2018 Pattison Lake Water Quality Report

Prepared by Thurston County Environmental Health Division

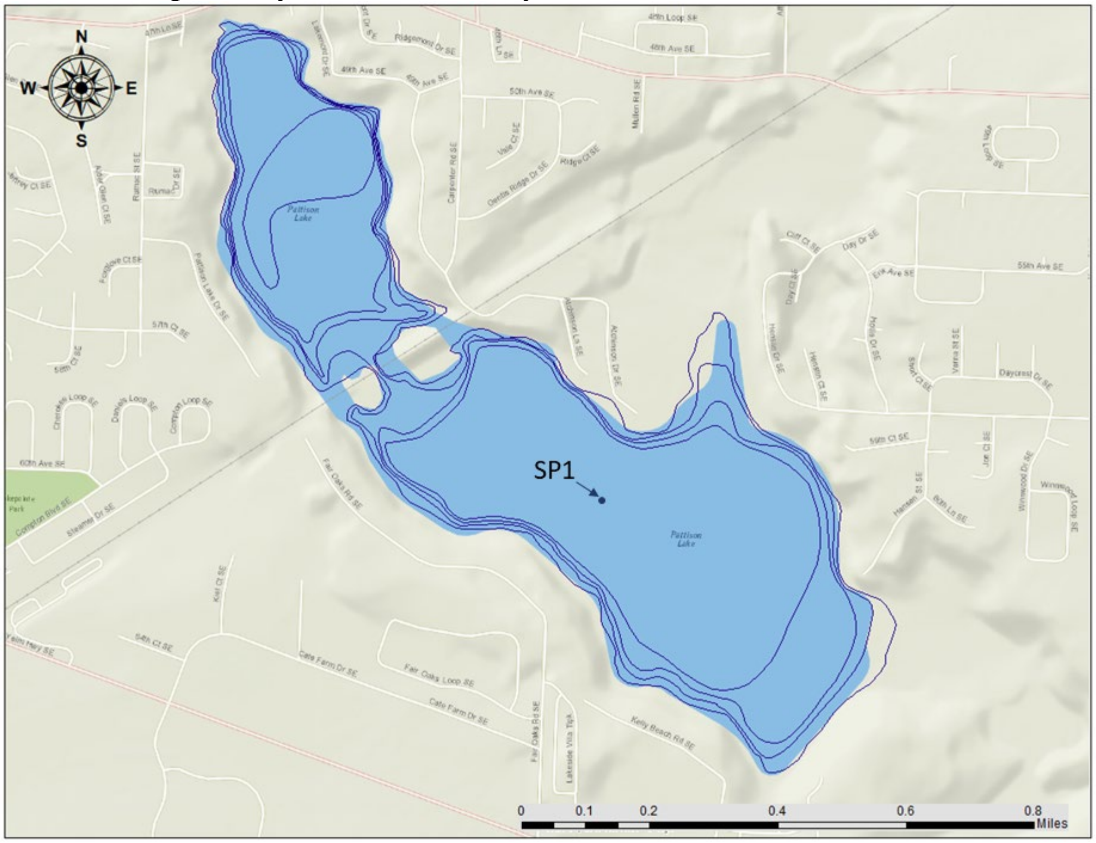


Figure 1. Pattison Lake map showing location of sample site SP1.

PART OF HENDERSON INLET WATERSHED

- **SHORELINE LENGTH**: 6.3 miles
- **LAKE SIZE**: 0.42 square miles (270 acres)
- **BASIN SIZE**: 3.8 square miles
- **MEAN DEPTH**: 4 meters (13 feet)
- **MAXIMUM DEPTH**: 6.7 meters (22 feet)
- **VOLUME**: 3,600 acre-feet

PRIMARY LAND USES:
The watershed is primarily suburban residential with some undeveloped forest cover primarily in wetland areas. The sample site SP1 is in the south basin (Figure 1).

PRIMARY LAKE USE:
Pattison Lake is used for fishing, swimming, and boating (under 5 mph).

PUBLIC ACCESS:
The Washington Department of Fish and Wildlife operates one public boat launch on the east side of the south basin.

GENERAL TOPOGRAPHY:
Pattison Lake is a Puget Sound lowland lake at an elevation of 154 feet above mean sea level. Decades ago it was divided into two basins, north and south, by placement of fill material for a railroad. Pattison Lake is second in a series of four lakes that begins with Hicks Lake. Hicks Lake drains into Pattison, and Pattison drains to Long Lake. The outlet from Long Lake flows through Lois Lake and ultimately becomes Woodland Creek, a tributary stream to Henderson Inlet.

GENERAL WATER QUALITY:
Fair – Pattison Lake is eutrophic. Water quality is impaired by high levels of nutrients and algal blooms, which interferes with recreation and sometimes produce scum and toxins. Trend analysis (2008 to 2018) revealed some positive results: the concentration of phosphorus declined, and transparency improved for half the sample season.

DESCRIPTION

Pattison Lake, located in southeast Lacey, is the second lake in a series of four lakes connected by extensive wetlands. The first lake in the chain, Hicks Lake, flows south to Pattison Lake. Pattison Lake is connected to Long Lake by a ditch constructed to float logs many years ago. Water exits Long Lake through a surface outlet at the north end and flows to Lois Lake and Woodland Creek, which discharges into Henderson Inlet in north Thurston County.

Shoreline modifications include a railroad dike, which crosses the lake and separates the two basins, and over 140 private docks (Thurston Regional Planning Council, 2008). In the 1980s, the Federal Clean Lakes Restoration Project was completed. This project included alum treatment, aquatic macrophyte control, and public education. In 1995, effectiveness monitoring showed a 0.001 mg/L increase of whole-lake phosphorus seven years after alum treatment (Welch and Cooke, 1995). Pattison Lake was listed on the 303(d) list for total phosphorus (TP) in 2004.

The Washington Department of Fish and Wildlife (WDFW) maintains a public boat ramp on the east side of the south basin. Pattison Lake is stocked with rainbow trout and supports natural populations of largemouth bass, yellow perch, black crappie, and rock bass.

METHODS

In 2018, Thurston County Environmental Health (TCEH) conducted monthly monitoring at Pattison Lake from May to October. Figure 1 shows the sample site SP1, located in the deepest part of the lake. Table 1 lists the types of data collected (TCEH, 2009) and Appendix A provides the raw data. The Custer Color Strip (Figure 2) has been used as a reference for water color since the 1990s.

Table 1. List of parameters, units, method, and sampling locations.

Parameter	Units	Method	Sampling Location
Transparency	meters	Secchi Disk	Depth where disk is no longer visible
Color	#1 to #11	Custer Color Strip	Color of water on white portion of Secchi Disk
Vertical Water Quality Profile	• Water Temperature (°C) • Dissolved Oxygen (mg/L) • pH (standard units) • Specific Conductivity (µS/cm)	YSI EXO1 Multi-parameter Sonde	~ 0.5 meter below the water surface to ~ 0.5 meter above the bottom sediments
Total Phosphorus	mg/L	Grab Samples with Kemmerer	Surface Sample: ~ 0.5 meter below the surface Bottom Sample: ~ 0.5 meter above the benthos
Total Nitrogen	mg/L	Grab Samples with Kemmerer	Surface Sample: ~ 0.5 meter below the surface Bottom Sample: ~ 0.5 meter above the benthos
Chlorophyll-a	µg/L	Composite of Multiple Grab Samples	Photic Zone
Phaeophytin-a	µg/L	Composite of Multiple Grab Samples	Photic Zone

Figure 2. TCEH compared water color to the Custer Color Strip.

Quality Assurance and Quality Control (QA/QC)

TCEH collected 10% field replicates and daily trip blanks to assess total variation (3 to 4 lakes sampled each day). The calibration of the Yellow Springs Instrument (YSI) EXO1 was verified before and after each sampling day. See Appendix B for QA/QC data.

The Seasonal Kendall Test

TCEH used the Seasonal Kendall test, a highly robust, non-parametric test, to identify trends from 2008 to 2018 (Appendix C). This test compares the relationship between data points at separate time periods and determines if there is a trend (positive or negative). The Seasonal Kendall test statistic was computed by performing a Mann-Kendall calculation for each sample month (May to October) from 2008 to 2018. TCEH calculated the Z statistic to determine if the trend was statistically significant and Theil-Sen estimator, also called Sen Slope, to estimate the magnitude of the trend over time.

RESULTS

Weather Conditions

Weather conditions during the 2018 sample season are provided in Table 2.

Table 2. Weather on sample days and the average, minimum, and maximum air temperatures for each month from Camelot-KWAOLYMP150 weather station.

Month	Weather on Sample Day	Temperature (° C) Monthly Average (Low/High)
May	Clear and Sunny (18°C); 0-3 mph SE wind	31 (14/23)
June	Mostly Cloudy (20°C); 0-3 mph S wind	31 (16/22)
July	Clear, (23°C); 5-10 mph S wind	34 (21/28)
August	Hazy from wildfire smoke, (22°C); 0-3 mph NNE wind	26 (18/36)
September	Sunny (19°C); 0-10 mph NNE wind	22 (17/29)
October	Fog (9°C); 0-5 mph S to SSW wind	16 (12/22)

Vertical Water Quality Profiles

During the summer, lakes often stratify into layers based on temperature and density differences.

- Epilimnion: upper warm, circulating strata in contact with the atmosphere
- Metalimnion: middle layer with steep thermal gradient (thermocline)
- Hypolimnion: deepest layer of colder, relatively stagnant water

The vertical water quality profiles illustrate how the water column at the south basin of Pattison Lake changed over the sample season. From May to August, warmer, more oxygenated water existed on the surface. Below this layer, the temperature and oxygen concentration declined with depth. The site SP1 began to stratify from May to June. Three discernable layers formed in July and August (Figures 3 to 5).

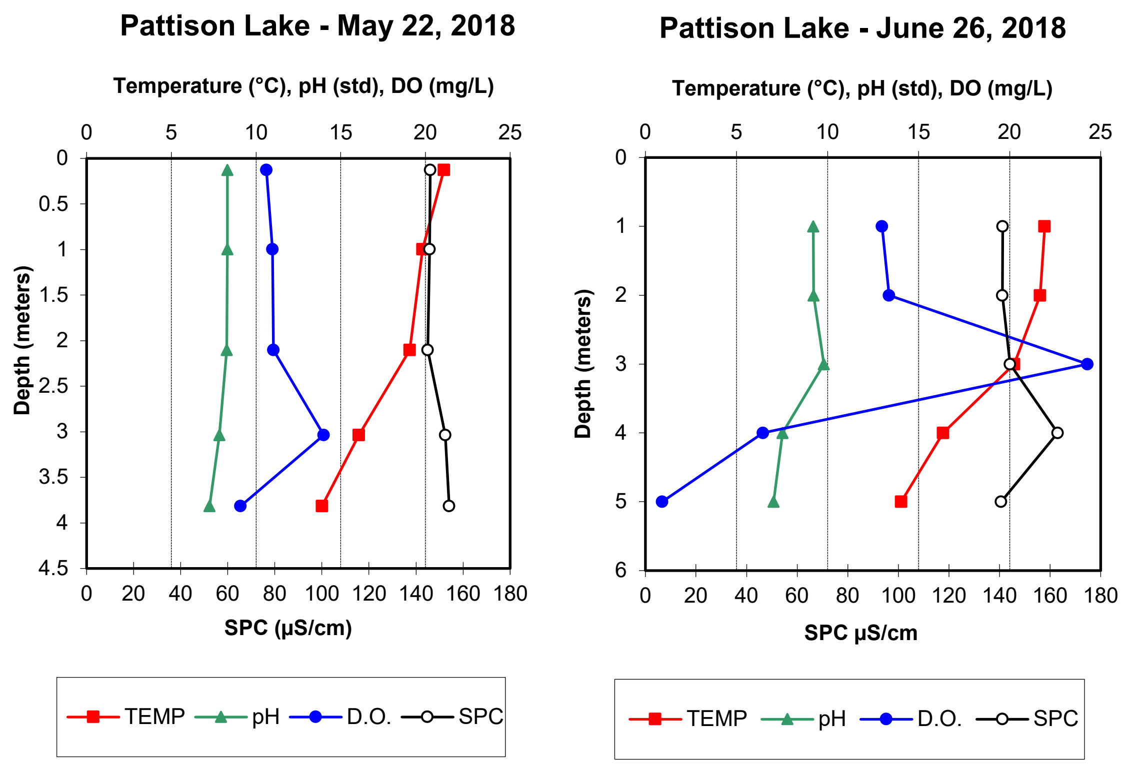


Figure 3. Vertical water quality profiles for SP1 collected during May and June 2018.

In May, the lake was beginning to stratify, but the layers were not yet well defined.

- May Photic Zone (Secchi Depth 3.59 meters) – Temperature 19.0 °C; DO 11.7 mg/L
- May Bottom Measurement (6.3 meters) – Temperature 13.9°C; DO 9.1 mg/L

In June, the average daily air temperature increased, heating the surface layer, the epilimnion. This heat was retained because the overnight air temperature remained warmer, as well (Table 2).

- June Epilimnion – Mean Temperature 21.8°C; Mean DO 13.2 mg/L
- June Hypolimnion – Mean Temperature 14.0°C; Mean DO 0.9 mg/L

The dissolved oxygen (DO) profile in May and June had a positive heterograde curve. The water column was sufficiently transparent to permit photosynthesis in deeper water, where excess oxygen accumulated due to the reduced mixing of the water column (Wetzel, 1983).

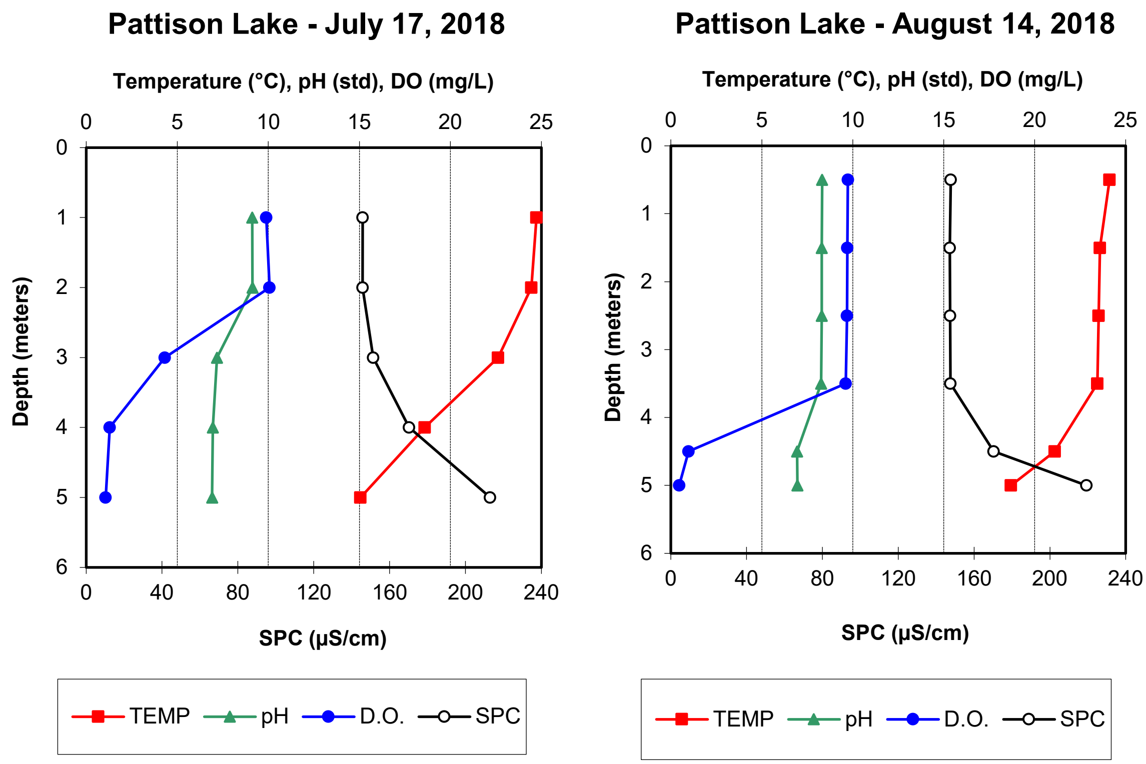


Figure 4. Vertical water quality profiles for SP1 collected during July and August 2018.

The average air temperature was highest in July (Table 2), likewise water temperatures the epilimnion increased to the summer peak. Three distinct layers were readily discernable, indicating that density differences hindered mixing of the water column.

- July Epilimnion – Mean Temperature 24.6°C; Mean DO 10.0 mg/L
- July Hypolimnion – Mean Temperature 16.8°C; Mean DO 1.2 mg/L

The average air temperature cooled in August, as did the temperature in the epilimnion. Higher wind speeds on the sample day, along with cooler temperatures increased the depth of the epilimnion from two meters in July to over three meters in August.

- August Epilimnion – Mean Temperature 23.7°C; Mean DO 9.7 mg/L
- August Hypolimnion – Mean Temperature 19.9°C; Mean DO 0.7 mg/L

The DO profile during thermal stratification in July and August was clinograde curve. Oxygen consuming processes or advection of low oxygen groundwater produced anoxic conditions in the hypolimnion. The epilimnion had much higher DO because this layer gained oxygen from the atmosphere and photosynthesis.

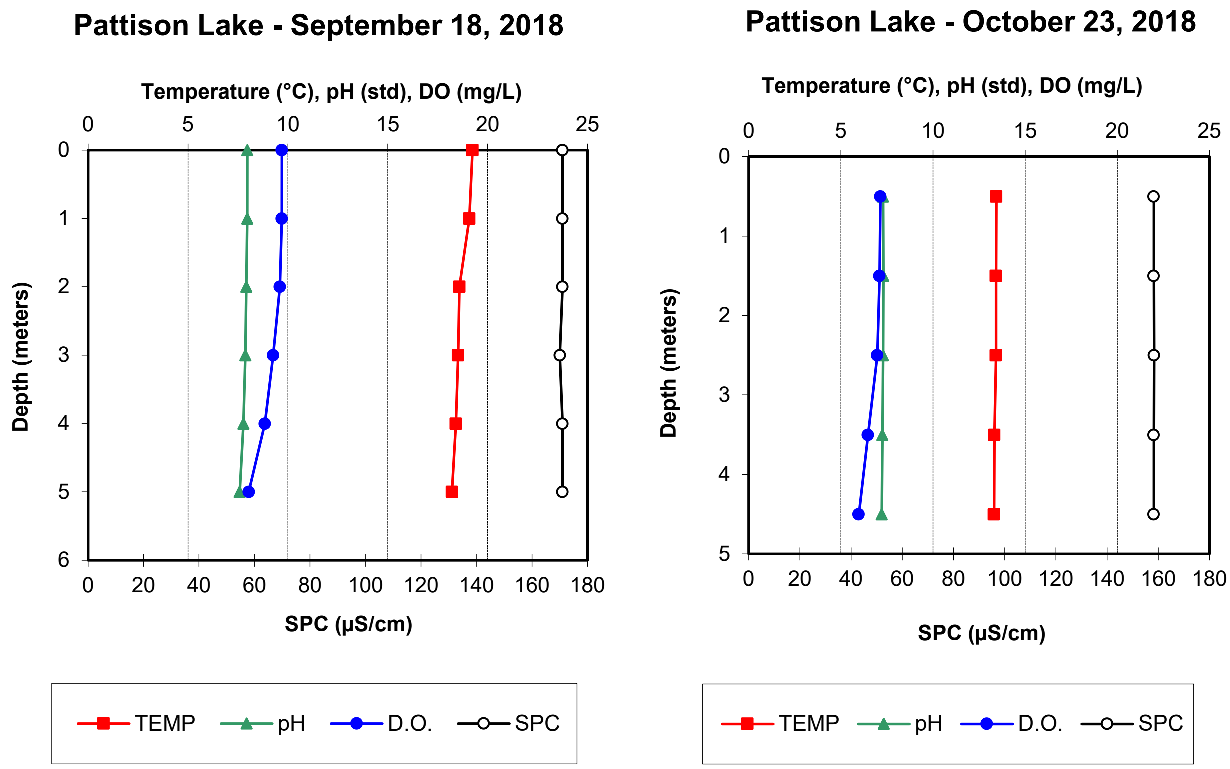


Figure 5. Vertical water quality profiles from SP1 collected during September and October 2018.

In September, air temperatures declined, especially overnight. Pattison Lake turned over. Only the upper half meter of surface water remained warmer and more oxygenated.

- September Photic Zone (Secchi Depth 1.3 meters) – Temperature 19.2°C; DO 9.7 mg/L
- September Bottom Measurement (5 meters) – Temperature 18.2°C; DO 8.0 mg/L

In October, fall arrived with colder weather. The surface water continued to cool and sink, diminishing temperature variation in the water column.

- October Photic Zone (Secchi Depth 1.5 meters) – Temperature 13.4°C; DO 7.1 mg/L
- October Bottom Measurement (4.5 meters) – Temperature 13.3°C; DO 6.0 mg/L

Surface Water Temperature Trends

The Seasonal Kendall analysis for trends for 2008 to 2018 shows that surface temperature has significantly increased at SP1 from May to August (Figure 6). Increased temperatures have many effects on freshwater environments. Warmer temperatures prolong thermal stratification and prevent mixing, enabling algal blooms to grow thicker and faster (Wells et al., 2015). Higher temperatures may increase the frequency and intensity of harmful algal blooms. Cyanobacteria (commonly known as blue-green algae) have a higher temperature optimum than eukaryotic phytoplankton, giving them a competitive advantage in warmer water. For example, Microcystis have temperature-dependent gas vacuoles that increase buoyancy, allowing this type of cyanobacteria to rise to more favorable light and temperature conditions under quiescent conditions (Michalek et al, 2013). In September, the trend was downward. No trend was detected in October.

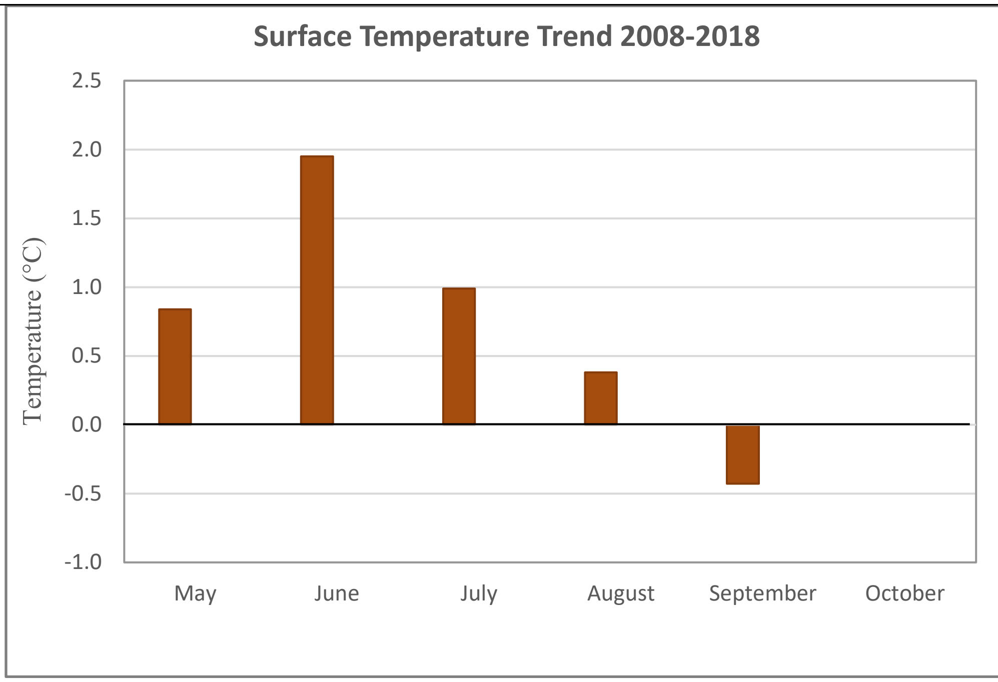


Figure 6. Surface temperature trend (+ or -) and magnitude of change (Theil-Sen estimator) for SP1 from 2008 to 2018. The lack of a bar means the site did not have a significant trend ($p<0.05$) for that time period.

Water Transparency and Color

Transparency of water to light has been used to approximate turbidity and phytoplankton populations. Secchi depth is closely correlated with the percentage of light transmission through water. The depth at which the Secchi disk is no longer visible approximates 10% of surface light, however suspended particles in the water affect accuracy. The health department recommends visibility of at least 1.2 meters, or four feet, at public swimming beaches.

Color can reveal information about a lake's nutrient load, algal growth, water quality and surrounding landscape. High concentrations of algae cause the water color to appear green, golden, or red. Weather, rocks and soil, land use practices, and types of trees and plants influence dissolved and suspended materials in the lake. Tannins and lignins, naturally occurring organic compounds from decomposition, can color the water yellow to brown.

Figure 7 shows the transparency and color for SP1 for 2018.

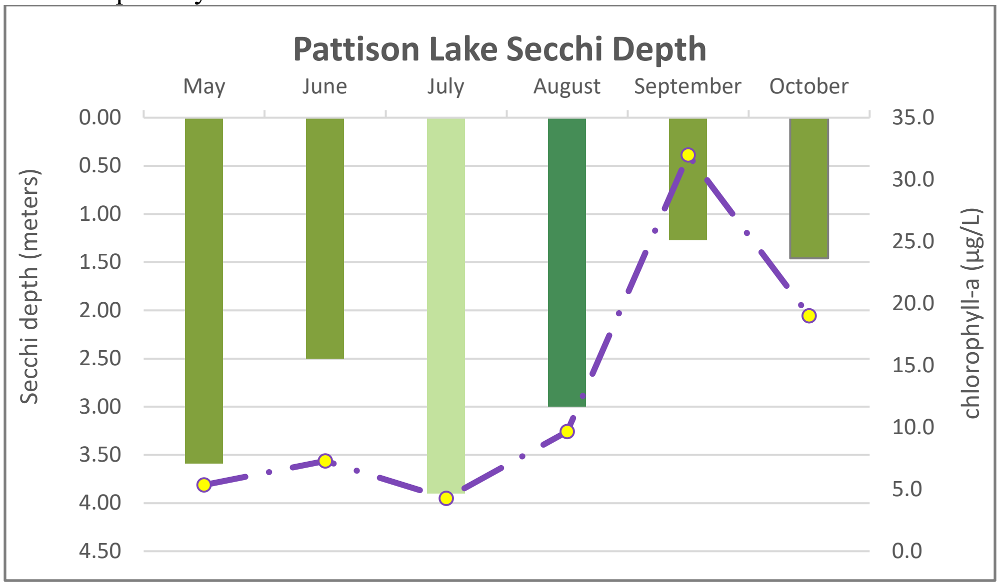


Figure 7. Water color, Secchi depths, and chlorophyll-a concentrations at SP1 in 2018.

In 2018, transparency was lowest in September (1.3 meters) and highest in May (3.6 meters) and July (3.9 meters). The mean transparency for the sample season was 2.62 meters. Secchi depth was negatively correlated with the chlorophyll-a concentration. Productivity, as measured by the chlorophyll-a concentration, was lowest (mean 6.6 µg/L) in the early summer from May to August, when the mean Secchi depth was 3.3 meters. In September and October water clarity was reduced (mean Secchi depth 1.4 meters) when the chlorophyll-a concentration increased (mean 25.5µg/L).

The color of the water (shown as the bar color in Figure 7), based on the reference Custer Color Strip, was #6 in July, #4 in August, and #3 the remainder of the sample season. Lake color was likely affected by changes in the algae and cyanobacteria communities; phytoplankton identification would provide more information about productivity and phytoplankton assemblages.

Figure 8 shows the annual average transparency (Secchi depth) compared to the long-term average (LTA). Positive values reflect transparency better than the long-term average. In 2018, transparency at SP1 was 0.3 meters higher than the long-term average.

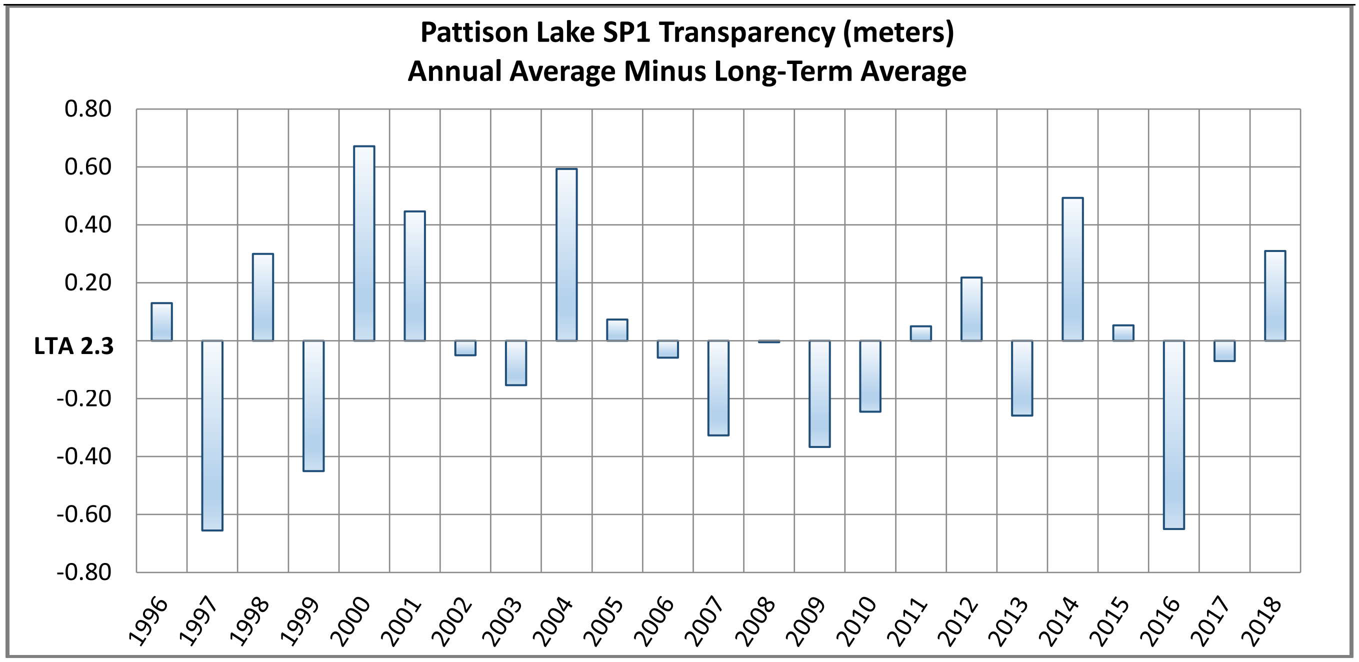


Figure 8. Transparency at SP1 compared to the long-term average (LTA).

The Seasonal Kendall test for 2008 to 2018 revealed significant upward trends ($p<0.05$) in transparency in May, July, and October (Figure 9). No significant trends existed in June, August, and September.

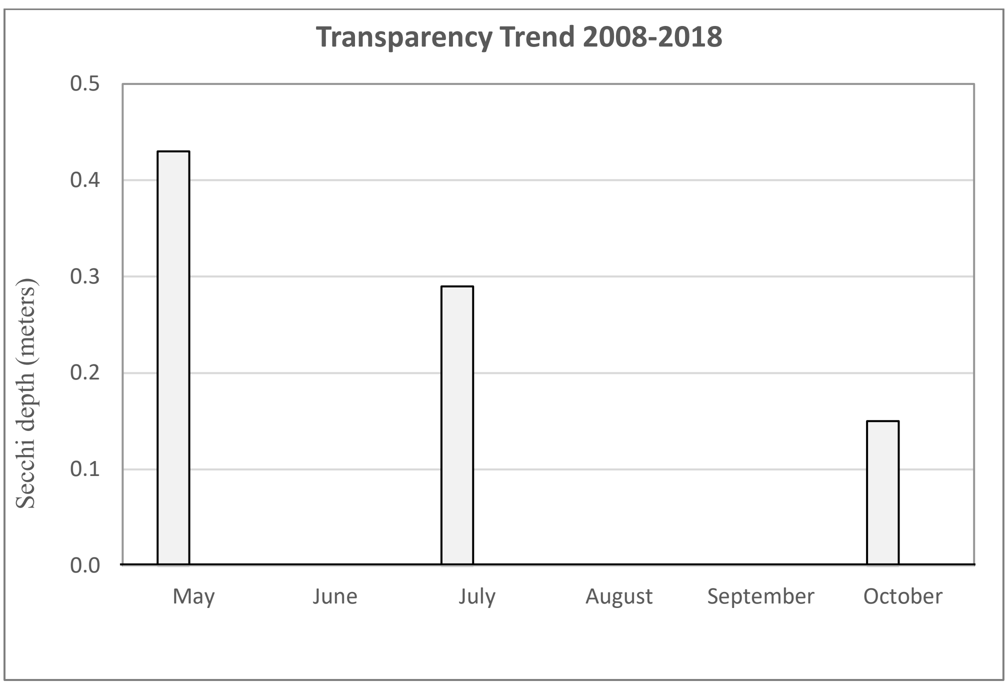


Figure 9. Surface temperature trend (+ or -) and magnitude of change (Theil-Sen estimator) for SP1 from 2008 to 2018. The lack of a bar means the site did not have a significant trend ($p<0.05$) for that time period.

Productivity

Pigments

Chlorophyll-a pigment is present in algae and cyanobacteria and is widely used to assess the abundance of phytoplankton in suspension. Phaeophytin is also a pigment, but it is not active in photosynthesis. It is a breakdown product of chlorophyll and is present in dead suspended material (Moss, 1967). Phaeophytin absorbs light in the same region of the spectrum as chlorophyll-a, and, if present can interfere with acquiring an accurate chlorophyll-a value. The ratio of chlorophyll-a to phaeophytin-a has been used as an indicator of the physiological condition of phytoplankton in the sample. Phaeopigments have been reported to contribute 16 to 60% of the measured chlorophyll-a content (Marker et al., 1980).

2018 Productivity Data

Figures 10 shows that the highest concentration of chlorophyll-a occurred after turnover in September and October. Transparency was lowest these two months (Figure 7); water clarity was negatively correlated to productivity. The concentration of DO at the surface and the ratio of chlorophyll-a to phaeophytin-a was lowest in October. The supply of oxygen at the surface was highest in May and June before the surface temperature peaked in July.

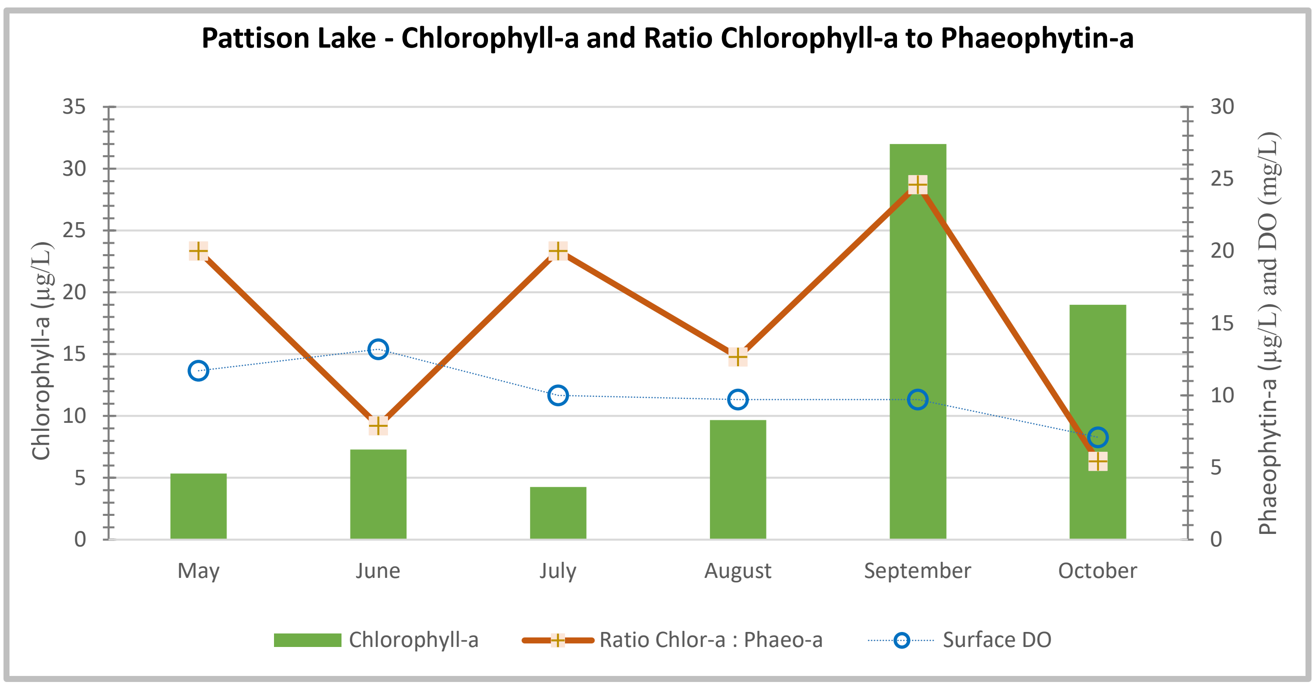


Figure 10. Chlorophyll-a concentration, ratio of chlorophyll-a to phaeophytin-a pigments, and DO concentration in the photic zone or epilimnion collected at SP1.

The Seasonal Kendall test for trends from 2008 to 2018 (Figure 11) for chlorophyll-a concentration indicates a significant ($p<0.05$) increase in chlorophyll-a concentration in August and September and a decrease from May to July and in October.

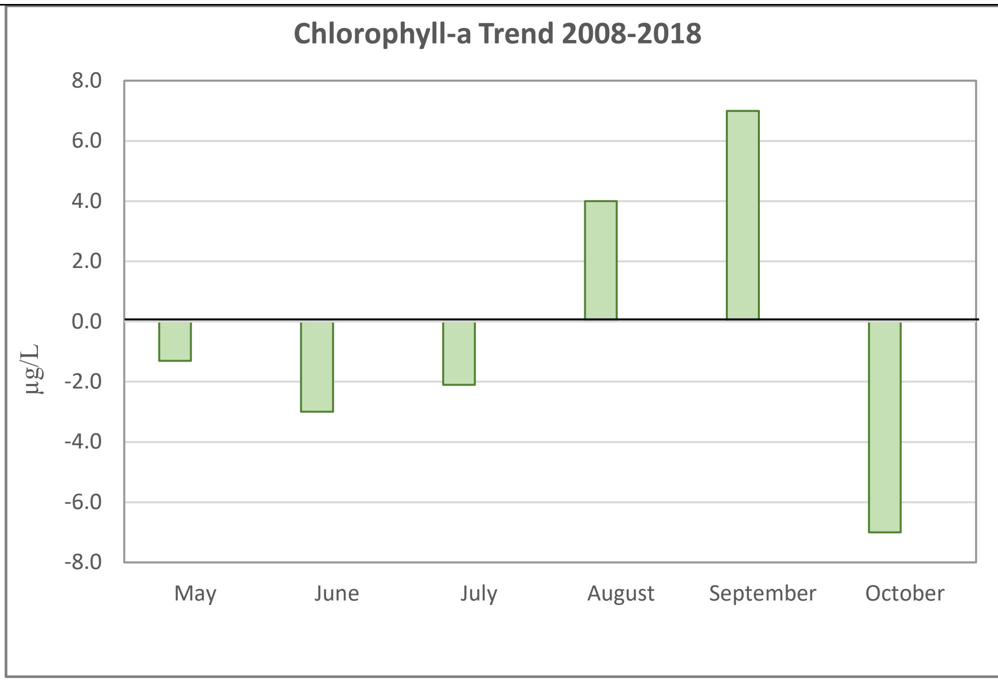


Figure 11. Chlorophyll-a trend (+ or -) and magnitude of change (Theil-Sen estimator) for SP1 from 2008 to 2018.

In 2018, TCEH tested ten samples for algal toxins. These samples were collected in July, September, October, and November. Four samples exceeded the Washington State Toxic Algae Advisory Level for microcystin and one sample for anatoxin-a (Appendix D).

Nutrients

Surface Nutrients

Inorganic nutrients, particularly the elements phosphorus and nitrogen, are vital for algal nutrition and cellular constituents. Over enrichment of surface waters leads to excessive production of autotrophs, especially algae and cyanobacteria (Correll, 1998). Figure 12 shows the total phosphorus (TP) and total nitrogen (TN) present in the surface waters at SP1.

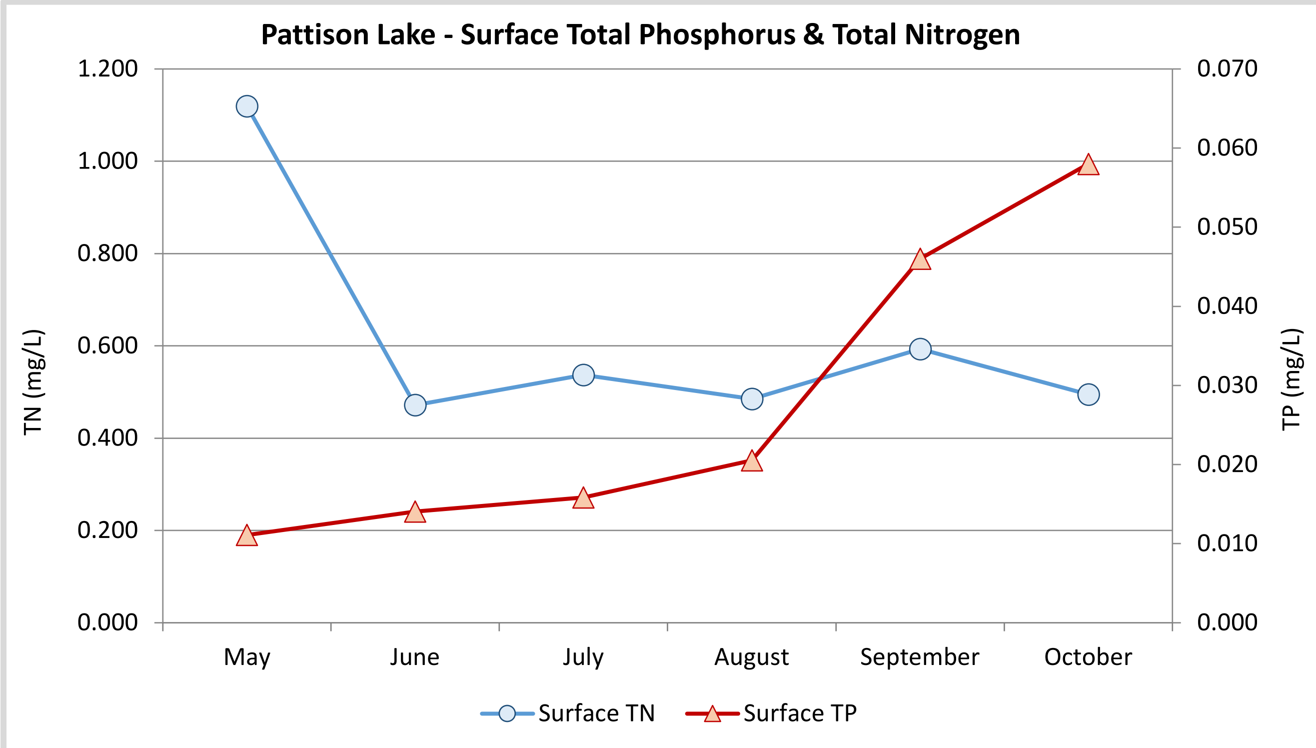


Figure 12. 2018 surface concentration of TP and TN at SP1.

The concentration of TN in surface waters was highest in May, when the lake was starting to stratify. The concentration of TP peaked after turnover in September and October. Thermal stratification reduced internal loading to surface waters from June to August; changes in the phytoplankton community and external sources likely affect nutrient levels during stratification.

Total Phosphorus

Compared to the rich supply of other elements required for nutrition or structure, phosphorus is the least abundant and most commonly limits biological productivity. Lakes in this region experience undesirable algae growth when the annual average surface phosphorus level reaches 0.030 mg/L (Gillion, 1983). Washington adopted numeric action values in the state water quality standards to protect lakes. The action level for the Puget Lowlands ecoregion is 0.020 mg/L (WAC, 2019). Figure 13 displays the TP concentration at SP1.

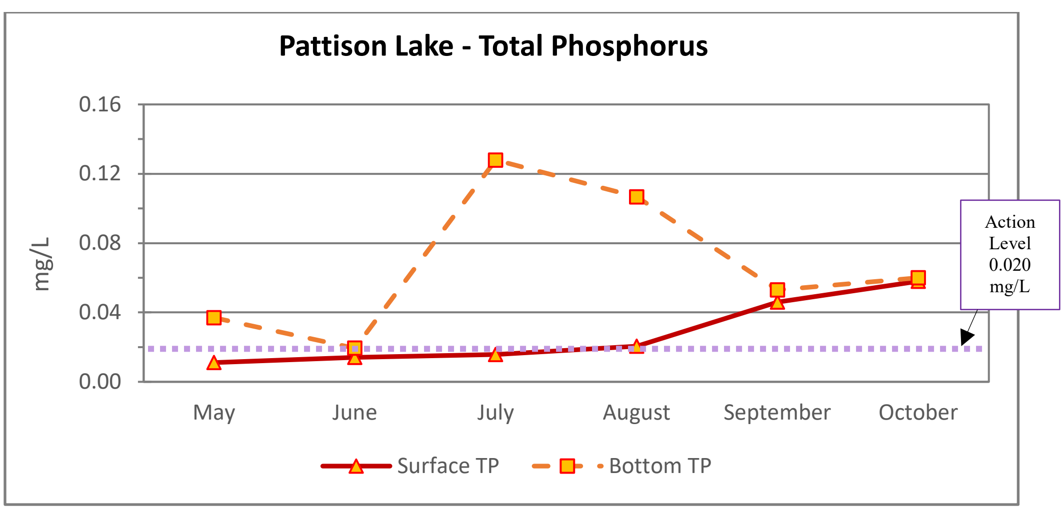


Figure 13. Concentration of Total Phosphorus at the surface and bottom at SP1 in 2018.

At SP1, the 2018 TP concentration was:

- TP Surface Mean 0.028 mg/L
- TP Surface Median 0.018 mg/L
- TP Surface Std Dev 0.018 mg/L
- TP Bottom Mean 0.067 mg/L
- TP Bottom Median 0.057 mg/L
- TP Bottom Std Dev 0.038 mg/L

The concentration was higher at the bottom in July and August. Three defined layers were recognizable in the vertical profiles during those two months (Figure 4) indicating thermal stratification. During stratification, the hypolimnion was mostly stagnant, not mixing with the oxygenated water above. At the same time, oxygen in the hypolimnion was consumed by redox processes like decomposition. Due to the lack of oxygen near the bottom, phosphorus stored in the sediments was released into the water column. This phosphorus accumulated in the hypolimnion, until turn-over later in September, when the water column mixed.

Figure 14 displays the average annual concentration of total phosphorus at SP1 from 1996 to 2018. The mean annual surface TP has been above the state action level (purple line at 0.020 mg/L) 91% of the sample seasons, every year except 1996 and 2013. Alum was applied in 1983 to reduce internal loading of phosphorus.

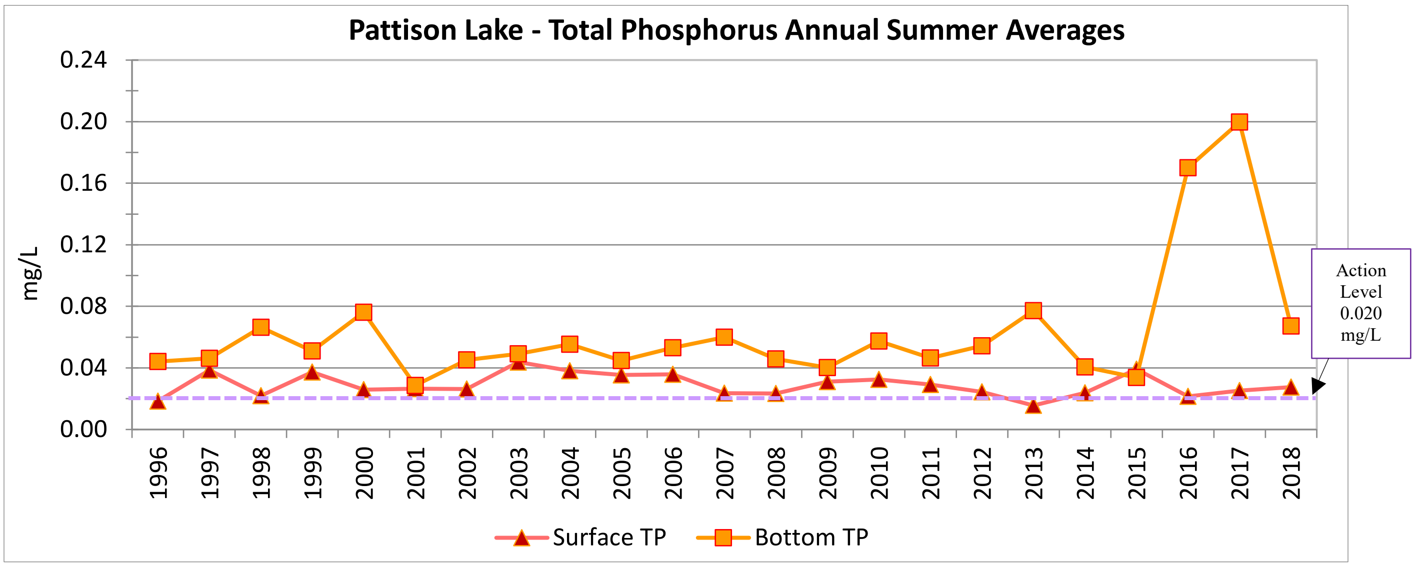


Figure 14. Average Annual Total Phosphorus at SP1 from 1996 to 2018.

For this 23-year period:

- TP Surface Mean 0.029 mg/L
- TP Surface Median 0.027 mg/L
- TP Surface Std Dev 0.007 mg/L
- TP Bottom Mean 0.063 mg/L
- TP Bottom Median 0.051 mg/L
- TP Bottom Std Dev 0.040 mg/L

The Seasonal Kendall test (2008 to 2018) revealed significant downward trends (Figure 15) in surface water TP concentrations at SP1 in May, June, and July. No significant trends were detected in August, September, or October.

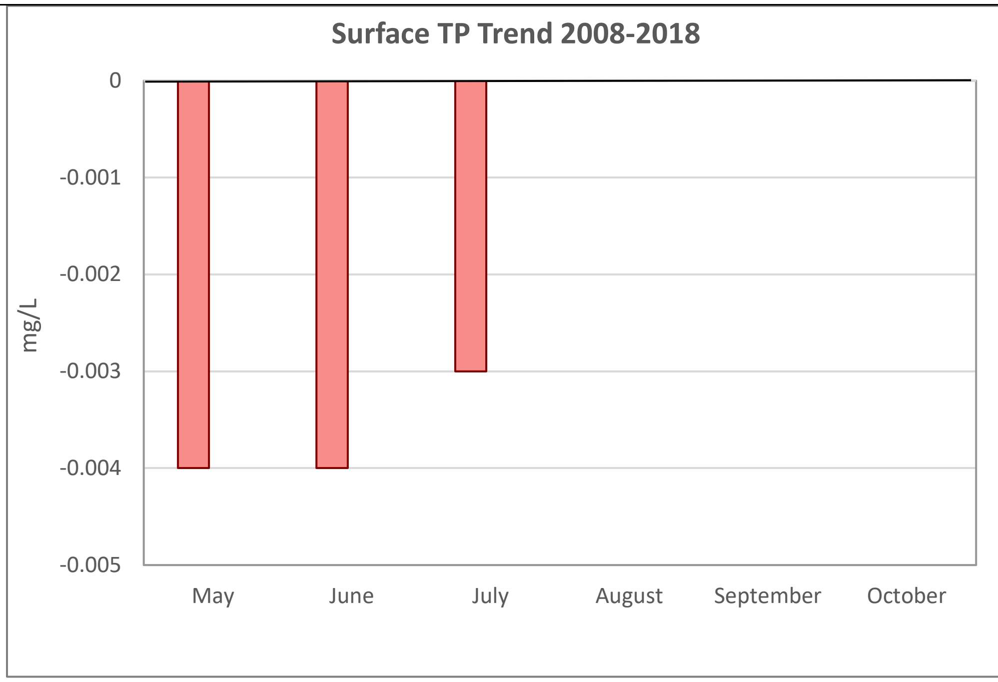


Figure 15. Surface TP trend (+ or -) and magnitude of change (Theil-Sen estimator) for SP1 from 2008 to 2018. The lack of a bar means the site did not have a significant trend (p<0.05) for that time period.

Nitrogen

Nitrogen is also limiting to lake productivity, but supplies are more readily augmented by inputs from external sources. The State of Washington does not have established action or cleanup levels for surface total nitrogen.

In 2018, the TN concentrations at SP1 were:

- TN Surface Mean 0.617 mg/L
- TN Surface Median 0.516 mg/L
- TN Surface Std Dev 0.228 mg/L
- TN Bottom Mean 1.034 mg/L
- TN Bottom Median 0.972 mg/L
- TN Bottom Std Dev 0.563 mg/L

The total nitrogen concentration was higher at the bottom in July and August because the hypolimnion was hypoxic during stratification; ammonia-nitrogen was released from the bottom sediments and accumulated in the hypolimnion. Figure 16 shows the 2018 TN concentrations for SP1.

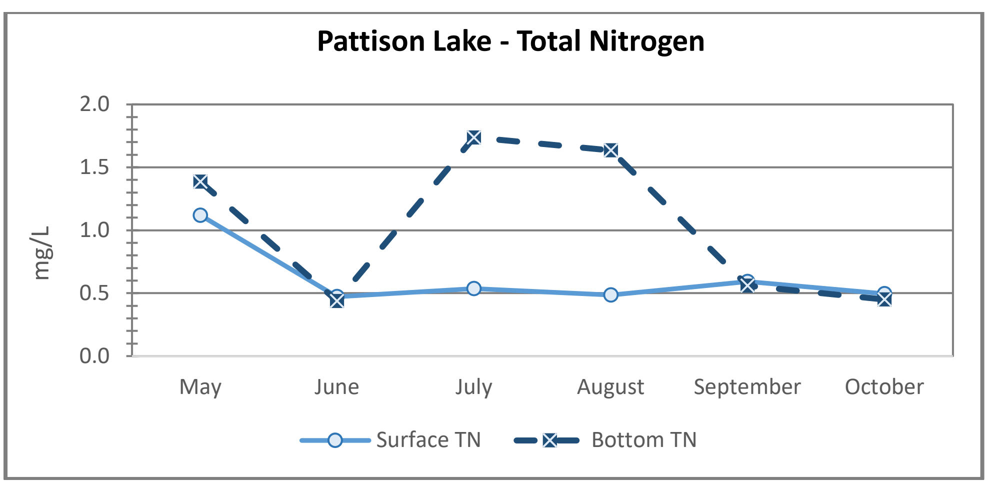


Figure 16. Concentration of Total Nitrogen at the surface and bottom at SP1 in 2018.

Figures 17 displays the average annual concentrations for total nitrogen from 1996 to 2018. The TN concentration for the 23-year period of record was:

- TN Surface Mean 0.689 mg/L
- TN Surface Median 0.665 mg/L
- TN Surface Std Dev 0.144 mg/L
- TN Bottom Mean 0.813 mg/L
- TN Bottom Median 0.765 mg/L
- TN Bottom Std Dev 0.251 mg/L

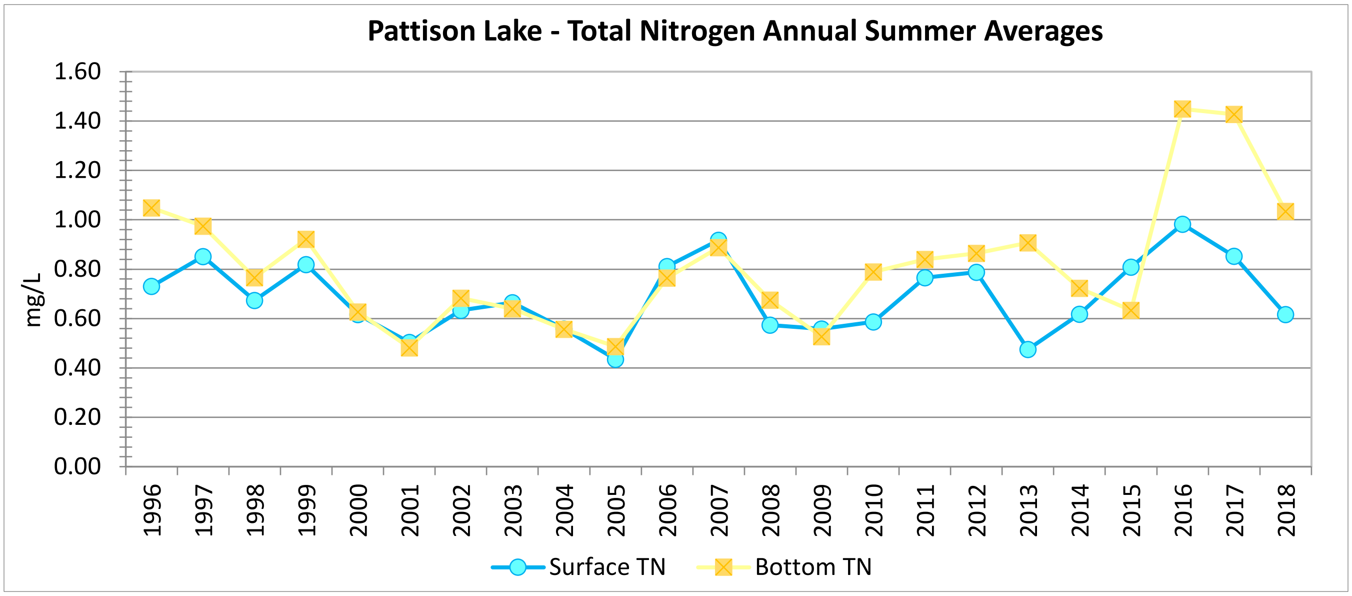


Figure 17. Average Annual Total Nitrogen at SP1 from 1996 to 2018.

The Seasonal Kendall test shows a significant (p<0.05) trends (Figure 18) of increasing surface TN concentrations from May to September. No significant trend was detected in October (Figure 18).

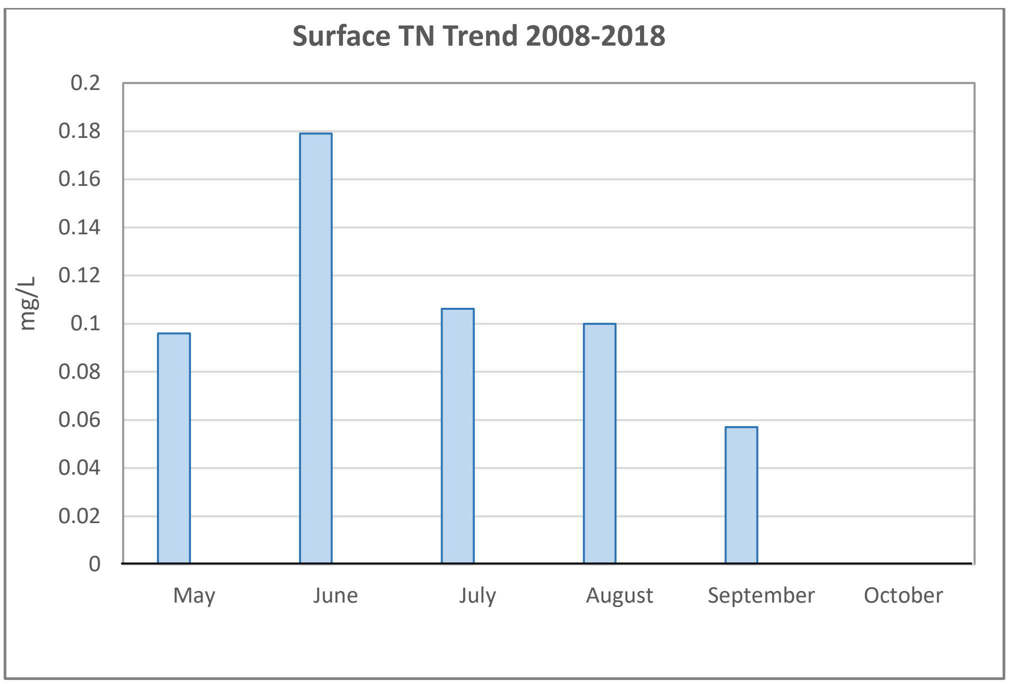


Figure 18. Surface TN trend (+ or -) and magnitude of change (Theil-Sen estimator) for SP1 from 2008 to 2018. The lack of a bar means the site did not have a significant trend (p<0.05) for that time period.

Nitrogen to Phosphorus Ratios

To prevent dominance by cyanobacteria (blue-green algae), the TN to TP ratio (TN:TP) should be above 10:1 (Moore and Hicks, 2004). Figure 19 shows the TN to TP ratio at SP1. Pattison Lake has been phosphorus limited since 1996.

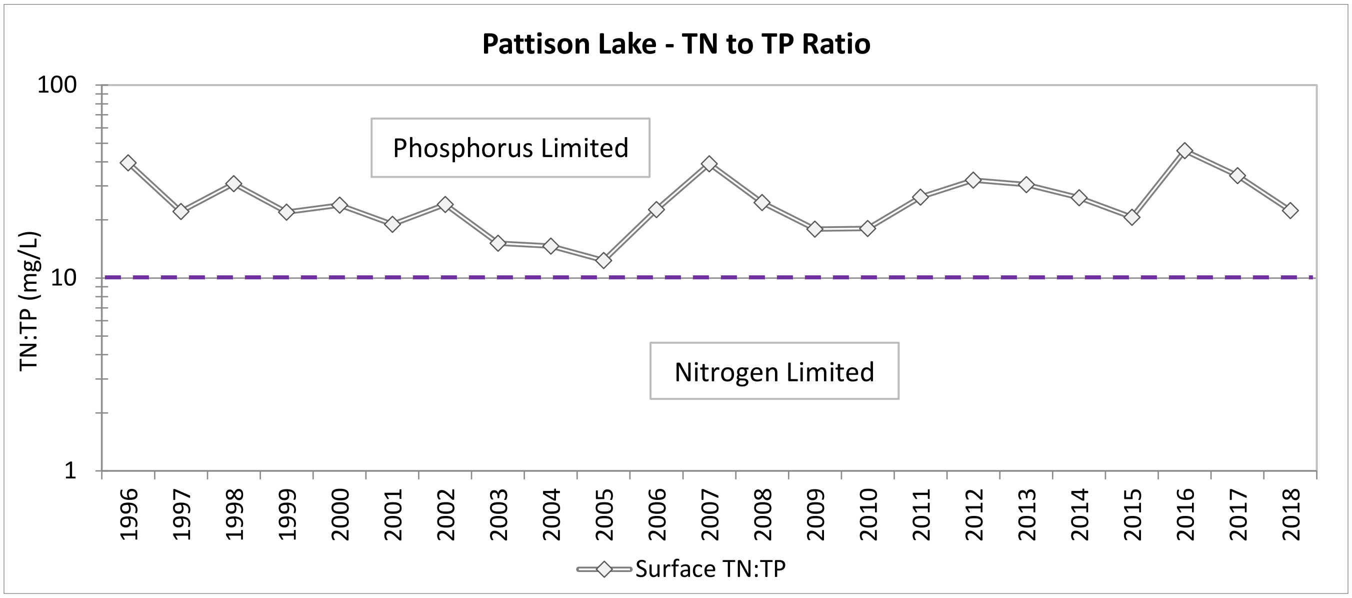


Figure 19. TN:TP at SP1 from 1996 to 2018.

Trophic State Indices (TSI)

The most commonly used method to classify lakes is called the Carlson's Trophic State Index (Carlson, 1977). Based on the productivity, this method uses three index variables: transparency (Secchi disk depth), chlorophyll-a, and phosphorus concentrations. Table 3 provides the index values for each trophic classification.

Table 3. Trophic State Index variables.

TSI Value	Trophic State	Productivity
0 to 40	oligotrophic	Low
41 to 50	mesotrophic	Medium
> 50	eutrophic	High

For SP1, the 2018 TSI results were:

- Chlorophyll-a: 56 eutrophic
- Total Phosphorus: 52 eutrophic
- Secchi Disk: 46 mesotrophic

The average of the three TSI variables is 51, which categorizes SP1 as eutrophic in 2018. Based on the chlorophyll-a concentration, SP1 has been classified as eutrophic 96% of the last 23 sample seasons (Figure 20). Since 1996, SP1 has been classified as eutrophic:

- 70% for TP concentration
- 22% for Secchi depth

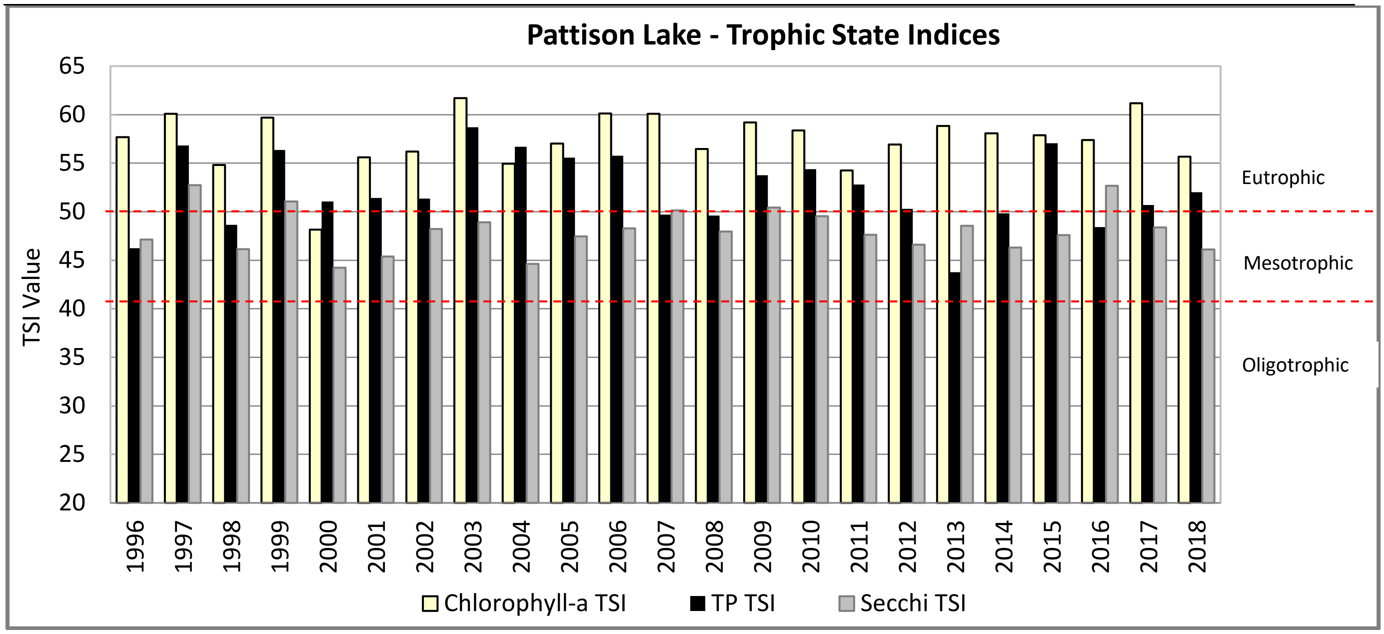


Figure 20. SP1 Trophic State Index from 1996 to 2018.

The Mann Kendall test (2008 to 2018) reveals significant downward trend ($p<0.05$) for the Secchi depth TSI value, indicating an increase in transparency. Analysis of Secchi depths for the same time period reveals that transparency has increased for half the sample season. No trend was found for TSI values calculated for chlorophyll-a or TP concentration (Appendix C).

SUMMARY

Thermal Stratification and Increased Temperature Trends

In 2018, the water column at Pattison Lake began to stratify in May and June. Three distinct layers were apparent in July and August. Pattison Lake turned-over in September. The trend from 2008 to 2018 was increased temperature in surface water at SP1 from May to August. The trend was downward toward lower temperatures in September. In October, no significant trends existed.

Water Clarity and Transparency Trends

In 2018, the mean transparency was 2.62 meters, 0.3 meters higher than the long-term average. Transparency ranged from 1.3 to 3.9 meters and was negatively correlated to the concentration of chlorophyll-a. The Seasonal Kendall test for trends (2008 to 2018) found increased transparency for half the sample season. The TSI values for Secchi depth revealed a significant trend of lower TSI values, which indicates marginally increased water clarity over the last decade.

Chlorophyll-a and Lower Productivity Trends

In 2018, the mean concentration of chlorophyll-a was 12.93 µg/L (range 4.3 to 32.0 µg/L). The highest productivity occurred in September and October. The Seasonal Kendall test for trends (2008 to 2018) in chlorophyll-a concentration indicates a significant ($p<0.05$) increasing trend in August (4.0 µg/L) and September (7.0 µg/L) and decreasing trends in May (1.3 µg/L), June (3.0 µg/L), July (2.1 µg/L), and October (7.0 µg/L).

In 2018, volunteers reported algal blooms with scum in July, September, October, and November. TCEH sampled Pattison Lake ten times for toxic algae in 2018 when surface scum was reported. The Washington State advisory level was exceeded on October 4th, October 17th, October 23rd, and October 30th. Microcystin toxin exceeded the advisory level on all four dates, with concentrations ranging from 7.1 to 52 µg/L. The concentration of anatoxin-a was over the advisory level on October 17th with a concentration of 2 µg/L (Appendix D).

Nutrients and Trends

The average TP concentration was 0.028 mg/L at the surface, above the action level (0.020 mg/L) for lower mesotrophic lakes in the Puget Sound Lowlands ecoregion. The Seasonal Kendall test (2008 to 2018) reveals significant downward trends for TP in surface water in May (0.004 mg/L), June (0.004 mg/L), and July (0.003 mg/L). No significant trends were identified for the remainder of the sample season.

The average surface TN concentration was 0.617 mg/L in 2018. The Seasonal Kendall test indicates a significant ($p<0.05$) upward trends of surface TN concentrations from May to September, ranging from the low of 0.057 mg/L in September to the high of 0.179 mg/L in June. No trend existed for October.

Classified as Eutrophic

In 2018, the Pattison Lake site SP1 was classified as eutrophic based on an average of the three TSI variables. The TSI trend from 2008 to 2018 was toward greater transparency. No trends were found for the TSI scores for TP concentrations and chlorophyll-a.

DATA SOURCES:

Thurston County Community Planning and Economic Development
(360) 786-5549 or
https://www.thurstoncountywa.gov/planning/Pages/water-gateway.aspx

Thurston County Environmental Health
(360) 867-2626 or
https://www.co.thurston.wa.us/health/ehrp/annualreport.html
For digital data contact: sarah.ashworth@co.thurston.wa.us

For correction, questions, and suggestions, contact the author of the 2018 report: renee.fields@co.thurston.wa.us

FUNDING SOURCE:

Thurston County funded monitoring in 2018.

LITERATURE CITED

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography. 22(2): 361-369

Correll, D.L. 1998. The role of phosphorus in the eutrophication of receiving waters: a review. Journal of Environmental Quality 27(2): 261-266.

Gillion, R.J. 1983. Estimation of nonpoint source loadings of phosphorus for lakes in the Puget Sound region, Washington. USGS Water Supply Paper 2240.

Marker, A.E., Nusch, H. Rai and Rieman, B. 1980. The measurement of photosynthetic pigments in freshwaters and the standardization of methods: conclusions and recommendations. Arch. Hydrobio. Beih. Ergebn. Limnol. 14:91-106.

Michalek, A.M., E.J. Anderson, D. Beletsky, S. Boland, N.S. Bosch, T.B. Bridgeman, J.D. Chaffin, K. Cho, R. Confessor, I. Doloğlu, J.V. DePinto, M.A. Evans, G.L. Fahnenstiel, L. He, J.C. Ho, L. Jenkins, T.H. Johengen, K.C. Kuo, E. LaPorte, X. Liu, M.R. McWilliams, M.R. Moore, D.J. Posselt, R.P. Richards, D. Scavia, A.L. Steiner, E. Verhamme, D.M. Wright, and M.A. Zagorski. 2013. Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. PNAS 110(16):6448-6452.

Moore, A. and Hicks, M. 2004. Nutrient criteria development in Washington State. Washington State Department of Ecology, Publication Number: 04-10-033.

Moss, Brian. 1967. Studies on the degradation of chlorophyll-a and carotenoids in freshwaters. New Phytol. 67: 49-59.

TCEH (TCEH), 2009. Surface water ambient monitoring program: standard operating procedures and analysis methods for water quality monitoring.

WAC. 2019. Chapter 173-201A, "*Water Quality Standards for Surface Water of the State of Washington.*" https://apps.leg.wa.gov/wac/default.aspx?cite=173-201a

Welch, E.B., Cooke, G.D. 1995. Internal phosphorus loading in shallow lakes: importance and control. Lake and Reservoir Management: 11(3): 273-81.

Wells, M.L., V.L. Trainer, T.J. Smayda, S.B.O. Karlson, C.G. Trick, R.M. Kudela, A. Ishikawa, S. Bernard, A. Wulff, D.M. Anderson, and W.P. Cochlan. 2015. Harmful algal blooms and climate change: learning from the past and present to forecast the future. Harmful Algae 49: 68-93.

Wetzel, R.G. 1983. Limnology, 2nd Edition. CBS College Publishing, New York, NY.

Appendices

Appendix A. Raw data

Table A-1 Raw data collected at the Pattison Lake site SP1.

Date	Time	Bottom Depth (meters)	Secchi (meters)	Water Color	Bottom Sample Depth (meters)	Surface TP (mg/L)	Bottom TP (mg/L)	Surface TN (mg/L)	Bottom TN (mg/L)	Chl a (µg/L)	Phae a (µg/L)	Lake Notes
5/22/2018	16:30	5.25	3.59	3	4.5	0.011	0.037	1.119	1.385	5.3	0.3	Composite Sample collected at the following depths (meters): 0.5, 1.0, 1.5, 2.5
6/26/2018	11:24	5.25	2.50	3	4.8	0.014	0.019	0.472	0.438	7.3	0.9	Composite Sample collected at the following depths (meters): 1, 2, 3; DO at 3 meters was 24.28 mg/L or 262% saturation
7/17/2018	11:28	5.10	3.90	6	4.4	0.016	0.128	0.537	1.738	4.3	0.2	Composite Sample collected at the following depths (meters): 0.5, 1, 2; bottom sample at 4.6 m had too much sediment; we collected pink/red algae on south side of lake for ID after fishermen notified us of its presence
8/14/2018	12:26	5.17	3.00	4	4.7	0.021	0.107	0.485	1.634	9.7	0.8	hazy from wildfire smoke; approx 78^{o}F; 0-3 mph wind; depth calibrated on EXO1
9/18/2018	14:02	5.20	1.27	3	4.5	0.046	0.053	0.593	0.558	32.0	1.3	
10/23/2018	13:20	5.19	1.46	3	4.6	0.058	0.060	0.495	0.451	19.0	3.5	

Appendix B. Quality Assurance/Quality Control

Table B-1 provides the amount of instrument drift for specific conductivity, dissolved oxygen (collected with optical sensor), and pH. The temperature thermistor was checked against a NIST thermometer on May 31, 2018 and difference was 0.04° C.

Table B-1. Instrument drift for Pattison Lake sample days in 2018.

End Date	SPC (µS/cm)	ODO (% sat)	pH (std units)
5/23/2018 7:34	0	-0.13	0.02
6/27/2018 7:28	-3.3	-0.85	0.07
7/18/2018 7:45	2.2	-0.82	0.11
8/15/2018 15:40	1.5	-0.01	0.17
9/19/2018 8:20	0.1	-0.29	-0.05
10/24/2018 7:40	-0.1	-0.03	0.01
RSD	0.01	-0.36	0.78

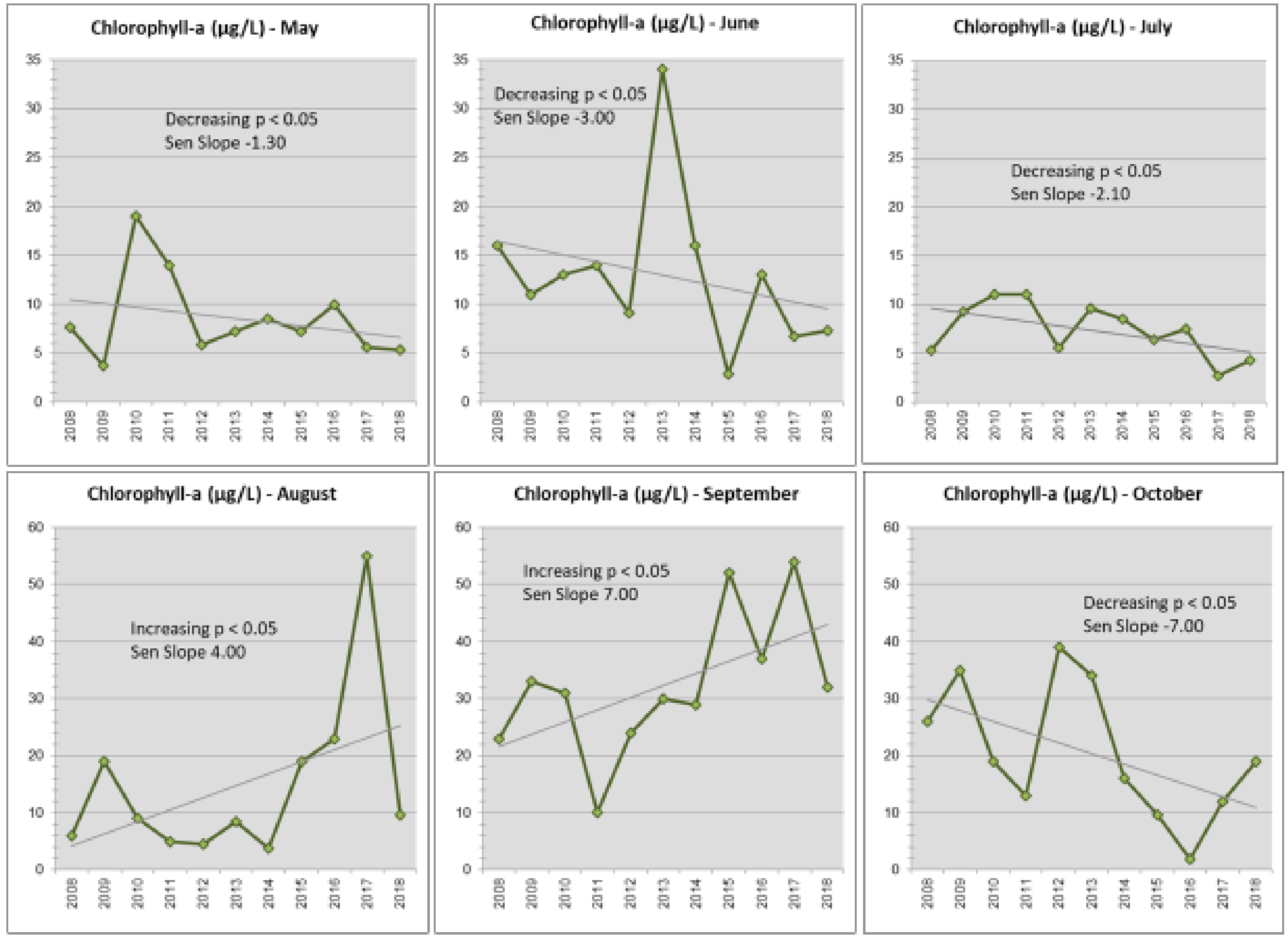
Appendix C. Trends

Appendix C. Trends

Trends
2008 to 2018

Pattison Lake
Site SP1

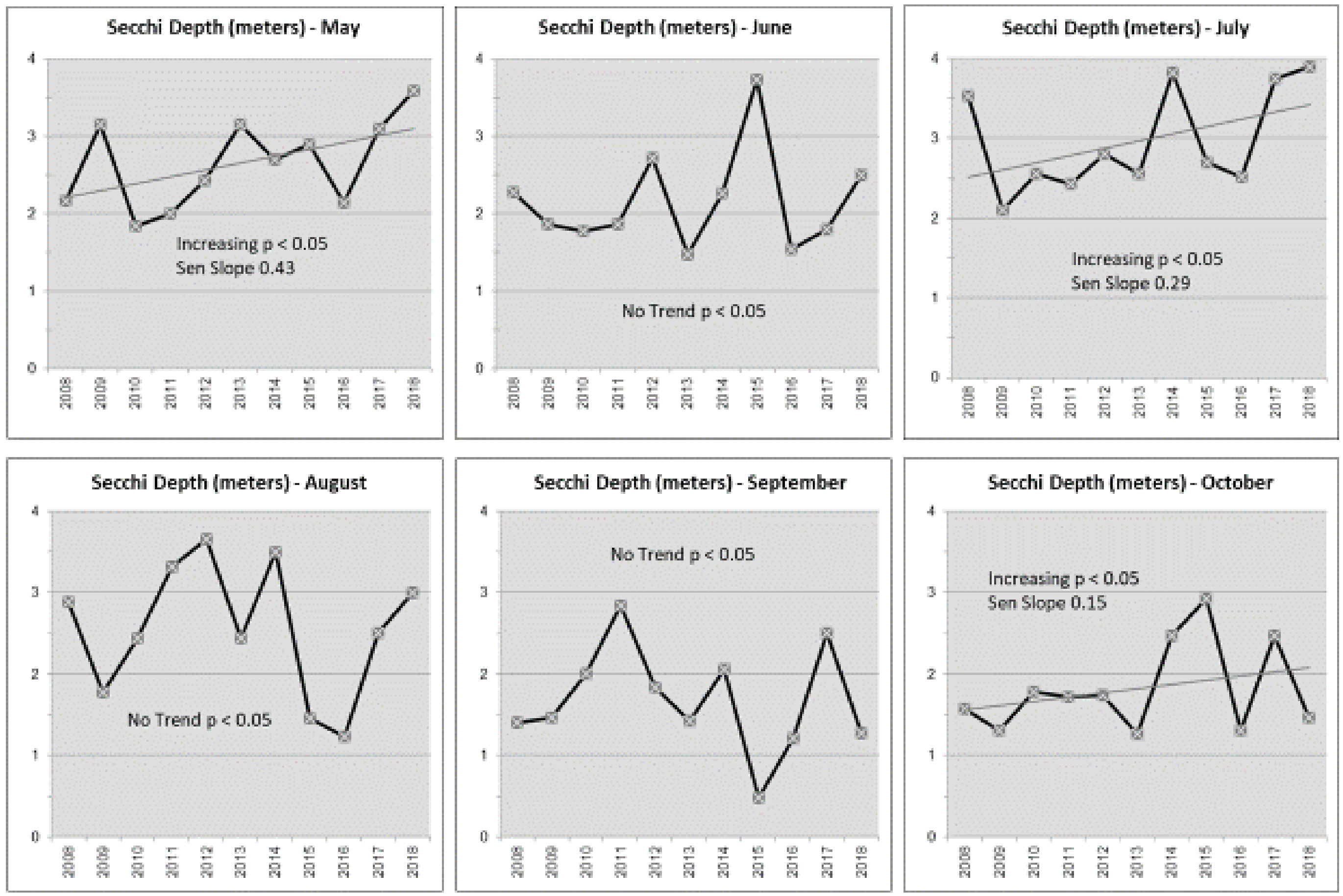
Chlorophyll-a
concentration
(µg/L)



Trends
2008 to 2018

Pattison Lake
Site SP1

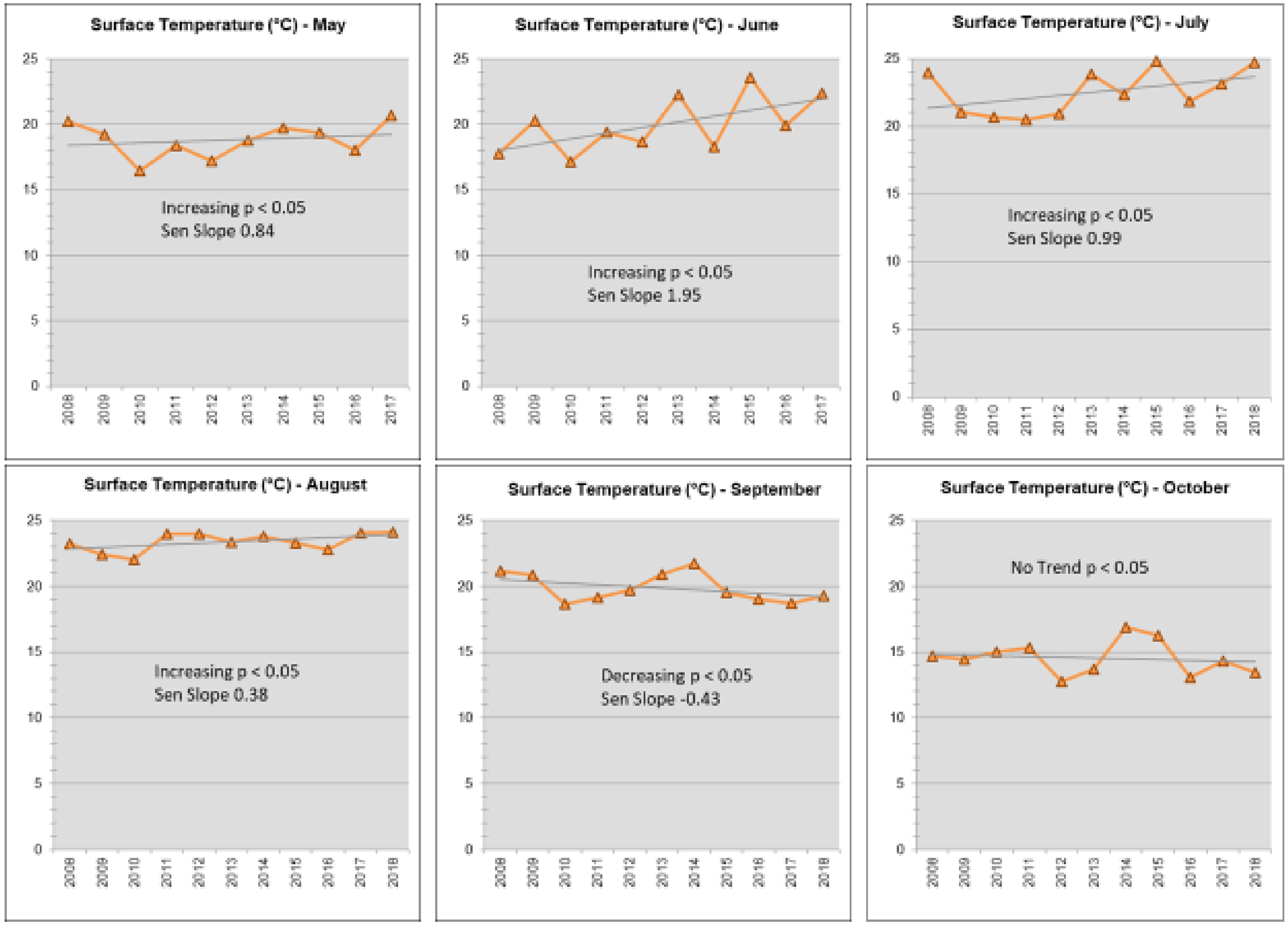
Secchi Depth
(meters)



**Trends
2008 to 2018**

**Pattison Lake
Site SP1**

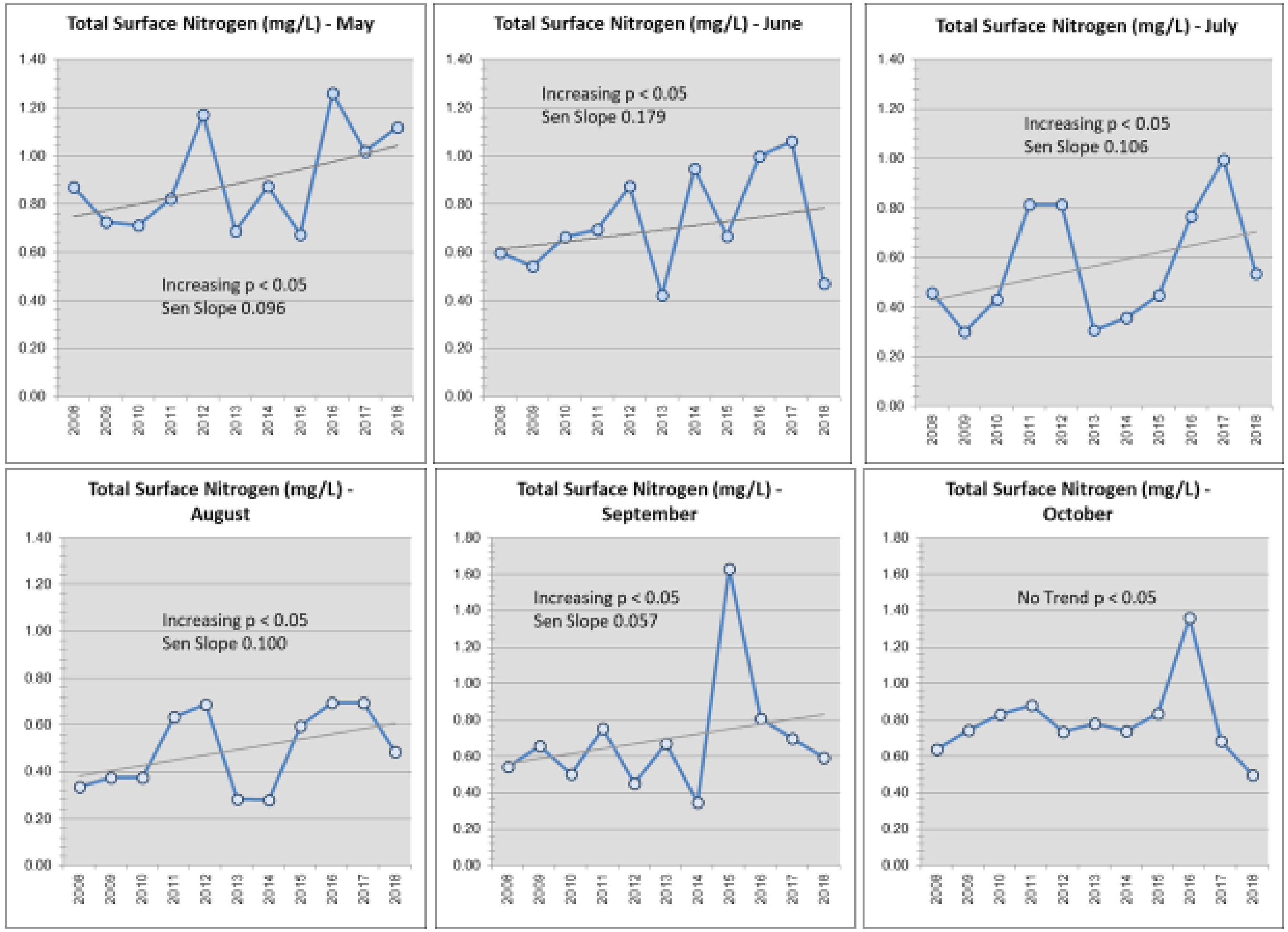
**Surface
Temperature
(°C)**



Trends
2008 to 2018

Pattison Lake
Site SP1

Total Nitrogen (TN) concentration (mg/L)



Trends
2008 to 2018

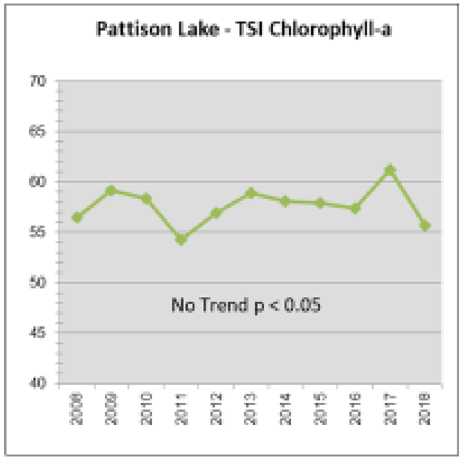
Pattison Lake
Site SP1

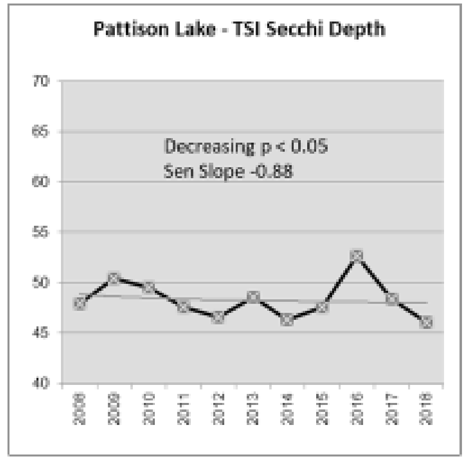
Total Phosphorus
(TP)
concentration
(mg/L)

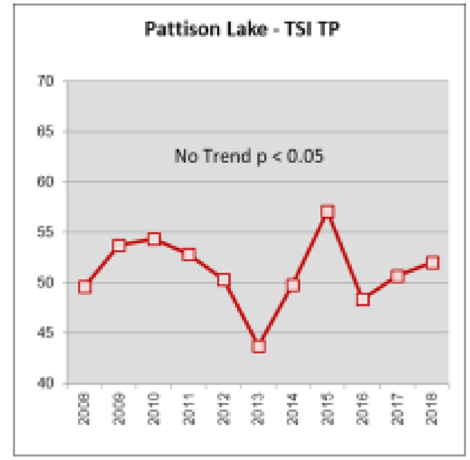
Trends 2008 to 2018

Pattison Lake Site SP1

TSI Values

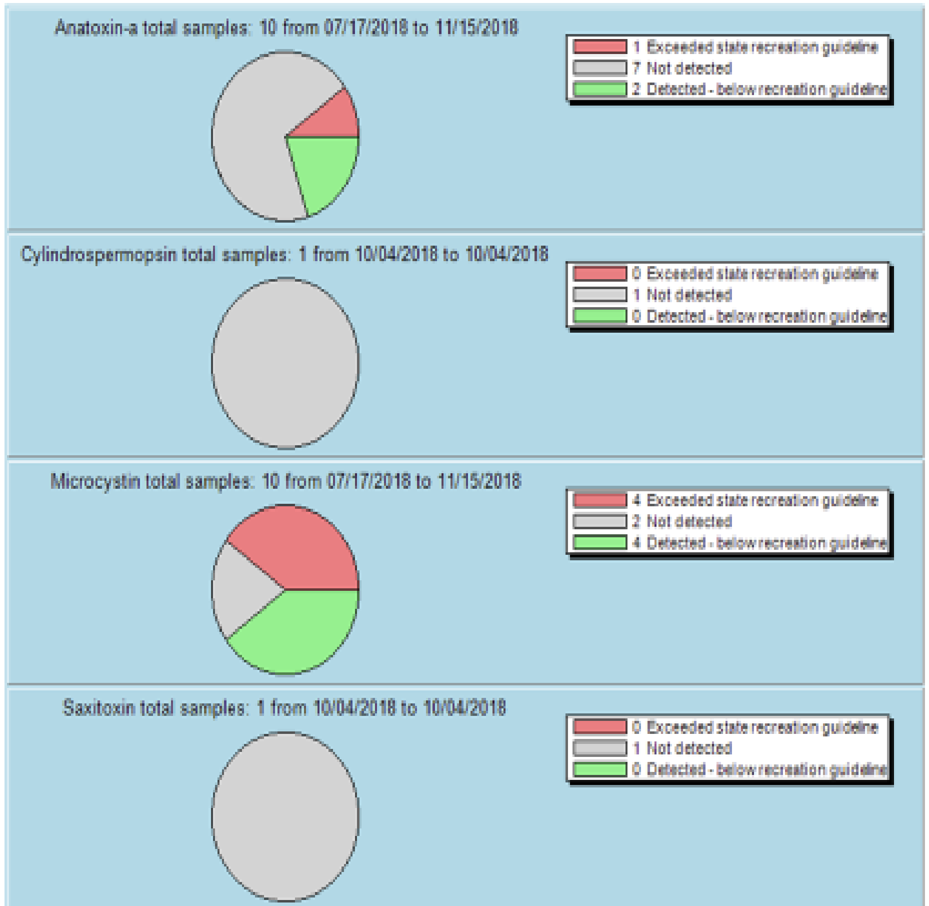




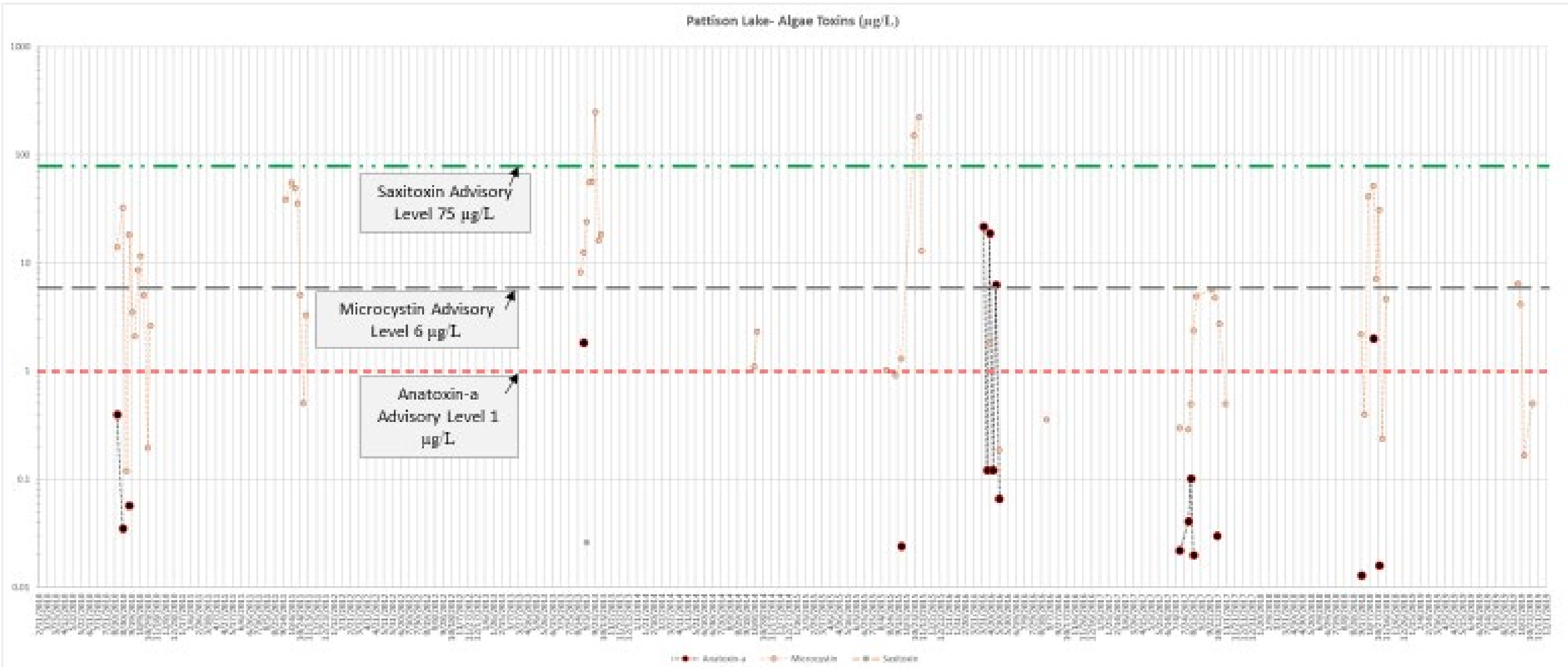


Appendix D. Toxic Algae

Appendix D. Toxic Algae



Data from Washington State Toxic Algae Freshwater Algae Bloom Monitoring Program
https://www.nwtoxicalgae.org/Default.aspx



Pattison Lake algae toxin samples with results above the method detection limit MDL from 2010 to 2019