Paw Paw Lake & Associated Drain Water Quality Trends with Recommendations for Future Data Collection and Effective Management Outcomes

Provided for: Paw Paw Lake Association (PPLA)

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1.0 EXECUTIVE SUMMARY

During the fall of 2021, the Paw Paw Lake Association (PPLA) met with Restorative Lake Sciences (RLS) to discuss the current and urgent issues on Paw Paw Lake that are resulting in degraded water quality and impaired lake use. The PPLA and RLS determined that a lot of scientific data has been collected on the lake basin and drains to date, but that data is not being used to ideal capacity in management decision-making. The purpose of this evaluation is to provide a comprehensive summary of all data collected to date and develop trends by parameter to show the changes in each parameter over time. Additionally, the report discusses the scientific method and data deficiencies which must be clarified so that all future data is consistently collected in the same manner and with the same methods. Only data collected with the same methodology can be compared over time. Some of the trend graphs display breaks in the data as data gaps were common among and within years. Whenever possible, a line of best fit was used to determine trends with incomplete data sets. Additionally, descriptive statistics such as means and standard deviations were computed to assist with graphic trend analysis.

Paw Paw Lake Basin Characteristics:

Paw Paw Lake is a large inland lake comprising 891 acres in surface area. The lake lies in sections 10,11,14,15, and 16 of Watervliet and Coloma Townships in Berrien County, Michigan (T. 3S, R. 17W). The lake has two distinct deep basins with the north basin occupying over 217 acres with a maximum depth of 50 feet and the south basin occupying approximately 674 acres with a maximum depth of 90 feet. The mean overall depth of the entire lake is approximately 29.3 feet which is very deep for an inland lake. The lake water volume is estimated to be around 26,130 acre-feet and the lake lies at an elevation of 621 above mean sea level. The length of the shoreline is approximately 46,090 feet (8.7 miles). The hydraulic retention time of the lake is estimated to be 1.97 years. There is an outlet at the east end of the lake near N. Watervliet road. The lake also has lengthy drains entering the basin and these are discussed in the drain section of this summary and again in Section 5.0 of this report.

Paw Paw Lake Trophic State:

Paw Paw Lake is classified as a eutrophic lake, which means that the nutrient concentrations are elevated, and thus aquatic vegetation and algae are prevalent. Previous evaluations on the lake by Water Quality Investigators (WQI) have determined a range of the Trophic State Index (TSI) which is a commonly used index to assign a score to inland lakes based on three water quality parameters: 1) secchi disk transparency, 2) chlorophyll-a, and 3) total phosphorus. The problem with this method is that it inaccurately biases the lake health by relying only on surface total phosphorus concentrations. This is problematic as surface concentrations are often very low whereas bottom concentrations can be several orders of magnitude higher and such bottom values may better indicate the true trophic status of the lake. The TSI in Paw Paw Lake was reported by WQI to range from 77-95 from 2004-2010. These values all fall within the eutrophic (50-80) and hyper-eutrophic (>80) categories.

Carrying Capacity Evaluation:

In 1995, a carrying capacity analysis was conducted on Paw Paw Lake to determine the degree of overburden of boats on the lake which can lead to injuries and shoreline impacts, among other issues. The outcome determined that approximately 802 acres of usable area were present. It was concluded that the lake was already overburdened at that time and development has continued to occur since. The PPLA may want to consider re-visiting this study to determine how much the current capacity has exceeded the 1995 recommended guidelines for boat use. This may be an important factor for protecting the lake shoreline.

Laminar Flow Aeration Pilot Study:

In 2015, a pilot project to evaluate the efficacy of a bottom-placed laminar flow aeration (LFA) system was initiated in the north lobe of Paw Paw Lake. There were a total of 19 diffusers with additions of bioaugmentation such as Nature's Liquid Balance® (by AquaFix®) and PureBacteria+® (by Organic Pond®). Water quality data were collected, and the system was not able to significantly improve the lake water quality. The system was not given a fair chance of a good scientific assessment as the system should not have been limited to such a small faction of the lake as many other areas of the lake likely influence the water quality in that region.

Paw Paw Lake Drains:

As noted in the WQI reports, there are numerous drains that enter into Paw Paw Lake in three areas: Sample Stations B (Little Paw Paw), C (Branch and Derby), and G (Sherwood). Additional sites along these drains contribute water to these key areas. Specific stations sampled in these three key drain reaches are discussed in Section 5.0. The Branch and Derby Drain annually contributes the largest nutrient and solid loads to the lake.

Although there have been improvements to this drain with time, including straightening of the drain to offer better drainage, the sediment traps often are inundated and overflow in the lake during heavy rainfall events. In 2021 the TSS loading rate was estimated to be 102,189 lbs./day. The TP loading rate was estimated to be 611 lbs./day. The N loading rate was estimated to be 1,048 lbs./day. These loads indicate that the nutrients from the Drain are increasing over time and a new mitigation strategy is urgently needed.

RLS has recommended additional mitigation improvements that should be considered for the Branch and Derby Drain. One such improvement is consideration of an emergent filtration wetland upland of the drain-lake confluence. This would allow for adequate filtration of solids and nutrients prior to entering the lake.

Recommendations for Future Water Quality Sampling:

Based on a review of the lake bathymetry (depth contours), there are many deep areas in Paw Paw Lake as supported by the great mean depth of 29.3 feet. The lake has been divided into two lobes-North and Middle lobes. This is not beneficial because making conclusions on either the North Lobe or Middle Lobe does not accurately portray the condition of all of Paw Paw Lake. Hydrologically, the division of these two lobes may not be possible due to the presence of another deep basin between the two lobes, and there is little benefit to this designation. WQI had originally sampled 6 basins throughout the lake, and this is preferred. This method allows for an accurate determination of water column characteristics as long as the data is collected as a profile from the surface to the bottom at each location. WQI had historically measured the profile only in the summer during stratification. Spring data is also important because it allows for the determination of the changes in dissolved oxygen and nutrients with depth. Much of the recently collected data was biased towards the surface or the lake bottom. A thorough understanding of the thermoclines and changes in parameters with depth is critical for determining lake health, especially relative to seasonality.

RLS compared previously collected spring surface data to summer surface data and there were marked differences. Thus, it is important to sample the same parameters in spring and summer for all of the proposed 6 deep basin sampling locations. The following physical parameters should be collected once in the spring and once in mid to late summer using calibrated equipment only. The parameters measured below should be measured in 0.5-meter increments:

1. Water temperature (measured in °C or °F)
2. Dissolved oxygen (DO measured in mg/L)
3. pH (measured in Standard Units SU)
4. Specific conductivity (measured in mS/cm)
5. Total Dissolved Solids (TDS measured in mg/L)
6. Secchi disk transparency (feet or meters)

The following chemical water quality parameters should be collected at the surface, mid-depth, and bottom of each of the N=6 water quality sampling stations:

1. Total Phosphorus (TP in mg/L or µg/L)
2. Ortho-Phosphorus (SRP in mg/L or µg/L)
3. Total Inorganic Nitrogen (TIN in mg/L or µg/L)
4. Total Kjeldahl Nitrogen (TKN in mg/L or µg/L)
5. Total Suspended Solids (TSS in mg/L or µg/L)
6. Chlorophyll-a (Chl-a in µg/L)

RLS completed an analysis of the lake basin water quality to date that was collected in the same manner and locations. Those data tables revealed the following conclusions about the lake basin:

1. Paw Paw Lake mean surface DO has increased slightly with time
2. Paw Paw Lake summer mean bottom DO has increased slightly with time
3. Paw Paw Lake experiences DO depletion beyond a depth of 20 feet in summer (stratified)
4. Paw Paw Lake mean surface summer water temperatures have increased with time
5. Paw Paw Lake mean bottom water temperatures have increased slightly with time
6. Paw Paw Lake mean summer surface conductivity has remained stable over time
7. Paw Paw Lake mean spring surface conductivity has declined with time
8. Paw Paw Lake mean surface summer pH has slightly increased with time
9. Paw Paw Lake mean surface spring pH has declined slightly with time
10. Paw Paw Lake mean summer surface total alkalinity has declined with time
11. Paw Paw Lake mean spring surface total alkalinity has increased with time
12. Paw Paw Lake mean summer deep basin total alkalinity has declined with time
13. Paw Paw Lake mean deep basin TP has increased with time
14. Paw Paw Lake mean spring surface TP has increased with time
15. Paw Paw Lake mean summer surface TP has increased with time.
16. Paw Paw Lake mean summer surface nitrate has declined with time
17. Paw Paw Lake mean spring surface nitrate has declined slightly with time
18. Paw Paw Lake mean deep basin nitrate has declined with time
19. Paw Paw Lake mean spring chlorophyll-a has declined slightly with time
20. Paw Paw Lake mean summer chlorophyll-a has declined slightly with time
21. Paw Paw Lake mean Secchi depth has declined with time

RLS completed an analysis of the aquatic vegetation communities to date that was collected in the same manner and locations. That data revealed the following conclusions about the lake vegetation:

1. The native aquatic plant cumulative cover has increased in recent year (2018-2020) but declined in 2021. This was likely due to the strong presence of Eurasian Watermilfoil (EWM) that prevented native aquatic plant germination in many areas (pre-fluridone aka SONAR).

2. The low native cumulative cover in 2012 and 2017 was likely due to excessive EWM that required fluridone treatment, as in 2021.
3. The submersed cover has increased in recent years (2018-2020) but declined in 2021 due to excessive EWM cover.
4. The emergent cover has fluctuated but remains stable during the past two years.
5. The EWM cover has declined with time but increased in 2020 which necessitated the use of a systemic herbicide such as fluridone.
6. The CLP cover has declined much since 2013 and is barely present now.
7. The Starry Stonewort (SS) has increased in the past two years with the highest growth noted in 2021.

RLS completed an analysis of the key drain water quality parameters to date that was collected in the same manner and locations. Those data tables revealed the following conclusions about the lake drains:

1. Branch and Derby Drain mean nitrate has increased with time
2. Branch and Derby mean TP has increased with time

Recommendations of improving the water quality in the lake basins and in the drains are offered in Section 6.0. These recommended improvements include a new sampling protocol that is consistent with critical parameters for the lake basin and drains, along with various Best Management Practices (BMP's) that could be implemented by riparians. The future of Paw Paw Lake will depend on these changes.

Overall, these summary conclusions can be made about the current state of Paw Paw Lake:

1. Paw Paw Lake is eutrophic (nutrient-rich) with low water clarity and dissolved oxygen depletion.
2. The Paw Paw Lake basin will contribute to deteriorate unless major drain improvements and NPS pollution reductions are made.
3. The watershed land uses are the major causes of Paw Paw Lake eutrophication.
4. Whole-lake aquatic herbicides such as SONAR are not recommended. Spot-treatments of invasives would be more targeted and effective.
5. There is a great need for better riparian education and a comprehensive lake management plan that can also evaluate efficacy of all implemented mitigation strategies.
6. Watershed sampling should be conducted by trained personnel during key rain events for optimum data.

2.0 LAKE ECOLOGY BACKGROUND INFORMATION

2.1 Introductory Concepts

Limnology is a multi-disciplinary field which involves the study of the biological, chemical, and physical properties of freshwater ecosystems. A basic knowledge of these processes is necessary to understand the complexities involved and how management techniques are applicable to current lake issues. The following terms will provide the reader with a more thorough understanding of the forthcoming lake management recommendations for Paw Paw Lake.

2.1.1 Lake Hydrology

Aquatic ecosystems include rivers, streams, ponds, lakes, and the Laurentian Great Lakes. There are thousands of lakes in the state of Michigan, and each possesses unique ecological functions and socio-economic contributions. In general, lakes are divided into four categories:

- Seepage Lakes,
- Drainage Lakes,
- Spring-Fed Lakes, and
- Drained Lakes.

Some lakes (seepage lakes) contain closed basins and lack inlets and outlets, relying solely on precipitation or groundwater for a water source. Seepage lakes generally have small watersheds with long hydraulic retention times which render them sensitive to pollutants. Drainage lakes receive significant water quantities from tributaries and rivers. Drainage lakes contain at least one inlet and an outlet and generally are confined within larger watersheds with shorter hydraulic retention times. As a result, they are less susceptible to pollution. Spring-fed lakes rarely contain an inlet but always have an outlet with considerable flow. The majority of water in this lake type originates from groundwater and is associated with a short hydraulic retention time. Drained lakes are similar to seepage lakes, yet rarely contain an inlet and have a low-flow outlet. The groundwater and seepage from surrounding wetlands supply the majority of water to this lake type and the hydraulic retention times are rather high, making these lakes relatively more vulnerable to pollutants. The water quality of a lake may thus be influenced by the quality of both groundwater and precipitation, along with other internal and external physical, chemical, and biological processes.

Paw Paw Lake may be classified as a drainage lake with three key inlets and an outlet located on the east side of the lake on N. Watervliet road. These inlets are drains and include the large Branch and Derby Drain, the Sherwood Drain, and Green Drain. The Forest Beach Drain has also been a contributor of runoff in the past.

2.1.2 Biodiversity and Habitat Health

A healthy aquatic ecosystem possesses a variety and abundance of niches (environmental habitats) available for all of its inhabitants. The distribution and abundance of preferable habitat depends on limiting human influence from development and overuse, while preserving sensitive or rare habitats. As a result of this, undisturbed or protected areas generally contain a greater number of biological species and are considered more diverse. A highly diverse aquatic ecosystem is preferred over one with less diversity because it allows a particular ecosystem to possess a greater number of functions and contribute to both the intrinsic and socio-economic values of the lake. Healthy lakes have a greater biodiversity of aquatic macroinvertebrates, aquatic macrophytes (plants), fishes, phytoplankton, and may possess a plentiful yet beneficial benthic microbial community (Wetzel, 2001).

2.1.3 Watersheds and Land Use

A watershed is defined as an area of land that drains to a common point and is influenced by both surface water and groundwater resources that are often impacted by land use activities. In general, larger watersheds possess more opportunities for pollutants to enter the eco-system, altering the water quality and ecological communities. In addition, watersheds that contain abundant development and industrial sites are more vulnerable to water quality degradation since from pollution which may negatively affect both surface and ground water. Since many inland lakes in Michigan are relatively small in size (i.e., less than 300 acres), they are inherently vulnerable to nutrient and pollutant inputs, due to the reduced water volumes and small surface areas. As a result, the living (biotic) components of the smaller lakes (i.e., fishery, aquatic plants, macro-invertebrates, benthic organisms, etc.) are highly sensitive to changes in water quality from watershed influences. Land use activities have a dramatic impact on the quality of surface waters and groundwater.

In addition, the topography of the land surrounding a lake may make it vulnerable to nutrient inputs and consequential loading over time. Topography and the morphometry of a lake dictate the ultimate fate and transport of pollutants and nutrients entering the lake. Surface runoff from the steep slopes surrounding a lake will enter a lake more readily than runoff from land surfaces at or near the same grade as the lake. In addition, lakes with steep drop-offs may act as collection basins for the substances that are transported to the lake from the land.

Land use activities, such as residential land use, industrial land use, agricultural land use, water supply land use, wastewater treatment land use, and storm water management, can influence the watershed of a particular lake. All land uses contribute to the water quality of the lake through the influx of pollutants from non-point sources (NPS) or from point sources.

Non-point sources are often diffuse and arise when climatic events carry pollutants from the land into the lake. Point-source pollutants are discharged from a pipe or input device and empty directly into a lake or watercourse.

Residential land use activities involve the use of lawn fertilizers on lakefront lawns, the utilization of septic tank systems for treatment of residential sewage, the construction of impervious (impermeable, hard-surfaced) surfaces on lands within the watershed, the burning of leaves near the lakeshore, the dumping of leaves or other pollutants into storm drains, and removal of vegetation from the land and near the water. In addition to residential land use activities, agricultural practices by vegetable crop and cattle farmers may contribute nutrient loads to lakes and streams. Industrial land use activities may include possible contamination of groundwater through discharges of chemical pollutants.

Inland waters such as lakes provide multiple benefits to riparian communities and local municipalities through a variety of ecosystem services. Stynes (2002) estimated that Michigan's 11,000 inland lakes support a recreational industry that is valued at approximately 15 billion dollars per year. Inland lakes also provide economic and aesthetic values to riparian waterfront property owners with increased residential lot property values and scenic views. A survey of approximately 485 riparians that represented five lakes in Kalamazoo County, Michigan, USA, was conducted in 2002 by Lemberg et *al*. (2002) and revealed that the most important benefit of lakefront ownership was the vista. Thus, lakes clearly provide aesthetic as well as recreational benefits to riparians and those that use them.

For some time, lakes have been under continuous stress from surrounding development and land use activities. A major source of this stress includes the anthropogenic contributions of nutrients, sediments, and pathogens to the lake water from the surrounding landscape (Carpenter et *al*., 1998). Nutrients have caused critical water quality issues such as the inundation of lakes with dense, filamentous green algae, or worse, toxic blue-green algae. Submersed aquatic vegetation also increases with high levels of phosphorus and leads to impedance of navigation and recreational activities, as well as decreases in water clarity and dissolved oxygen that lead to widespread fish kills. The existence of excess phosphorus in inland waterways has been well established by many scholars (Carpenter et *al*., 1998; Millennium Ecosystem Assessment, 2005, among numerous others). Major sources of phosphorus for inland waterways include fertilizers from riparian lawns, septic drain fields, and non-point source transport from agricultural activities in the vicinity of a water body. Non-point source effluents such as phosphorus are difficult to intercept due to the diffuse geographical dispersion across a large area of land. Additionally, watersheds generally export more non-point source loads relative to point source loads as a result of the reductions of point source pollution required by the Clean Water Act of 1972 (Nizeyimana et *al*., 1997; Morgan and Owens, 2001).

3.0 PAW PAW LAKE BASIN AND IMMEDIATE WATERSHED CHARACTERISTICS

3.1 The Paw Paw Lake Basin

Paw Paw Lake is a large inland lake comprising 891 acres in surface area (Figure 1). The lake lies in sections 10,11,14,15, and 16 of Watervliet and Coloma Townships in Berrien County, Michigan (T. 3S, R. 17W). The lake has two distinct deep basins with the north basin occupying over 217 acres with a maximum depth of 50 feet and the south basin occupying approximately 674 acres with a maximum depth of 90 feet. The mean overall depth of the entire lake is approximately 29.3 feet which is very deep for an inland lake.

The lake water volume is estimated to be around 26,130 acre-feet and the lake lies at an elevation of 621 above mean sea level. The length of the shoreline is approximately 46,090 feet (8.7 miles). The hydraulic retention time of the lake is estimated to be 1.97 years.

There is an outlet at the east end of the lake near N. Watervliet road . The lake also has three key drains discussed later in the report.

Figure 1. Aerial photo of Paw Paw Lake in Berrien County, Michigan.

3.2 The Paw Paw Lake Immediate Watershed

An immediate watershed is the area around the lake directly draining into the lake. The lake immediate watershed has been previously mapped. The Lake Paw Paw Lake immediate watershed is approximately 9,248 acres. The watershed to lake ratio is 10.4 which indicates a large watershed.

RLS provides many immediate watershed improvements that can be executed by Paw Paw Lake riparians in Section 5.0. These recommended improvements are to support the five key designated uses for the Paw Paw Lake watershed including the fisheries, other indigenous wildlife and aquatic life, total body contact, navigation, and fish consumption. During heavy rainfall, the Branch and Derby Drain contributed approximately 611 lbs. of total phosphorus per day in 2021 and 1,048 lbs. of nitrogen per day in 2021. The other drains do not contribute has much nutrient and solids but are still measurable sources.

4.0 PAW PAW LAKE WATER QUALITY DATA & TRENDS

Water quality is highly variable among Michigan's inland lakes, although some characteristics are common among particular lake classification types. The water quality of each lake is affected by both land use practices and climatic events. Climatic factors (i.e. spring runoff, heavy rainfall) may alter water quality in the short term; whereas, anthropogenic (man-induced) factors (i.e., shoreline development, lawn fertilizer use) alter water quality over longer time periods. Furthermore, lake water quality helps to determine the classification of particular lakes (Table 1). Lakes that are high in nutrients (such as phosphorus and nitrogen) and chlorophyll-*a*, and low in transparency are classified as eutrophic; whereas those that are low in nutrients and chlorophyll-*a*, and high in transparency are classified as oligotrophic. Lakes that fall in between these two categories are classified as mesotrophic. Paw Paw Lake is classified as eutrophic (nutrient-rich) basins due to the measured elevated nutrients and reduced mean Secchi transparency and marked dissolved oxygen depletion with depth (Figure 2), and elevated chlorophyll-*a* concentrations.

Water Quality Investigators (WQI) had previously selected six water quality sampling stations throughout Paw Paw Lake. Beginning in 2007, WQI sampled these six deepest basins at irregular intervals. Deep basin profile data is very important for understanding lake mixing and health. Collection of only surface samples can substantially skew water quality data since many surface nutrients are significantly lower than bottom nutrient concentrations. The selection of six stations for a lake the size of Paw Paw is adequate.

In recent years, the lake has been divided the lake into two "lobes" which consisted of the north and south (main lake) lobes. Based on a careful limnological review of the lake bathymetric map, this is not recommended. The depths of the "north lobe" and "main lake" are all considered deep and prone to mixing and the area in between is also fairly deep. Thus, the lake likely mixes twice per year with spring and fall turnover with some transfer among basins. Additionally, the lake circulation patterns likely cross from the north lobe into the main lake and vice versa. From a limnological perspective, it does not make sense to isolate the lake into lobes.

Restorative Lake Sciences (RLS) recommends continued annual spring and late summer water quality sampling during isothermic (temperature is similar from the surface to the bottom) and stratified (presence of a strong thermocline) periods, respectively. Ideally, this would occur in April and August of each year. RLS recommends retaining the original six water quality sampling stations as profiles (top, middle, bottom) where physical water quality parameters such as water temperature, dissolved oxygen, pH, specific conductivity are collected at 0.5-meter depth increments.

This is important since determination of the depths at which dissolved oxygen disappears is critical to understanding the nutrient cycling in the lake (i.e., internal loading under low dissolved oxygen), and also for understanding how much of the lake remains anaerobic (without oxygen) for a determined period of time. Typically, dissolved oxygen depletion only occurs when the lake is stratified as in early to late summer. This will depend upon the arrival of summer and intense warming of the lake upper layers due to sustained warm air temperatures. In addition to the physical water quality parameters discussed above in 0.5-meter increments, chemical water quality parameters such as key nutrients should also be collected. Tables 2-4 display the means and standard deviations for key water quality parameters sampled for the surface and deep basin between 1987-2021. Due to numerous data gaps, only consistently collected data was used in the analysis to allow for precise trends over time.

Table 1. General lake trophic classification table (MDNR, 1982).

Lake Trophic State	Secchi Depth (meters)	Chlorophyll-*a* ($\mu g\ L^{-1}$)	Total Phosphorus ($\mu g\ L^{-1}$)
Oligotrophic	>4.6	<2.2	<0.010
Mesotrophic	2.3-4.6	2.2-6.0	0.010-0.020
Eutrophic	0.9-2.2	6.1-22	0.021-.050
Hypereutrophic	<0.9	>22	>0.050

Table 2. Paw Paw Lake spring surface water quality data. Note: Only data with adequate sample sizes were used to calculate these means and standard deviations (means ±standard deviaton).

Year	Chl-a (µg/L)	Nitrates (µg/L)	Total Alkalinity (mg/L $CaCO_3$)	pH (SU)	Conductivity (mS/cm)	Total Phosphorus (µg/L)
1987	--	--	--	8.6	282	--
2004	16.6±5.5	90±24	58±7.4	8.7±0.2	152±16.4	21.0±4.9
2005	6.3±1.3	49±9.6	78±3.6	8.5±0.1	213±15.0	19.0±2.9
2006	6.2±1.2	141±21	102±5.4	7.9±0.2	280±20.0	22.0±1.5
2007	6.3±1.6	305±15.3	79±8.9	8.5±0.3	242±26.0	20.0±2.7
2008	10.0±1.5	187±10.3	94±3.4	9.0±0.1	234±5.5	24.0±0.7
2009	3.8±1.3	151±9.2	74±2.3	8.4±0.5	198±4.5	21.0±0.7
2010	4.3±1.3	115±39.6	88±5.7	8.5±0.2	234±22.0	23.0±4.0
2011	--	110±22.4	135±47.6	--	--	46.0±10.2
2016	11.0±4.0	--	--	8.5±0.7		31.0±14.4

Table 3. Paw Paw Lake mean summer surface water quality data. Note: Only data with adequate sample sizes were used to calculate these means and standard deviations.

Year	Water Temp (°F)	Dissolved Oxygen (mg/L)	pH (SU)	Conductivity (mS/cm)	Nitrate (µg/L)	Total Phosphorus (µg/L)	Chl-a (µg/L)
1987	66.2	7.6	8.5	260	5.0	14	4.0
2004	75.2±0.0	8.8±0.5	8.6±0.1	292±8.4	26.0±6.7	16.0±2.0	8.5±1.4
2005	78.8±0.0	8.4±0.1	8.2±0.3	281±10.7	26.0±10.6	16.0±5.0	2.8±1.8
2006	77.0±0.0	7.2±0.3	8.4±0.1	280±0.0	32.0±5.2	25.0±3.5	4.4±0.5
2007	76.0±1.0	9.3±0.3	8.8±0.1	283±4.7	81.0±15.0	27.0±1.2	3.9±0.3
2008	77.0±0.0	7.6±0.3	8.5±0.1	263±6.0	40.0±9.6	27.0±2.6	12.0±0.5
2009	77.0±0.0	8.1±0.3	8.1±0.2	227±30	62.0±93.0	26.0±4.0	12.7±5.6
2010	75.0±1.0	7.5±0.3	8.4±0.1	241±4.0	10.0±3.0	16.0±3.1	1.7±0.6
2011	--	--	9.2±0.9	250±2.8	100.0±0.0	32.0±11.7	8.2±1.8
2015	--	5.8±0.5	10.0±0.1	296±2.2	--	55.0±9.3	--
2016	76.3±6.4	8.3±0.7	8.7±0.1	283±0.0	--	46.0±22.3	8.5±5.7
2018	83.9	8.7	--	252	--	--	--
2019	73.0	7.5	--	249	--	--	--
2020	75.9	9.1	--	258	--	--	--
2021	74.0	8.7	--	298	--	--	--

Table 4. Paw Paw Lake mean summer deep basin water quality data. Note: Only data with adequate sample sizes were used to calculate these means and standard deviations.

Year	Total Alkalinity (mg/L CaCO3)	Bottom Total Phosphorus (µg/L)	pH (SU)	Conductivity (mS/cm)	Nitrate (µg/L)	Total Phosphorus (µg/L)	Chl-a (µg/L)
2007	126±9.1	31	7.8±0.5	321±23	107±56	24±3.0	2.7
2008	122±7.2	56	8.0±0.4	277±12.0	168±240	36±11	6.7±4.0
2009	117±5.8	132	7.8±0.3	269±8.8	175±233	48±35	9.8
2010	124±13	218	7.8±0.4	269±25	22±15	66±70	1.2
2015	--	50	9.2±0.3*	320±7.0	--	49±18	--
2016	--	1730**	7.5±0.1	--	--	290±584	--

*This value is likely inaccurate and due to lack of proper probe calibration or probe malfunction. Normal values for lake pH rarely exceed 8.9 S.U. **This bottom TP concentration was recorded but may be an outlier and consequently increases the mean TP value.

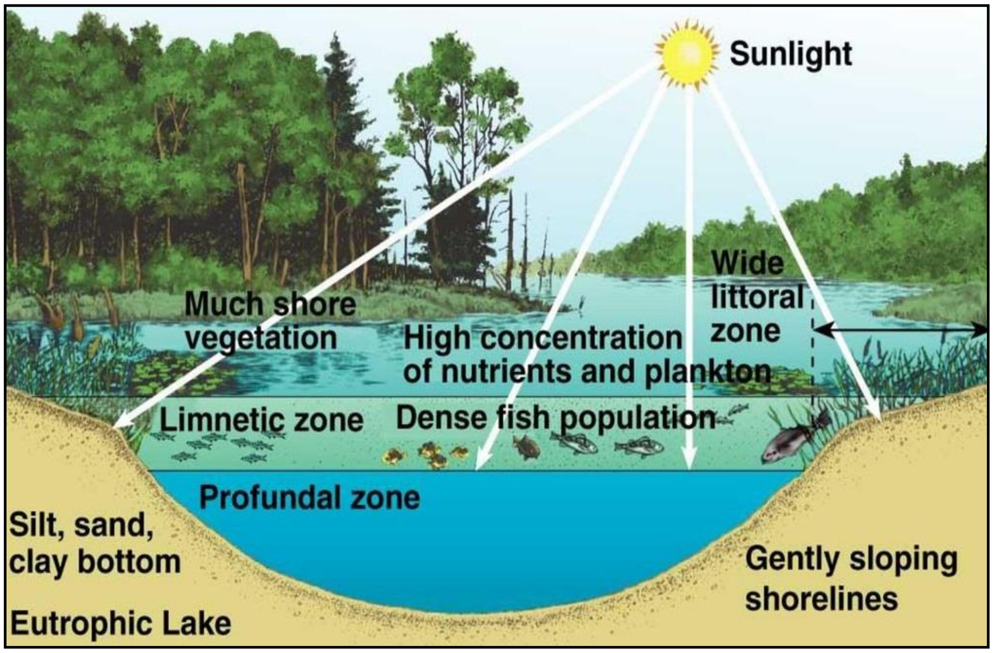


Figure 2. Diagram showing a nutrient-rich, eutrophic lake ecosystem (Photo adapted from Brooks/Cole Thomson learning online).

4.1 Water Quality Parameters

Parameters such as dissolved oxygen (in mg/L), water temperature (in °F), specific conductivity (mS/cm), turbidity (NTU's), total dissolved solids (mg/L), total suspended solids (mg/L), pH (S.U.), total phosphorus and ortho-phosphorus (also known as soluble reactive phosphorus or SRP measured in mg/L), total Kjeldahl nitrogen and total inorganic nitrogen (in mg/L), chlorophyll-*a* (in µg/L), and Secchi transparency (in feet or meters) are parameters that respond to changes in water quality and consequently serve as indicators of change.

Historical data collected by Water Quality Investigators (WQI) consisted of parameters such as water temperature, dissolved oxygen, and Secchi disk transparency all measured in the field. The type of probe and status of calibration was not noted at any time. Water quality parameters such as chlorophyll-*a*, phosphorus, nitrate nitrogen, alkalinity, pH, and conductivity were all performed in the WQI laboratory according to the APHA (1985) Standard Methods for the Examination of Water and Wastewater. When possible, RLS highly recommends the use of EPA methods for all parameters as well as analysis at a NELAC-certified laboratory.

Recent data collected did not specify the laboratory used, sampling equipment used, or the analysis methods. In the development of trend data, it is important to analyze data that is collected with the same methods over time and also to consider any differences in measurement units as these also have to be similar (or converted) in order for trends to accurately be created.

Mean data by parameter are shown in the following section. A map showing the historical sampling locations for all water quality samples is shown below in Figure 3. These stations are recommended for all future lake basin water quality sampling.

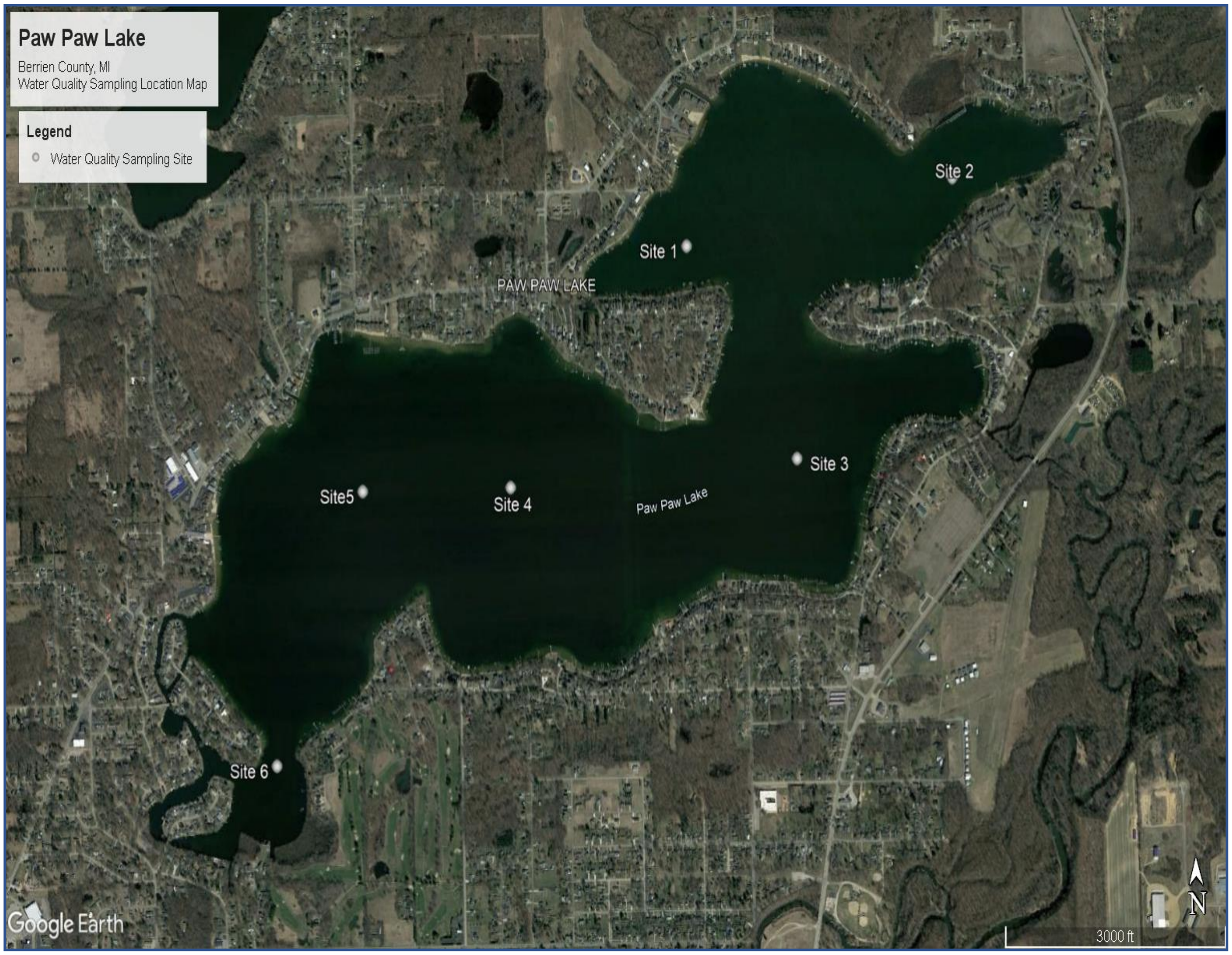


Figure 3. Historical locations for water quality sampling in Paw Paw Lake. Note: These stations were originally created by Water Quality Investigators (WQI).

4.1.1 Dissolved Oxygen

Dissolved oxygen is a measure of the amount of oxygen that exists in the water column. In general, dissolved oxygen levels should be greater than 5 mg L^{-1} to sustain a healthy warm-water fishery. Dissolved oxygen concentrations may decline if there is a high biochemical oxygen demand (BOD) where organismal consumption of oxygen is high due to respiration. Dissolved oxygen is generally higher in colder waters. It is unclear what type of probes were used in the past, but RLS recommends that dissolved oxygen be measured in milligrams per liter (mg/L) with the use of a calibrated dissolved oxygen meter.

The bottom of the lake produces a biochemical oxygen demand (BOD) due to microbial activity attempting to break down high quantities of organic plant matter, which reduces dissolved oxygen in the water column at depth. Furthermore, the lake bottom is distant from the atmosphere where the exchange of oxygen occurs. A decline in the dissolved oxygen concentrations to near zero may result in an increase in the release rates of phosphorus (P) from lake bottom sediments.

Very little historical data has been collected on spring and fall dissolved oxygen concentrations and thus trends could not be created for those seasons. Most spring dissolved oxygen concentrations are at or above saturation level and tend to range from 9-13 mg/L which is high and favorable. Based on the limited spring dissolved oxygen data, the dissolved oxygen concentrations ranged from 11-12.7 mg/L which is within a normal range for spring dissolved oxygen concentrations. Due to the abundance of dissolved oxygen with cooler spring water temperatures, it is usually not measured. It would be useful as previously mentioned by RLS to sample Paw Paw Lake in the spring during isothermic conditions. This data will allow for the determination of the quantity of dissolved oxygen depletion as the season progresses and to determine changes in nutrients with seasonality.

Historical data for surface summer dissolved oxygen concentrations and deep basin dissolved oxygen concentrations are shown in Figures 4 and 5 below. Figure 6 displays the rapid loss of DO with depth during summer stratified periods.

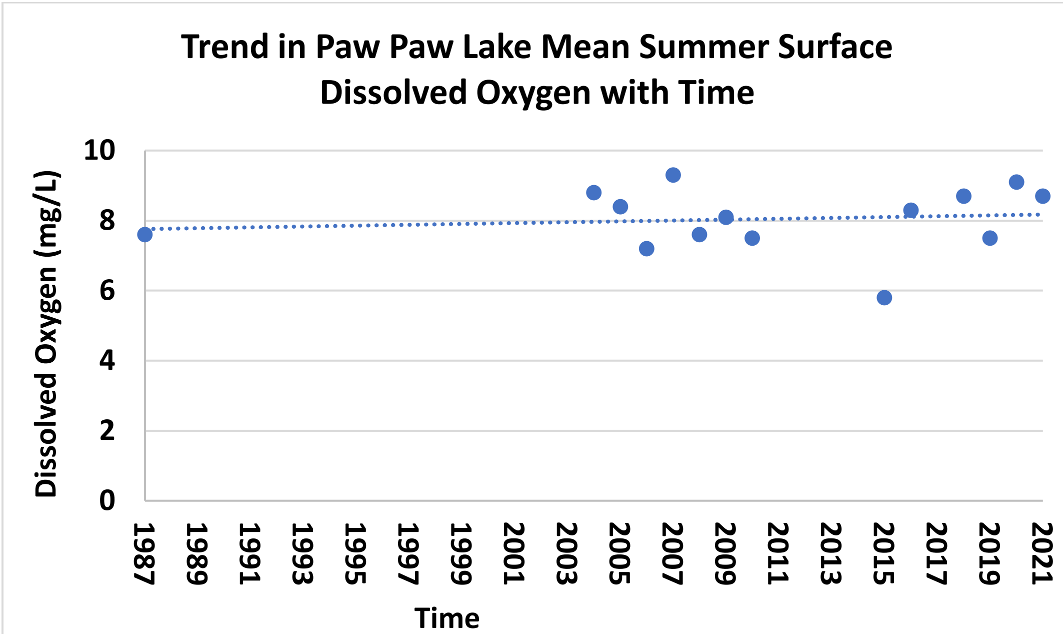
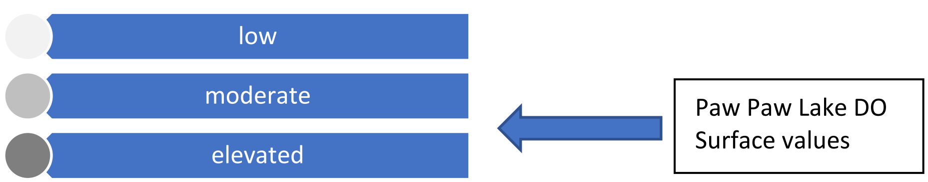


Figure 4. Trend in Paw Paw Lake mean summer surface dissolved oxygen with time.



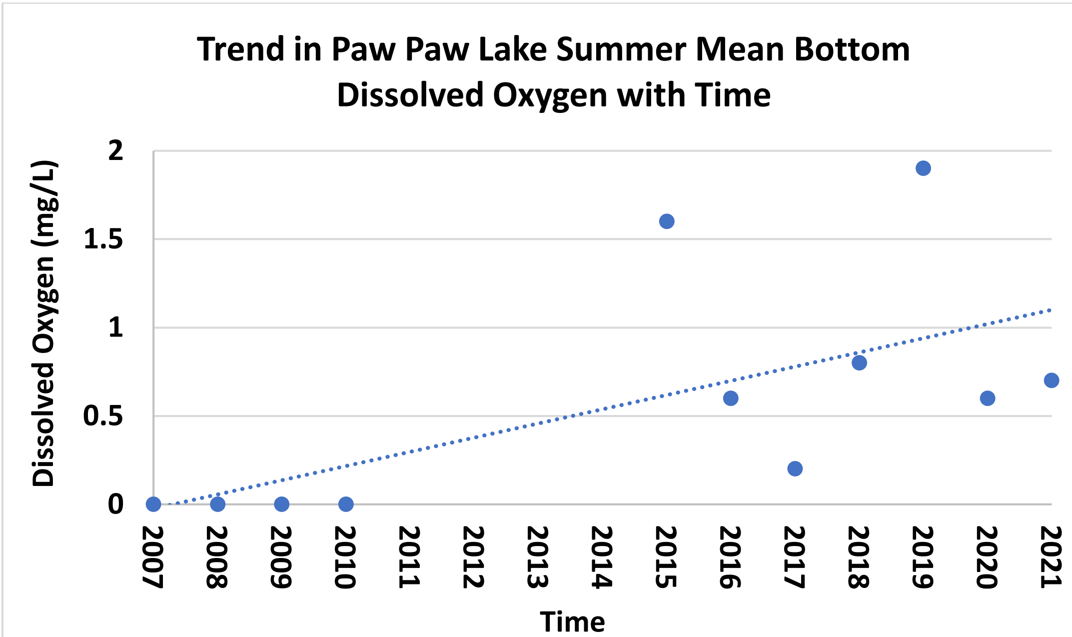
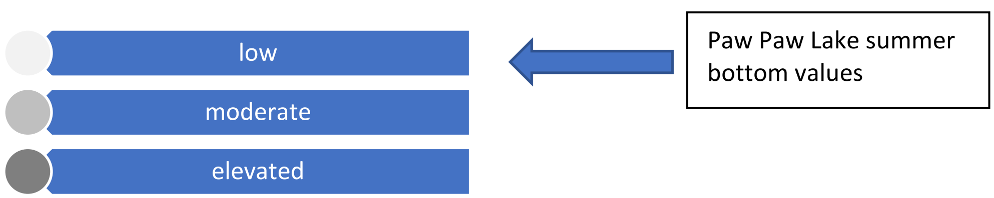


Figure 5. Trend in Paw Paw Lake mean summer bottom dissolved oxygen with time.



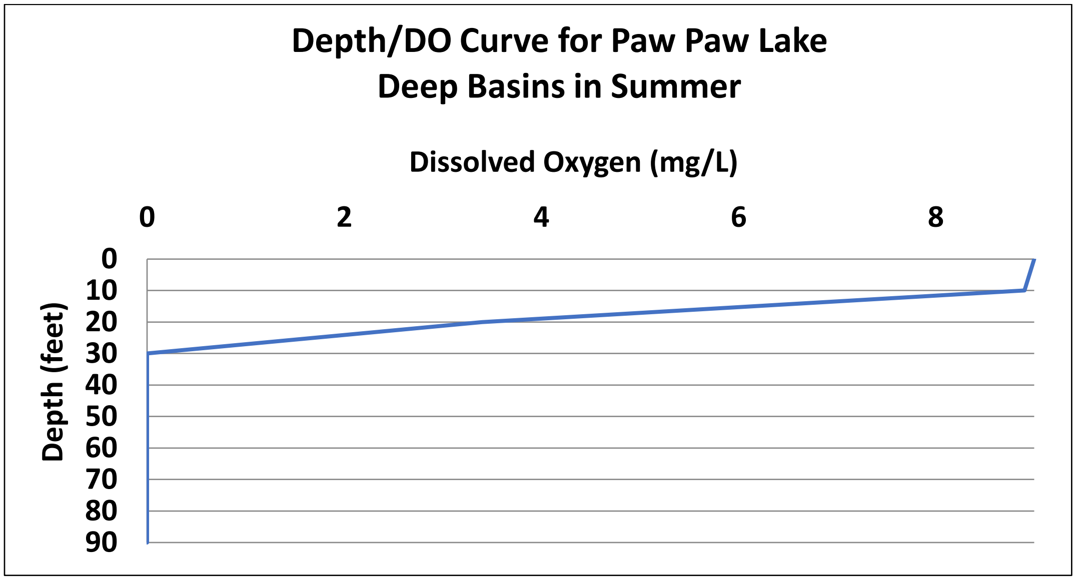


Figure 6. Typical summer depth/dissolved oxygen profile for Paw Paw Lake. Note the substantial loss of dissolved oxygen beyond a depth of 20 feet.

4.1.2 Water Temperature

A lake's water temperature varies within and among seasons, and is nearly uniform with depth under the winter ice cover because lake mixing is reduced when waters are not exposed to the wind. When the upper layers of water begin to warm in the spring after ice-off, the colder, dense layers remain at the bottom. This process results in a "thermocline" that acts as a transition layer between warmer and colder water layers. During the fall season, the upper layers begin to cool and become denser than the warmer layers, causing an inversion known as "fall turnover" (Figure 7). In general, shallow lakes will not stratify and deeper lakes may experience single or multiple turnover cycles. Paw Paw Lake experiences spring and fall turnover events. Water temperature is measured in degrees Fahrenheit (ºF) with the use of a calibrated submersible thermometer.

These water temperatures are favorable to support a cold water and warm water fishery with cold water fishes present in deeper waters during the summer months. Cooler water temperatures generally also hold more dissolved oxygen. A limitation exists though without DO as fish require a DO concentration of ≥5.0 mg/L for survival. Figures 8-9 display the trends in surface and bottom temperatures with time.

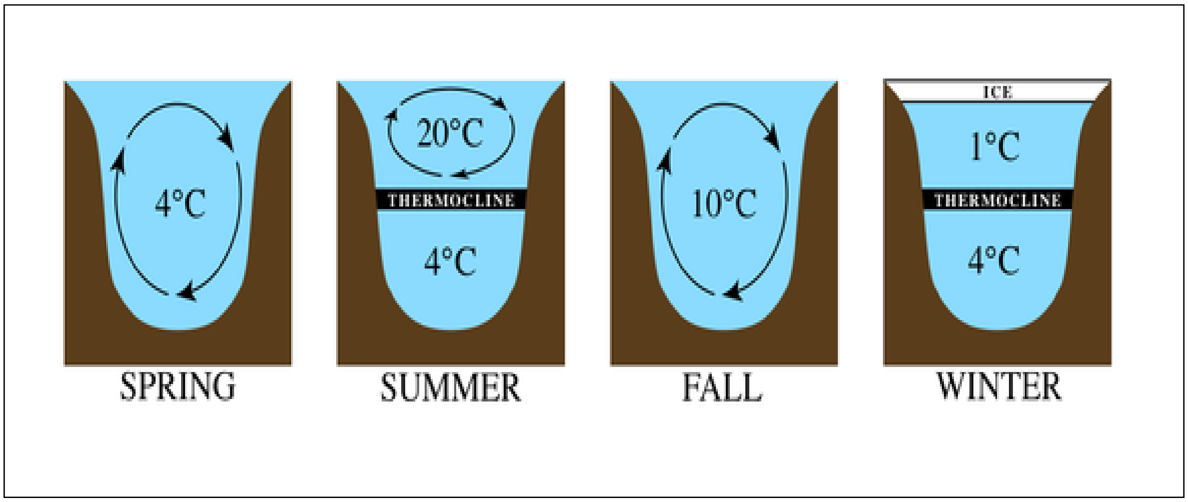


Figure 7. The lake thermal stratification process.

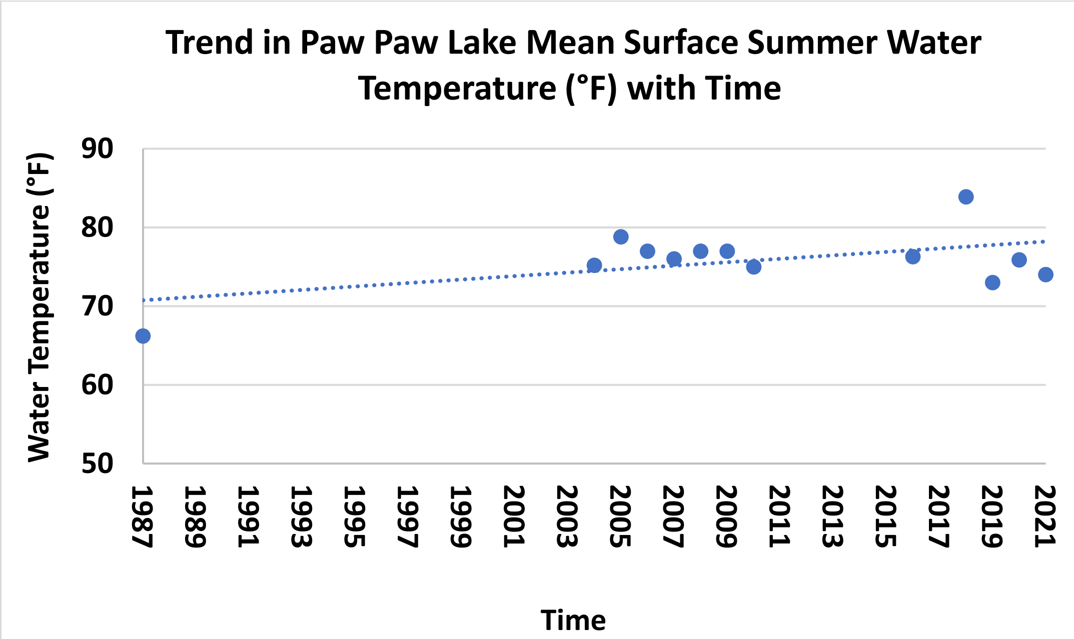


Figure 8. Trend in Paw Paw Lake mean surface summer water temperature with time.

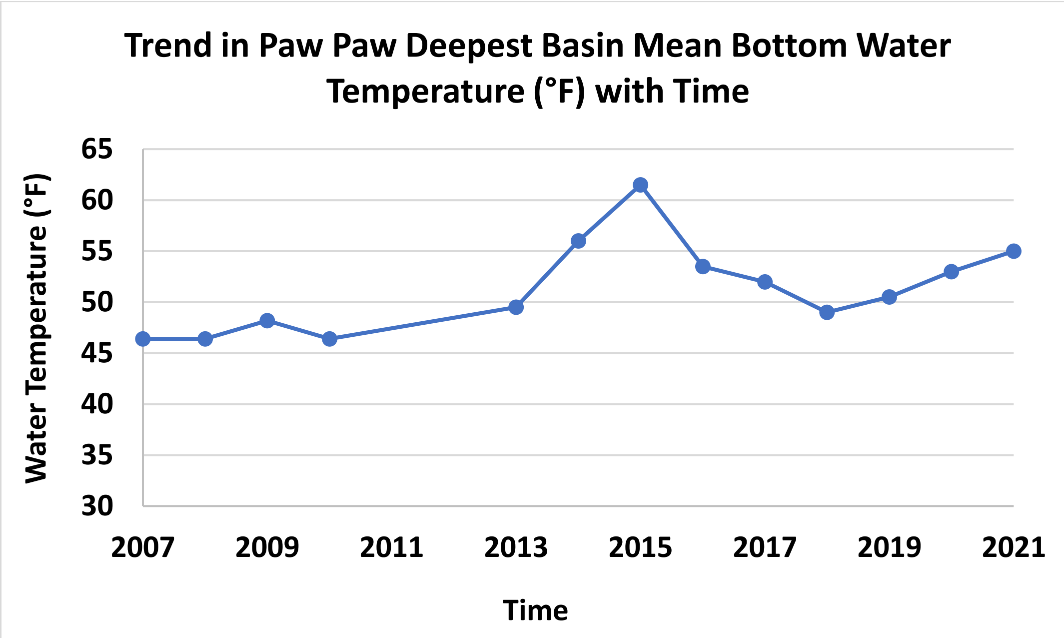
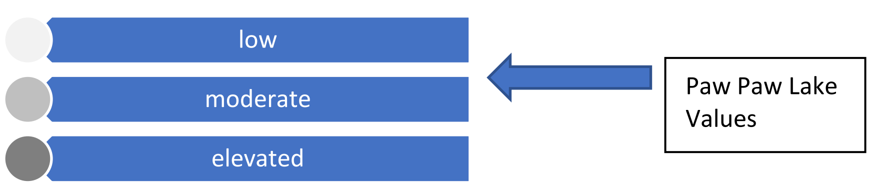


Figure 9. Trend in Paw Paw Lake mean bottom water temperatures with time.

4.1.3 Specific Conductivity

Specific conductivity is a measure of the number of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. Conductivity generally increases with water temperature and the amount of dissolved minerals and salts in a lake. Specific conductivity is measured in micro Siemens per centimeter (µS/cm) with the use of a calibrated conductivity probe and meter. These values are moderate for an inland lake which means that the lake water contains ample dissolved metals and ions such as calcium, potassium, sodium, chlorides, sulfates, and carbonates. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e., road salt influences) on Paw Paw Lake over a long period of time, or to trace the origin of a substance to the lake in an effort to reduce pollutant loading. Elevated conductivity values over 800 mS cm^{-1} can negatively impact aquatic life. Figures 10-11 display the trend in mean summer and spring conductivity with time. These values are moderate and favorable.



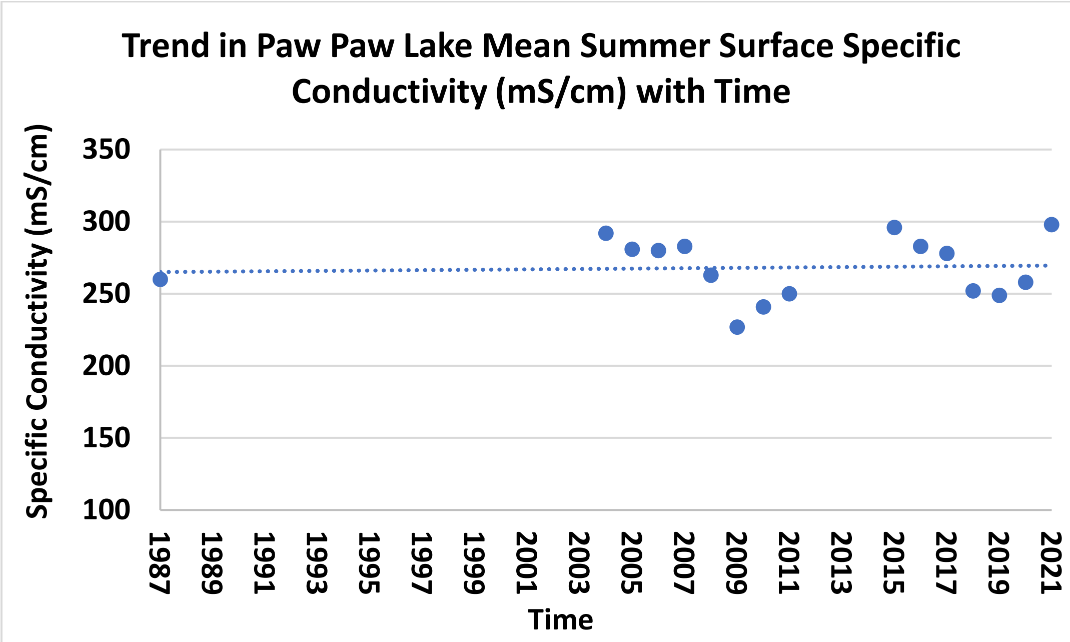


Figure 10. Trend in Paw Paw Lake mean summer surface specific conductivity with time.

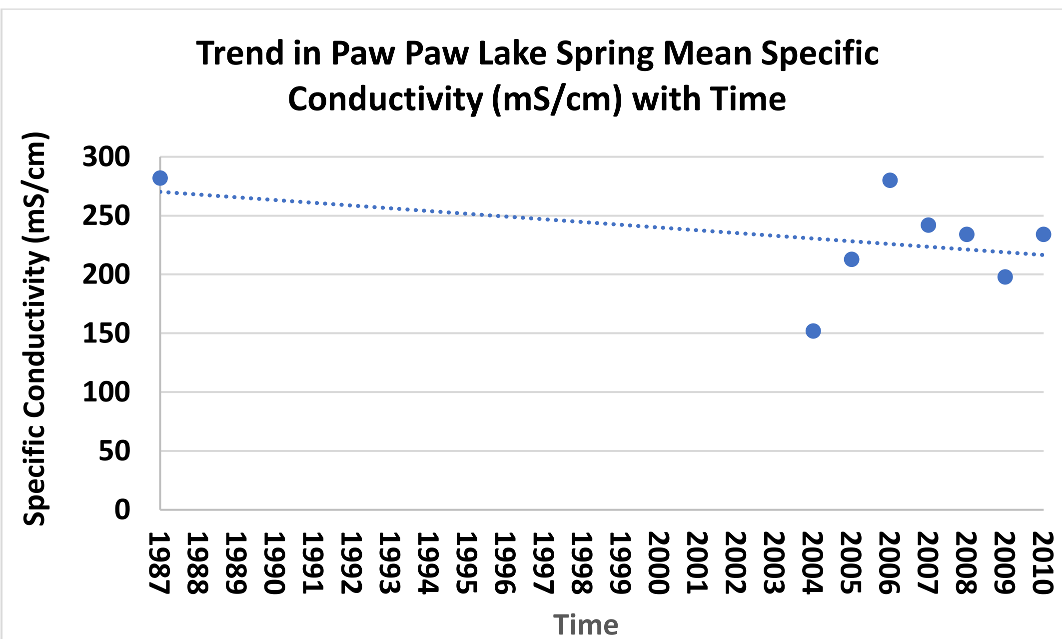


Figure 11. Trend in Paw Paw Lake mean spring surface specific conductivity with time. Note: The 1987 data point is not an outlier, but the trend is an estimate given the lack of data between 1987 and 2010. The specific conductivity means have been higher in the spring and thus seasonal testing is critical. This may be due to increased spring runoff.

4.1.4 Turbidity, Total Dissolved Solids, and Total Suspended Solids

Water quality data for the parameters including turbidity, total dissolved solids, and total suspended solids have been scarce but should be collected in the future. These parameters are indicators of the amount of solids in the water column and how they may be contributing to reduced water clarity over time in addition to the presence of biological substances such as chlorophyll-a. Additionally, such data may serve as key indicators for drain inputs.

Turbidity

Turbidity is a measure of the loss of water transparency due to the presence of suspended particles. The turbidity of water increases as the number of total suspended particles increases. Turbidity may be caused by erosion inputs, phytoplankton blooms, storm water discharge, urban runoff, re-suspension of bottom sediments, and by large bottom-feeding fish such as carp. Particles suspended in the water column absorb heat from the sun and raise water temperatures. Since higher water temperatures generally hold less oxygen, shallow turbid waters are usually lower in dissolved oxygen. Turbidity is measured in Nephelometric Turbidity Units (NTU's) with the use of a calibrated turbidity meter. The World Health Organization (WHO) requires that drinking water be less than 5 NTU's; however, recreational waters may be significantly higher than that.

Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the amount of dissolved organic and inorganic particles in the water column. It is measured with a calibrated probe in mg/L. Particles dissolved in the water column absorb heat from the sun and raise the water temperature and increase conductivity.

Total Suspended Solids (TSS)

Total suspended solids are the measure of the number of suspended particles in the water column. Particles suspended in the water column absorb heat from the sun and raise the water temperature. Total suspended solids were measured in mg/L and analyzed in the laboratory with Method SM 2540 D-11. The lake bottom contains many fine sediment particles that are easily perturbed from winds and wave turbulence. Spring values would likely be higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. TSS can also be contributed to the lake from drains as the primary source.

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4.1.5 pH

pH is the measure of acidity or basicity of water. pH is measured with a calibrated pH electrode and pH-meter in Standard Units (S.U). The standard pH scale ranges from 0 (acidic) to 14 (alkaline), with neutral values around 7. Most Michigan lakes have pH values that range from 7.0 to 9.5 S.U. Acidic lakes (pH < 7) are rare in Michigan and are most sensitive to inputs of acidic substances due to a low acid neutralizing capacity (ANC).

This range of pH is neutral to slightly alkaline on the pH scale and is ideal for an inland lake. The pH tends to rise when abundant aquatic plants are actively growing through photosynthesis or when abundant marl deposits are present. The trend in mean surface pH for summer and spring are displayed in Figures 12-13. Outliers above a pH of 8.9 S.U. are likely due to poor instrument calibration or a damaged probe.

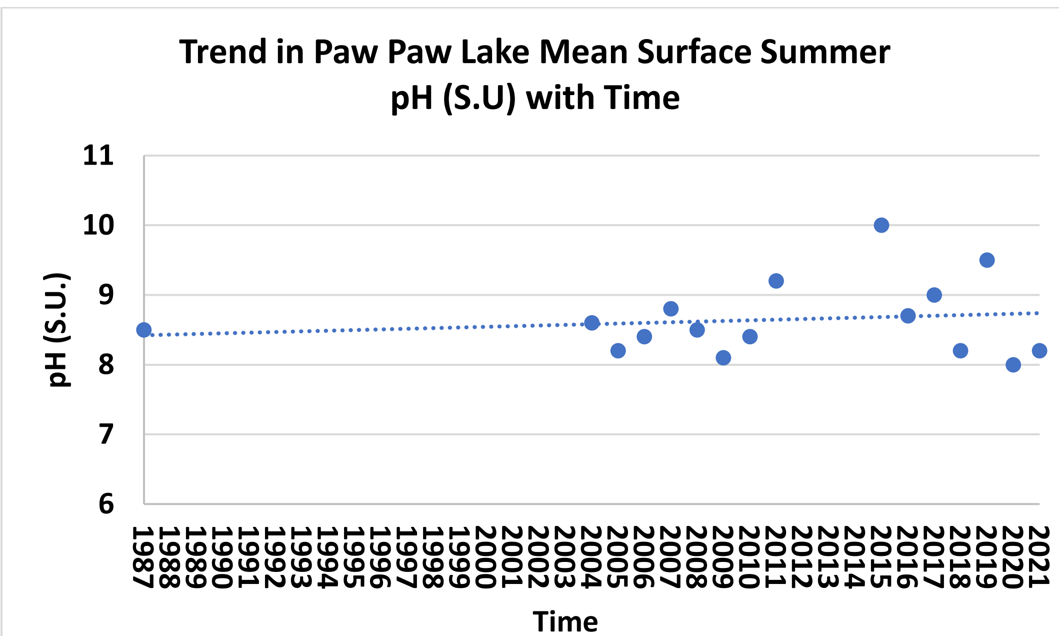


Figure 12. Trend in Paw Paw Lake mean surface summer pH with time.

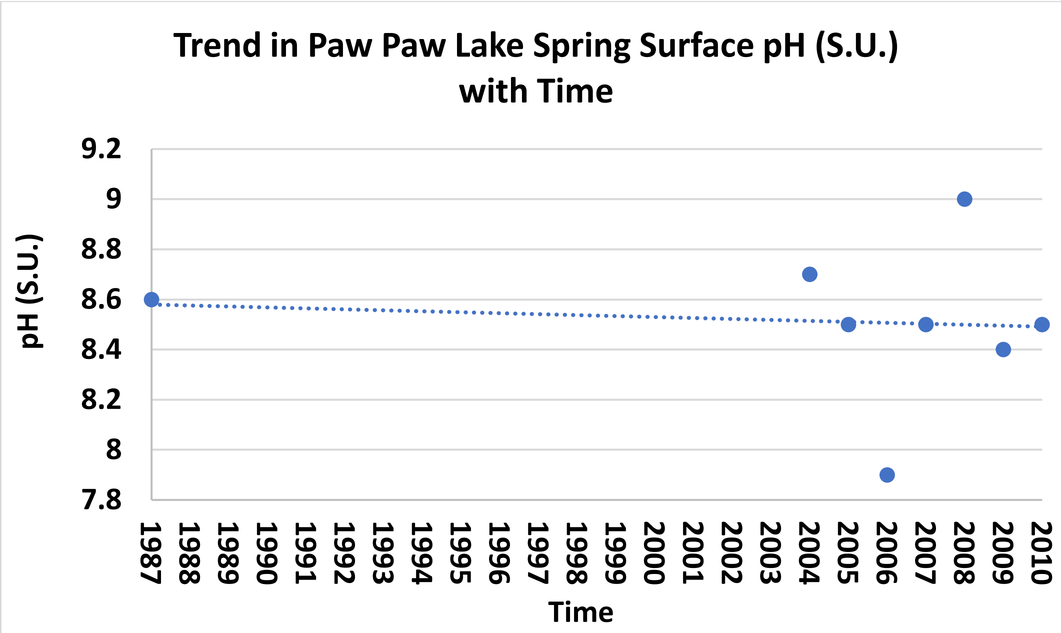
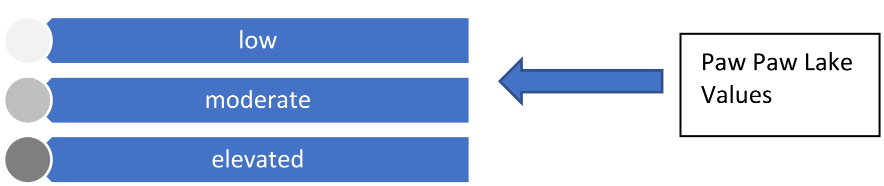


Figure 13. Trend in Paw Paw Lake mean spring surface spring pH with time.

4.1.6 Total Alkalinity

Total alkalinity is a measure of the pH-buffering capacity of lake water. Lakes with high alkalinity (> 150 mg/L of $CaCO_3$) are able to tolerate larger acid inputs with less change in water column pH. Many Michigan lakes contain high concentrations of $CaCO_3$ and are categorized as having "hard" water. Total alkalinity is measured in milligrams per liter of $CaCO_3$ through the acid titration Method SM 2320 B-11.

Total alkalinity may change on a daily basis due to the resuspension of sedimentary deposits in the water and respond to seasonal changes due to the cyclic turnover of the lake water. Historical data on total alkalinity agree with current values. Figures 14-16 demontsrate the changes in total alkalinity with time.



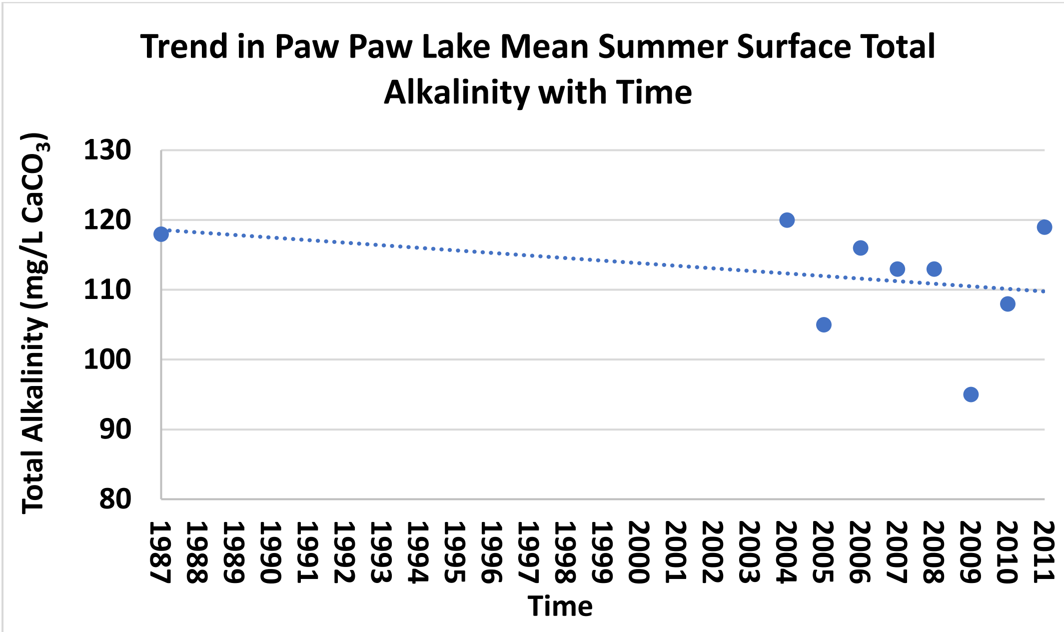


Figure 14. Trend in Paw Paw Lake mean summer surface total alkalinity with time.

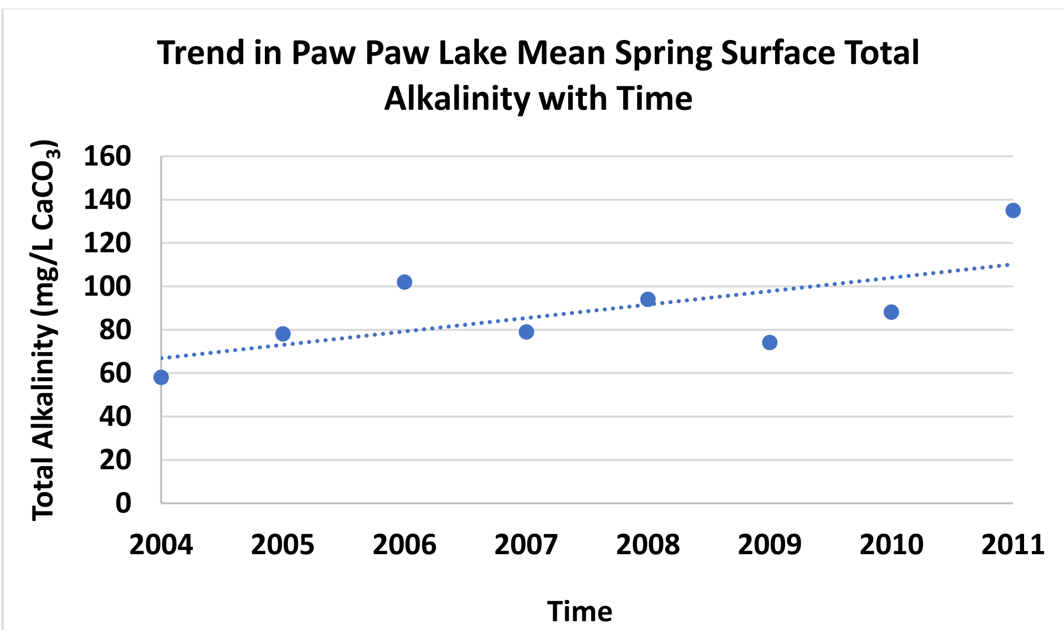


Figure 15. Trend in Paw Paw Lake mean spring surface total alkalinity with time.

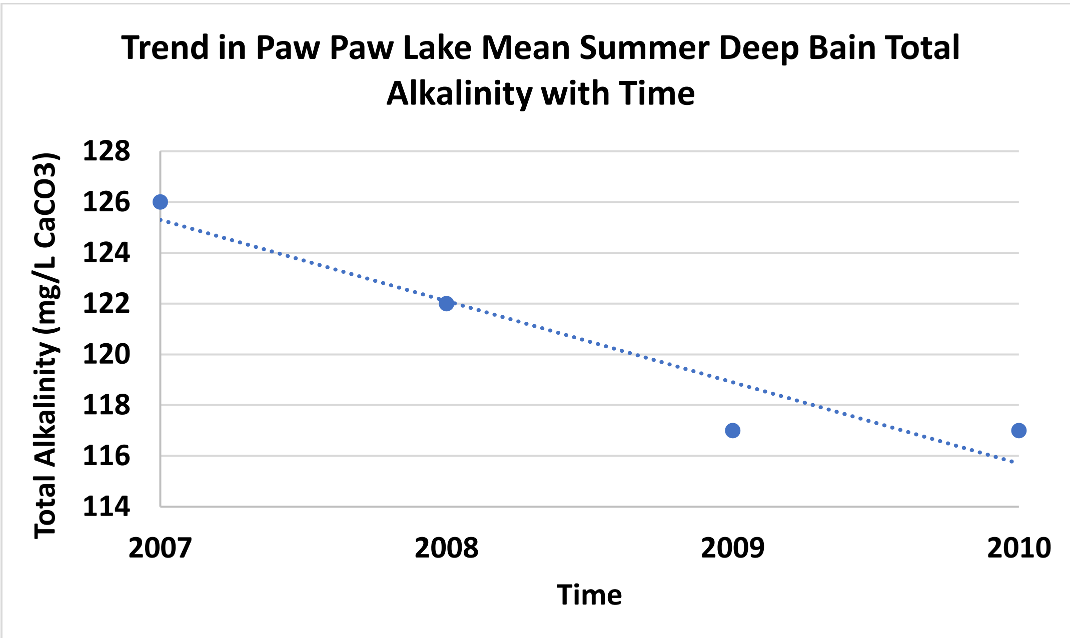
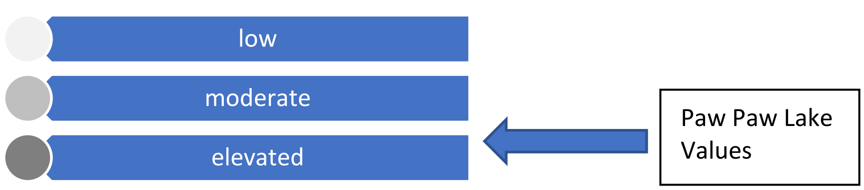


Figure 16. Trend in Paw Paw Lake mean summer deep basin total alkalinity with time. Note: This parameter was not reported in years beyond 2010 but is recommended to better understand phosphorus dynamics which interacts with alkalinity.

4.1.7 Total Phosphorus and Ortho-Phosphorus (SRP)

Total Phosphorus

Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the water column. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. Lakes which contain greater than 0.020 mg/L of TP are defined as eutrophic or nutrient-enriched. TP concentrations are usually higher at increased depths due to the higher release rates of P from lake sediments under low oxygen (anoxic) conditions. Phosphorus may also be released from sediments as pH increases. Total phosphorus was measured in milligrams per liter (mg/L) or micrograms per liter (µg/L) with the use of Method EPA 200.7 (Rev. 4.4). Figures 17-19 demonstrate the change in mean TP with time for the surface and deep basins.



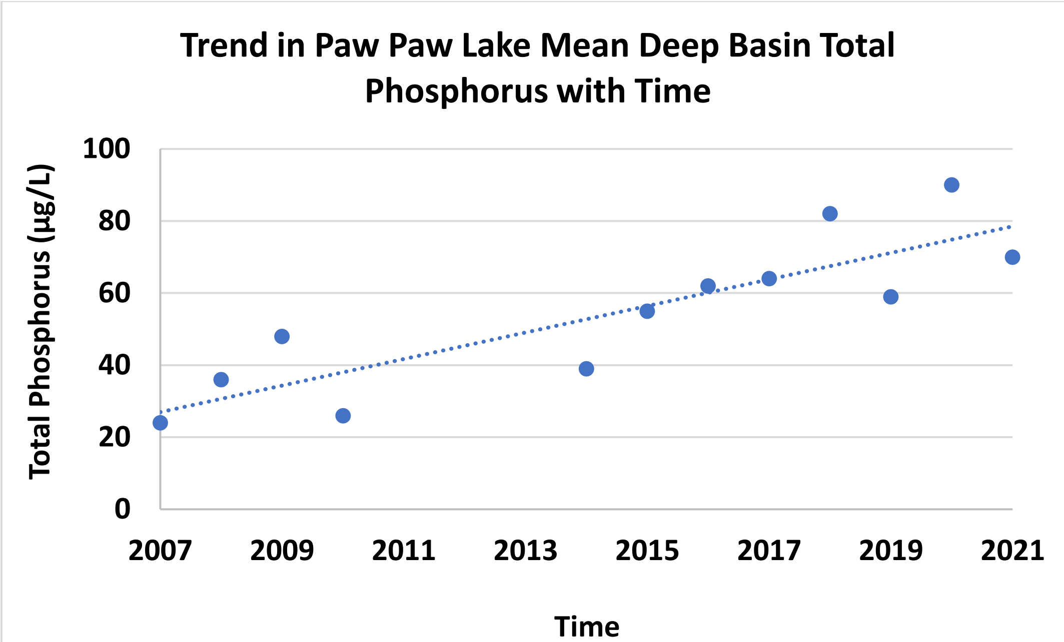


Figure 17. Trend in Paw Paw Lake mean deep basin total phosphorus with time.

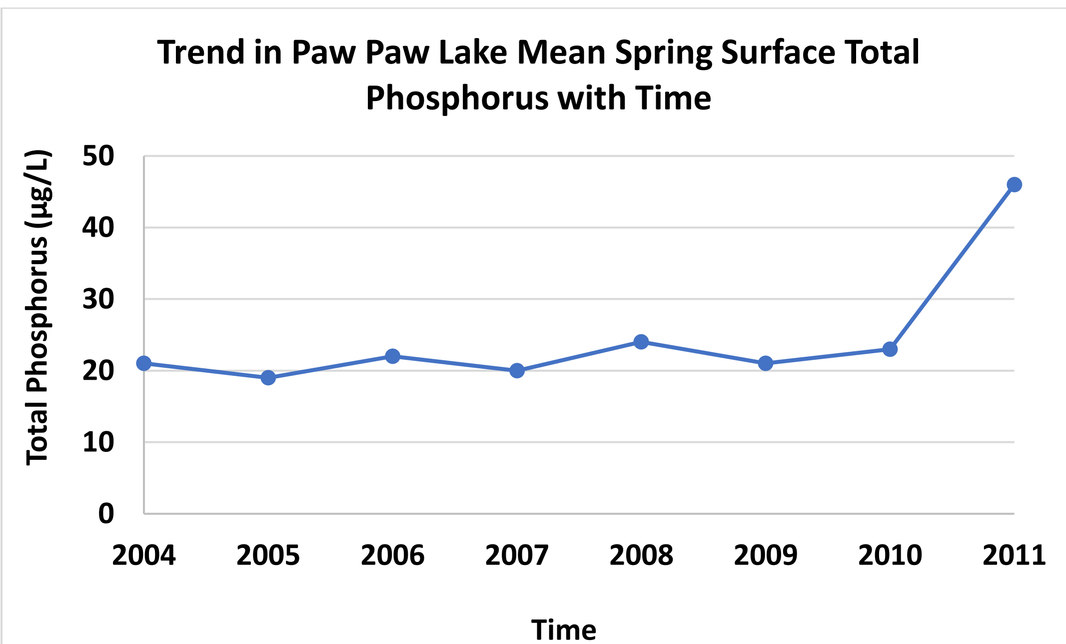


Figure 18. Trend in Paw Paw Lake mean spring surface total phosphorus with time.

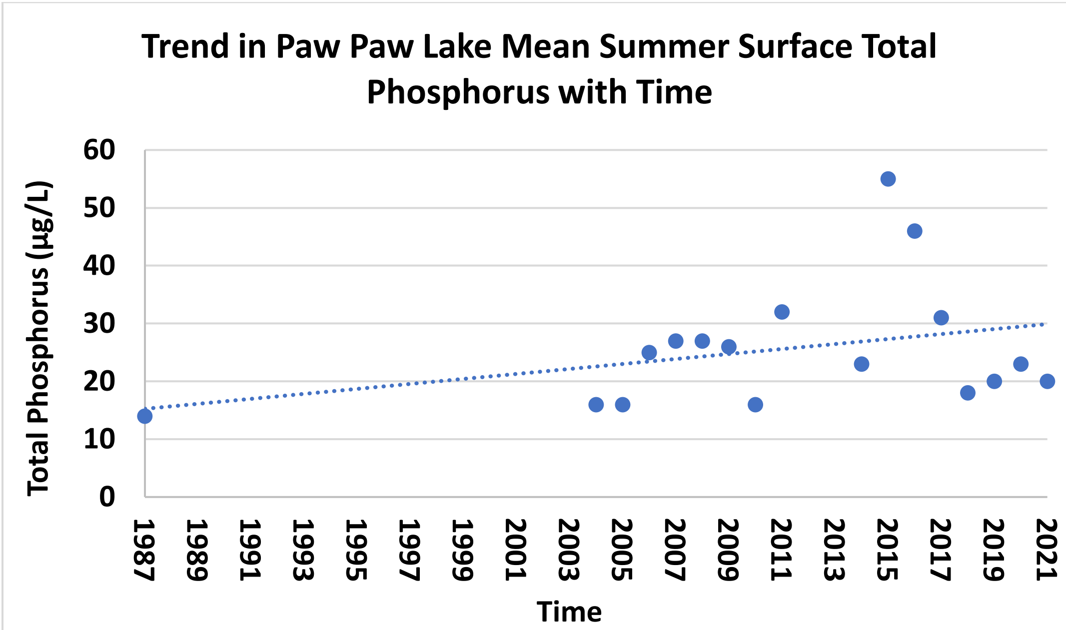
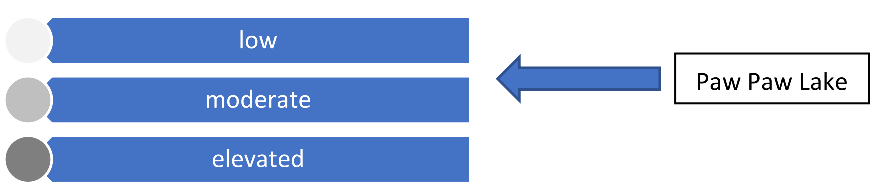


Figure 19. Trend in Paw Paw Lake mean summer surface total phosphorus with time.

Ortho-Phosphorus

Ortho-Phosphorus (also known as soluble reactive phosphorus or SRP) is measured with Method SM 4500-P (E-11). SRP refers to the most bioavailable from of P used by all aquatic life. **Historical data on SRP have been limited but these values are favorable and have been at or below the laboratory detection limit, especially at the water surface. In the deepest basin, the values ranged from 10-100 µg/L which is highly variable. Most of the data collected to date has been from surface waters that tend to also be lower in SRP than deeper waters. It is important that future collection of SRP data include profile data to avoid biasing based on surface water concentrations that are usually lower. In addition, SRP samples have been collected only at the surface and lake bottom. It is important to calculate weighted means based on depth for this parameter to accurately determine the SRP throughout the water column. This is important for understanding the use of SRP by aquatic biota.**



4.1.8 Total Kjeldahl Nitrogen and Total Inorganic Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), and organic nitrogen forms in freshwater systems. TKN is analyzed with Method EPA 351.2 (Rev. 2.0). Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e., burning of fossil fuels), wastewater sources from developed areas (i.e., runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through groundwater or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001). In lakes with an abundance of nitrogen (N: P > 15), phosphorus may be the limiting nutrient for phytoplankton and aquatic macrophyte growth. Alternatively, in lakes with low nitrogen concentrations (and relatively high phosphorus), the blue-green algae populations may increase due to the ability to fix nitrogen gas from atmospheric inputs. Lakes with a mean TKN value of 0.66 mg L^{-1} may be classified as oligotrophic, those with a mean TKN value of 0.75 mg L^{-1} may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg L^{-1} may be classified as eutrophic. **TKN data has not been historically collected in Paw Paw Lake, but it is recommended to determine the presence of this form of nitrogen for use by biota such as blue-green algae that have been problematic in Paw Paw Lake.**

The total inorganic nitrogen (TIN) consists of only the nitrate (NO_3), nitrite (NO_2), and ammonia (NH_3) forms of nitrogen without the organic forms of nitrogen. **Historically, only the nitrate form has been analyzed. This is unfortunate, because it is often the ammonia form that is elevated and contributes to nitrogen loads in freshwater systems.** Nitrite is very rare in aquatic systems but should still be analyzed due to significant health impacts if it is present. Sampling of both TKN and TIN (all inorganic nitrogen forms) is recommended in the future. Figures 20-22 demonstrate the change in mean spring and summer surface and deep basin nitrate with time.

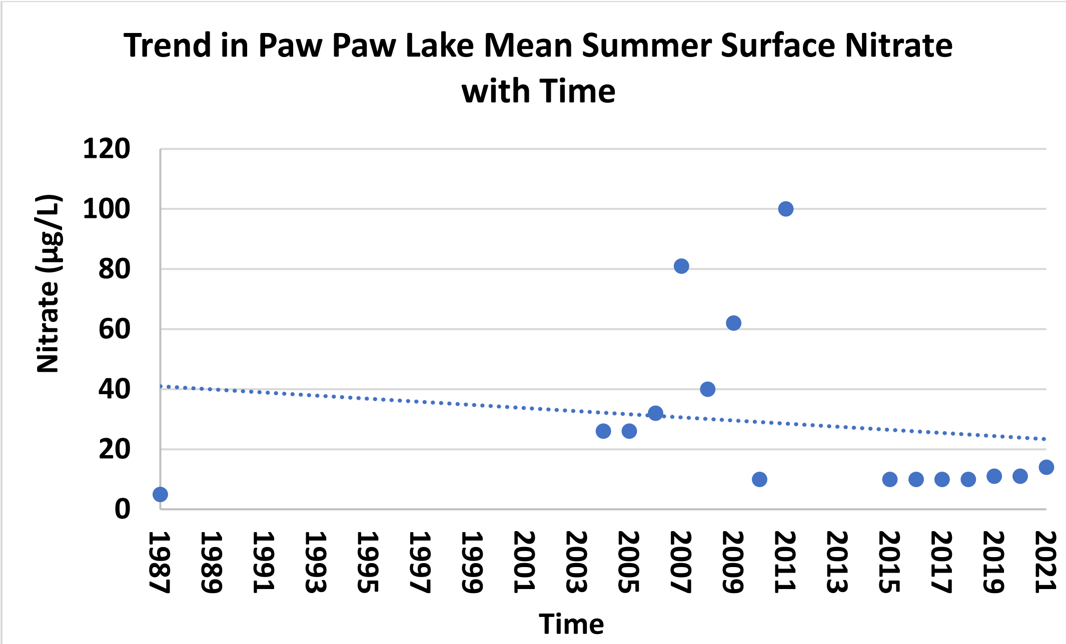


Figure 20. Trend in Paw Paw Lake mean summer surface nitrate with time.

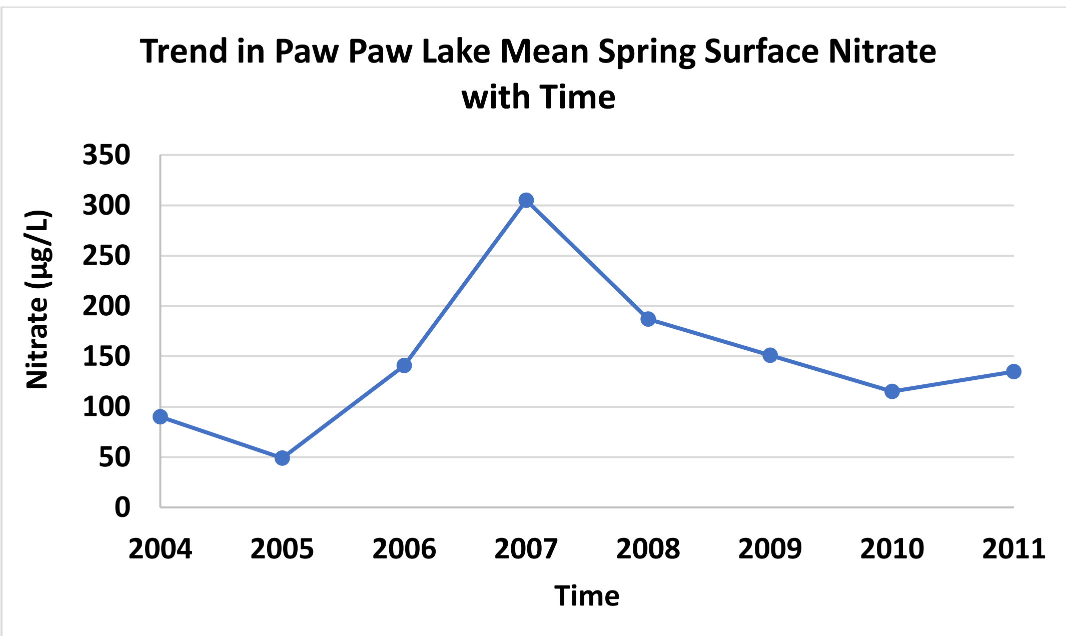


Figure 21. Trend in Paw Paw Lake mean spring surface nitrate with time.

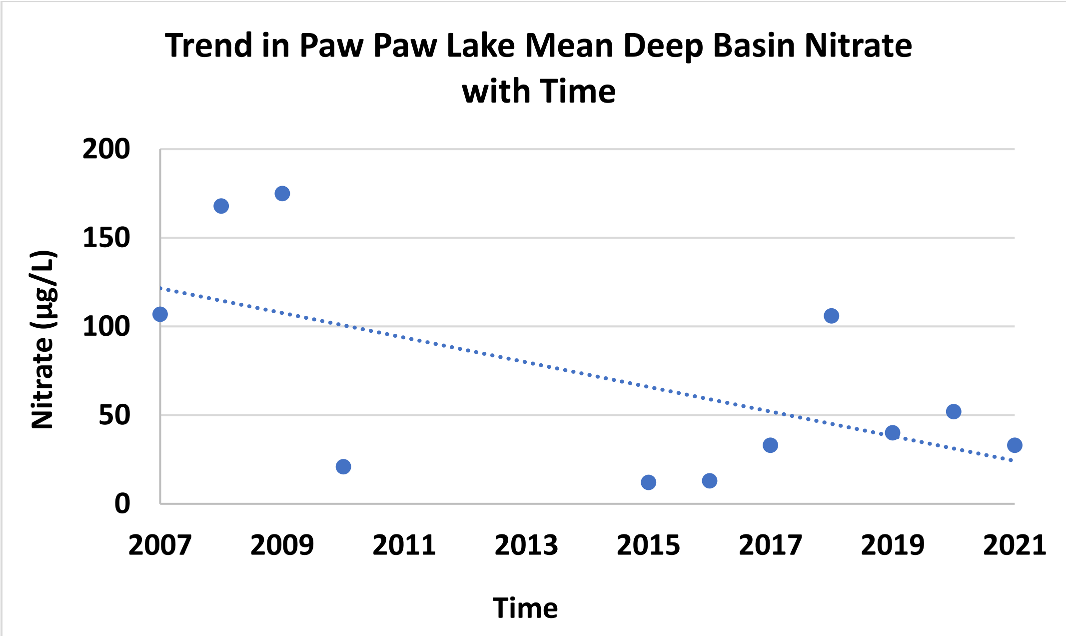


Figure 22. Trend in Paw Paw Lake mean deep basin nitrate with time.

4.1.9 Chlorophyll-a and Algal Community Composition

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, often in the form of planktonic algae. Chlorophyll-*a* water samples are usually collected with an integrated tube or composite sampler and transferred to amber bottles preserved with magnesium carbonate. High chlorophyll-*a* concentrations are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg L^{-1} are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg L^{-1} are found in nutrient-poor or oligotrophic lakes. Chlorophyll-*a* is usually measured in micrograms per liter (µg/L) with method SM 10200H. The chlorophyll-*a* concentrations in Paw Paw Lake were determined by collecting composite (depth-integrated) samples of the algae throughout the water column (photic zone) at the deep basin site from just above the lake bottom to the lake surface. **In Paw Paw Lake, both spring and summer chlorophyll-*a* concentrations have declined with time. This may be due to the presence of Zebra Mussels that selectively graze on favorable green algae but leave behind blue-green algae that is less palatable. This may also explain how higher nutrient levels are resulting in more blue-green algae than green algae given the drop in chlorophyll-*a*. Figure 23-24 show the trend in mean spring and summer chlorophyll-*a* with time.**

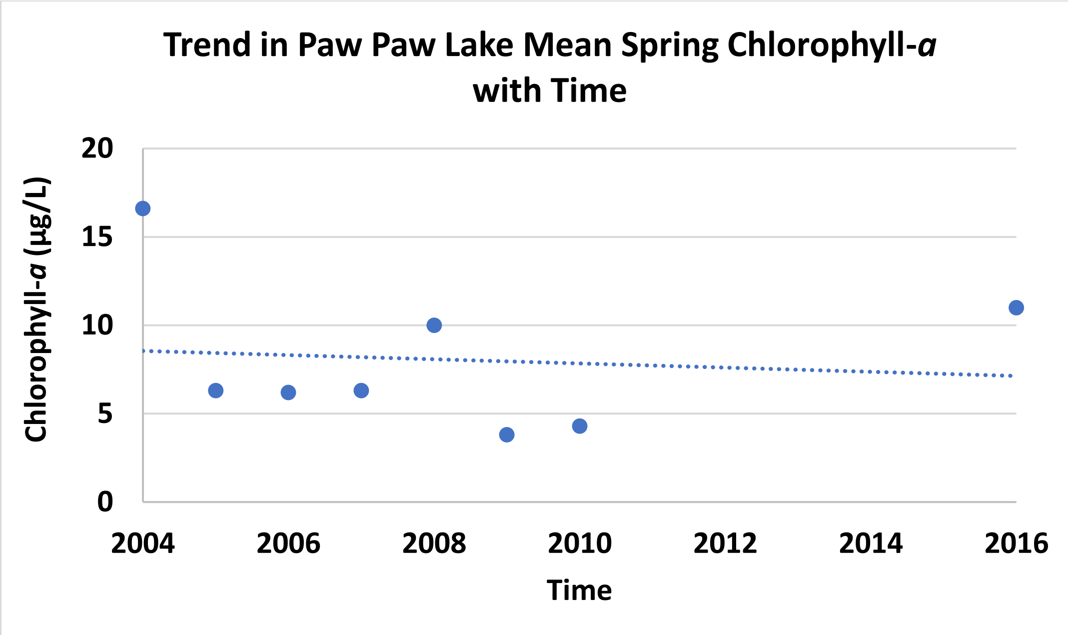


Figure 23. Trend in Paw Paw Lake mean spring chlorophyll-*a* concentrations with time.

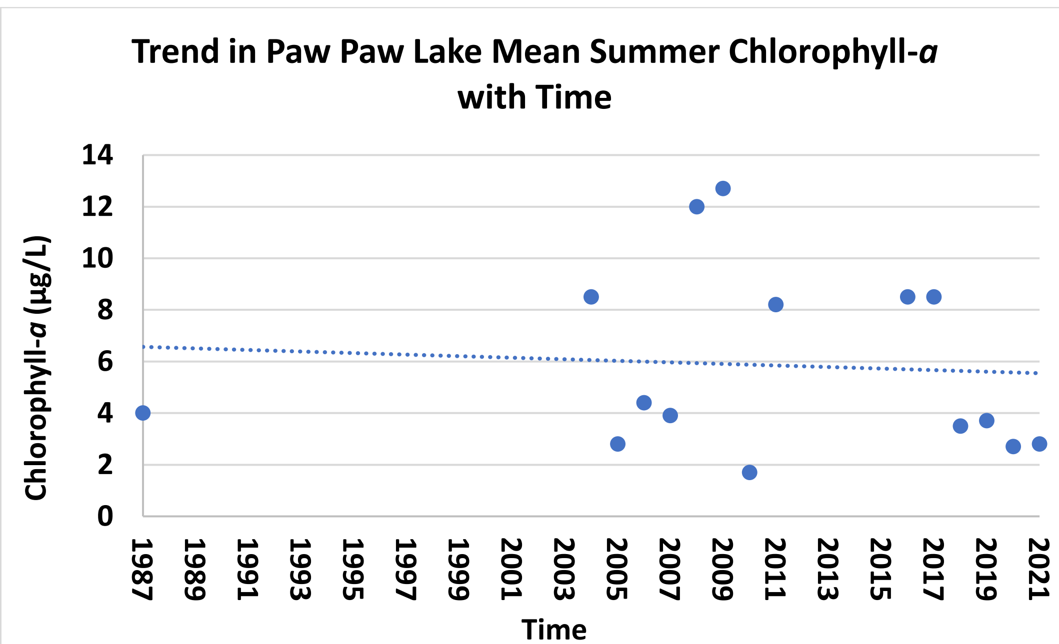


Figure 24. Trend in Paw Paw Lake mean summer chlorophyll-*a* concentrations with time.

Determination of Algal Genera in Paw Paw Lake:

To date, there has not been detailed data collected on the various algal genera in Paw Paw Lake. This is important to determine the health of the lake food chain relative to primary production. To determine the presence of algal genera from the composite water samples collected from the deep basins of Paw Paw Lake, a 500 ml of preserved sample should be collected, and a 1-mL subsample placed to settle onto a Sedgewick-Rafter counting chamber. The ocular micrometer scale should also be calibrated. The samples should be observed under a compound microscope at 400X magnification and scanned at 100X magnification to allow for the detection of a broad range of taxa present. **All taxa should be identified to at least the Genus level in a table. This should be conducted during spring and late summer.**

Blue-Green Algae (Cyanobacteria) in Paw Paw Lake:

Blue-green algae such as *Microcystis* sp. have been prevalent in Paw Paw Lake. *Microcystis* colonies are a few micrometers in diameter and are evenly distributed throughout a gelatinous matrix. Younger colonies are spherical and older ones are more irregularly shaped. There are numerous gas vesicles, and the algae can thrive at the surface with minimal photo-degradation (breaking down) by the sun. When the sunlight is excessive, the algae can break down and release toxins and lower the dissolved oxygen in the water column. **The algae are the only type known to fix nitrogen gas into ammonia for growth. *Microcystis* has also been shown to overwinter in lake sediments (Fallon et *al.*, 1981). In addition, it may thrive in a mucilage layer with sediment bacteria that can release phosphorus under anaerobic conditions (Brunberg, 1995).** They assume a high volume in the water column (Reynolds, 1984) compared to diatoms and other single-celled green algae. The blue-green algae have been on the planet nearly 2.15 billion years and have assumed strong adaptation mechanisms for survival. In general, calm surface conditions will facilitate enhanced growth of this type of algae since downward transport is reduced. *Microcystis* may also be toxic to zooplankton such as *Daphnia* which is a zooplankton present in most lakes (Nizan et *al.*, 1986). Without adequate grazers to reduce algae, especially blue greens, the blue-green population will continue to increase and create negative impacts to water bodies. Sources of nutrients for this algae in Paw Paw Lake include drains, lawn fertilizers, and lakeshore dumping.

The presence of algal blooms (Figure 25) that appear opaque and green and reside near the water surface usually consist of blue-green algae. Although not all blue-green algae produce toxins, samples collected from Paw Paw Lake in August of 2018 demonstrated above-detection levels for microcystin LA and LR, although blooms have been noted for several years. Loftin et *al.*, (2008) define a bloom as a count of algal cells between 20,000-100,000 cells per milliliter. Table 5 below displays the lower limits for acceptable water use for the most common toxins.

Figure 25. A widespread blue-green algal bloom on Paw Paw Lake (June 13, 2013).

Table 5. EPA recommended values for recreational use of water bodies. Adapted from: "Recommendations for Cyanobacteria and Cyanotoxin Monitoring in Recreational Waters", Office of Water EPA 823-R-19-001, September 2019.

Table 1. EPA Recommended Values for Recreational Criteria and Swimming Advisories for Cyanotoxins

Total Microcystins Magnitude (µg/L)	Cylindrospermopsin Magnitude (µg/L)	Duration	Frequency
8	15	1 in 10-day assessment period across a recreational season	Not more than 3 excursions in a recreational season in more than one year [b]

4.1.10 Secchi Transparency

Secchi transparency is a measure of the clarity or transparency of lake water, and is measured with the use of an 8-inch diameter standardized Secchi disk during calm to light wind conditions. Secchi disk transparency is measured in feet (ft) by lowering the disk over the shaded side of a boat around noon and taking the mean of the measurements of disappearance and reappearance of the disk (Figure 26). Elevated Secchi transparency readings allow for more aquatic plant and algae growth. Eutrophic systems generally have Secchi disk transparency measurements less than 7.5 feet due to turbidity caused by excessive planktonic algae growth. **The mean Secchi transparency in Paw Paw Lake to date is approximately 6.5±1.5 feet which is low.** This transparency indicates that an abundance of solids such as suspended particles and algae are present throughout the water column which increases turbidity and reduces water clarity. Secchi transparency is variable and depends on the amount of suspended particles in the water (often due to windy conditions of lake water mixing) and the amount of sunlight present at the time of measurement. **These low measurements also indicate that light is quite limited for the healthy growth of submersed aquatic plants. Buoyant blue-green algae such as *Microcystis* sp. are able to use the sunlight on the surface for accelerated growth. This even further reduces the light for aquatic vegetation. Figure 27 displays the trend in mean Secchi transparency with time.**

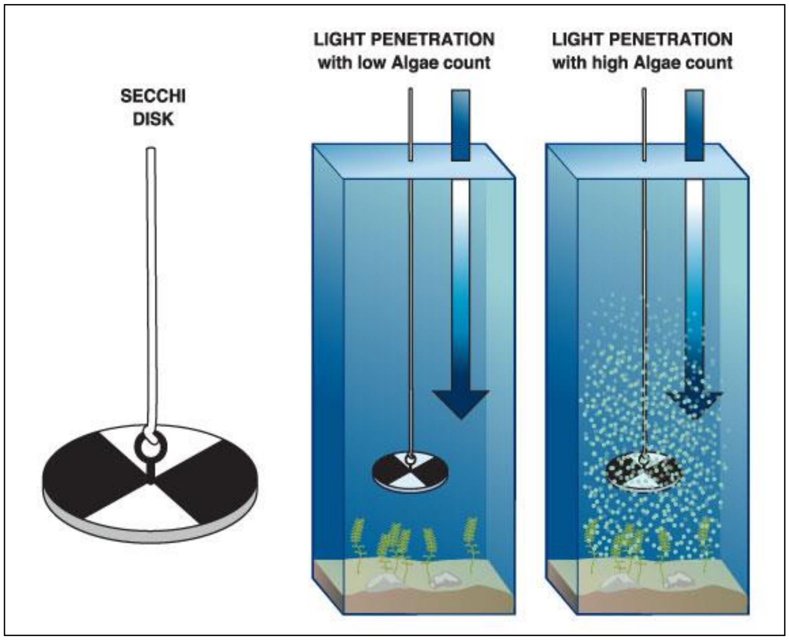


Figure 26. Measurement of water transparency with a Secchi disk.

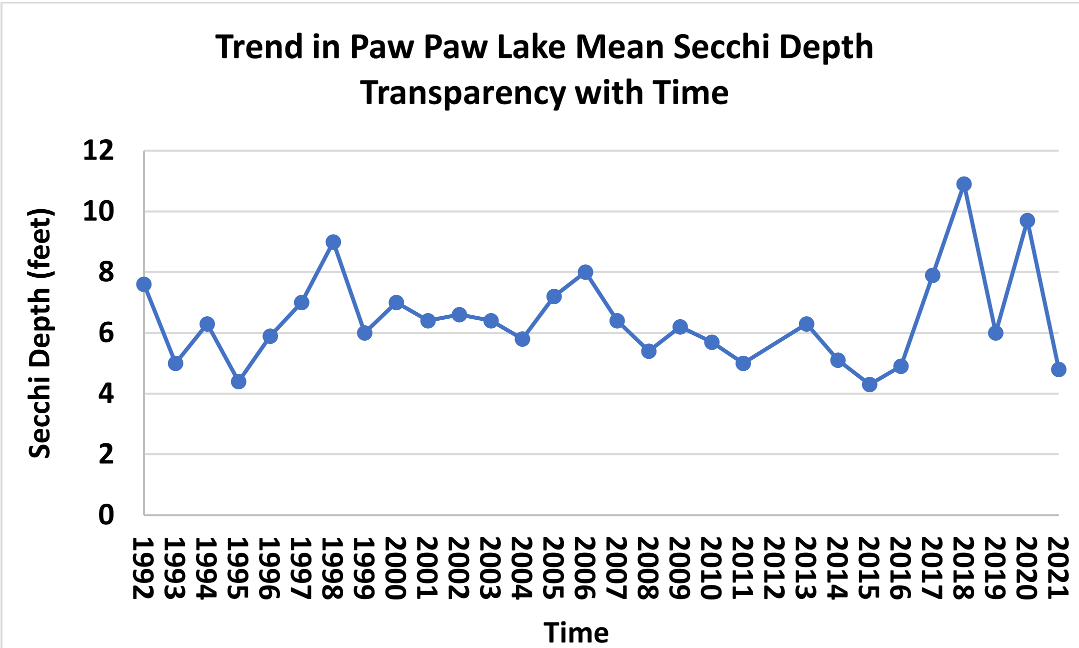
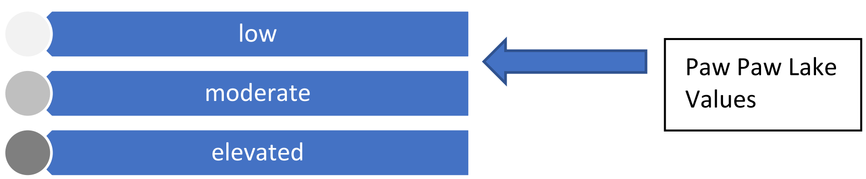


Figure 27. Trend in Paw Paw Lake mean Secchi depth transparency with time.



4.1.11 Sediment Organic Matter

Organic matter (OM) contains a high amount of carbon which is derived from biota such as decayed plant and animal matter. Detritus is the term for all dead organic matter which is different than living organic and inorganic matter. OM may be autochthonous or allochthonous in nature where it originates from within the system or external to the system, respectively. Sediment OM is measured with the ASTM D2974 Method and is usually expressed in a percentage (%) of total bulk volume. Many factors affect the degradation of organic matter including basin size, water temperature, thermal stratification, dissolved oxygen concentrations, particle size, and quantity and type of organic matter present. There are two major biochemical pathways for the reduction of organic matter to forms which may be purged as waste. First, the conversion of carbohydrates and lipids via hydrolysis are converted to simple sugars or fatty acids and then fermented to alcohol, CO_2, or CH_4. Second, proteins may be proteolyzed to amino acids, deaminated to NH_3+, nitrified to NO_2- or NO_3-, and denitrified to N_2 gas. Bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979).

In 2004, WQI collected n=3 samples of sediment that were analyzed for percentage of mineral content. The percentage of organic matter could be calculated by subtracting the % mineral fraction from 100. Thus, the samples reported sediment organic matter percentages of 14%, 22%, and 20%. This number of samples is too low for the lake size and if future organic matter percentages are desired, then a sample size of 30-50 sediment samples would offer better data regarding the bottom type.

4.2 Paw Paw Lake Aquatic Vegetation Communities & Management

Aquatic plants (macrophytes) are an essential component in the littoral zones of most lakes in that they serve as suitable habitat and food for macroinvertebrates, contribute oxygen to the surrounding waters through photosynthesis, stabilize bottom sediments (if in the rooted growth form), and contribute to the cycling of nutrients such as phosphorus and nitrogen upon decay. In addition, decaying aquatic plants contribute organic matter to lake sediments which further supports healthy growth of successive aquatic plant communities that are necessary for a balanced aquatic ecosystem. An overabundance of aquatic vegetation may cause organic matter to accumulate on the lake bottom faster than it can break down. Aquatic plants generally consist of rooted submersed, free-floating submersed, floating-leaved, and emergent growth forms. The emergent growth form (i.e., Cattails, Native Loosestrife) is critical for the diversity of insects onshore and for the health of nearby wetlands. Submersed aquatic plants can be rooted in the lake sediment (i.e., Milfoils, Pondweeds), or free-floating in the water column (i.e., Coontail). Nonetheless, there is evidence that the diversity of submersed aquatic macrophytes can greatly influence the diversity of macroinvertebrates associated with aquatic plants of different structural morphologies (Parsons and Matthews, 1995). Therefore, it is possible that declines in the biodiversity and abundance of submersed aquatic plant species and associated macroinvertebrates, could negatively impact the fisheries of inland lakes.

Alternatively, the overabundance of aquatic vegetation can compromise recreational activities, aesthetics, and property values.

There are three invasive aquatic plant species in Paw Paw Lake that threaten the biodiversity of native aquatic vegetation and include: 1) Eurasian Watermilfoil (EWM), 2) Curly-leaf Pondweed (CLP), and 3) Starry Stonewort (SS). A genetic analysis on the hybridity of the milfoil has not been conducted within the past five year but is recommended. Starry Stonewort was the most recent invasive to reside in the lake in 2018 and was found in the bay at the northeast end of lake and along the north shore peninsula. In 2021, it was also found in the southwest corner of the lake.

Paw Paw Lake has an extensive aquatic vegetation management history dating back to 1996. Whole-lake treatments using the systemic herbicide fluridone (SONAR AS®) were reported in 2012, 2017, and 2021. The earliest data set of aquatic vegetation was collected by the Michigan Department of Environmental Quality (MDEQ) now named EGLE. Data from 2012-2013 was collected by JF New and the remainder of the data has been collected by PLM. During the fluridone treatments, a 750 foot isolation distance from the outlet is required. Due to the prevalence of numerous private wells around the lake, the use of the systemic herbicide 2,4-D for the control of milfoil would be contraindicated.

In 2008, Weed Patrol, Inc. treated 0.25 acres of emergent Spatterdock near the margins of the lagoon and also the swim area both near the Chalet Du Paw Paw Condominiums. The herbicide used was glyphosate which was applied in September. An additional 1.33 acres of a combination of nuisance Milfoil and Coontail were treated with diquat (Reward®), native pondweeds were treated with Hydrothol 191®, algae was treated with copper sulfate, and all contact herbicides were applied with an adjuvant to keep the product on the plants during treatment. RLS recommends against the use of copper sulfate as this bioaccumulates in lake sediments and can harm sediment biota.

In 2021, a whole-lake fluridone (SONAR AS®) treatment was conducted by PLM. The treatment dates included the initial 6 ppb treatment on May 18, 2021 and a required “bump” treatment on June 24, 2021. On September 15, 2021, SeClear G® was used to treat Starry Stonewort which required a total of 300 lbs. of product. Figures 28-33 demonstrate the changes in various aquatic plant communities with time.

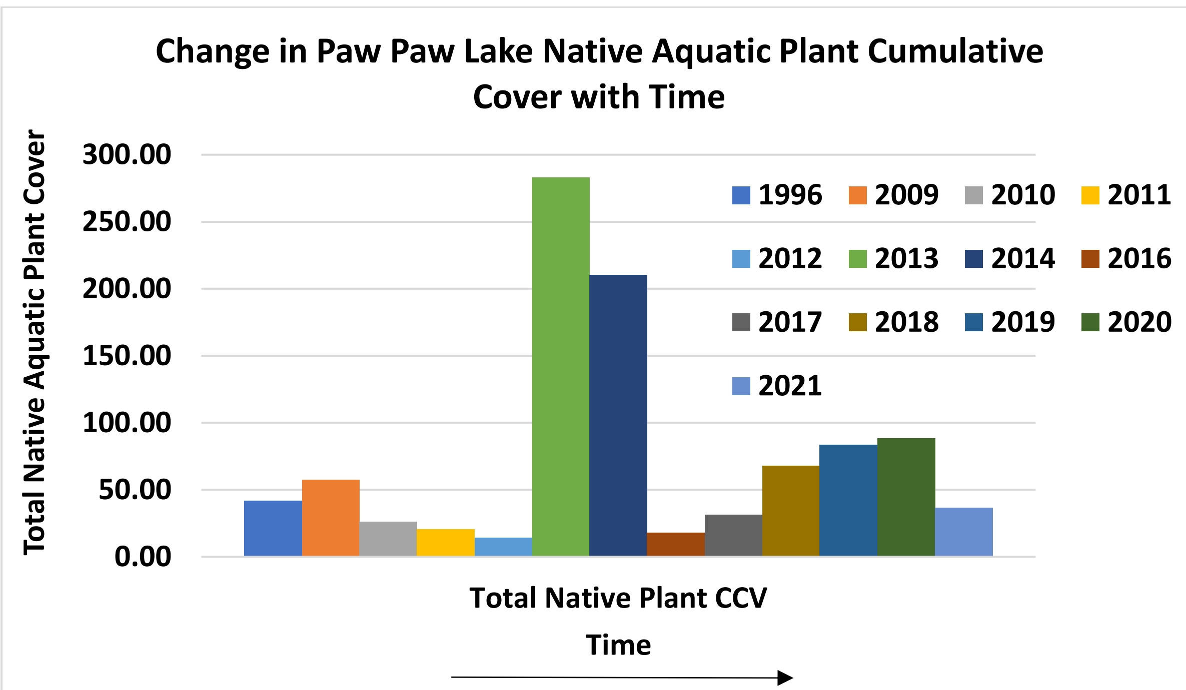


Figure 28. Change in Paw Paw Lake native aquatic plant cumulative cover with time.

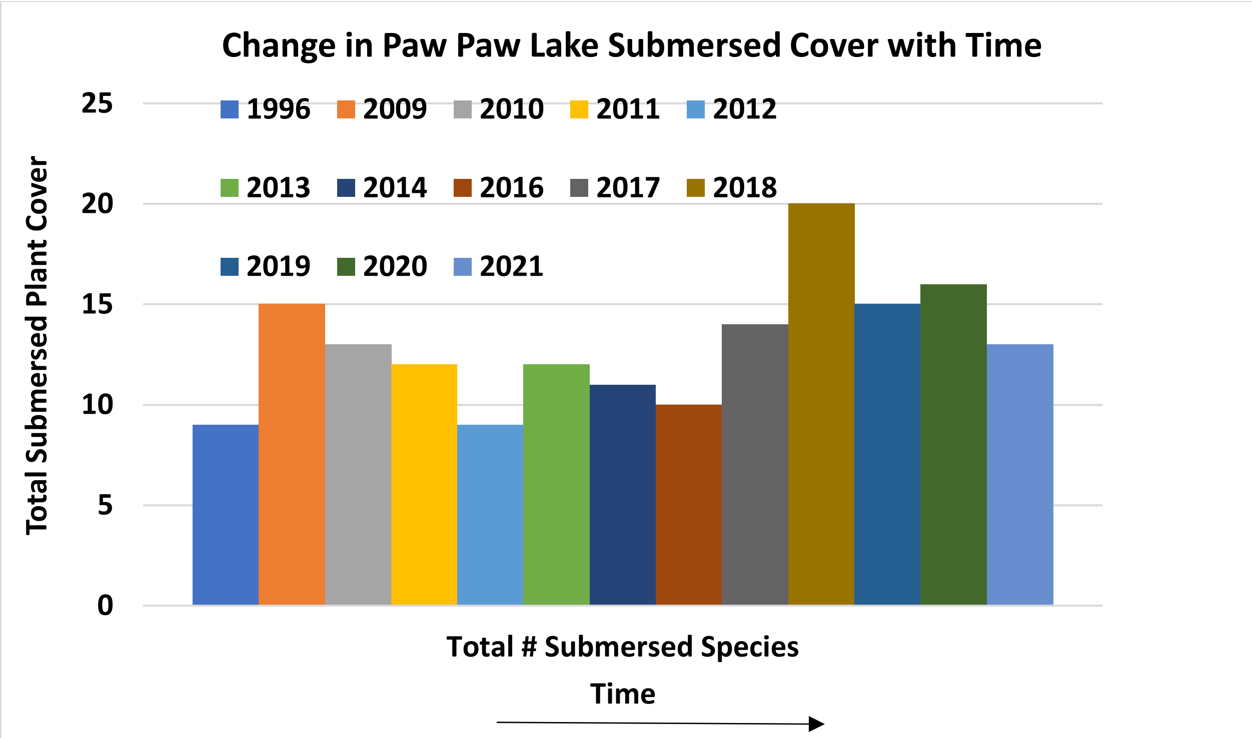


Figure 29. Change in Paw Paw Lake submersed cover with time.

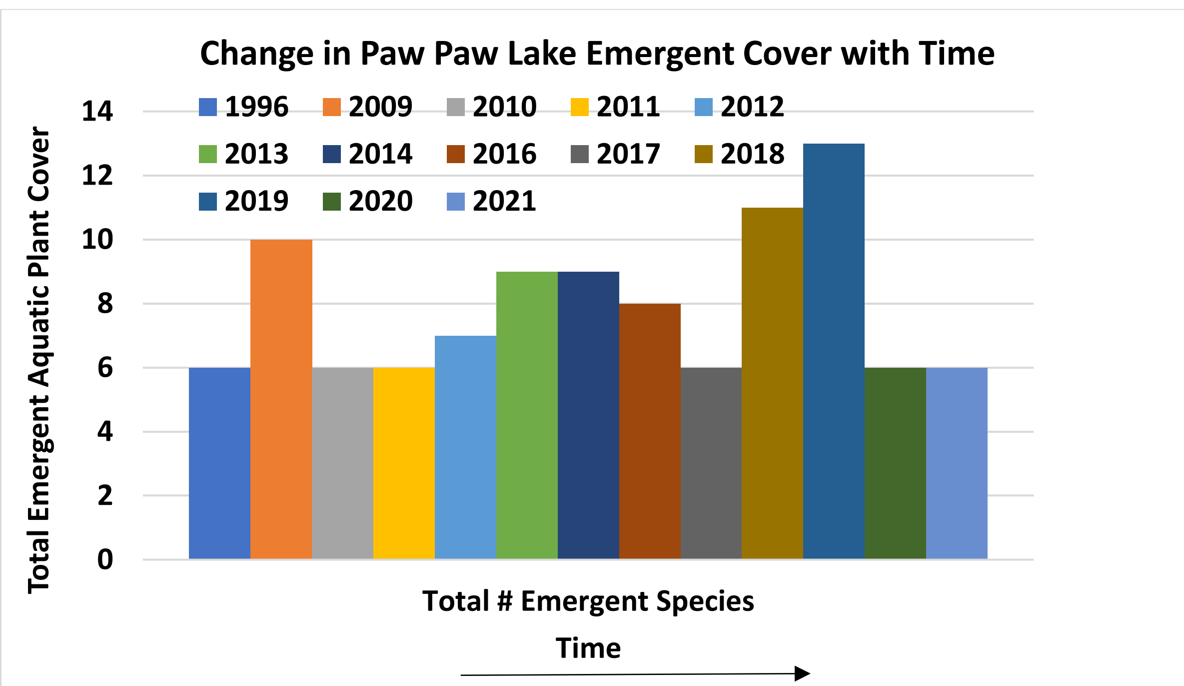


Figure 30. Change in Paw Paw Lake emergent cover with time.

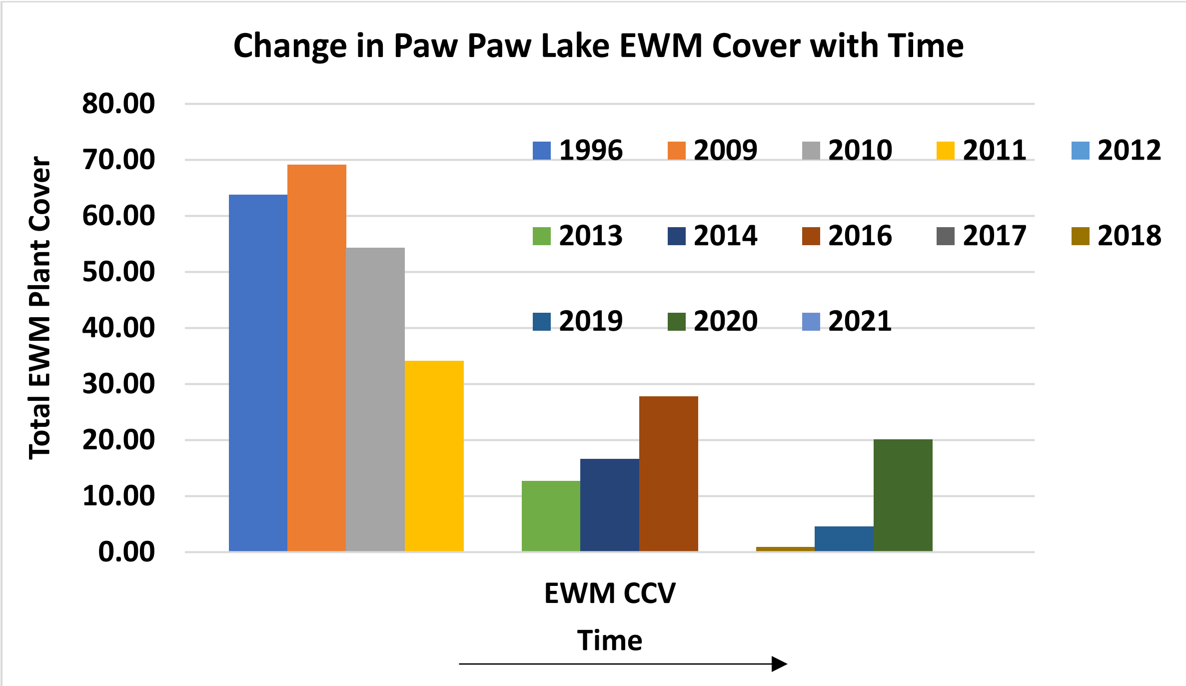


Figure 31. Change in Paw Paw Lake EWM cover with time.

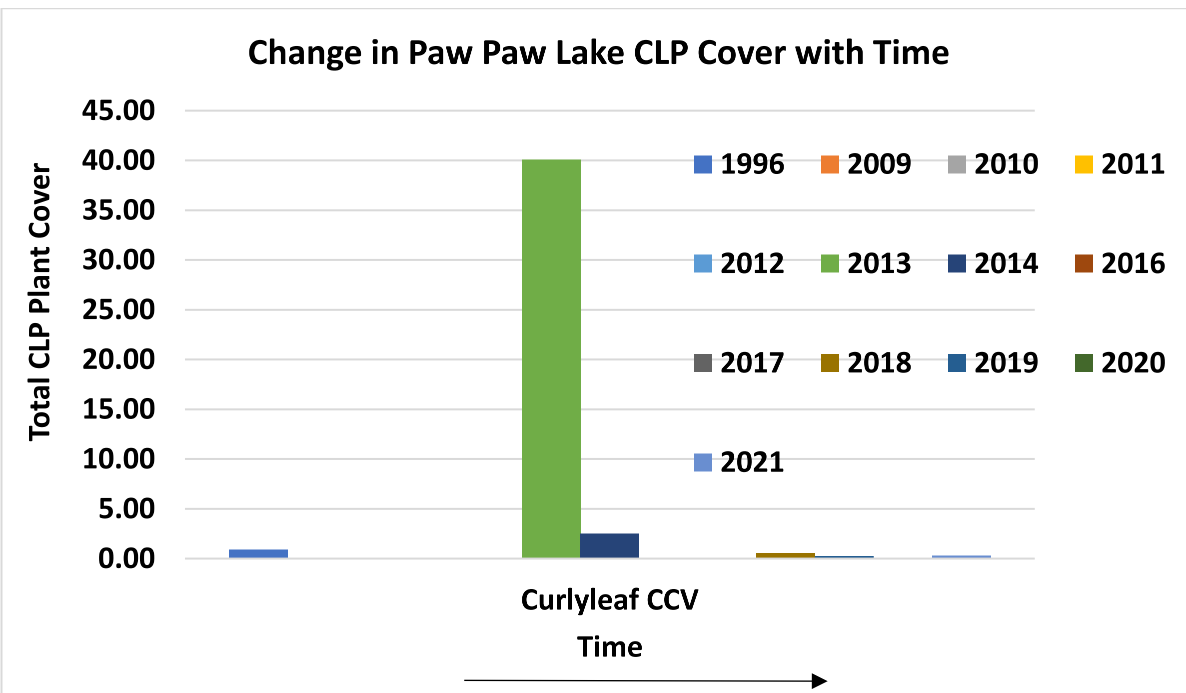


Figure 32. Change in Paw Paw Lake CLP cover with time.

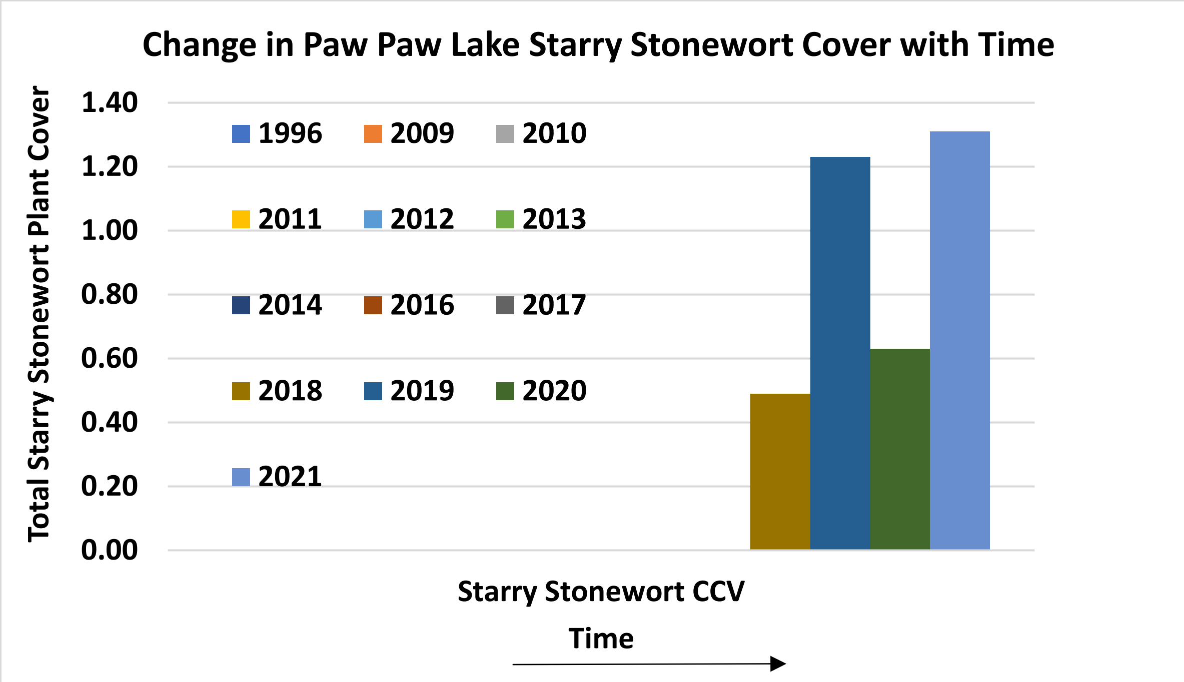


Figure 33. Change in Paw Paw Lake Starry Stonewort cover with time.

The following conclusions can be made regarding the trends in aquatic vegetation communities in Paw Paw Lake:

1. The native aquatic plant cumulative cover has increased in recent year (2018-2020) but declined in 2021. This was likely due to the strong presence of Eurasian Watermilfoil (EWM) that prevented native aquatic plant germination in many areas (pre-fluridone aka SONAR AS®).
2. The low native cumulative cover in 2012 and 2017 was likely due to excessive EWM that required fluridone treatment, as in 2021.
3. The submersed cover has increased in recent years (2018-2020) but declined in 2021 due to excessive EWM cover.
4. The emergent cover has fluctuated but remains stable during the past two years.
5. The EWM cover has declined with time but increased in 2020 which necessitated the use of a systemic herbicide such as fluridone.
6. The CLP cover has declined much since 2013 and is barely present now.
7. The Starry Stonewort (SS) has increased in the past two years with the highest growth noted in 2021.

5.0 PAW PAW LAKE DRAIN WATER QUALITY DATA TRENDS

Lake improvement methods consist of strategies to reduce invasive aquatic plants, reduce the transport of invasive species, reduce nuisance algae, improve water quality, reduce lake sedimentation and nutrient transport, and facilitate proper immediate watershed management.

The following sections offer useful and effective methods for improving the overall condition of Paw Paw Lake. Watershed improvements are discussed in section 5.2 of this report for immediate watershed management, which is critical for reducing nutrient loads to the lake and achieving great success with the water quality improvement program. Figures 34-36 below demonstrates the water flow paths for each of the key drains as developed by WQI. RLS reviewed historical data for these drains and provide statistical summary data tables and associated graphs of key water quality parameters in the section below. Many of the smaller drains (all except for the Branch and Derby Drain) were sampled many years ago and thus they should be re-sampled in the locations recommended to determine if nutrient loads have changed over time. If mitigation is not properly placed in key problem areas, then the loads will continue to be a threat to the overall health of Paw Paw Lake. Figure 37 shows the drain reaches in the immediate watershed.

As noted in the WQI reports, there are drains that enter into Paw Paw Lake in three areas: Sample Stations B, C, and G. Additional drains contribute water to these key areas. Below is a list of all drains sampled by WQI from 2003-2010 which were sampled for water quality parameters such as nitrate nitrogen, total alkalinity, pH, specific conductivity, and total phosphorus:

Station A: located near the Little Paw Paw Lake outlet

Station B: located on the Little Paw Paw Lake drain at the Paw Paw Lake entry

Station C: located where the Branch and Derby Drain enters Paw Paw Lake

Station D: located on the Branch and Derby Drain between the Beck/Peck/Grove Drain inlet and the McConnell and Olcott Drain inlet.

Station E: located on the Branch and Derby Drain downstream of the Green Drain inlet

Station F: located on the Green Drain prior to Branch and Derby Drain at entry of wetland exit at Branch and Derby Drain.

Station G: located on the Sherwood Drain where it flows into Paw Paw Lake.

Station H: located on the Beck/Peck/Grove inlet prior to discharge into the Branch and Derby Drain.

Station I: located on the McConnell and Olcott Drain where it discharges into the Branch and Derby Drain.

Station J: located on the Branch and Derby Drain above the Green Drain inlet prior to the modified Green Drain.

Station K: located on the Green Drain at M-140.

Station L: located at the modified Green Drain at wetland output at Branch and Derby Drain.

Station M: located on the Branch and Derby Drain at North Watervliet Road

Station N: located on the Branch and Derby Drain at 48th Ave.

Station O: located on the Branch and Derby Drain at CR 376

Station P: located on the McConnell and Olcott Drain at M-140

Station Q: located on the McConnell and Olcott Drain at 48th Ave.

Station R: located on the Delfield and Crumb Drain at Interlocken Rd.

Station S: located on the Delfield and Crumb Drain at Coloma North Rd.

Station T: located on the Dedrick Drain at Hagar Shore Rd.

Station U: located on the Forest Beach Drain at Forest Beach Rd.

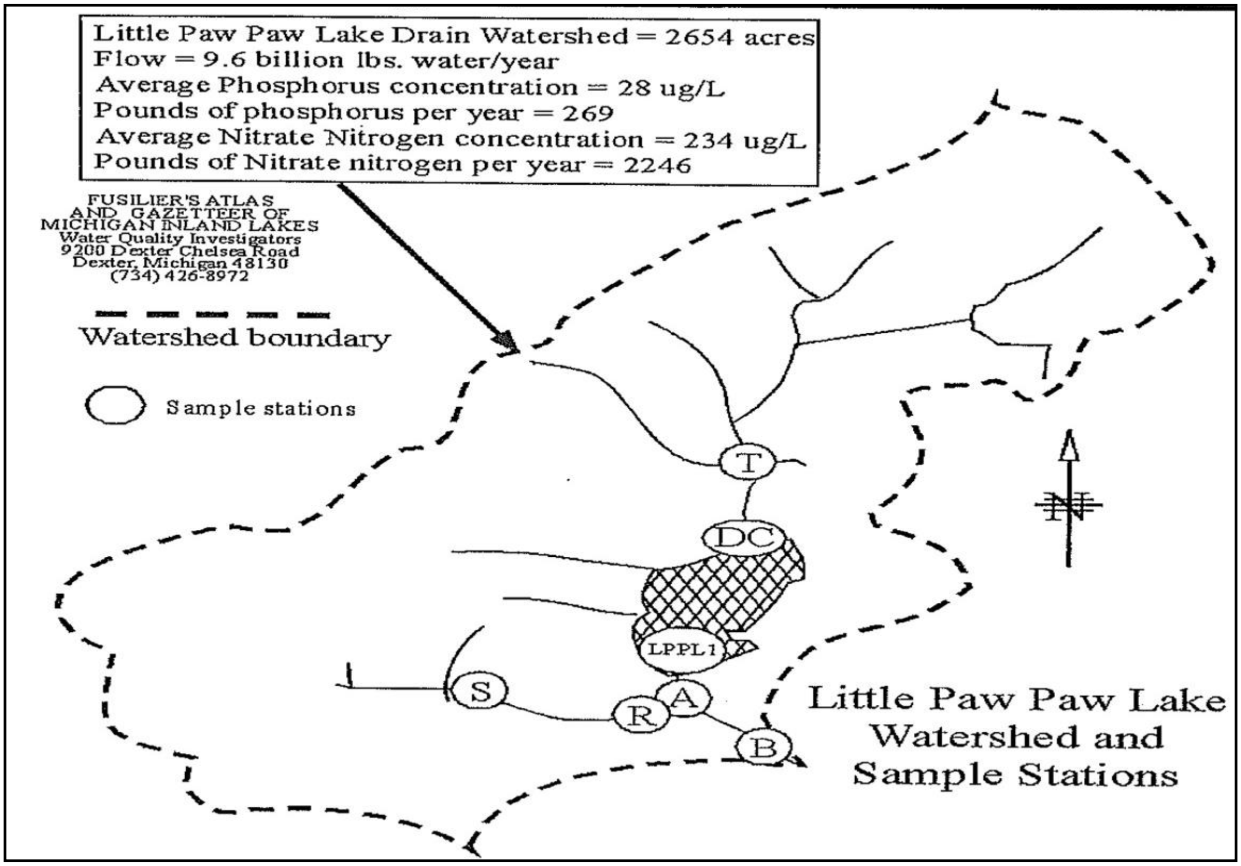


Figure 34. WQI Map of water quality sampling locations in the Little Paw Paw Lake Drain.

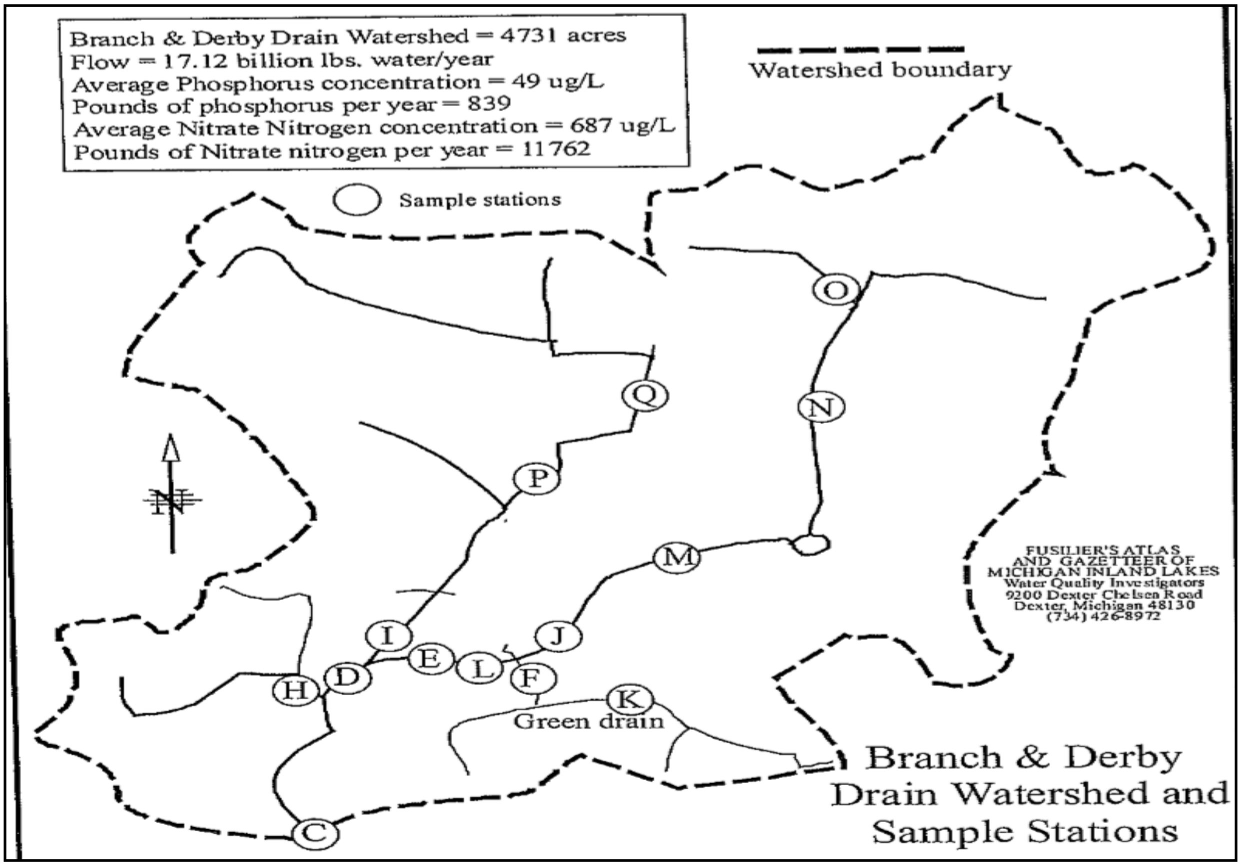


Figure 35. WQI Map of water quality sampling locations in the Green & Branch and Derby Drains.

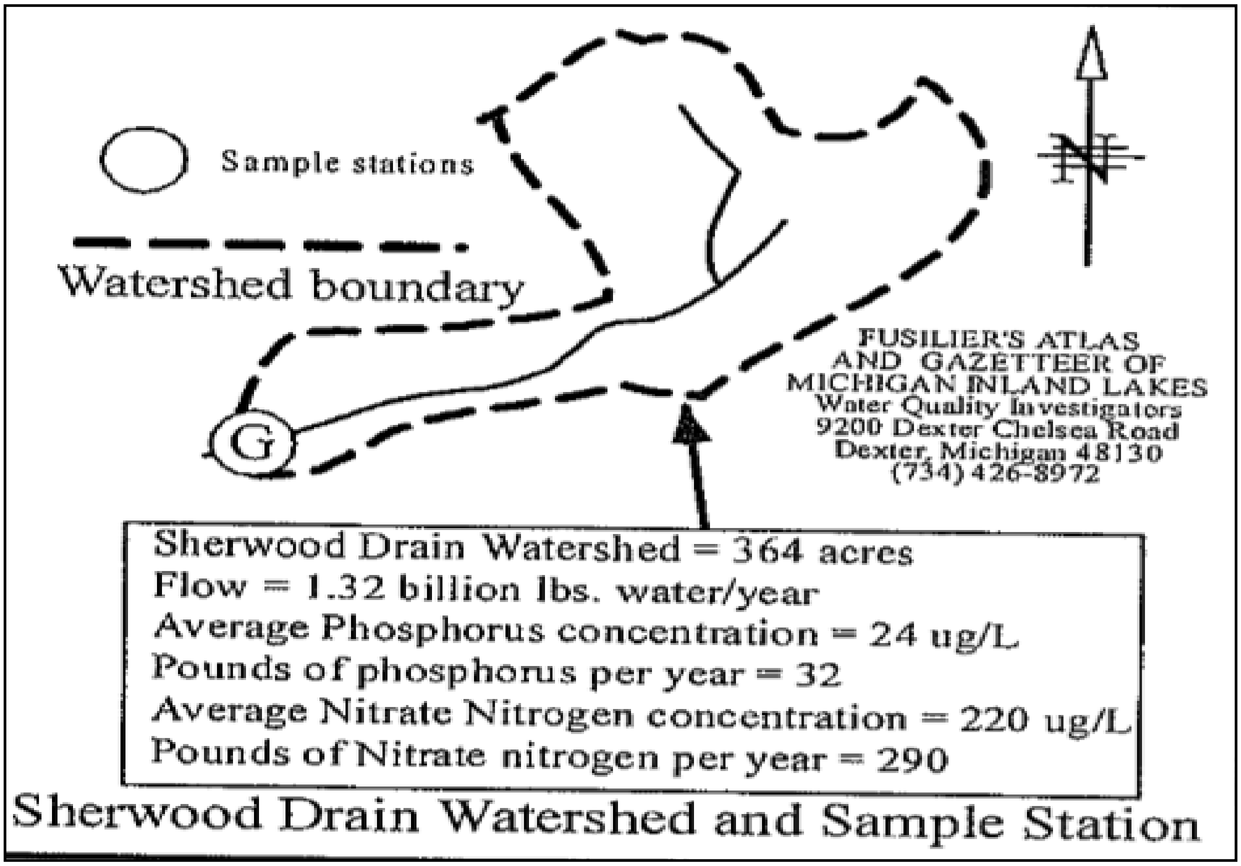


Figure 36. WQI Map of water quality sampling locations in the Sherwood Drain.

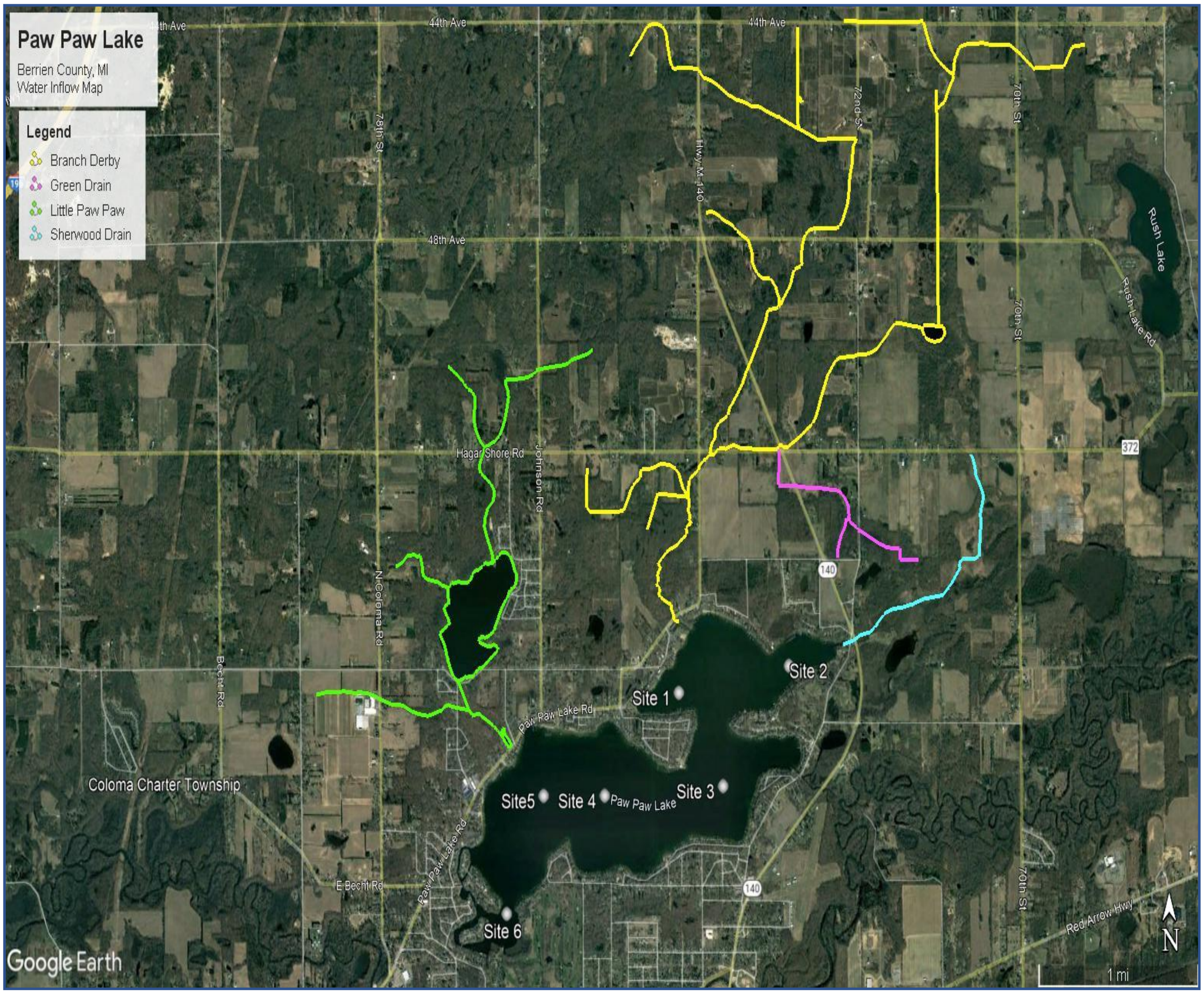


Figure 37. Paw Paw Lake Drain inflow water courses (Branch Derby Drain in yellow; Green Drain in pink; Little Paw Paw Drain in green; Sherwood Drain in aqua blue).

Branch and Derby Drain:

The Branch and Derby Drain is the largest contributor of nutrients to Paw Paw Lake and crosses two counties that include Berrien and Van Buren Counties in Michigan. The drain is approximately 6 miles in length. The Drain was historically straightened to allow for better drainage, but this has allowed for more direct transfer of solids and a limited ability of the Drain to settle out solids (and associated nutrients) that may enter the lake. A catch basin was placed in the Drain and has shown significant sediment deposition in 2019-2021. Based on a review of recent solids data, the catch basin only captures solids during periods of low precipitation. This is a concern as heavy rainfall events have increased in recent years. In the early 1980's Condominiums were built on the Drain. The Lake Pointe Condos have their own Special Assessment District (SAD) to periodically fund dredging of the Drain to allow for adequate navigation.

Table 6 summarizes water quality data for key nutrients. In addition to the data below, total suspend solids (TSS) data have been scarce but are important. In 2008, WQI estimated the TSS concentration to range from 49-1,353 mg/L which is variable but high and unfavorable. In 2016, the TSS loading rate was determined to be 1,747 lbs./day. The TP loading rate was estimated at 463 lbs./day. The N loading rate was estimated to be < 1 lb./day. In 2021 the TSS loading rate was estimated to be 102,189 lbs./day. The TP loading rate was estimated to be 611 lbs./day. The N loading rate was estimated to be 1,048 lbs./day. These loads indicate that the nutrients from the Drain are increasing over time and a new mitigation strategy is urgently needed.

In the WQI report, specific sites labelled C-Q which were along the Branch and Derby Drain were sampled for water quality parameters such as nitrate, phosphorus, total alkalinity, pH, and specific conductivity between 2003-2010. Table 6 below displays the mean plus standard deviations for those drains. Site C is at the mouth near the lake. Site L is close to Spicer's Sites A4-A6. Sites I and E are close to Spicer's Sites A2 and A3, respectively. Sites M and P are not being sampled currently but should be considered as those concentrations were high. If these sites are not considered in future sampling, key nutrient and solid sources may be missed and not mitigated. Figures 38-39 display the trends in the Branch and Derby nitrate with time.

In the 2021 Spicer report, it was reported that the Drain contains and thus contributes much higher nutrient and solid concentrations than the ambient mean Paw Paw Lake concentrations. This results in excessive loading to the lake which impairs water quality over time.

Table 6. Branch & Derby Drain sampling locations by WQI (2003-2010). Numbers in red are highest.

Drain Sampling Site	Nitrate (µg/L)	Total Alkalinity (mg/L $CaCO_3$)	pH (SU)	Specific Conductivity (mS/cm)	Total Phosphorus (µg/L)
C	797±690	91±26	8.2±0.4	253±69	126±179
H	440±283	113±24	8.1±0.6	335±92	26±13
I	766±465	67±18	8.1±0.5	252±60	37±43
E	695±692	87±40	8.3±0.5	278±112	34±24
J	337±250	114±13	8.6±0.6	340±109	27±7
D	535±353	77±40	8.4±0.6	229±92	26±14
F	184±139	122±27	8.1±0.4	298±55	47±23
L	708±1234	103±12	8.2±0.4	307±89	73±78
M	1389±1985	97±13	8.5±0.4	363±92	78±77
N	631±197	82±16	8.2±0.4	296±71	37±20
O	506±248	70±19	8.1±0.4	248±82	37±11
P	946±680	72±22	8.3±0.5	294±53	49±41
Q	1413±701	53±4	7.9±0.4	252±61	28±16

Table 7. Mean total phosphorus (TP) and total nitrate concentrations for specific sampling dates from 2015-2017 in the Branch and Derby Drain during heavy rainfall. These data were supplied only in graphical form with a lack of tabular data, so these means were difficult to calculate.

Date	TP (µg/L)	Nitrate (µg/L)
7-13-15	553	1800
7-14-15	350	1800
8-3-15	704	1700
8-10-15	300	1300
8-11-15	144	1200
9-18-15	130	1000
10-16-16	696	1200
4-7-17	157	--
5-1-17	383	183
6-29-17	340	533
10-24-21	--	--

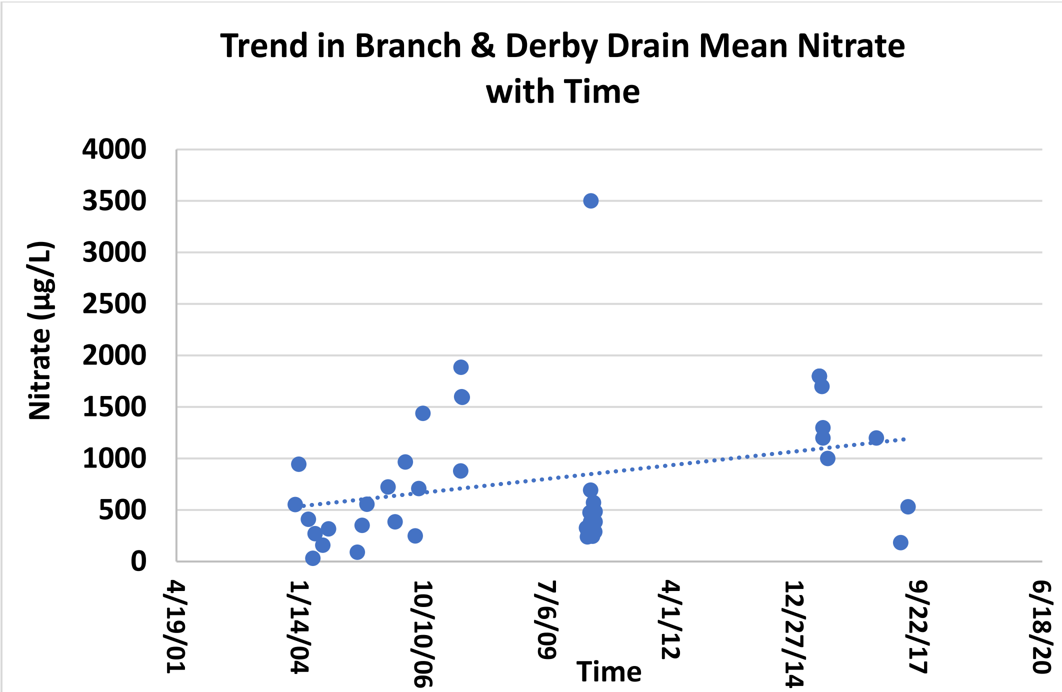


Figure 38. Trend in mean nitrate with time in the Branch and Derby Drain.

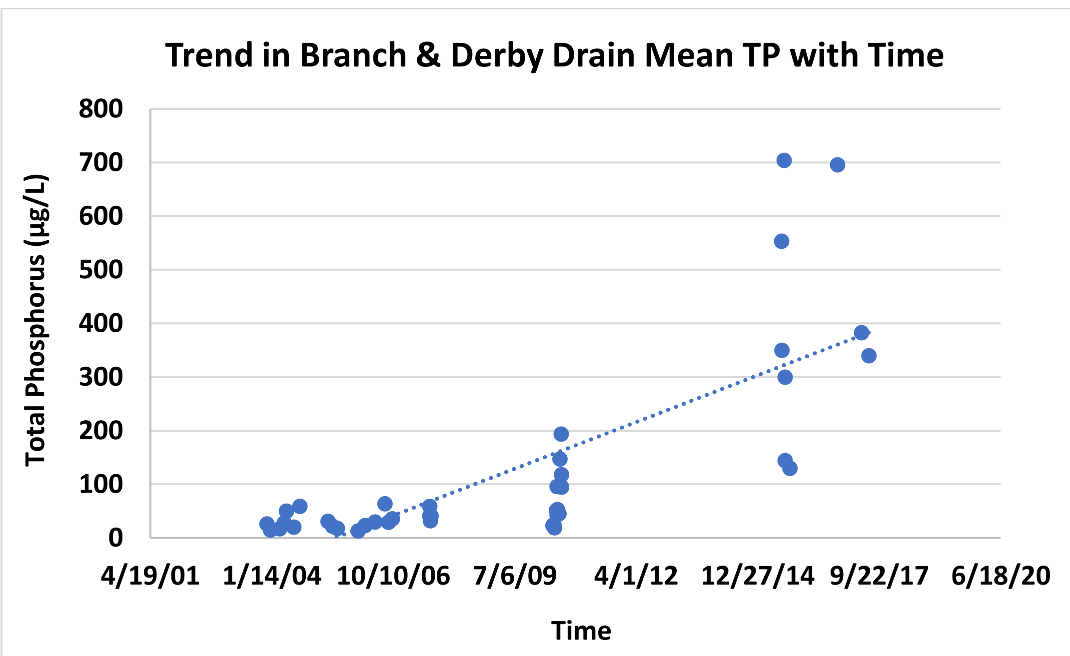


Figure 39. Trend in mean total phosphorus with time in the Branch and Derby Drain.

Forest Beach Drain:

This drain is likely a storm drain that contributes to the lake only during very high rainfall events. WQI sampled this drain in 2007 and determined that the mean nitrate concentration was 1,467±114 mg/L. The mean total phosphorus was 104±31 mg/L. These nutrient loads are very high, and this drain should be re-visited for future sampling and mitigation if mitigation has not yet been applied to the drain. This is especially important given the possibility that the nearby golf course could potentially contribute nutrient loads to the drain.

Green Drain:

This drain enters into the larger Branch and Derby Drain. WQI sampled this drain in 2005 and determined that the mean nitrate concentration was 260±142 mg/L. The mean total phosphorus was 66±38 mg/L. These nutrient loads are moderately high, and this drain should be re-visited for future sampling and mitigation if mitigation has not yet been applied to the drain.

Little Paw Paw Drain:

WQI sampled 5 key locations on this drain between 2003-2010. Table 8 below displays the means and standard deviations for water quality parameters such as nitrate, pH, specific conductivity, total phosphorus, and total alkalinity. Locations S,T, and R have especially elevated nitrate and total phosphorus loads (as shown in red).

Table 8. Little Paw Paw Drain water quality data collected by WQI 2003-2010.

Drain	Years	Nitrate (µg/L)	TP (µg/L)	pH (SU)	Specific Conductivity (mS/cm)	Total Alkalinity (mg/L $CaCO_3$)
T	2006-7	735±340	46±50	7.8±0.1	192±57	53±10
S	2006-7	1337±467	70±28	7.7±0.2	188±25	59±13
R	2006-7	1240±615	91±50	8.1±0.5	233±74	75±30
B	2003-2010	225±224	27±12	8.3±0.4	203±69	71±22
A	2003-2007	162±125	25±10	8.3±0.4	187±48	65±20

5.1 Paw Paw Lake Drain NPS Nutrient Reduction

In addition to the aquatic plant management methods presented that reduce the invasive aquatic plant communities, there are methods to improve the water quality within the lake basin. The majority of pollutants entering the lake are from non-point sources (NPS) and will continue to contribute to increased algal blooms and submersed aquatic vegetation growth, especially relative to invasive species with a faster growth rate and ability to spread rapidly such as Eurasian Watermilfoil. **The largest contributors of NPS to Paw Paw Lake include fertilizer use and three drains, especially the Branch and Derby Drain. Septic systems are not a concern as the lake utilizes a sanitary sewer system.** Nutrient loads have increased over the past few decades and persistent reduction will require continuous improvements to the watershed and through riparian BMP's.

The Michigan Department of Environment, Great Lakes, and Energy (EGLE) regulates some activities through the Inland Lakes and Streams Program, pursuant to Part 301 of the Natural Resources Environmental Protection Act, P.A. 451 of 1994, as amended. Currently regulated activities include permits for shoreline improvements and beach alterations, wetland mitigation, and dredging. Non-point source pollutants from adjacent lands are loosely regulated, generally through the derivation of Total Maximum Daily Loads (TMDL's) pursuant to the federal Clean Water Act of 1972 (CWA) for water bodies that do not meet state Water Quality Standards (WQS). An initial goal of the CWA was to reduce the discharge of all pollutants into navigable waters by 1985. This goal was clearly not achieved and thus the policy was not as effective as previously assumed. A TMDL is the maximum amount of a specific pollutant a water body can absorb and still maintain good water quality. In Michigan, waters that do not meet WQS must be studied to determine the TMDL's for specific pollutants. Once the TMDL's are established for the water body by EGLE, they are submitted to the United States Environmental Protection Agency (EPA) for approval. Once approved, the TMDL's are implemented through the regulation of National Pollutant Discharge Elimination System (NPDES) permits for point source pollutants or through improvement programs for non-point source pollution. The WQS strive to maintain waters with acceptable dissolved oxygen concentrations for the fishery, suitable conditions for recreation, and the protection of high-quality waters.

A primary problem with the current TMDL system is that sites need to be monitored frequently to determine what the TMDL should be and once determined if the system is showing signs of improvement. Although EGLE maintains a current list of waters with TMDL's throughout the state, the impairments still exist on many water bodies.

The monitoring frequency needed to obtain accurate information is often not executed and the runoff of phosphorus from farmland is often unmeasured and unknown. Furthermore, intense monitoring of agricultural non-point pollutant loads are expensive and transaction costs associated with regulation policies are usually high (Dosi and Zeitouni, 2001).

In order to reduce nutrients entering Paw Paw Lake which have been increasing over time and resulting in enhanced algae growth, the following Best Management Practices (BMP's) are recommended and can be implemented by most Lake Paw Paw riparians:

5.1.1 Paw Paw Lake Shoreline Erosion Prevention

Although erosion was well controlled in most locations, the following section offers protection tips for riparians to implement. Erosion negatively impacts numerous resources including public use areas; water quality from nutrient-rich soils eroding into the lake; and fisheries and wildlife habitat being diminished from both turbidity and a lack of suitable vegetative cover.

Fetch, the distance across a body of water to produce a wind-driven wave, ranges from less than ½ mile to just over 2 miles. Sustained east or west wind speeds could produce waves that are a maximum height of 0.48 meters. These values were calculated using the formula of $0.332 \sqrt{\text{fetch}}$.

Shoreline bathymetry also plays a big part in determining the degree of erosion at a particular shoreline site. Sites with straight shorelines and exposed points that are exposed to long wind fetches from prevailing wind directions are vulnerable to more frequent and higher waves. Additionally, where the water deepens abruptly and there is less resistance or bottom roughness to influence the wave, exposed shorelines are susceptible to larger waves. Lastly, heavy human foot traffic and mowed areas, all contribute to substantial shoreline erosion in certain reaches of the lake. A loss of vegetative cover in these locations accelerates erosion and sedimentation.

These findings suggest that a combination of the above factors such as long fetches and high winds produce significant wave heights. Water manipulation and exposed shorelines with abrupt and deep lake depths adjacent to them contribute to substantial shoreline erosion. There is a wide range of erosion control methods that can be used in a cost-effective manner to address the shoreline erosion problems.

Higher priority should go to sites where structures or amenities are threatened. A lake-wide shoreline erosion inventory is recommended along with development of any needed site-specific BMP's.

Figure 40 demonstrates how a shoreline without riprap, or a seawall should appear with vegetation of the soils on the lakeshore. The use of rip-rap or a soft shoreline is recommended to stabilize shoreline land. For more information on soft shorelines and their benefits, functions, and designs, visit the Michigan Natural Shoreline Partnership (MNSP) at: mishorelinepartnership.org. Figure 41 shows a recent planting of a natural shoreline on an inland Michigan lake.

Figure 40. A photograph of a well-vegetated and stabilized shoreline on a lake (©RLS).

Figure 41. A photograph of a newly planted soft shoreline.

5.1.2 Additional BMP's for Paw Paw Lake Water Quality

Inland waters such as lakes provide multiple benefits to riparian communities and local municipalities through a variety of ecosystem services. Stynes (2002) estimated that Michigan's 11,000 inland lakes support a recreational industry that is valued at approximately 15 billion dollars per year. Inland lakes also provide economic and aesthetic values to riparian waterfront property owners with increased residential lot property values and scenic views. A survey of approximately 485 riparians that represented five lakes in Kalamazoo County, Michigan, USA, was conducted in 2002 by Lemberg et *al*. (2002) and revealed that the most important benefit of lakefront ownership was the vista. Thus, lakes clearly provide aesthetic as well as recreational benefits to riparians and those that use them.

For some time, lakes have been under continuous stress from surrounding development and land use activities. A major source of this stress includes the anthropogenic contributions of nutrients, sediments, and pathogens to the lake water from the surrounding landscape (Carpenter et *al*., 1998). Nutrients have caused critical water quality issues such as the inundation of lakes with dense, filamentous green algae, or worse, toxic blue-green algae.

Submersed aquatic vegetation also increases with high levels of phosphorus and leads to impedance of navigation and recreational activities, as well as decreases in water clarity and dissolved oxygen that lead to widespread fish kills. The existence of excess phosphorus in inland waterways has been well established by many scholars (Carpenter et *al*., 1998; Millennium Ecosystem Assessment, 2005, among numerous others). Major sources of phosphorus for inland waterways include fertilizers from riparian lawns, septic drain fields, and non-point source transport from agricultural activities in the vicinity of a water body. Non-point source effluents such as phosphorus are difficult to intercept due to the diffuse geographical dispersion across a large area of land. Additionally, watersheds generally export more non-point source loads relative to point source loads as a result of the reductions of point source pollution required by the Clean Water Act of 1972 (Nizeyimana et *al*., 1997; Morgan and Owens, 2001).

Beginning in 2007 and continuing to the present day, the USEPA Office of Water and Office of Research and Development has partnered with multiple stakeholders at both the state and federal levels to derive comparisons among the nation's aquatic resources which include lakes, wadable streams, large rivers, coastal estuaries, and wetlands. During the assessment, 1,028 lakes have been sampled along with 124 reference lakes and 100 lakes which were re-sampled. Lakes were selected from the National Hydrography Data Set (NHD) using a set of criteria that addressed trophic status, locale, and physical characteristics. Water quality indicators such as biological integrity, habitat quality, trophic status, chemical stressors, pathogens, and paleolimnological changes were measured.

Although 56% of the nation's lakes possessed healthy biological communities, approximately 30% of lakes had the toxin Microcystin, which is produced by the blue-green algae *Microcystis*. This was also the case for Paw Paw Lake.

Approximately 49% of the lakes had mercury concentrations in fish tissues that exceeded healthy limits. The key stressors of the lakes were determined to be poor shoreline habitat and excessive nutrients. A favorable outcome of the inventory revealed that half of the lakes exhibited declines in phosphorus levels compared to levels noted in the early 1970's. Despite this observed decline, many of our inland lakes continue to experience degradations in water quality.

Elder (1985) discusses the sink-source interactions between wetlands and rivers or other waterways. He cites timing and duration of flooding events as being the key predictors of nutrient and material transport from the wetland to the waterway. **It is important to retain many of the wetland features, as any entry portals cut through the wetland (i.e., via cutting emergent cattails or other vegetation), may cause overland flow which could carry nutrients and sediments directly from wetlands into Paw Paw Lake.** Wetlands have been traditional for the treatment of storm water in that they filter out nutrients and sediments. However, during very intense rainfall events, the hydric (saturated) soils in the wetland may actually contribute nutrients to Paw Paw Lake.

Best Management Practices (BMPs) are land management practices that treat, prevent, or reduce water pollution. Structural BMPs are physical improvements that require construction during installation. Examples of structural BMPs include check dams, detention basins, and rock riprap. BMPs that utilize plants to stabilize soils, filter runoff, or slow water velocity are categorized as Vegetative BMPs. Managerial BMPs involve changing operating procedures to lessen water quality impairments. Conservation tillage and adoption of ordinances are examples of these types of BMPs. For inland lakes, the emphasis should be on BMPs that are designed to reduce storm water volume, peak flows, and/or nonpoint source pollution through proper storm water management and erosion control practices. Below is a summary of BMPs that are designed to meet these requirements. Identifying opportunities for implementation of BMPs is based on several factors including stakeholder willingness/preferences, cost, time, and effectiveness of specific management options.

When choosing a BMP, advantages and disadvantages must be weighed against physical site constraints, management goals, and costs. The physical characteristics of a specific site makes some BMPs more beneficial than others. In fully developed areas or on small sites, the use of BMPs that require a lot of land, such as ponds and basins, may not be practical. Vegetative BMPs may not be suitable for some sites due to space limitations and economic restrictions. BMP maintenance can be implemented by watershed/conservation districts, local governments, homeowner/lake associations, or the private sector.

Local ordinances are the most common method used to control the operation of storm water systems and to establish how storm water controls will be administered.

These ordinances are adopted by governing bodies and because they are part of the local law, have enforcement power. For Michigan lakes, this includes the Drain Code, Soil Erosion and Sedimentation Control Act, post-construction storm water management ordinances, among others. Additionally, ordinances can generate methods of collecting funds to construct, maintain, operate and expand storm water management systems.

To gain support from stakeholders, demonstration projects can be initially implemented and monitored to gain a better understanding of effectiveness and help guide future modifications and additional projects. Through measurement and analysis, demonstration projects reveal unanticipated barriers, making the adoption and implementation of future projects more feasible.

Many of the observed and measured impairments consisted of high total nitrogen, high total phosphorus, high total and dissolved solids, presence of easily ponded soils, presence of easily erodible soils, and relative position in the landscape to drains and other watercourses. Osborne and Wiley (1988) emphasize the importance of maintaining a healthy vegetation buffer zone around a water body to protect it from land use activities that contribute nutrient and sediment loads. The selection of BMP's should be a collective decision by all listed stakeholders and include evaluation of the best methods for the improvements based on cost, scientific efficacy, and sustainability. Such a program will select the BMP's and also determine long-term goals for sustainability of the selected improvements.

It is critical to realize that watershed management is an adaptive process where the results of each finding determine the next objectives so that future goals can be achieved. Each watershed is unique relative to impairments and solutions such as BMP's are highly site-specific. Such a program will be critical for the future health of Paw Paw Lake since a lack of NPS prevention would result in further water quality degradation.

The increased developmental pressures and usage of aquatic ecosystems necessitate inland lake management practices as well as watershed Best Management Practices (BMP's) to restore balance within Paw Paw Lake. For optimum results, BMP's should be site-specific and tailored directly to the impaired area (Maguire et *al.*, 2009). Best Management Practices (BMP's) can be implemented to improve a lake's water quality. The guidebook, Lakescaping for Wildlife and Water Quality (Henderson et *al*. 1998) provides the following guidelines:

1) Maintenance of brush cover on lands with steep slopes (>6% slope)
2) Development of a vegetation buffer zone 25-30 feet from the land-water interface with approximately 60-80% of the shoreline bordered with vegetation
3) Limiting boat traffic and boat size to reduce wave energy and thus erosion potential (reference the prior Carrying Capacity Study)
4) Encouraging the growth of dense shrubs or emergent shoreline vegetation to control erosion

5) Using only native genotype plants (those native to a particular lake and region) around the lake since they are most likely to establish and thrive than those not acclimated to growing in the area soils
6) Avoid the use of lawn fertilizers that contain phosphorus (P). P is the main nutrient required for aquatic plant and algae growth, and plants grow in excess when P is abundant. When possible, water lawns with lake water that usually contains adequate P for successful lawn growth. If you must fertilize your lawn, assure that the middle number on the bag of fertilizer reads "0" to denote the absence of P**. If possible, also use low N in the fertilizer or use lake water. N also contributes to excessive blue-green algae growth.**
7) Preserve riparian vegetation buffers around a lake (such as those that consist of Cattails, Bulrushes, and Swamp Loosestrife), since they act as a filter to catch nutrients and pollutants that occur on land and may run off into a lake. As an additional bonus, Canada geese (*Branta canadensis*) usually do not prefer lakefront lawns with dense riparian vegetation because they are concerned about the potential of hidden predators within the vegetation. Figure 42 demonstrates a lakefront property with poor management of the shoreline. This allows for increased runoff of fertilizers or nutrients to the lake which result in increased milfoil and algae growth.

Figure 42. An example of poor shoreline management with no vegetation buffer present. ©RLS

8) Do not burn leaves near the lake shoreline since the ash is a high source of P. The ash is lightweight and may become airborne and land in the water eventually becoming dissolved and utilized by aquatic vegetation and algae.
9) Assure that all areas that drain to a lake from the surrounding land are vegetated and that no fertilizers are used in areas with saturated soils.
10) The construction of impervious surfaces (i.e., paved roads and walkways, houses) should be minimized and kept at least 100 feet from the lakefront shoreline to reduce surface runoff potential. In addition, any wetland areas around a lake should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat. Construction practices near the lakeshore should minimize the chances for erosion and sedimentation by keeping land areas adjacent to the water stabilized with rock, vegetation, or wood retaining walls. This is especially critical in areas that contain land slopes greater than 6%.
11) In areas where the shoreline contains metal or concrete seawalls, placement of natural vegetation or tall emergent plants around the shoreline is encouraged. Erosion of soils into the water may lead to increased turbidity and nutrient loading to a lake. Seawalls should consist of riprap (stone, rock), rather than metal, due to the fact that riprap offers a more favorable habitat for lakeshore organisms, which are critical to the ecological balance of the lake ecosystem. Riprap should be installed in front of areas where metal seawalls are currently in use. The riprap should extend into the water to create a presence of microhabitats for enhanced biodiversity of the aquatic organisms within a lake. The emergent aquatic plants, *Schoenoplectus* sp. (Bulrushes) or Cattails present around a lake may offer satisfactory stabilization of shoreline sediments and assist in the minimization of sediment release into a lake.

5.1.3 Paw Paw Lake Public Education and Local Government Engagement

In 1997, EGLE and the United States Geological Survey (USGS) formed the Lake Water-Quality Assessment Monitoring Program (LWQA) to assess the conditions of over 700 inland lakes by 2015. Even though these efforts are critical to determine the baseline conditions of many recreational lakes in the state, they do not establish a long-term process for the conservation and management of these systems. Many environmental management programs have failed because of a scarcity in stakeholder participation. One major cause of this scant participation is due to a lack of adequate education regarding the complexities of environmental issues and resources to help assist individuals with solving challenging environmental problems. Yet, the State of Michigan has 1,240 townships and numerous other municipalities that incorporate many passionate minds to assist with service to their local communities. There exist some great, untapped resources that could be utilized to help govern and conserve lake resources. There have been significant increases in public education and awareness in regard to issues that compromise inland lakes over the past decade and historically. The creation of the Michigan Lake and Stream Associations (MLSA) over 60 years ago along with the Michigan Sea Grant, the

Michigan Chapter of the North American Lake Management Society (McNALMS), and many other small yet effective water resource protection programs have provided the public with awareness tools to begin protection strategies of a particular lake or water resource. Education is thus an important piece in the sustainability puzzle.

Figure 43 demonstrates a sound model for stakeholder engagement that applies to both lake and immediate watershed management that can be used to implement this proposed lake improvement program and adaptively revise goals into the future as Paw Paw Lake conditions change.

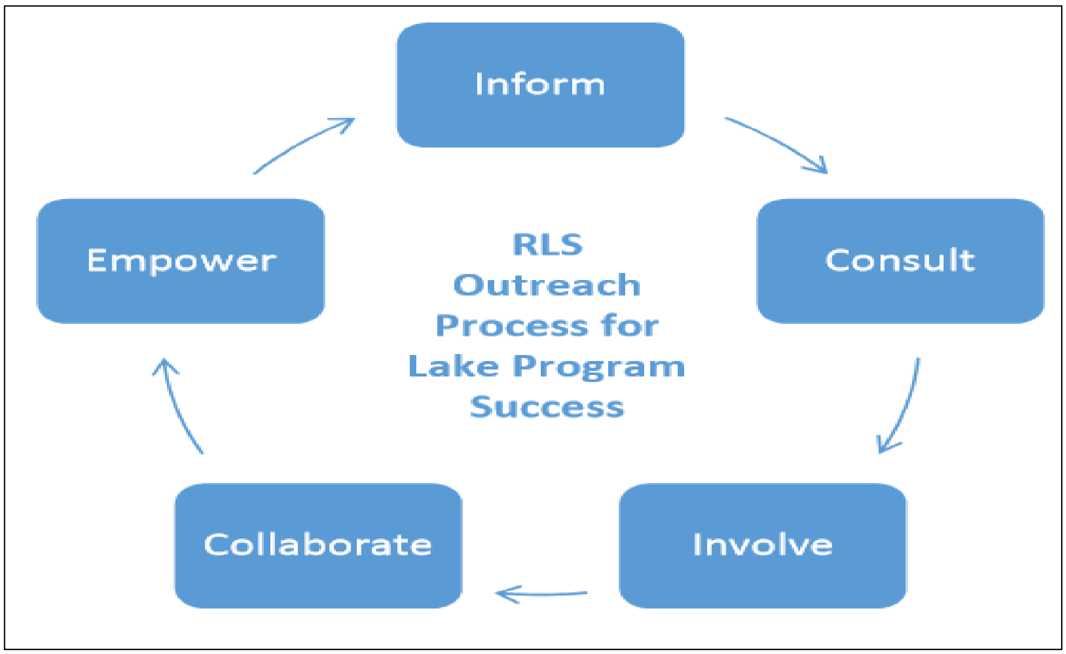


Figure 43. A flow model showing steps for successful lake and watershed program improvements.

As proposed by Feeny et *al*. (1999), sustainability of an NPS pollution program must include both human and resource valuation which are not mutually exclusive. Furthermore, the socio-political structure of the community that utilizes a resource and the interactions with the larger political system has impacts on managerial qualities of local groups in reference to the shared resource (Ostrom, 1987; 1988). **Surface waters such as Paw Paw Lake should then be considered a "commons" where management and policy implementation of NPS pollution control should consider the nature of the resource, decision-making strategies by stakeholders, property rights of riparians, and attributes of relationships among resource users and regulators.** Due to the nature of this multiple ownership of the "commons", world views held by each stakeholder will have to be considered for significant advances in a program.

If this concept is implemented in the process of an NPS pollution control program, then the local governments and citizens can develop a mutualistic trust that would be derived from attentive exchange of personal values and the needs of the local government, the riparians, and the water resource.

Furthermore, strategies recommended by Middendorf and Busch (1997), included public involvement in research *a priori* to establish common research priorities and increase a wider range of values in the decision-making process. These strategies may assist the municipalities towards a sustainable program because public involvement combined with the expertise of scientific innovations would perpetuate a self-driven program where common goals can be continuously evaluated from metrics developed by all stakeholders. A measure of sustainability can then be assessed through the projected measurement of selected metrics over an extended period of time. **Evaluation metrics for a Paw Paw Lake NPS pollution control program may consist of 1) measurements of pollutant loads and transport dynamics, 2) changes in water quality parameters and 3) indices of biotic integrity (IBIs), among many others. It should be cautioned that such metrics may be site-specific given the heterogeneity in surface water ecology; however, this potential outcome only emphasizes the need for local governance and involvement for the long-term adaptive management of water resources.** Changes in the perceptions of all stakeholders both before and after implementation of the program may also be evaluated to determine the efficacy of the program in terms of sustainability and betterment of the local community. The evaluation process should be initiated by an independent party or through statistical methods to assure that conclusions are not obscured by influences of political agendas, world views, or biases.

Although it may be useful to dissect the components and operations of other adaptive water resource programs, it would be wise to form an innovative program through the lenses of multiple viewpoints possessed by the stakeholders. The primary research problems or objectives will ultimately determine the critical aspects of a program which allows an objective structure to serve as the foundation of the program. Sustainability of an innovative program will then ultimately depend on the ability of the objective program structure to adapt to community and governance needs and lead to water resource improvement. A successful program for NPS pollution reduction would likely harbor the many characteristics described above with regards to stakeholder dynamics and composition, local governance, and objectivity of the determined research problems. With the increases in human population around water resources and the pollution thresholds of many surface waters exceeded, current legislative Acts must also incorporate prevention and monitoring sections to accompany existing improvement clauses. With these modifications, a sustainable framework will exist for all municipalities to utilize for the detection and reduction of NPS pollution in their jurisdictions.

Successful Strategies Used by Stakeholders for a Sustainable Paw Paw Lake NPS Pollution Management Program

Goldston (2009) discusses the challenges involved with the influence of science on the adoption of environmental policy. Emphasis is placed on the necessity to separate scientific inquiry from questions regarding policy. Thus, it may be advantageous for the formation of a cohesive board that could identify the scientific and policy questions to be investigated prior to the conductance of any intense research. In Minnesota, the formation of Watershed Management Organizations (WMOs) which interact with Local Government Units (LGUs), has provided the state with a powerful group of resources for surface water management that allows for a transfer of scientific knowledge from the WMOs to the LGUs which have taxation authority. The Minnesota Legislature passed the Metropolitan Area Surface Water Management Act in 1982 which mandates local governments in the seven-county metro area to prepare and implement surface water management plans in coordination with WMOs. In Michigan, the two governing Acts which involve protection of surface waters include Public Act (PA) 188 and allows townships and municipalities to levy taxes for surface water and other environmental improvements, and PA 451 which allows statutorily formed boards to levy taxes for water quality improvements. Both Acts were designed more for solution implementation than for prevention programs that are urgently needed to address the NPS pollution effects on surface waters.

If communication regarding a sustainable program was strictly between riparians and the local municipality, a voice for the necessary lifestyle adjustment would be absent with counterproductive consequences. With this realization, the outside can objectively assess the existing surface water conditions and offer unbiased solutions to be considered by the riparians and the LGUs. Kimmerer (2002) discusses the positive role that Traditional Ecological Knowledge (TEK) can have on issues regarding environmental sustainability. TEK is distinguished from Scientific Ecological Knowledge (SEK) in that social and spiritual attributes of the culture cannot be separated from the knowledge in the former. Riparian communities may be a significant source of TEK since many riparians have resided on particular lakes for decades and have likely experienced interactions with the lake system that may be shielded from the objective views of an expert scientist. Additionally, bias that may be unknowingly present in the sampling methods or by the researcher can be reduced through having multiple investigators work on a common water quality issue (Rutherford and Ahlgren 1991).

Objective assistance on the issues pertaining to NPS pollution may be provided to municipalities by the private sector, which may assist in the determination of initial goals and implementation of objective solutions (Plummer 2002). In order to ascertain that decisions made by the private sector are effectively targeted, riparians may contribute a wealth of knowledge regarding their collective needs which reduces uncertainty in the eyes of the municipality officials and garners needed support for successful immediate watershed management.

6.0 PAW PAW LAKE IMPROVEMENT PROGRAM RECOMMENDATIONS

Maintaining a Healthy Lake Ecosystem:

A healthy Paw Paw Lake aquatic ecosystem will possess a variety and abundance of niches (environmental habitats) available for all of its inhabitants. The distribution and abundance of preferable habitat will depend on limited influence from humans and development, and preservation of sensitive or rare habitats. As a result of this, undisturbed or protected areas generally contain a greater number of biological species and are thus more diverse. A highly diverse aquatic ecosystem is preferred over one with less diversity because it will allow a particular ecosystem to possess a greater number of functions and contribute to both the intrinsic and socio-economic values of the lake.

In reference to the bathymetric lake contours of Paw Paw Lake, it is apparent that nearly 75% of the lake volume occupies depths beyond 20 feet. A review of the scientific water quality data to date revealed rapid dissolved oxygen depletion beyond a depth of 20 feet during stratified periods (May-September). This means that the lake fishery will likely inhabit the littoral zone where vegetation is abundant and dissolved oxygen concentrations are acceptable. As a result, the healthy abundance of native aquatic vegetation is critical the fishery for habitat as well as oxygen production through photosynthesis. Over-management of this vegetation is not advised and must be limited to only invasive and very dense nuisance native plants.

Aquatic Vegetation Management:

It is estimated that approximately 75% of Paw Paw Lake is not able to have submersed aquatic vegetation due to deep water with reduced light penetration. This makes the littoral zone extremely important relative to protection of the existing native aquatic plant communities. The use of fluridone is complicated since the product is applied to the entire lake and much product can be lost to the deep basins. Spot-treatment with systemic liquid or granular triclopyr or ProcellaCOR® is recommended for future EWM control. This approach would also be supported by the MDNR (Jermalowicz-Jones, *personal communication*).

Furthermore, targeted aquatic plant management should be specific to invasive species only. This would include Eurasian Watermilfoil, Starry Stonewort, and curly-leaf Pondweed.

It is critical to realize that Eurasian Watermilfoil and all other invasives can never be eradicated from a lake ecosystem. Seeds from previous plants have deposited into lake sediments and may regerminate at any time. If the Eurasian Watermilfoil is not reduced in the Paw Paw Lake ecosystem, it will reduce native aquatic plant biodiversity, spread rigorously to many areas of the lake, threaten navigation and especially recreation, and possibly reduce property values.

A professional limnologist/Certified Lake Professional (CLP) should perform regular GPS-guided whole-lake surveys each year in the late spring or summer and before and after control methods are implemented to evaluate efficacy.

Continuous monitoring of the lake for potential influxes of other exotic aquatic plant genera (i.e., *Hydrilla*) that could also significantly disrupt the ecological stability of Paw Paw Lake is critical. The lake manager should oversee all management activities and is usually responsible for the creation of invasive Eurasian Watermilfoil management, survey maps and lake scans, direction of the contractors to target-specific areas of removal, recommendations for implementation of watershed best management practices that riparians can utilize, administrative duties such as the review of contractor invoices, and continued lake management education.

It has been proven that lakes with a healthy biodiversity are more resilient, which means that they can bounce back after disturbances such as extreme climatic or pollution events. BMP's to increase this resilience have been offered in this report and should be followed. **Paw Paw Lake is facing significant issues that degrade water quality over time, including inputs of nutrients from surrounding drains and the use of fertilizers, which all lead to a decline in lake health. The high nutrients have also led to increased blue-green algal blooms that secrete toxins such as *Microcystis* that can become public and pet health hazards and result in lake advisories. These algae also reduce light to aquatic plants and favor an algal-dominated state. Over time, the result of the overabundance of algae is higher turbidity, lower water clarity, and fewer aquatic plants (especially the native submersed types that cannot tolerate low light conditions). The quantities of nutrients entering the lake from drains are greater than the residual concentrations in the lake basins. Thus, the lake basin will continue to deteriorate unless drain improvements and other NPS reductions are made.**

A complete list of recommended lake improvement options for the proposed lake improvement plan can be found in Table 9 below. It is important to coordinate these methods with objectives so that baseline conditions can be compared to post-treatment/management conditions once the methods have been implemented. Lastly, it is critical to remember that this process is adaptive, and objectives and goals will change based on management outcomes.

Recommendations for the Branch and Derby Drain:

The Branch and Derby Drain is the largest contributor of nutrients to Paw Paw Lake and crosses two counties that include Berrien and Van Buren Counties in Michigan. The drain is approximately 6 miles in length. The Drain was historically straightened to allow for better drainage, but this has allowed for more direct transfer of solids and a limited ability of the Drain to settle out solids (and associated nutrients) that may enter the lake. A catch basin was placed in the Drain but is susceptible to loading of solids and nutrients that are much higher than the ambient mean lake concentrations. This leads to excessive loading to the lake which impairs water quality over time. Based on a review of recent solids data, the catch basin only captures solids during periods of low precipitation.

This is a concern as heavy rainfall events have increased in recent years. In the early 1980's Condominiums were built on the Drain. The Lake Pointe Condos have their own Special Assessment District (SAD) to periodically fund dredging of the Drain to allow for adequate navigation. Recent recommendations have been made regarding the possible re-routing of the Drain. This may be difficult as it would not be recommended to connect that drain to the Green or Sherwood Drains as those enter the lake as well. Another possible alternative would be to build a constructed wetland with emergent aquatic vegetation to filter out the solids and relieve excessive removal capacity of catch basins. Such constructed wetlands could be developed in existing wetlands or through the augmentation of high significance wetlands that were determined though the Michigan Geographic Framework, V13a (Sub watersheds: SWMPC, 2007).

Additionally, the use of autosamplers for water quality sampling has some disadvantages. First, they rely on batteries which can lose charge during important rainfall recording events. Second, it is often recommended to have scientists sample during actual rainfall events of varying intensities to capture peak flow conditions. This requires actual on-foot site visits during the rainfall events. Samples are then immediately taken to an EPA-certified laboratory to guarantee accuracy and reliability of the data. RLS recommends sampling of the A1-A5 sites along with consideration of sites reported with high nutrient loads from WQI.

In addition to Table 9, specific management recommendations for improvement include the following changes:

1. Consider sampling of key drain sites without autosamplers. This should be conducted with trained scientists during key rainfall events and during baseflow. RLS recommended sampling at Sites C, I, E, L, M, and P. Sampling should include parameters such as TSS, TP, SRP, TKN, TIN, and chlorides. Flow rates in cfs should be measured with a calibrated digital flow meter.
2. Stakeholder meeting with local farms should be held and possible assistance from the NRCS should be considered. A major goal is to reduce runoff from these farms before they enter the Branch and Derby Drain.
3. In the lake basin, a total of N=6 sampling sites should be selected where top, middle, and bottom samples of various water quality parameters are measured twice—once in the spring and once in mid-summer. Those sites are identical to ones previously determined by WQI and represent the health of the entire lake basin. At each site, the following parameters should be collected:
   A. Water temperature
   B. Dissolved Oxygen
   C. pH
   D. Specific Conductivity
   E. Total Dissolved Solids
   F. Total and Ortho-Phosphorus
   G. Total Kjeldahl Nitrogen and Total Inorganic Nitrogen
   H. Algal Community Composition and Chlorophyll-a

Also recommended would be the collection of lake bottom sediment samples to be analyzed for factions of clay, sand, fines, and gravel. This will help determine the type of "muck" on the bottom and the possible origins as well as assist with mitigation strategies for reducing deposits in sensitive areas of the lake.

4. Submit lake EWM samples for genetic testing to determine the current hybridity strains and how they are responding to systemic herbicides. This will assist with better weed management outcomes.
5. Consider avoidance of whole-lake fluridone (SONAR®) treatments. These have not maintained long-term control and are not site-specific. The use of intensive GPS Point Intercept surveys (instead of AVAS) will allow for better detection of most EWM which is needed to reduce cover over time.
6. RLS does not recommend the use of copper sulfate as this product can exacerbate cyanobacteria blooms and can bioaccumulate in the lake bottom, reducing the health of the lake benthos (bottom food chain).
7. RLS recommends that a Certified Lake Professional (CLP) serve as the lake manager and work with lake contractors to oversee management activities, objectively analyze all scientific data, and make recommends for further improvements.

Table 9. List of Paw Paw Lake improvement methods with primary and secondary goals and locations for implementation.

Paw Paw Lake Proposed Improvement Method	Primary Improvement Goal	Secondary Improvement Goal	Where to Implement in Paw Paw Lake
Utilize a data-driven methodology consistent over time for input to the lake improvement plan	Collection of appropriate data to enable time base analysis of strategic and operational metrics following industry best practices and standards	Provide fact-based inputs for setting priorities, decision-making and action plan development	Entire lake basin and drains annually (lake basin in spring and summer and drains 3-5 times per year during heavy rainfall and baseflow)
Annual whole lake aquatic plant surveys	Maintain an updated inventory of all invasive species in the lake for treatment	Maintain updated inventory of all native species in the lake	Entire lake basin and canals annually with necessary follow-up spot-surveys
Spot-treatments of invasive species only (EWM and SS)	Reduce the presence of EWM, CLP, and SS	Protect native species from invasive cover	Only in areas where EWM, CLP, and SS are found
Spring and Summer water quality monitoring of lake and major drains	Monitor all key physical & chemical water quality parameters	Graph trends over time for all parameters to visually see changes in water quality with time	In the 6 deep basins and in all major drains entering the lake
Limnologist/Lake Ecologist	Provide knowledge and advising to the Lake Paw Paw community	Promote lake health and balance through gathering of data and information for management	Annually for entire lake; Attend board meetings to present valuable information
Riparian/Community Education/Local Gov't Engagement	To raise awareness of lake/watershed issues and empower all to participate in lake protection	Long-term sustainability requires ongoing awareness and action	Entire lake community and those who frequent the lake; may also include relevant stakeholders
Re-visit Lake Carrying Capacity Evaluation/Update data to current use	To determine how increase in boat use has increased and impacts on lake	To reduce stress on lake along with other previously mentioned BMP's	Entire Lake including canals
Investigate all possible BMP's for drains and lakefront riparians	To reduce nutrient and solid loads to lake	To improve water quality of Paw Paw Lake through load reductions	Immediate watershed including riparian community

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