugated green algae and desmids population was observed when compared to the algal community observed in 2016, and no algae-produced toxin was detected at any of the five sample sites.

The improvement in dissolved oxygen, chlorophyll-a, total phosphorus, and clarity and the reduction of conjugated green algae and desmids may be attributed in part to cooler summer temperatures, fewer rain events bringing in runoff high in nutrients, and the presence of zebra mussels. Additionally, the Sonar treatment for aquatic invasive plant species may also be effective on different species of algae, thus reducing certain populations.

INTRODUCTION

Paw Paw Lake is an 891 acre inland lake located in Sections 10, 11, 14, 15 and 16 of Watervliet and Coloma Townships in Berrien County, MI. The lake consists of two general areas, a 217 acre basin (north lobe) with a maximum depth of 50 feet, and a 674 acre basin (middle lake) with a maximum depth of 90 feet. The two distinct areas of Paw Paw Lake are separated by a shelf about 30 feet in depth.

Spicer Group, Inc. and GEI Consultants teamed up to perform water quality monitoring on Paw Paw Lake during 2017, in order to assess Paw Paw Lake's water quality in comparison to previous years and to generate water quality data to facilitate informed decision-making for future lake management and improvement practices. 2017 water quality monitoring efforts were consistent with efforts communicated in a proposal transmitted to the Paw Paw Lake Improvement Board in November, 2016. There were five water sampling events, in which total phosphorus (TP), ortho-phosphate (SRP), total suspended solids (TSS), nitrate, ammonia, chlorophyll-a (Chlor-a), dissolved oxygen (DO), temperature, pH, specific conductivity, and algae classification were measured. Samples were collected at a total of 12 sample sites, where 6 sample sites were located in the north lobe, and 6 sample sites were located in the middle lake. At each of the 12 sample sites, a "top" and "deep" sample were collected, and a dissolved oxygen profile was taken. A "top" sample denotes a sample taken in the upper portion of the water column (epilimnion) of the lake, and a "deep" sample denotes a sample taken in the lower portion of the water column (hypolimnion) of the lake. As the lake reached stratification in June, the thermocline, which separates the epilimnion and hypolimnion, was at about 22 – 30 feet in depth.

Zebra mussels (*Dreissena polymorpha*) were also observed in significant numbers in 2017, and Spicer and GEI worked with the lake board to develop an information summary for property owners.

The following sections summarizes data collection methods, general results, observations, and conclusions. For event-specific notes and analytical laboratory reports, refer to Appendix A for Field Activity Summaries. For greater detail and photos of the algae found during analysis, please refer to Appendix B for GreenWater Laboratory's analytical reports. For trophic status indicator calculations, refer to Appendix C.

PAW PAW LAKE
WATER QUALITY MONITORING 2017
BERRIEN COUNTY, MICHIGAN

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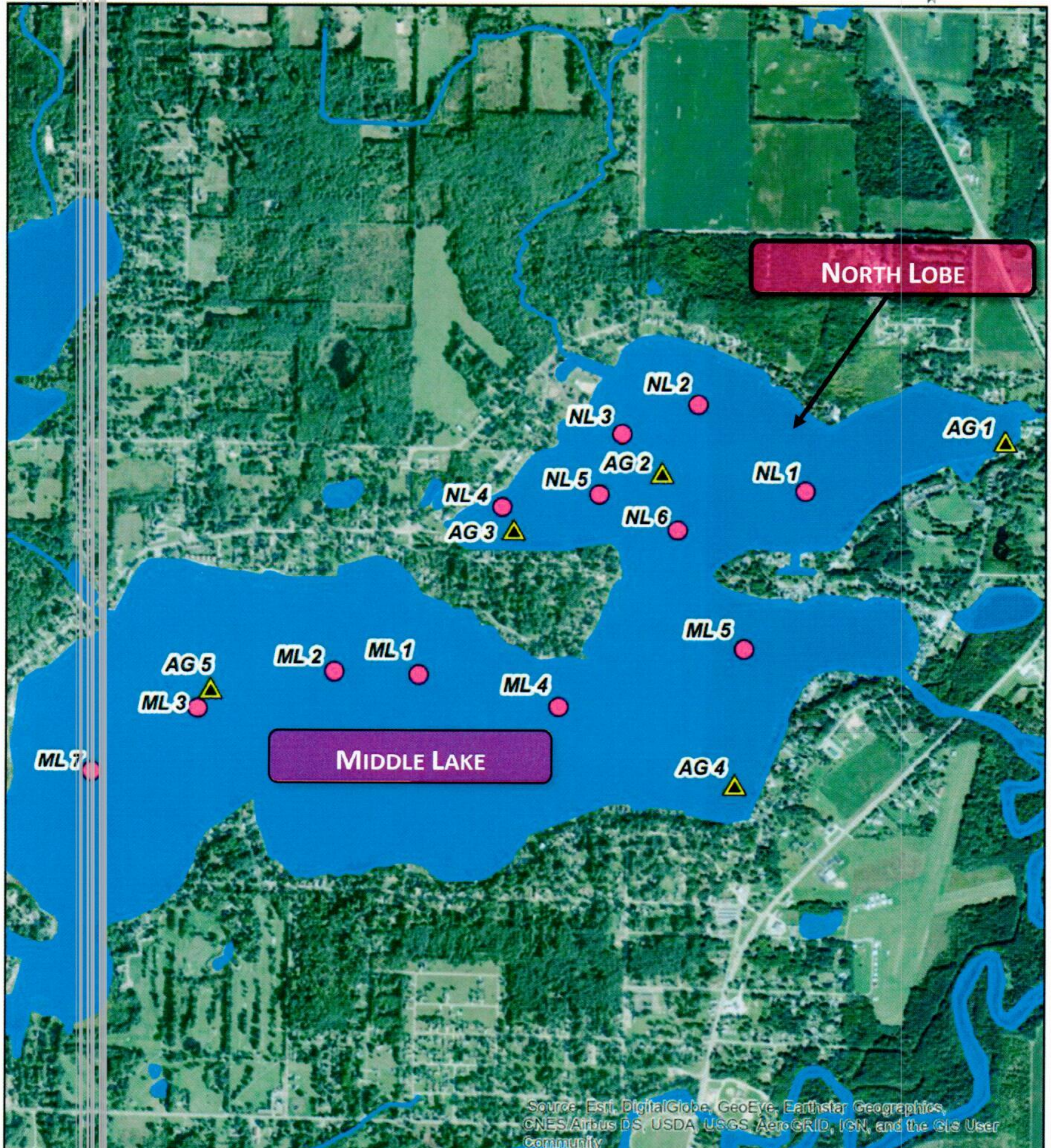

2017 Algae Sample Site

2017 Sample Site

Watercourses

Paw Paw Lake

NOTES:
SITES SAMPLED FROM APRIL - OCTOBER 2017 FOR TP, SRP, TSS, AMMONIA, NITRATE, CHLOROPHYLL-A.

Spicer group

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DRAWING #1 *DATE: APRIL 2017*

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METHODS

The 2017 Paw Paw Lake water quality monitoring plan called for the analyzation of water quality in real time for specific conductivity, dissolved oxygen, pH, temperature, and visibility with a Quanta Hydrolab® Multi-Parameter Probe and attached Secchi disk. The Quanta unit was calibrated and maintenanced monthly to ensure that quality measurements were accurate. All other parameters, including ammonia, nitrate, SRP, TP, and TSS, were analyzed in the laboratory from water samples collected in the field during May, June, July, August, and October of 2017.

Water samples and water quality data (dissolved oxygen, temperature, pH, specific conductivity) were collected in the epilimnion and in the hypolimnion. Epilimnion monitoring was conducted within the photic zone (the portion of the water column exposed to sunlight) and hypolimnion monitoring data was collected approximately one foot above the maximum depth of each site.

EPILIMNION SAMPLE COLLECTION

Surface water samples were collected by dipping a pre-cleaned, 500 mL polyethylene sample bottle prepared by Fibertec, a NELAC certified laboratory who runs the analyses for TP, SRP, and TSS for this project, into the lake at a given sample site. These samples were analyzed for TP, SRP, nitrate and ammonia. An additional sample was collected from the photic zone, which was determined by Secchi disk measurement for the specific site. The photic zone was generally 10-15 feet deep. Photic zone water samples were analyzed for TSS and Chlor-a, and were collected by affixing a cleaned bottle with perforated cap to a sampling pole and raising and lowering the bottle through the photic zone.

HYPOLIMNION SAMPLE COLLECTION

Hypolimnion samples were collected with a Van Dorn sampler, , as pictured in Figure 1. Both horizontal and vertical configurations were used to grab sample during the monitoring period, as one configuration provided larger collection volumes, and the other served as a backup sampler if the other sampler failed. Field personnel took care to avoid disturbing bottom sediments with the Quanta or Van Dorn, as doing so could bias results for total suspended solids, nutrients (TP, SRP, ammonia, and nitrate) and specific conductivity.

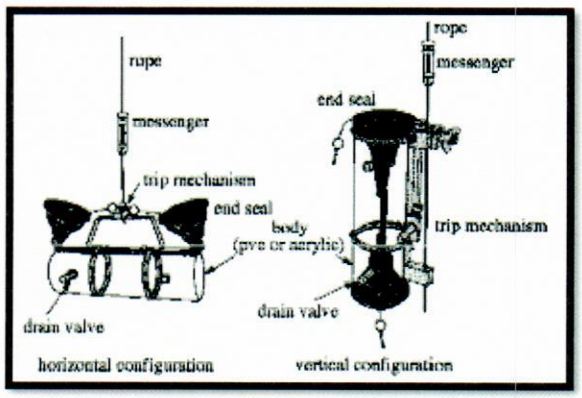


Figure 1 – Van Dorn Sampler Configurations

LAKE STRATIFICATION ANALYSIS

In addition to epilimnion and hypolimnion evaluation, lake stratification was monitored by measuring temperature and dissolved oxygen from the surface to the maximum depth at each site in two foot intervals with the Quanta Unit. Thermocline graphs can be found in each field activity summary for each site in Appendix A.

SAMPLE SUBMITTAL AND ANALYSIS

All samples collected were preserved according to analysis method requirements and submitted within the designated hold time. Soluble reactive phosphorus, total phosphorus, and total suspended solids were analyzed by Fibertec, a NELAC certified laboratory, in Holt, MI. Chlorophyll-a samples were first filtered by Spicer and GEI representatives using filtration equipment shipped to the Spicer office by the Great Lakes Environmental Center (GLEC) located in Traverse City, MI. After filtration, the samples were wrapped in aluminum foil, labeled, and priority shipped to GLEC, also a NELAC certified laboratory, for analysis. Ammonia and nitrate samples were analyzed by Michigan State University's Soil and Plant Nutrient Laboratory, located in East Lansing, MI. Algae samples were sent to GreenWater Laboratories in Palatka, Florida for algae ID and enumeration, potentially toxigenic scan (PTOX), and toxin analysis. All samples were immediately placed on ice after collection and remained on ice until the samples were delivered to their respective laboratories. Below is a summary of each test, analytical method utilized, and the laboratory that ran the test on water samples submitted during the 2017 monitoring season.

TEST	HOLD TIME	LABORATORY	ANALYTICAL METHOD	REPORTING LIMIT
Dissolved Oxygen	NA	Quanta Unit – SGI/GEI	Quanta	0.01 mg/L
Depth	NA	Quanta Unit – SGI/GEI	Quanta	0.1 feet
Temperature	NA	Quanta Unit – SGI/GEI	Quanta	0.1 °F
Specific Conductivity	NA	Quanta Unit – SGI/GEI	Quanta	0.001 mS/cm
pH	NA	Quanta Unit – SGI/GEI	Quanta	0.01 units
Secchi Depth	NA	Quanta Unit – SGI/GEI	Quanta	0.1 feet
Ammonia	28 Days	MSU Soil and Plant Nutrient Laboratory	SM 4500-NH3 D-1997	0.02 mg/L
Nitrate	48 Hours	MSU Soil and Plant Nutrient Laboratory	EPA 0300.0	0.023 mg/L
Ortho-phosphate (Soluble Reactive Phosphorus)	48 Hours	Fibertec	EPA 0300.0	0.05 mg/L
Total Phosphorus	28 Days	Fibertec	SM 4500-P E-1999	0.01 mg/L
Chlorophyll-a	25 Days	Great Lakes Environmental Center	SM 10200 H	0.0007 mg/L
Total Suspended Solids	7 Days	Fibertec	SM 2540 D-1997	2.5 mg/L
Algal ID and Enumeration	-	GreenWater	Microscope	NA
4-Toxin Scan • Microcystins/ nodularin • Saxitoxin • ANTX-A • CYN	48 Hours	GreenWater	• US EPA Method 546 & Ohio EA DES 701.0 • Abraxis PN 52255B • ANTX-A Method 545 • CYN Method 545	• 0.15 ng/mL • 0.09 ng/mL • 0.05 ng/mL • 0.05 ng/mL

Table 1 – Summary of analytical methods and test methods utilized for water quality data collection.

RESULTS AND DISCUSSION

As expected, water quality parameters varied throughout the spring, summer, and fall and are summarized below. Results from 2017 are compared to previous years' data via geometric means for both the epilimnion and hypolimnion. For more detailed analytical results, refer to Appendix A for Field Activity Summaries, which include thermocline data, nutrient results, laboratory reports and field notes for each of the 12 sample sites on each of the five monitoring dates from 2017.

SECCHI DEPTH

Secchi depth is a measurement of water clarity and was measured approximately seven to eight feet in 2017 (Figure 2). The higher the Secchi depth, the higher the water clarity is. Water clarity is often associated with "good" water quality. However, invasive species like zebra and quagga mussels can cause large increases in water clarity and allow for more light to hit the bottom of the lake, thus increasing the growth of aquatic plants. Therefore, a happy medium is desired for water clarity: not too clear to allow for excess growth of aquatic plants and not too cloudy so that the water appears dirty and does not allow for a productive, healthy lake.

In recent years, Paw Paw Lake has exhibited an overall healthy range of water clarity. Within the course of a year, clarity is typically highest during spring and mid-fall and lowest during the late summer months. In 2017, Paw Paw Lake experienced a large increase in Secchi Depth during all five months of monitoring. This could be due in part to the increase in zebra mussel population, cooler summer temperatures, and less rainfall, meaning less runoff from tributary drains.

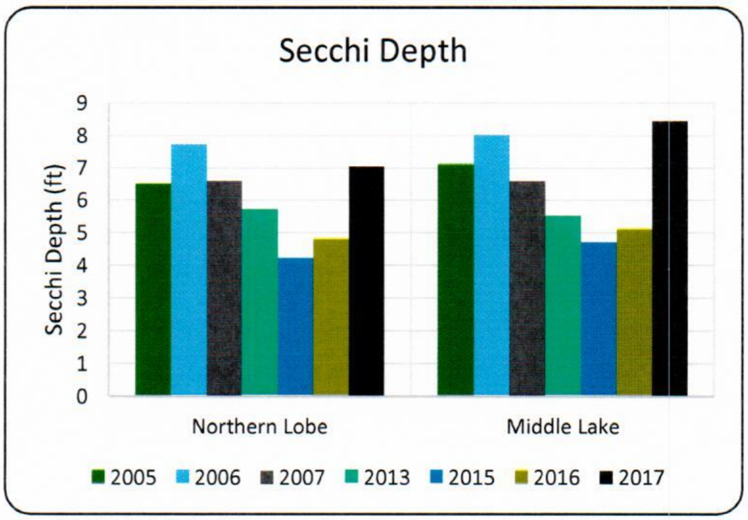


Figure 2 – Paw Paw Lake clarity (geometric mean) measured by Sechhi Depth

PH

pH was generally 7.5 – 9 in Paw Paw Lake in 2017 and varied with depth (Figure 3). pH is a measurement of hydrogen ion concentration in water, but is more commonly understood as a measurement of how acidic (pH ranging from 0 – 7) or basic (pH ranging from 7 – 14) the water is. Michigan tends to have more basic water due to the large amount of limestone, composed of $CaCO_3$, present in the terrain.

In inland lakes, pH can also be indicative of how productive a lake is and how much photosynthesis is occurring within a body of water. The pH will be higher if the lake is very productive and there is a lot of plant growth. Ideally, the pH of Michigan water bodies should be within a range of 6.5 – 9.0. Paw Paw Lake has had the tendency to be more basic than acidic. pH has increased from 2016 to 2017, and can be due to CO_2 levels in the lake. The more dissolved CO_2 there is in the lake, the lower pH will be. CO_2 levels can be impacted by photosynthesis, which causes a decrease in concentration, and can be influenced by respiration and decomposition, which causes an increase in concentration. CO_2 concentration can also be an explanation for the difference in pH in the epilimnion and hypolimnion of Paw Paw Lake. The epilimnion has high levels of dissolved oxygen, and is in the photic zone of the lake, where photosynthesis takes place and therefore has a higher pH. The hypolimnion is very deep and receives little light or oxygen, and is just above the layers of organic matter at the bottom of the lake, where decomposition of the material, which uses oxygen and produces CO_2 takes place. This results in a lower pH in the hypolimnion.

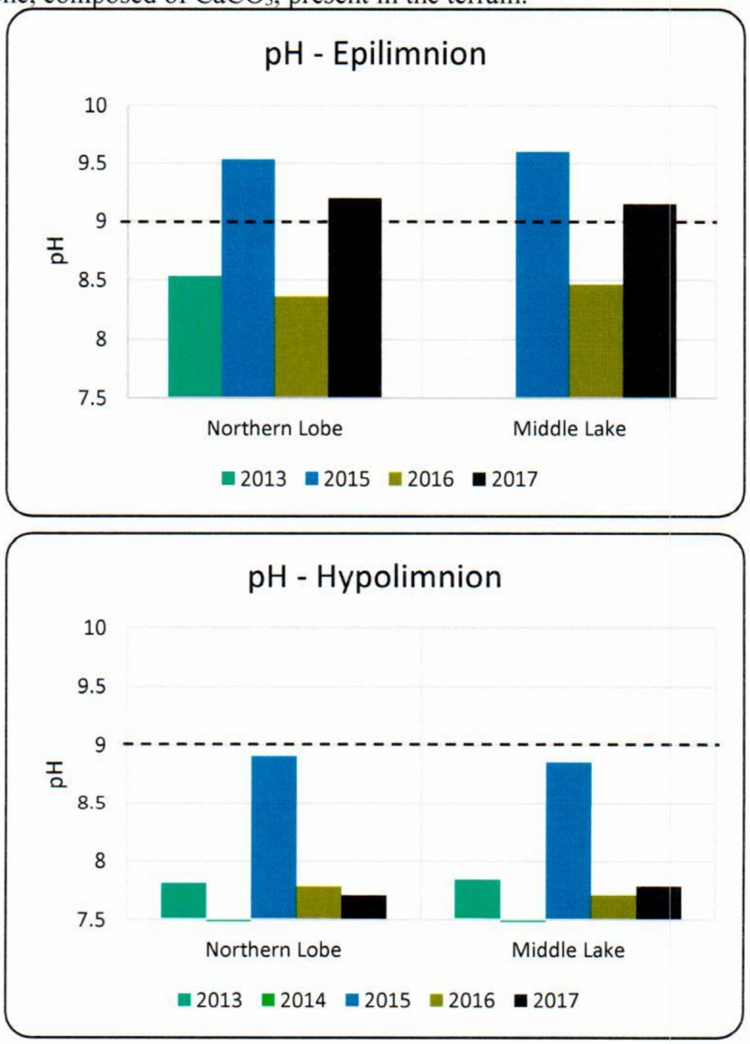


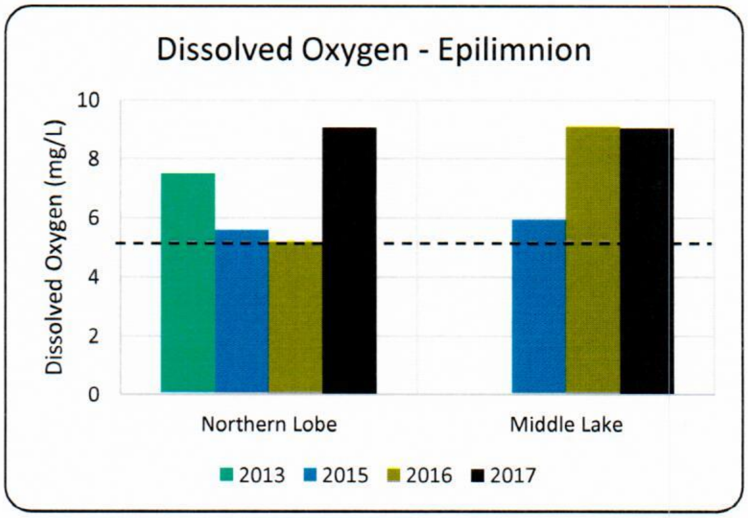
Figure 3 – Annual pH of hypolimnion and epilimnion

DISSOLVED OXYGEN

Dissolved oxygen levels varied with depth and averaged less than 5 mg/L in the hypolimnion and approximately 9 mg/L in the epilimnion (figure 4). Dissolved oxygen is a measurement of how much oxygen gas is dissolved in the water and is typically measured in milligrams per liter (mg/L). It is important to have high enough dissolved oxygen concentrations within the water to support the aquatic wildlife that are native to the lake.

Dissolved oxygen can be reduced by excess algal growth, water that's too warm, and not enough wave action and can be increased by more wave action, cooler temperatures, and non-invasive aquatic plants. The state of Michigan has developed water quality standards for dissolved oxygen. Paw Paw Lake is considered a "warm water fishery," and has a water quality standard of 5.0 mg/L for dissolved oxygen.

During 2017, dissolved oxygen levels increased substantially in the north lobe of the lake and remained about the same in the middle lake area. Again, this can be due in part to cooler summer temperatures, less rain events, an increase in aquatic plant photosynthesis, and a decrease in algae. In comparison to the epilimnion, the hypolimnion is very low in dissolved oxygen. This can be due to the decay of organic material on the lake's bottom, lack of photosynthetic activity, and the lack of flow between the upper and lower layers of the lake. Dissolved oxygen in the hypolimnion tends to be higher in the spring and early summer months, drops during mid-summer, and increases again around lake turnover time in the fall.



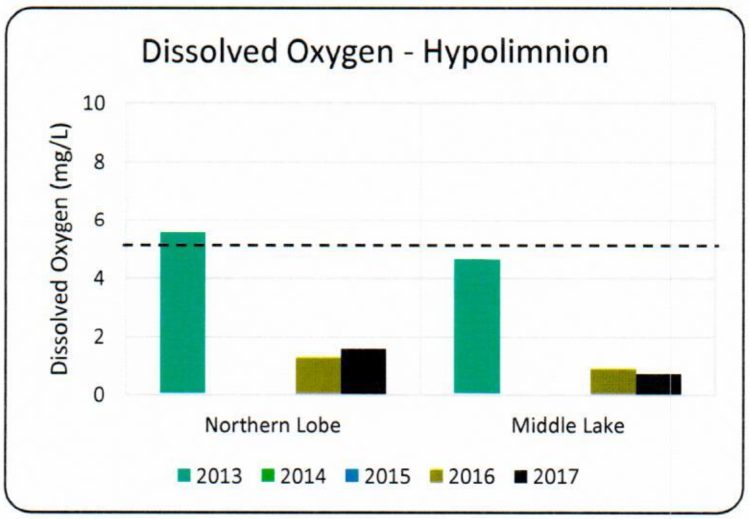
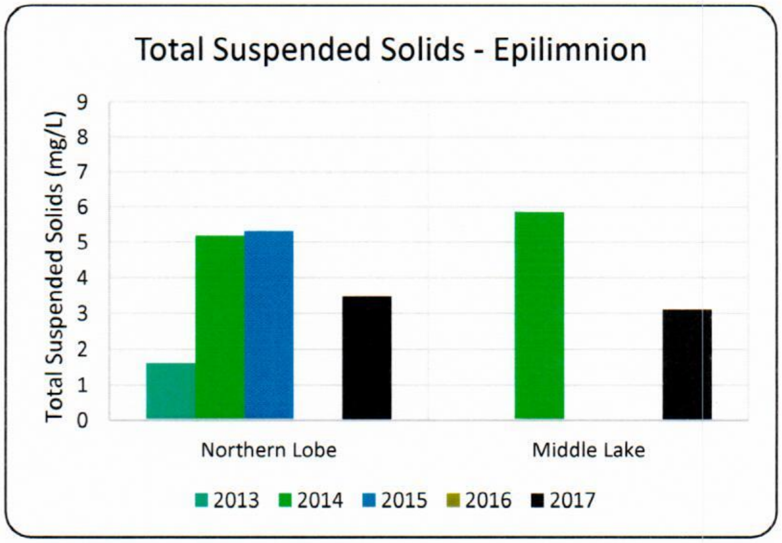


Figure 4 – Annual dissolved oxygen of hypolimnion and epilimnion

TOTAL SUSPENDED SOLIDS

Total suspended solids are small particles that consist of organic material, clay, and other particulate matter suspended in the water and generally ranged from 3-4 mg/L in 2017 (Figure 5). TSS is susceptible to binding with some types of contaminants including nutrients, metals, and hydrocarbons (which is more common in urban areas). While TSS occurs naturally in some waterways, an excessive increase in TSS can lead to a decrease in visibility and an increase in other undesired contaminants previously mentioned, in addition to smothering fish eggs and other aquatic wildlife. Therefore, low concentrations of TSS are desired.

TSS can be introduced into Paw Paw Lake via incoming streams and rivers or by the stirring up of bottom sediments. The state of Michigan does not have a numerical standard for how much total suspended solids is too much. Rather, a narrative standard is applied, meaning that the waters of the state should not have un-natural characteristics attributed to TSS (i.e. excessive cloudiness, films, foams, etc.) (R 323.1050 Physical characteristics. Rule 50.). Typically, water with a TSS value of less than 20 mg/L are considered to be "clear."



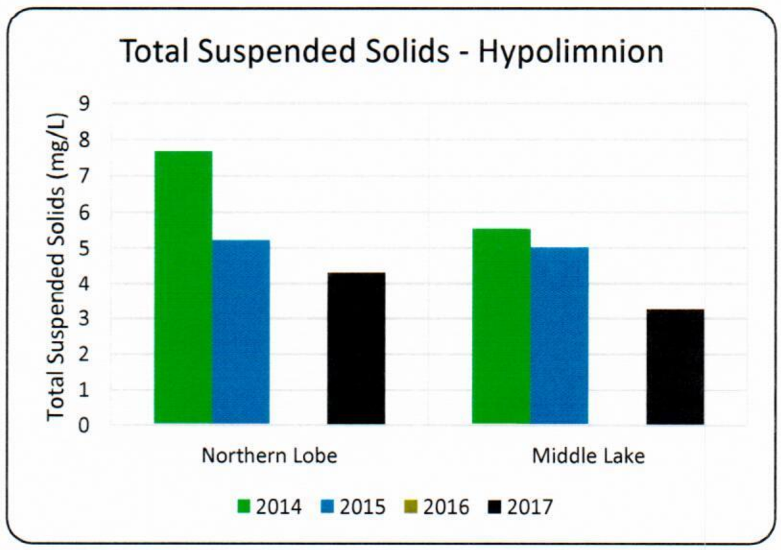
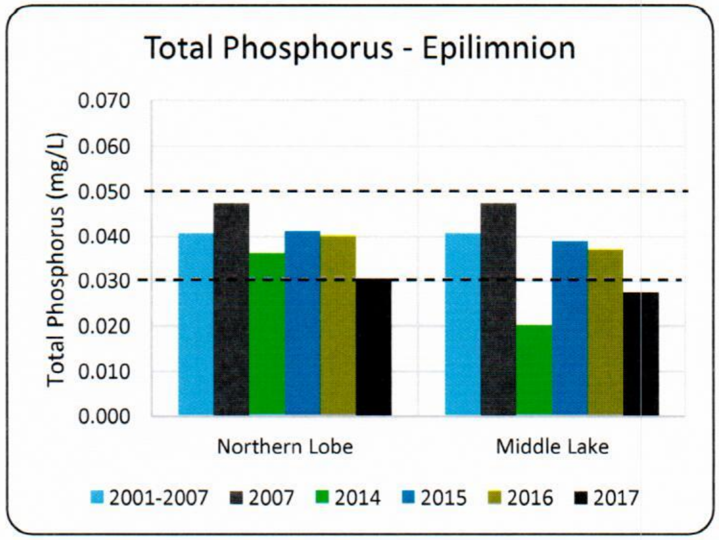


Figure 5 – Annual total suspended solids of hypolimnion and epilimnion

TSS concentration in the epilimnion, hypolimnion, north lobe and middle lake of Paw Paw Lake were relatively the same concentration during 2017. In comparison to 2016, it appears as though 2017 had higher TSS concentrations, however, this may not necessarily be true. Different laboratories have been used over the years for analysis, and each laboratory has their own set of quality standards and methods, meaning that some labs have higher reporting concentrations than others. For example, the same sample can be submitted to two different laboratories, and one reports the result as 9 mg/L and the other reports non-detection, or "U." This is because the first laboratory had a reporting limit of 2.5 mg/L and the other laboratory had a reporting limit of 10 mg/L. Regardless, even the highest concentration of TSS observed in Paw Paw Lake was of no concern and is normal for an inland lake in southern Michigan.

TOTAL PHOSPHORUS

In 2017, phosphorus levels were greater in the hypolimnion when compared to the epilimnion, 0.054 – 0.064 mg/L and 0.026 – 0.030 mg/L, respectively (Figure 6). Phosphorus is an element that is a major component in all lifeforms, which includes everything from a human being to green algae. Phosphorus can also be found in inorganic forms like in rocks. Therefore, as the name says, total phosphorus is the measurement of how much of all types of phosphorus, both organic and inorganic, are within the water, and is measured in milligrams per liter (mg/L).



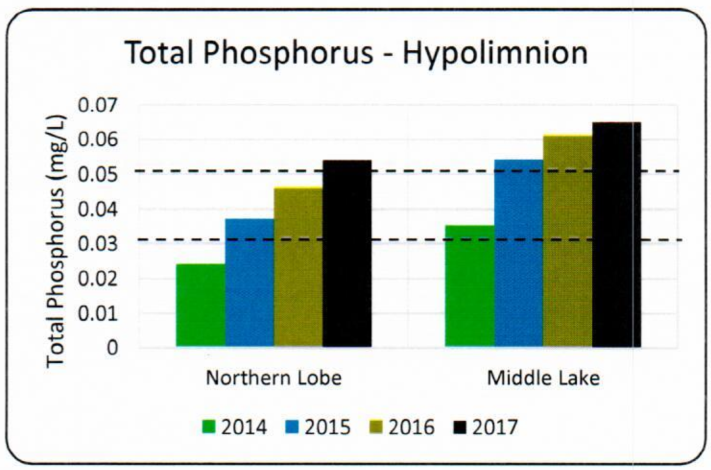


Figure 6 – Annual total phosphorus of hypolimnion and epilimnion

The main concern regarding inland lakes and phosphorus is that if there is too much phosphorus within the water, it can lead to excess algal and plant growth. Excess algal growth can lead to reduced dissolved oxygen, reduced clarity, unpleasant odors/discolored water, and other undesirable water quality issues. Excess aquatic plant growth can be an issue for motor boats, as propellers can get caught up in it. Phosphorus causes such a large impact on plant and algal growth because it is the limiting nutrient for plant and algal growth.

TP has been monitored extensively on Paw Paw Lake since 2001. For the most part, TP has remained fairly consistent through the years, ranging between approximately 0.035 and 0.045 mg/L in the epilimnion. However, in 2017, TP has dropped substantially from 2016 levels. This can be due to cooler water temperatures, reduced mixing of the epilimnion and hypolimnion, reduced runoff from tributary drains due to few rain events, and presence of the zebra mussel. TP concentrations tend to be higher in the hypolimnion in both the Middle Lake and North lobe portions of Paw Paw Lake. This can be due to the decay of organic material at the lake's bottom, or the settling of decaying algae, plants, and natural animal waste materials.

Michigan does not have defined water quality standards for inland lakes, but is in the process of creating them. However, both Wisconsin and Illinois have water quality standards for total phosphorus at 0.030 mg/L (drainage, stratified lakes) and 0.050 mg/L (reservoir or lake with a surface area of >20 acres), respectively.

CHLOROPHYLL-A

Chlorophyll-A has decreased since 2017 (Figure 7) and is used as a measurement to determine the relative amount of algal presence within the water and is measured in milligrams per liter (mg/L). While this measurement does not give an exact concentration of how many algal cells are present within the water, it does serve as a reliable indicator of how much is in the water.

Michigan does not currently have a water quality standard for chlorophyll-A. However, the state of Minnesota does have water quality standards for waterways that are similar to Paw Paw Lake. These include lakes and reservoirs in the North Central Hardwood Forest Ecoregion, where the standard is 0.014 mg/L, and lakes and reservoirs in Western Corn Belt Plains and Northern Glaciated Plains Ecoregions, where the standard is 0.022 mg/L. Ideally, chlorophyll-A concentration should be lower than these standards. During the year of 2017, Paw Paw Lake was well below both of the water quality standards. This is due to the fact that total phosphorus and water temperature was lower this year than in recent, previous years.

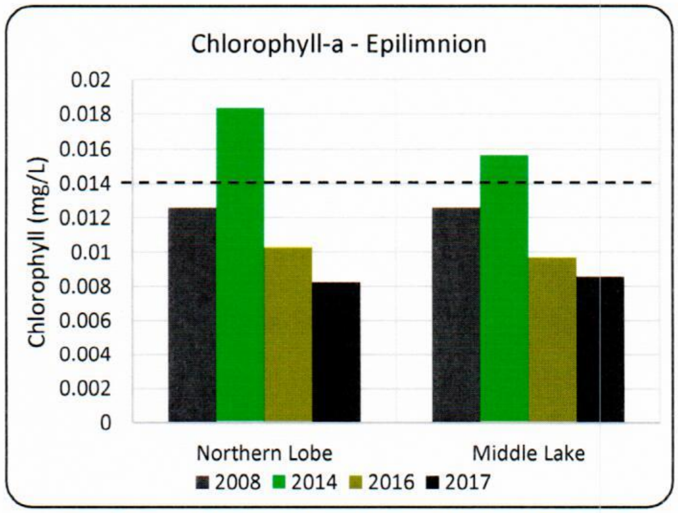


Figure 7 – Annual chlorophyll-a of hypolimnion and epilimnion

SPECIFIC CONDUCTIVITY

Specific Conductivity is the measure of the water's capability to conduct electricity, and typically has a positive correlation to total dissolved solids. Therefore, the higher the specific conductivity, the higher the concentration of total dissolved solids. In Paw Paw Lake, the specific conductivity is relatively low, and uniform throughout the water column. However, the hypolimnion has a slightly higher concentration than the epilimnion. This trend has been consistent through all the years that specific conductivity has been monitored on the lake.

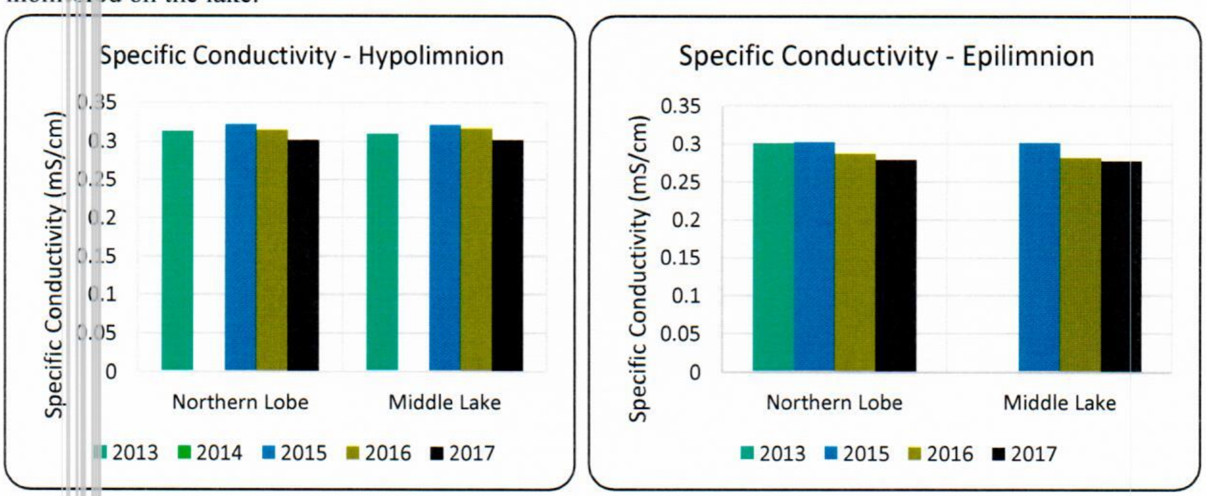
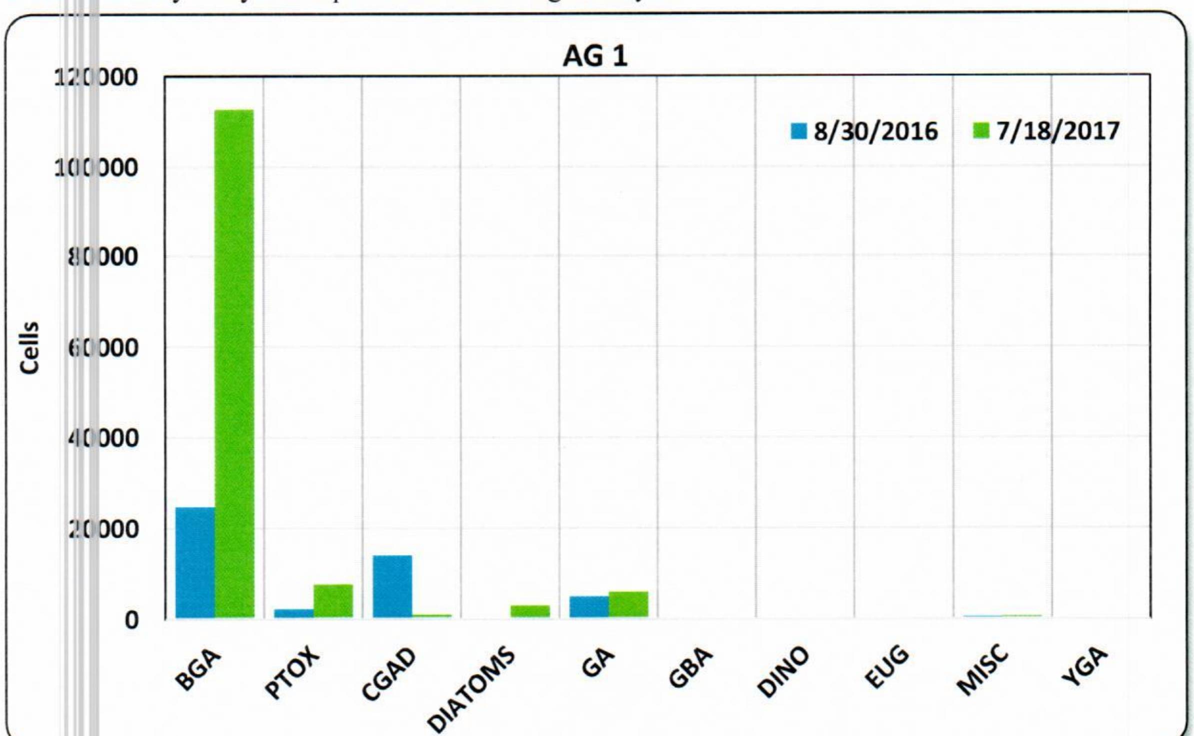


Figure 8 – Annual specific conductivity of hypolimnion and epilimnion

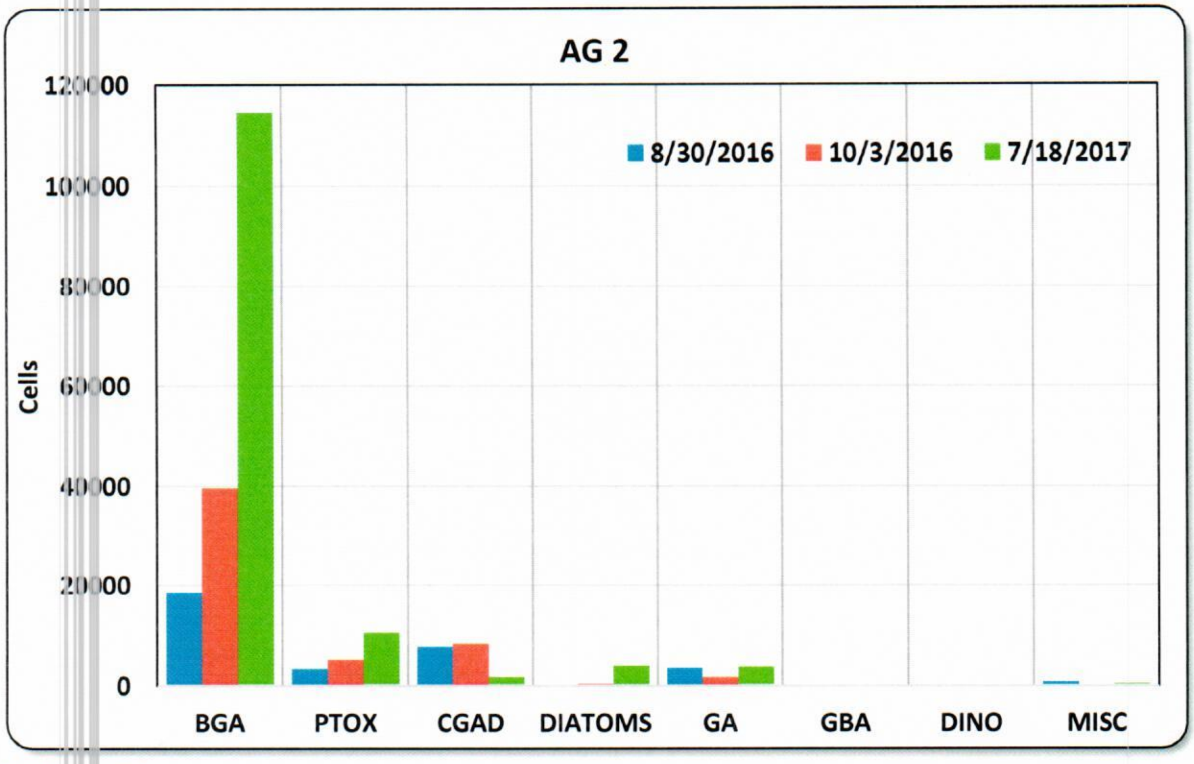
ALGAL ID AND ENUMERATION

The algal community was first assessed in 2016 with additional evaluation in 2017. Algal analysis is relatively new to the water quality monitoring protocol on Paw Paw Lake, as it was initiated in August of 2016. There was inquiry about what types of algal blooms were being observed on the lake and if those blooms could lead to algae produced toxins, such as microcystins, saxitoxin, anatoxin-a, and cylindrospermopsin. There have been a total of three algae sample events since it has been incorporated in to lake analysis. Samples were taken at five sample sites around the lake in August and October of 2016 and July of 2017. Results have shown that the dominant algae in the lake for all three sample events are blue-green algae, ranging from 38 – 93% of the cells present in the samples analyzed. A percentage of the blue-green algae population classifies as potentially toxigenic cyanobacteria, also known as "PTOX." During the 2016 sample events, PTOX cyanobacteria made up 5 – 23% of the cells in the samples analyzed, and in 2017 PTOX cyanobacteria made up 6 – 15% of the cells in the samples. Overall, there was a reduction in the PTOX population from 2016 to 2017. While these types of cyanobacteria were present in both 2016 and 2017, toxins, including anatoxin-a, cylindrospermopsin, microcystins/nodularins, and paralytic shellfish toxins, were not detected in any of the samples during any of the sample events.

Additionally, there was a substantial reduction in conjugating green algae and desmids population from 2016 to 2017. In 2016, the conjugating green algae and desmids made up 13 – 30% of the total cell population, and in 2017, they made up 1 – 15% of the total cell population. An explanation for a reduction in their population could be due to the presence of zebra mussels or other organisms in the water that feed specifically on this type of algae that experienced a boom in population due to environmental conditions during 2017. Below is a data summary of all algae data collected during the three sample events conducted between the 2016 and 2017 monitoring periods. For more information on algae analysis, refer to Appendix B for laboratory analytical reports and further algal analysis.



a. Site AG 1



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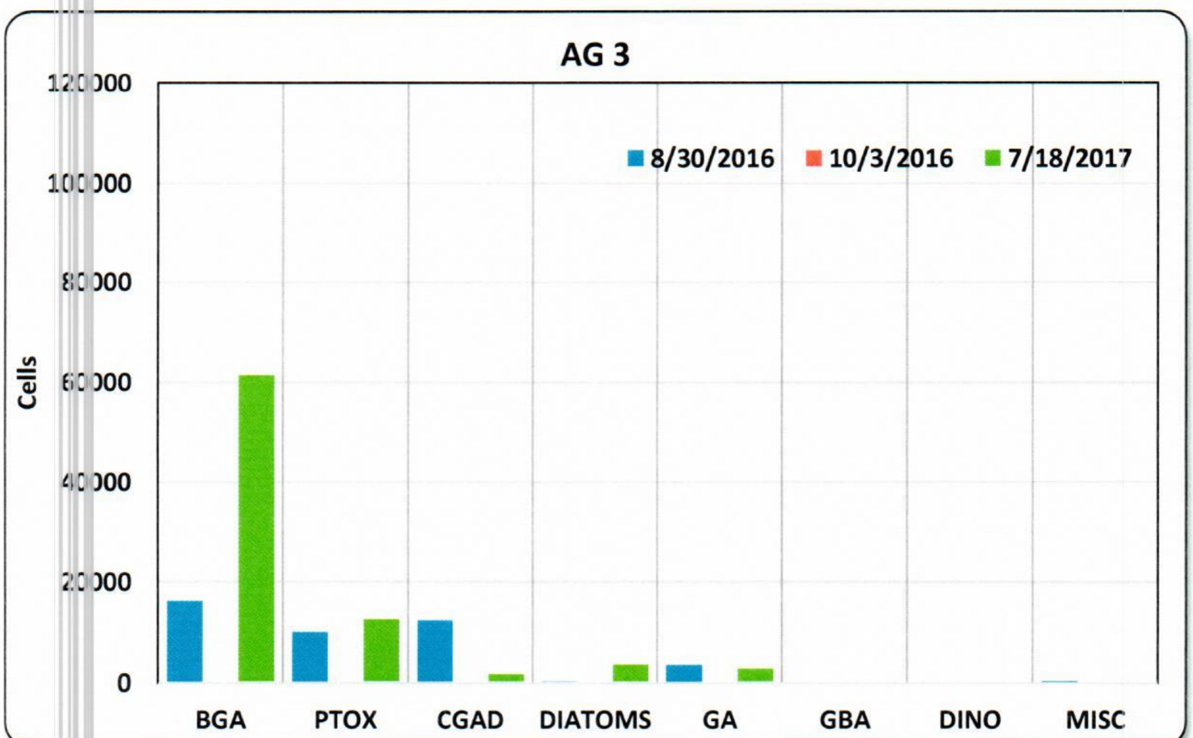

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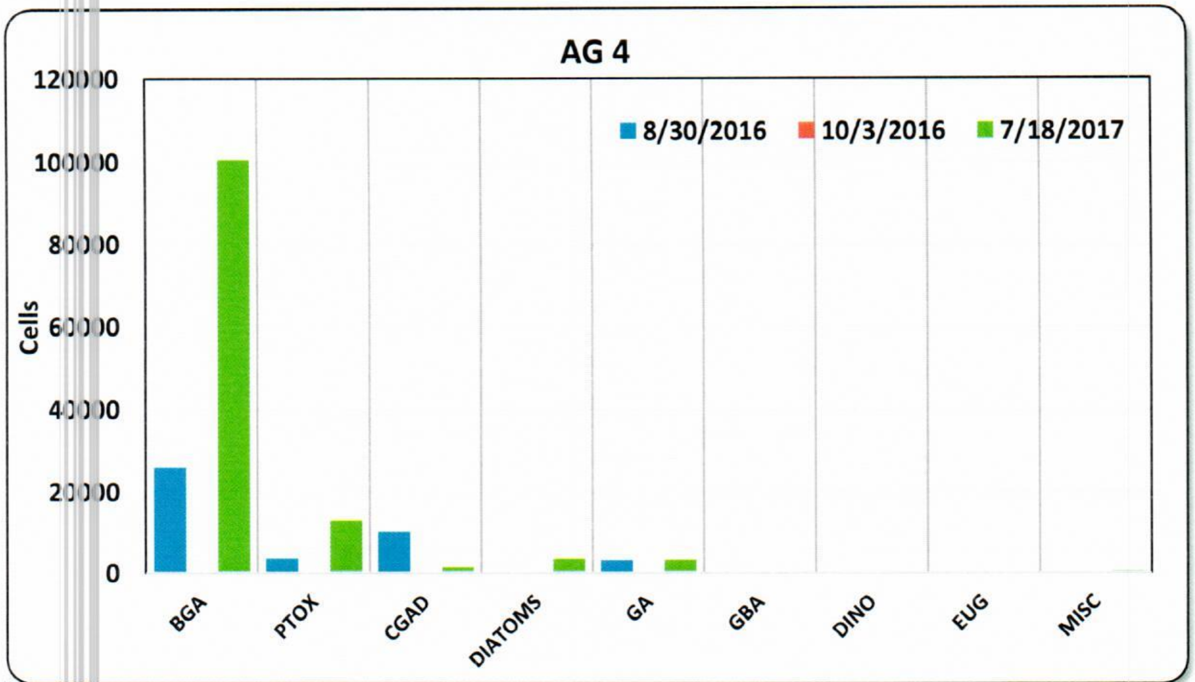
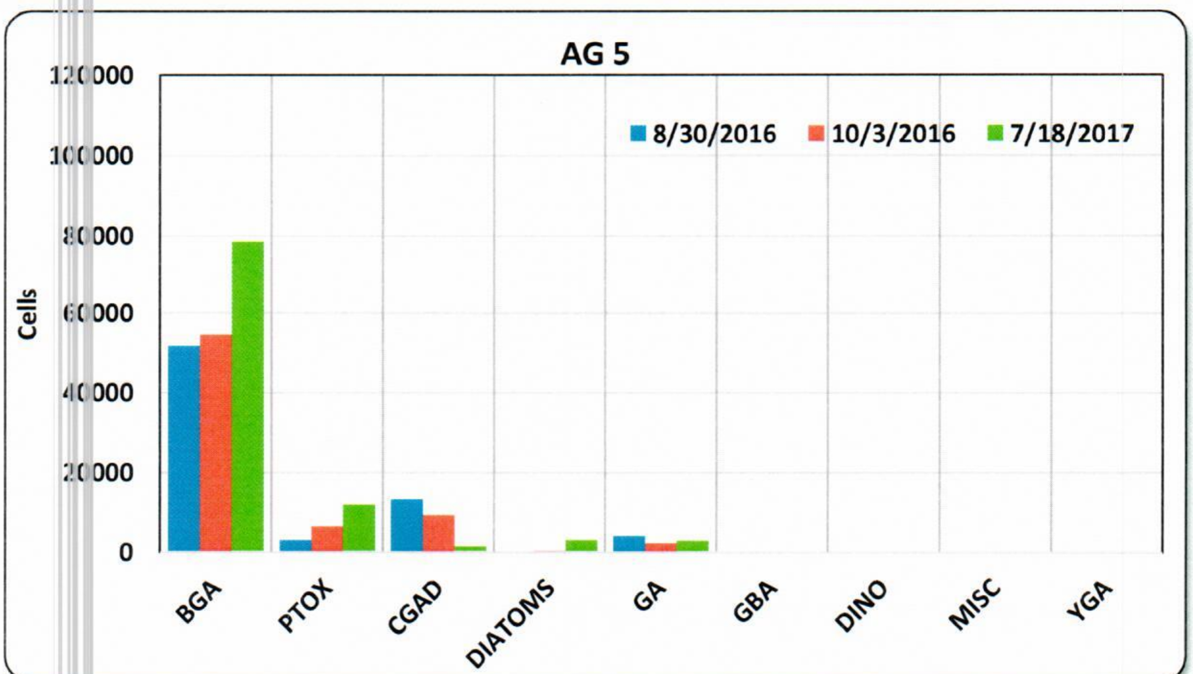


d. Site AG 4



e. Site AG 5

Figure 9 (a – e) – Algae population analysis for sites AG 1, AG 2, AG 3, AG 4, and AG 5 for three sample events: 8/30/2016, 10/3/2017, and 7/18/2017. BGA – Blue green algae, PTOX – Potentially toxigenic blue green algae, CGAD – Conjugated green algae and desmids, Diatoms – Diatoms, GA – Green algae, GBA – Golden-brown algae, DINO – Dinoflagellates, EUG – Euglenophytes, MISC – Miscellaneous, YGA – Yellow-green algae.

ZEBRA MUSSELS

At the request of the Paw Paw Lake Improvement Board during a July 2017 meeting, Spicer Group and GEI looked into zebra mussel background information, and the impact that they have on the health of inland lakes.

Zebra mussels are a non-native freshwater mollusk. Native to Eastern Europe and Western Russia, the mussels were brought to the Great Lakes in the ballast water of ships. The first report of zebra mussels in the Great Lakes region was in Lake Erie in 1988.

The mussels were presumably introduced into Paw Paw Lake in boat bilge water or were attached to boats that were exposed to zebra mussels in other lakes prior to being launched in Paw Paw Lake. In 1993, zebra mussels were discovered in Little Paw Paw Lake (according to Michigan Sea Grant Inland Lakes Zebra Mussel Infestation). Since Little Paw Paw Lake and Paw Paw Lake are connected, it is likely that Paw Paw Lake also had an introduction of zebra mussels in the early 90's. There was a substantial increase in zebra mussel population during 2017. Water quality parameters can have an impact on mussel population size. The following table summarizes these parameters:

PARAMETER	NO POTENTIAL FOR ADULT SURVIVAL	LITTLE POTENTIAL FOR LARVAL DEVELOPMENT	MODERATE POTENTIAL FOR NUISANCE INFESTATIONS	HIGH POTENTIAL FOR MASSIVE INFESTATIONS
Calcium (mg Ca/L)	<8	8 – 15	15 – 30	30 – 80
pH	<7.0, >9.5	7.0 – 7.8, **9.0 – 9.5**	7.8 – 8.2, **8.8 – 9.0**	8.2 – 8.8
Alkalinity, total (mg $CaCO_3$/L)	<30	30 – 55	55 – 100	100 – 280
Hardness, total (mg $CaCO_3$/L)	<30	30 – 55	55 – 100	100 – 280
Dissolved Oxygen (mg/L) (% Saturation)	<3, (<25%)	3 – 7 (25 – 50%)	7 – 8 (50 – 75%)	**≥8 (75%)**
Temperature (°F)	<50, >89.6	78.8 – 89.6	50 – 68	**68 – 78.8**

Table 2. Summary of parameters that provide an environment conducive to zebra mussel population expansion. (Engineers, June 2013) Parameters that are highlighted in **bold** are the ranges that Paw Paw's Lake epilimnion falls into. Depending on calcium and calcium carbonate concentrations ($CaCO_3$), Paw Paw Lake has the potential for nuisance to massive zebra mussel infestation. It is recommended that samples for calcium, alkalinity and hardness are collected in order to better predict the extent to which zebra mussels can survive in this environment.

The increase in zebra mussel population may be attributed to the increase in dissolved oxygen and pH, and slight decrease in surface water temperatures during 2017. Zebra mussels are efficient filter feeders, feeding primarily on phytoplankton and zooplankton. Due to their filter feeding capabilities, zebra mussels can cause a great increase in water clarity and decrease in phytoplankton and zooplankton diversity. As previously stated in the Secchi depth and Algal ID and Enumeration sections, both of these outcomes have been observed in Paw Paw Lake in 2017; Secchi depth increased from about 5 feet to 8 feet, and the conjugated green algae and desmids saw a substantial reduction in population. Additionally, by removing phytoplankton and zooplankton in the water column, total phosphorus is reduced. Again, this trend was also observed in Paw Paw Lake, as TP concentrations were reduced from 0.040 – 0.035 mg/L in 2016 to < 0.030 mg/L in 2017. Although there may be perceived benefits to presence of zebra mussels in the water, there are drawbacks too. These include the increase of PTOX cyanobacteria, reduction of phytoplankton and zooplankton diversity, reduction of food sources for a variety of aquatic species, and are a nuisance for riparian landowners who own boats, docks, and sprinkler systems that source water from the lake.

CONCLUSIONS

Overall, Paw Paw Lake exhibits water quality characteristics typical of developed, inland lakes in lower Michigan. According to its trophic state indicator, which ranges from 45.33 – 53.67, Paw Paw Lake classifies as a mesotrophic to eutrophic lake. The calculations used to determine the trophic status of Paw Paw Lake take chlorophyll-a, Secchi depth, and total phosphorus measurements into consideration. Table 2 below summarizes different levels of trophic statuses and their respective environmental and ecological conditions.

TROPHIC STATUS	TROPHIC STATE INDICATOR	CHLOR-A (MG/L)	SECCHI (FT)	TP (MG/L)	FISHERIES AND RECREATION
Oligotrophy – Clear water, oxygen throughout the year in the hypolimnion	<30	<0.00095	>26	<0.006	Salmonid fisheries dominate.
Hypolimnia of shallower lakes may become anoxic	30 – 40	0.00095 – 0.0026	13 – 26	0.006 – 0.012	Salmonid fisheries in deep lakes only.
Mesotrophy – Water moderately clear; increasing probability of hypolimnetic anoxia during summer.	**40 – 50**	**0.0026 – 0.0073**	**7 – 13**	**0.012 – 0.024**	**Hypolimnetic anoxia results in loss of salmonids. Walleye may predominate.**
Eutrophy – Anoxic hypolimnia, macrophyte problems possible	**50 – 60**	**0.0073 – 0.0200**	**3 – 7**	**0.024 – 0.048**	**Warm-water fisheries only. Bass may dominate.**
Blue-green algae dominate, algal scums and macrophyte problems.	60 – 70	0.0200 – 0.0560	1.6 – 3	0.048 – 0.096	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
Hypereutrophy – Light limited productivity. Dense algae and macrophytes	70 – 80	0.0560 – 0.1550	0.8 – 1.6	0.096 – 0.192	-
Algal scums, few macrophytes	>80	>0.1550	<0.8	0.192 – 0.384	Rough fish dominate; summer fish kills possible.

Table 3. Trophic state indicators (TSI) for total phosphorus, chlorophyll-a and Secchi depth. Based on Paw Paw Lake's average annual chlorophyll-a, Secchi and total phosphorus measurements, the lake is classified as a mesotrophic to eutrophic lake. (Simpson, 1996)

The relationship between the TSI variables can give further insight to lake conditions when they are compared to one another. The relationship between the variables and lake conditions are summarized in Table 4.

RELATIONSHIP BETWEEN TSI VARIABLES	**LAKE CONDITIONS**
TSI (Chl-a) = TSI(TP) = TSI(SD)	Algae dominate light attenuation; TN:TP ~33:1
TSI(Chl-a) > TSI (SD)	Large particulates, such as *Aphanizomenon* flakes, dominate
TSI(TP) = TSI(SD) > TSI(Chl-a)	Non-algal particulates or color dominate light attenuation
TSI(SD) = TSI(Chl-a) > TSI(TP)	Phosphorus limits algal biomass (TN:TP > 33:1)
TSI(TP) > TSI(Chl-a) = TSI(SD)	Algae dominate light attenuation, but some factors such as nitrogen limitation, zooplankton grazing or toxics limit algal biomass

Table 4. Relationship between TSI variables and lake conditions. In the north lobe of Paw Paw Lake, TSI(SD) = 47.83, TSI (Chl-a) = 49.97, TSI(TP) = 53.67, therefore, the relationship is TSI(TP) > TSI(Chl-a) = TSI(SD), meaning that algae dominates light attenuation, but some factors such as nitrogen limitation, zooplankton grazing or toxics limit algal biomass. The middle lake of Paw Paw Lake has the following variables: TSI(SD) = 45.33, TSI (Chl-a) = 50.75, TSI(TP) = 51.68. The relationship is TSI(Chl-a) > TSI(SD), meaning that large particulates, such as *Aphanizomenon* flakes, dominate. (Simpson, 1996)

In 2017, water quality in Paw Paw Lake improved according to several metrics: phosphorus and chlorophyll-a levels decreased and water clarity increased by about 5 feet when compared to 2016. There has also been an increase in the blue-green algae population and a decrease in the conjugated green algae and desmid population. Paw Paw Lake also saw an increase in depth for the thermocline, where in 2017, the thermocline ranged from 22 to 30 feet in depth, in comparison to 2016, where the thermocline started at about 15 feet in depth. Many of the observed water quality changes in Paw Paw Lake this year may be attributed to the presence of a sizable zebra mussel population, cooler summer temperatures, and fewer rain events bringing in nutrients from tributary drains.

RECOMMENDATIONS

During the year 2017, Spicer Group and GEI have accomplished the following items in accordance with the current lake improvement plan and approved scope of work:

- Attended three board meetings (April, July, September) to present data and provide improvement input
- Generated water quality data during a total of five monitoring events (May, June, July, August, and October). Parameters included: DO, TP, TSS, SRP, Nitrate, Ammonia, Temperature, pH, Specific Conductivity, chlorophyll-a, Algal ID and enumeration, anatoxin-a, cylindrospermopsin, microcystins/nodularins, and paralytic shellfish toxins.
- Provided assistance and input on zebra mussel public statement

- Compiled water quality data from 2001 – 2017 to assess major changes or trends in Paw Paw Lake
- Provided a formal written report, a concise summary report (at the request of board members), and an annual monitoring summary that highlighted major trends or observations from 2017. The latter was to inform Paw Paw Lake property owners of the current status of Paw Paw Lake in comparison to years passed and other Michigan inland lakes.
- Unrelated to this report, but related to Paw Paw Lake, Spicer Group installed, programmed, and collected water samples with ISCO automated samplers on the Branch and Derby Drain from April to October. After the data collection process was complete, a PowerPoint presentation summarizing the year's results was created and presented to the board.

Our recommendations for 2018 include the following items:

1. **Update the Paw Paw Lake Improvement Plan** – It is important for a lake board to have a lake improvement plan that clearly states goals, action items to achieve the goals, and associated timelines. The latest 5 year lake improvement plan is dated May 2, 2016 and was never finalized. Therefore, it is proposed that Spicer and GEI, in cooperation with the lake board, update the lake improvement plan so that it accurately reflects current lake improvement goals and serves as a guide for upcoming years.

2. **Continued Water Quality Monitoring** – Currently, there are no lake improvement activities planned that require additional water quality monitoring data for permit purposes. However, obtaining year-to-year water quality data is extremely beneficial for understanding Paw Paw Lake's overall health and trophic status. Current and historic water quality data is necessary to make the best decisions possible for future lake improvement activities and assessing the effectiveness of current improvement activities. Another benefit of yearly monitoring is that if a permit for lake improvement activities is ever desired, a library of data is readily available for the permit application, which typically requires up-to-date water quality monitoring data.

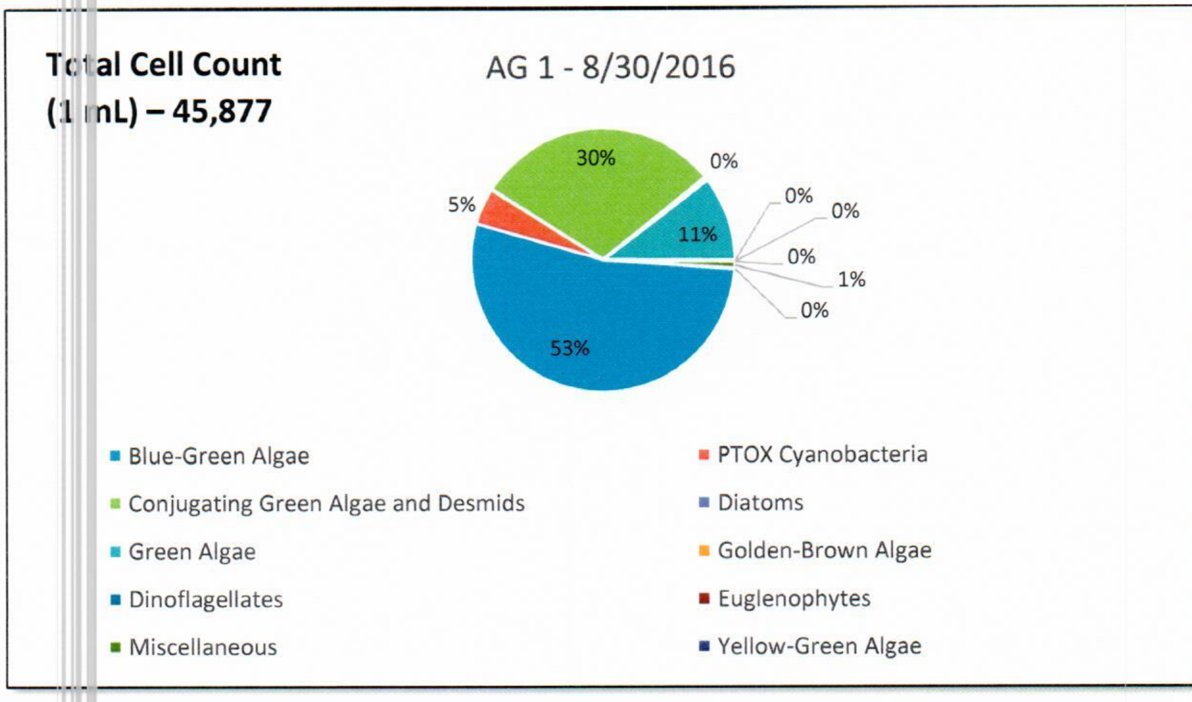
   As such, we recommend that water quality monitoring continue in 2018 but at a reduced frequency (3 sample events instead of 5-7). This will ensure that quality data for Paw Paw Lake is generated but at a reduced cost when compared to previous years.

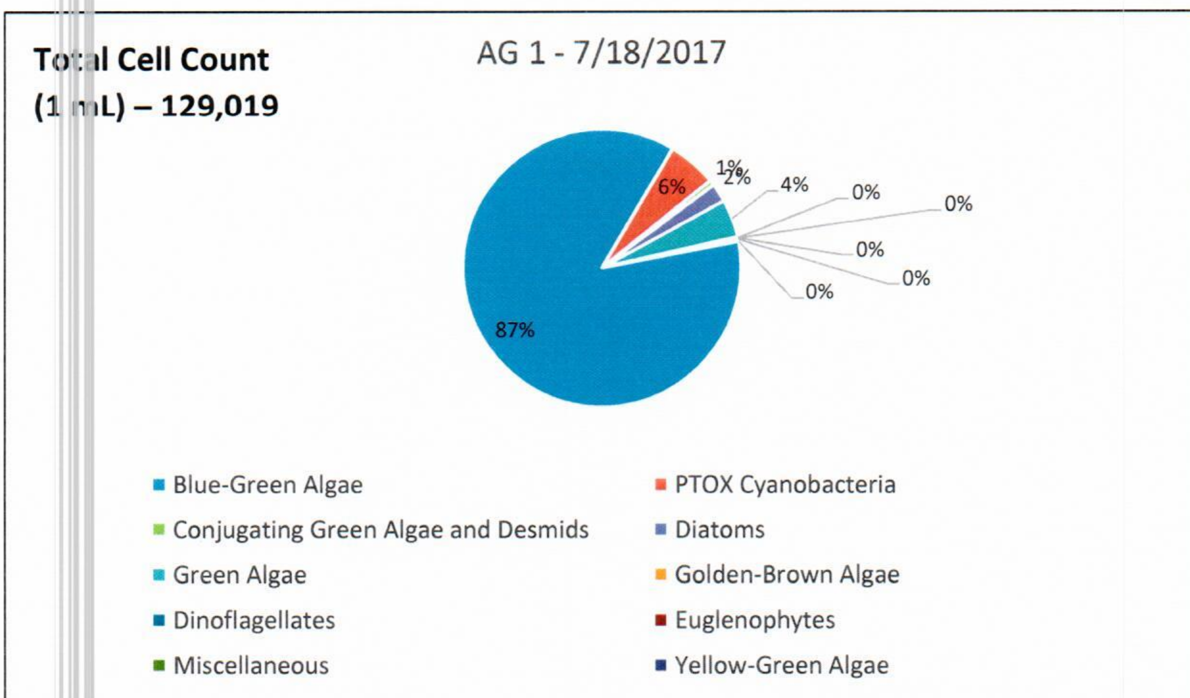
3. **Algae Monitoring** –It is recommended that algae monitoring continue in late summer and early fall of 2018, as the types and quantity of algae that can grow in the lake can have a large impact on the water quality and recreational value of the lake. Observing year to year changes in algae species and quantity can give insight as to which treatment methods, if any, should be employed to control algal growth.

In 2018, Spicer Group and GEI can continue to provide as needed services including, but not limited to, attendance at annual lake board meetings, input into new issues (e.g., zebra mussels), and technical and permitting guidance.

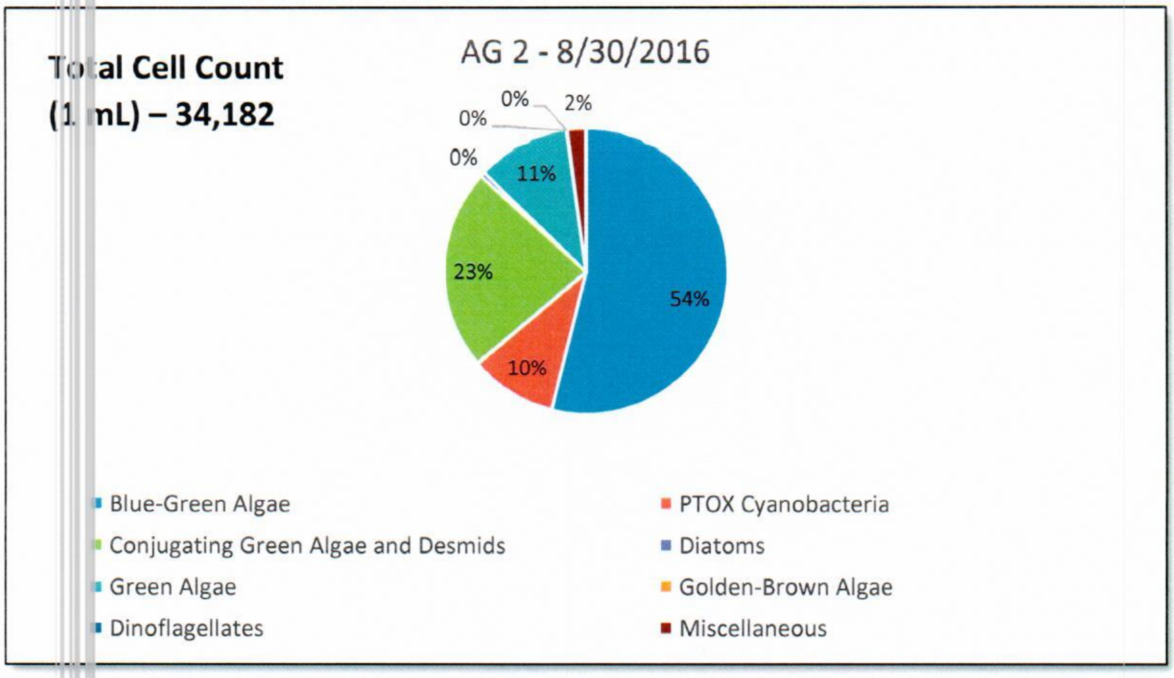
ADDITIONAL FIGURES

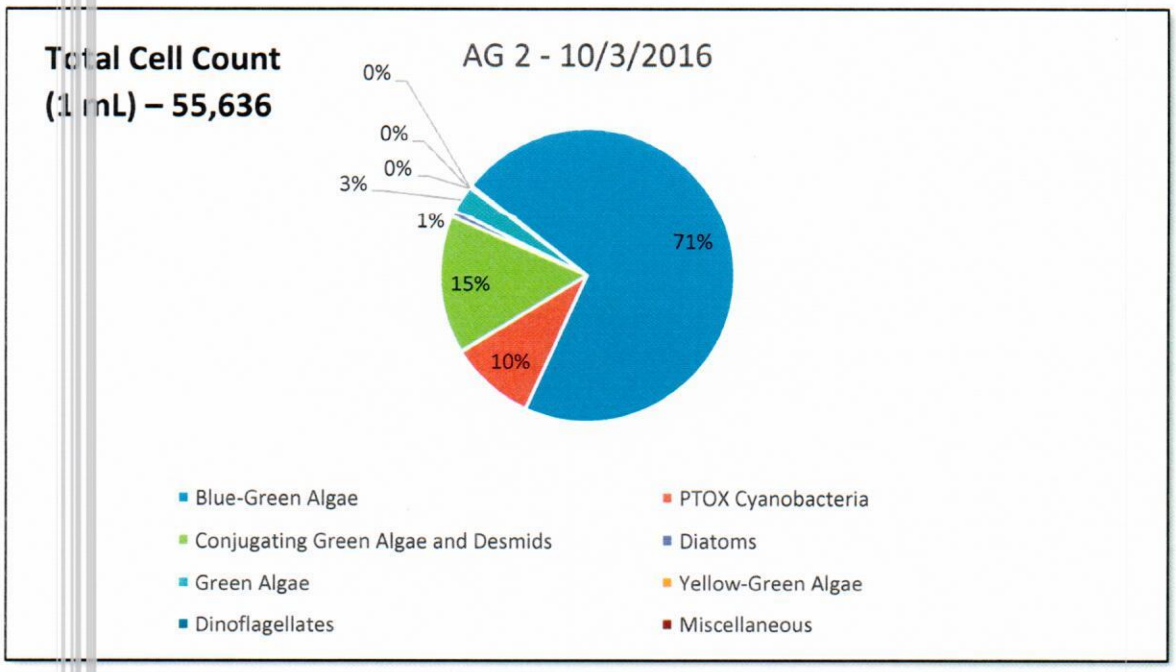
ALGAE POPULATION ANALYSIS
SITE AG 1



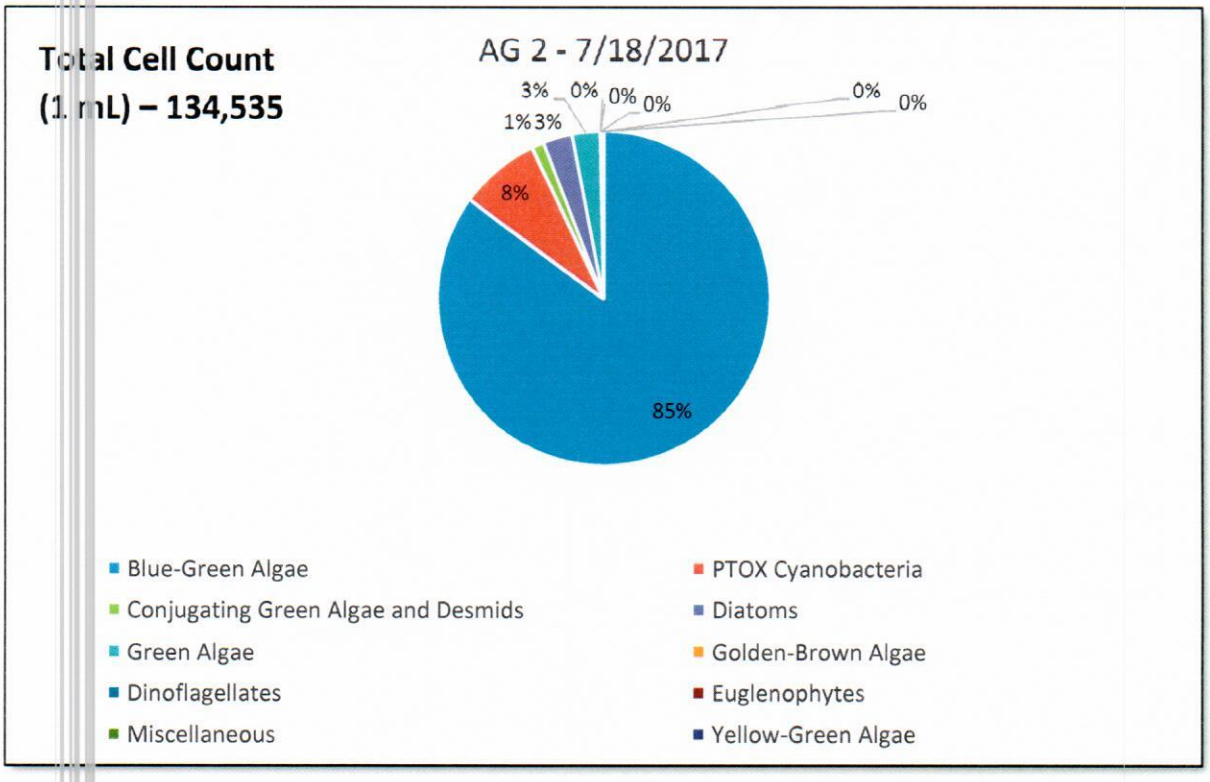


SITE AG 2

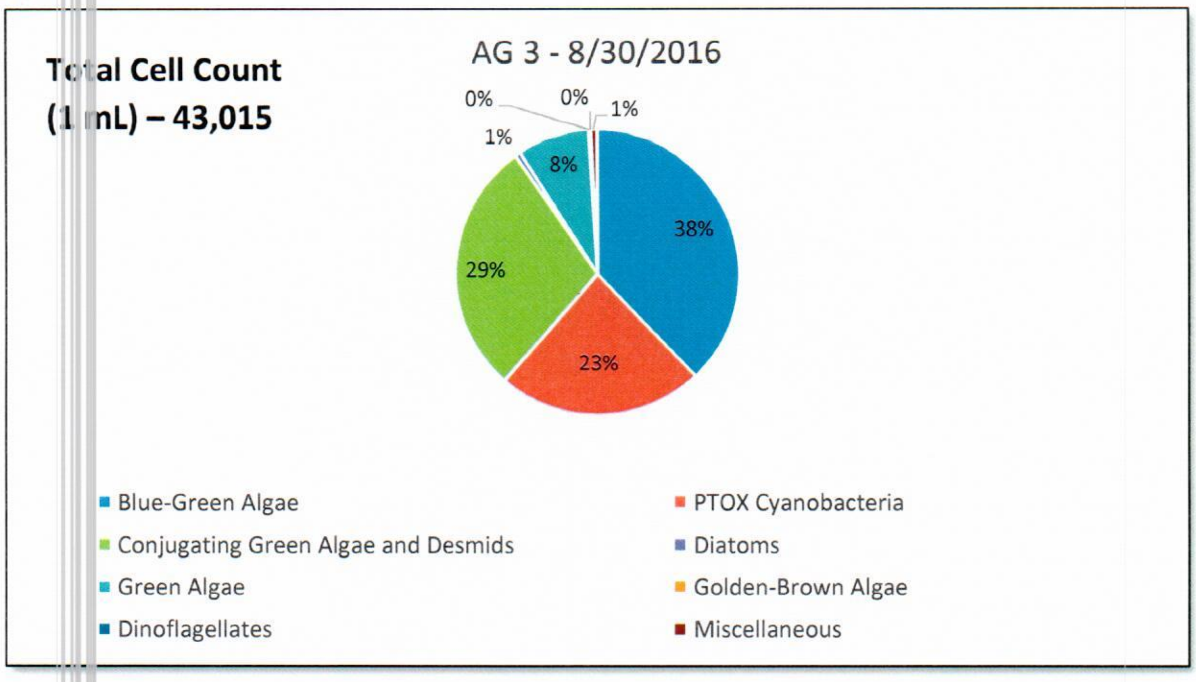

Total Cell Count
(1 mL) – 34,182
AG 2 - 8/30/2016
0%
2%
0%
0%
11%
23%
54%
10%
Blue-Green Algae
PTOX Cyanobacteria
Conjugating Green Algae and Desmids
Diatoms
Green Algae
Golden-Brown Algae
Dinoflagellates
Miscellaneous

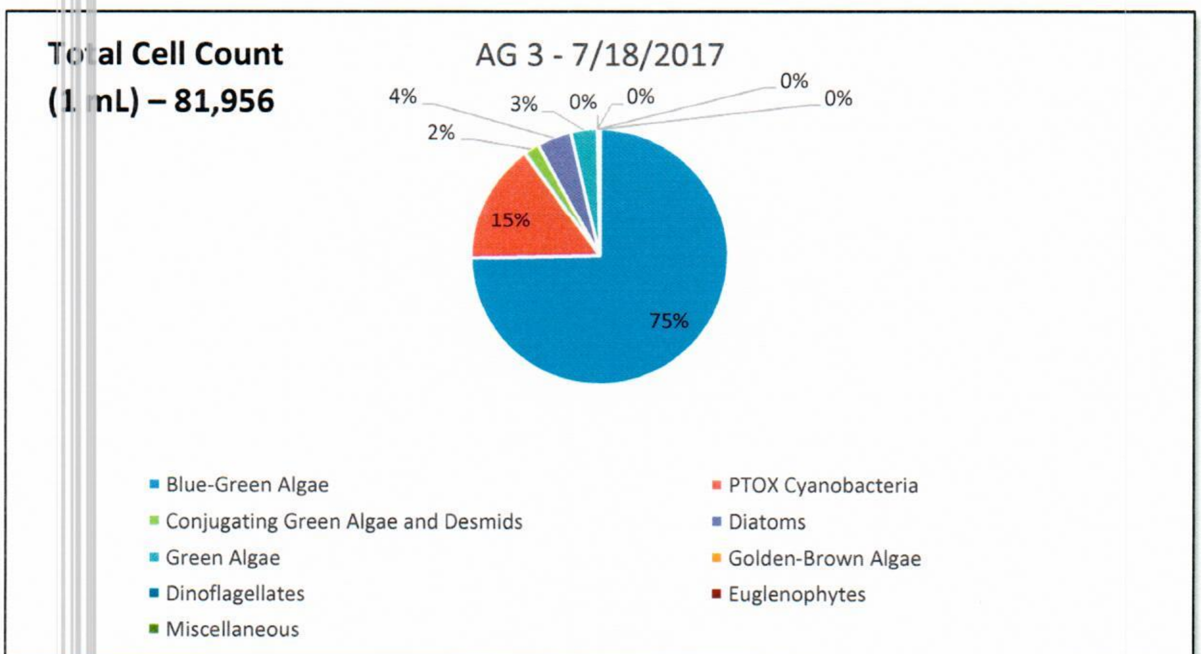

Total Cell Count
(1 mL) – 55,636
AG 2 - 10/3/2016
0%
0%
0%
3%
1%
71%
15%
10%
Blue-Green Algae
PTOX Cyanobacteria
Conjugating Green Algae and Desmids
Diatoms
Green Algae
Yellow-Green Algae
Dinoflagellates
Miscellaneous

SITE AG 2, CONTINUED

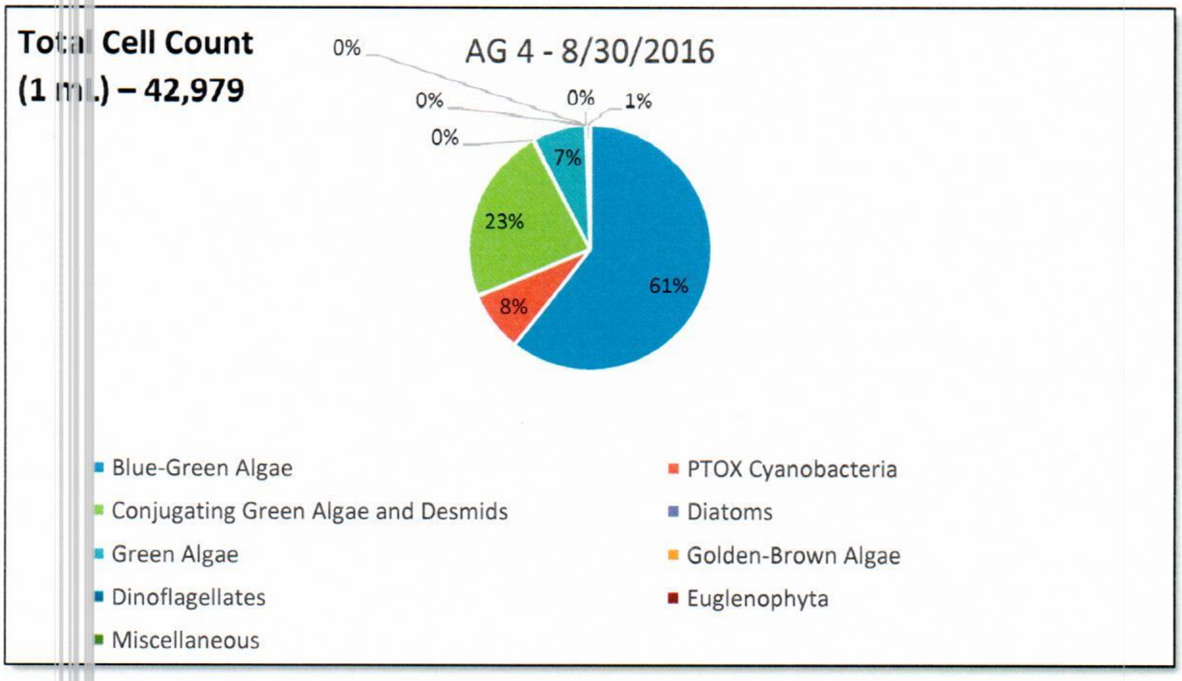


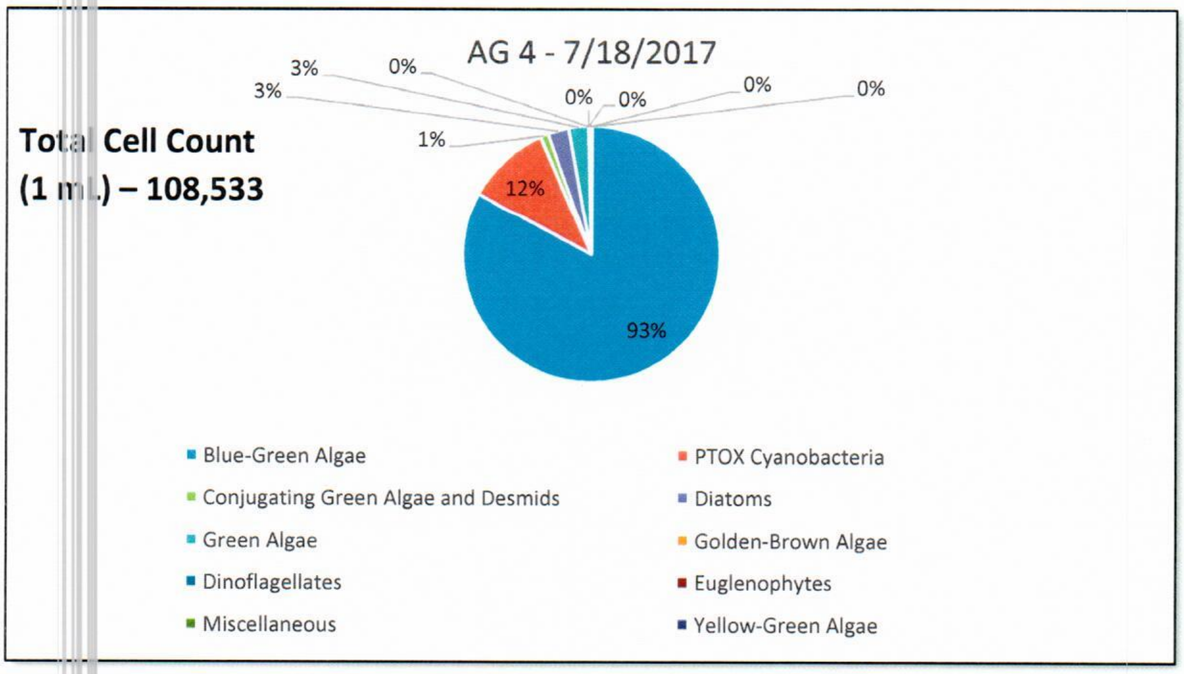
SITE AG 3


Total Cell Count
(1 mL) – 43,015
AG 3 - 8/30/2016
0%
0%
1%
1%
8%
38%
29%
23%
Blue-Green Algae
PTOX Cyanobacteria
Conjugating Green Algae and Desmids
Diatoms
Green Algae
Golden-Brown Algae
Dinoflagellates
Miscellaneous

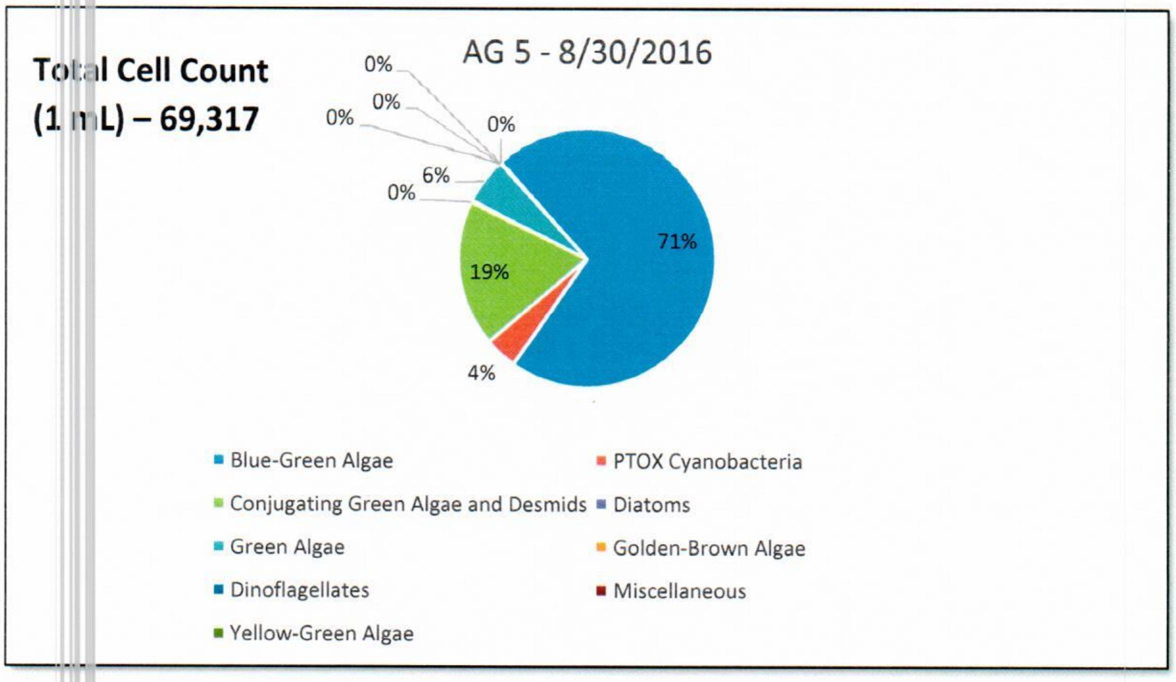

Total Cell Count
(1 mL) – 81,956
AG 3 - 7/18/2017
4%
3%
0%
0%
0%
0%
2%
15%
75%
Blue-Green Algae
PTOX Cyanobacteria
Conjugating Green Algae and Desmids
Diatoms
Green Algae
Golden-Brown Algae
Dinoflagellates
Euglenophytes
Miscellaneous

SITE AG 4

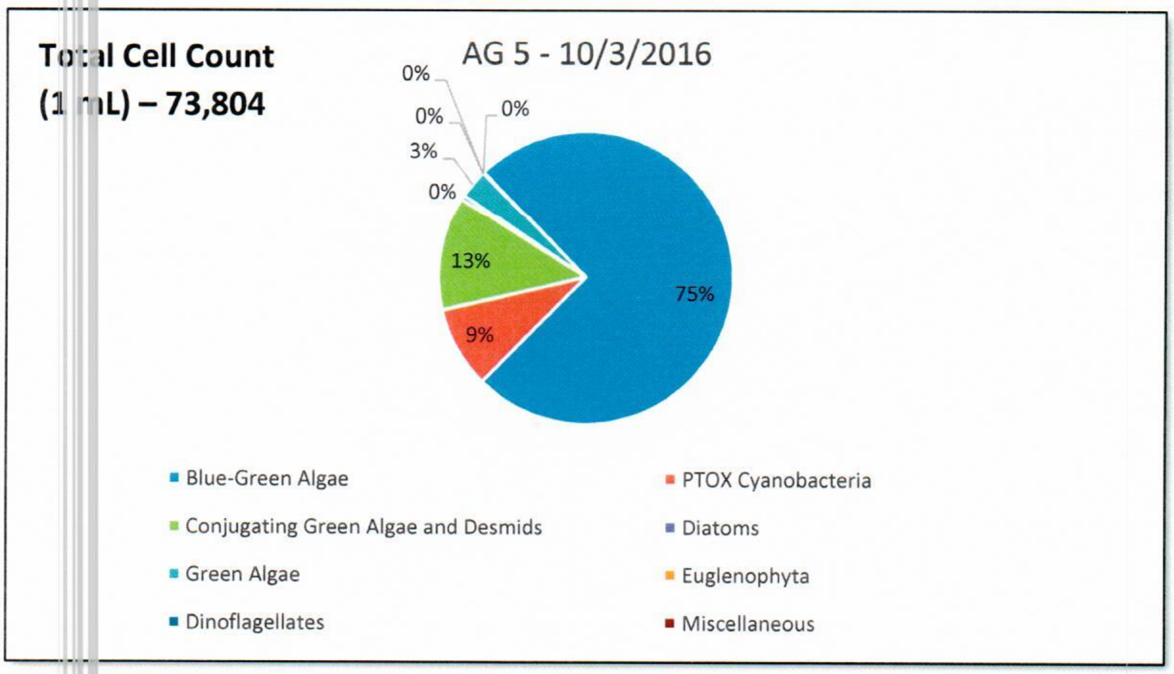

Total Cell Count
(1 mL) – 42,979
AG 4 - 8/30/2016
0%
0%
0%
0%
1%
7%
23%
8%
61%
Blue-Green Algae
Conjugating Green Algae and Desmids
Green Algae
Dinoflagellates
Miscellaneous
PTOX Cyanobacteria
Diatoms
Golden-Brown Algae
Euglenophyta


AG 4 - 7/18/2017
3%
3%
0%
0%
0%
0%
0%
1%
12%
93%
Total Cell Count
(1 mL) – 108,533
Blue-Green Algae
Conjugating Green Algae and Desmids
Green Algae
Dinoflagellates
Miscellaneous
PTOX Cyanobacteria
Diatoms
Golden-Brown Algae
Euglenophytes
Yellow-Green Algae

SITE AG 5

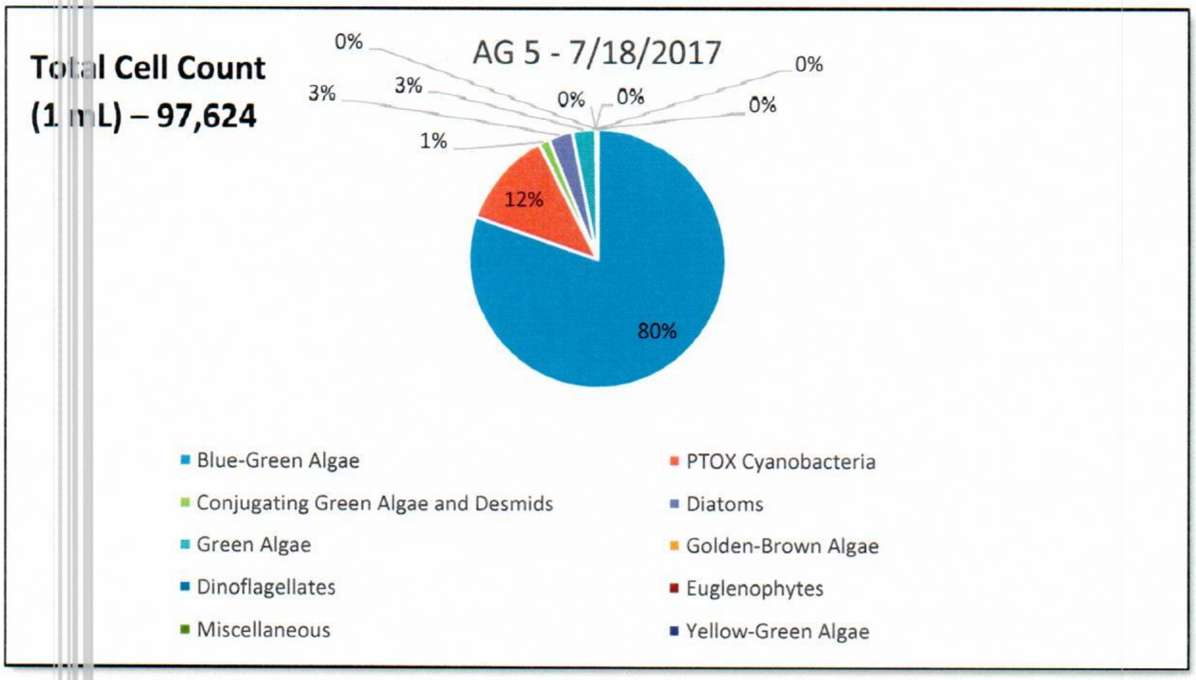


Total Cell Count
(1 mL) – 69,317
AG 5 - 8/30/2016
0%
0%
0%
0%
6%
0%
71%
19%
4%
Blue-Green Algae
PTOX Cyanobacteria
Conjugating Green Algae and Desmids
Diatoms
Green Algae
Golden-Brown Algae
Dinoflagellates
Miscellaneous
Yellow-Green Algae



Total Cell Count
(1 mL) – 73,804
AG 5 - 10/3/2016
0%
0%
0%
3%
0%
13%
75%
9%
Blue-Green Algae
PTOX Cyanobacteria
Conjugating Green Algae and Desmids
Diatoms
Green Algae
Euglenophyta
Dinoflagellates
Miscellaneous

SITE AG 5, CONTINUED



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