2018 Long Lake Water Quality Report

Prepared by Thurston County Environmental Health Division

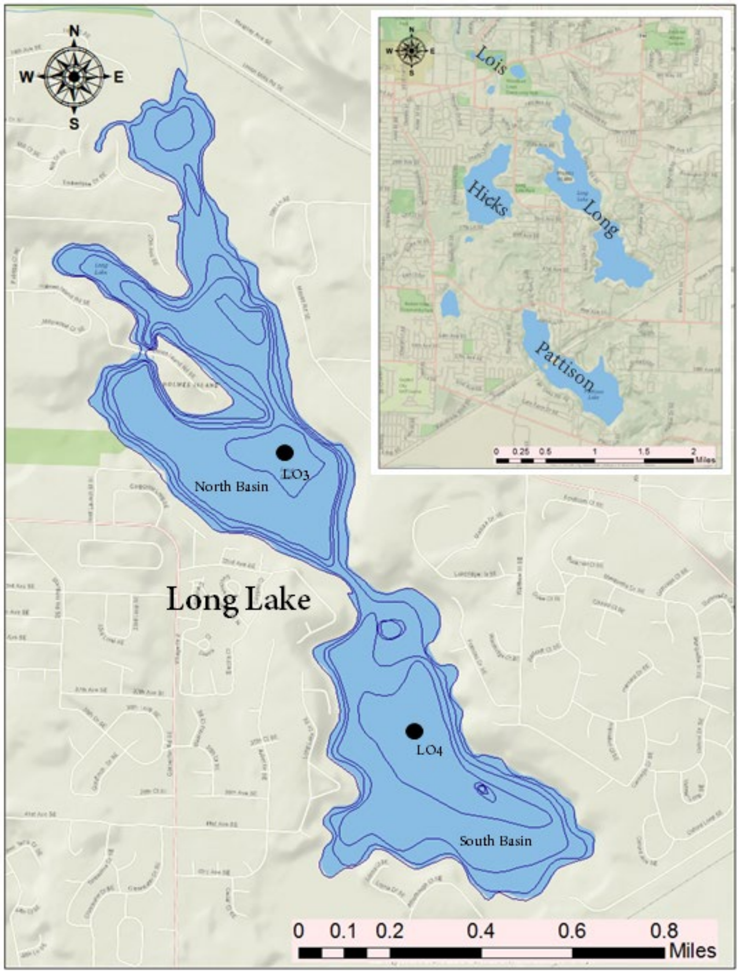

Figure 1. Long Lake map showing location of sample sites LO3 and LO4

HENDERSON INLET WATERSHED

- **SHORELINE LENGTH**: 7.1 miles
- **LAKE SIZE**: 0.52 square miles
- **BASIN SIZE**: 8.25 square miles
- **MEAN DEPTH**: 3.7 meters (12 feet)
- **MAXIMUM DEPTH**: 6.4 meters (21 feet)
- **VOLUME**: 3,900 acre-feet

PRIMARY LAND USES:

Primarily urban and suburban residential use, with a small percentage in agriculture and forest. Dense residential development exists along the lake shore.

PRIMARY LAKE USES:

Fishing, boating, swimming and other water sports.

PUBLIC ACCESS:

Washington Department of Fish and Wildlife public boat launch; City of Lacey, Long Lake Park; 10 small private community entries.

GENERAL TOPOGRAPHY:

The watershed is relatively flat with extensive wetlands between the lakes.

GENERAL WATER QUALITY:

Good to Fair - The lake is nutrient-rich and experiences nuisance blue-green algae (cyanobacteria) blooms at times. Many areas of the lake have emergent aquatic plants that interfere with recreational activities. Invasive aquatic plants, Eurasian water milfoil and fragrant water lily, are present in the lake and are being controlled through a combination of chemical and non-chemical methods.

DESCRIPTION

Long Lake is the third lake in a series of four lakes connected by extensive wetlands. The first lake in the chain, Hicks Lake, flows south to Pattison Lake. A ditch constructed to float logs between Pattison and Long Lakes many years ago still connects the two lakes (Thurston Regional Planning Council, 2008). 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.

Long Lake has two basins, north and south, which are connected by a narrow, shallow channel. The north basin is deeper (6 meters) than the south basin (4 meters). A small creek discharges into the south basin of Long Lake.

The Long Lake Management District supports activities, such as water quality monitoring, aquatic weed surveys and control, and alum (aluminum sulfate) treatments. In 2008, the south basin was treated with alum to reduce phosphorus and nuisance algae blooms.

METHODS

In 2018, Thurston County Environmental Health (TCEH) conducted monthly monitoring at Long Lake from May to October. Figure 1 shows the sample sites, LO3 (north basin) and LO4 (south basin). Each site is located in the deepest part of the basin. Table 1 lists the types of data collected 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 (3-4 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 2007 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.

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 Long Lake was thermally stratified from May to August (Figures 3 to 5). Warmer, more oxygenated water existed on the surface in the epilimnion. Below this layer, the temperature and oxygen concentration declined with depth. Stratification was more apparent at the north basin site (LO3). The shallower south basin site (LO4) exhibited some signs of stratification, but the upper layers tended to mix more readily.

In May and June, the difference between the top and bottom strata were apparent, especially at LO3. Higher winds in June mixed the surface layers.

The temperature and oxygen concentration differences between the surface (epilimnion) and the bottom (hypolimnion) were:

- LO3 Surface – Temperature 20.3 to 20.5°C; DO 9 to 9.8 mg/L
- LO3 Bottom – Temperature 11.1 to 14.4°C; DO 0.7 mg/L

The shallower south basin was less stratified than the north basin in May and June:

- LO4 Surface – Temperature 20.5 to 22.2°C; DO 8.7 to 9.0 mg/L
- LO4 Bottom – Temperature 14.6 to 20.2°C; DO 0.5 to 2.5 mg/L

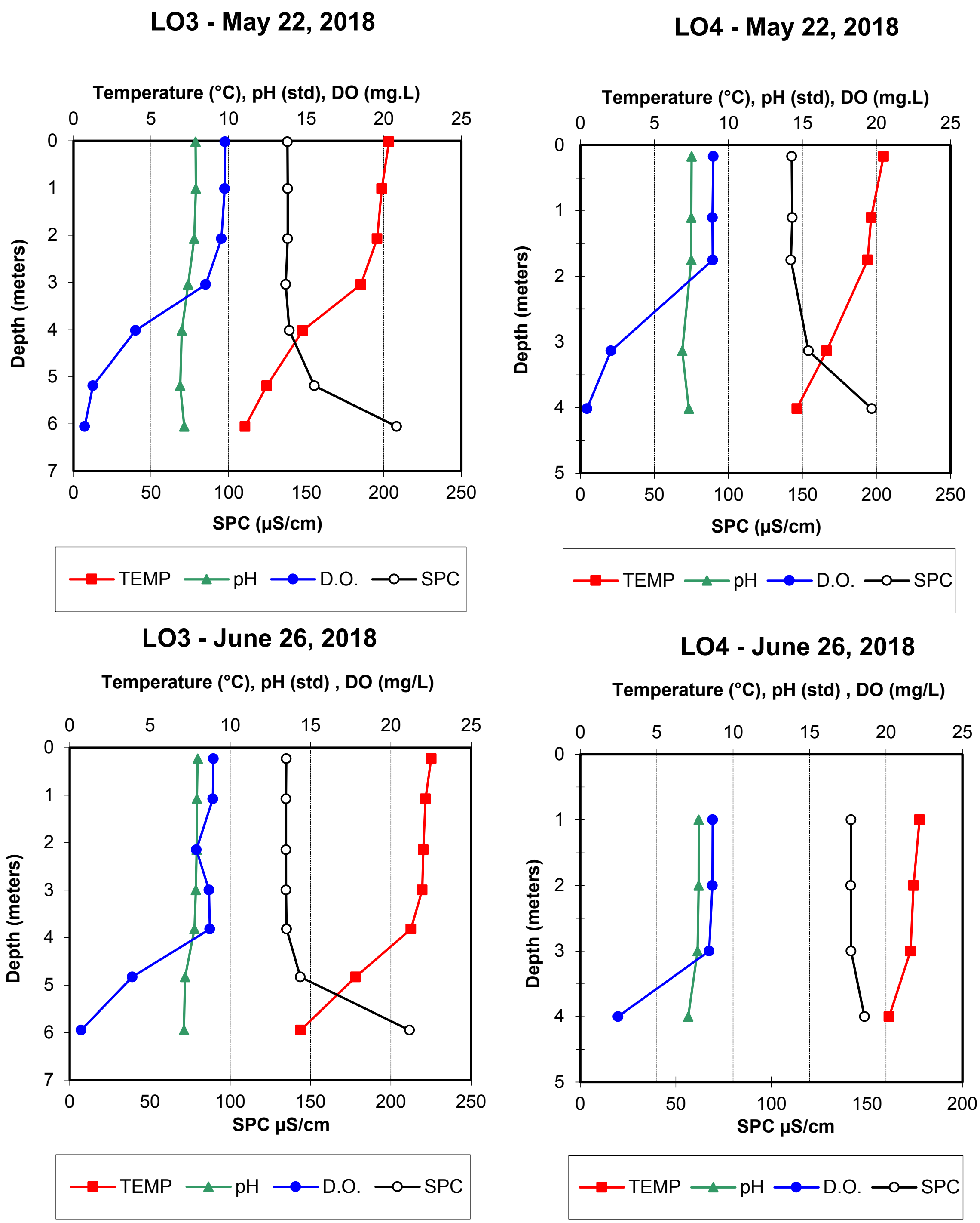

Figure 3. Vertical water quality profiles for LO3 and LO4 collected during May and June, 2018.

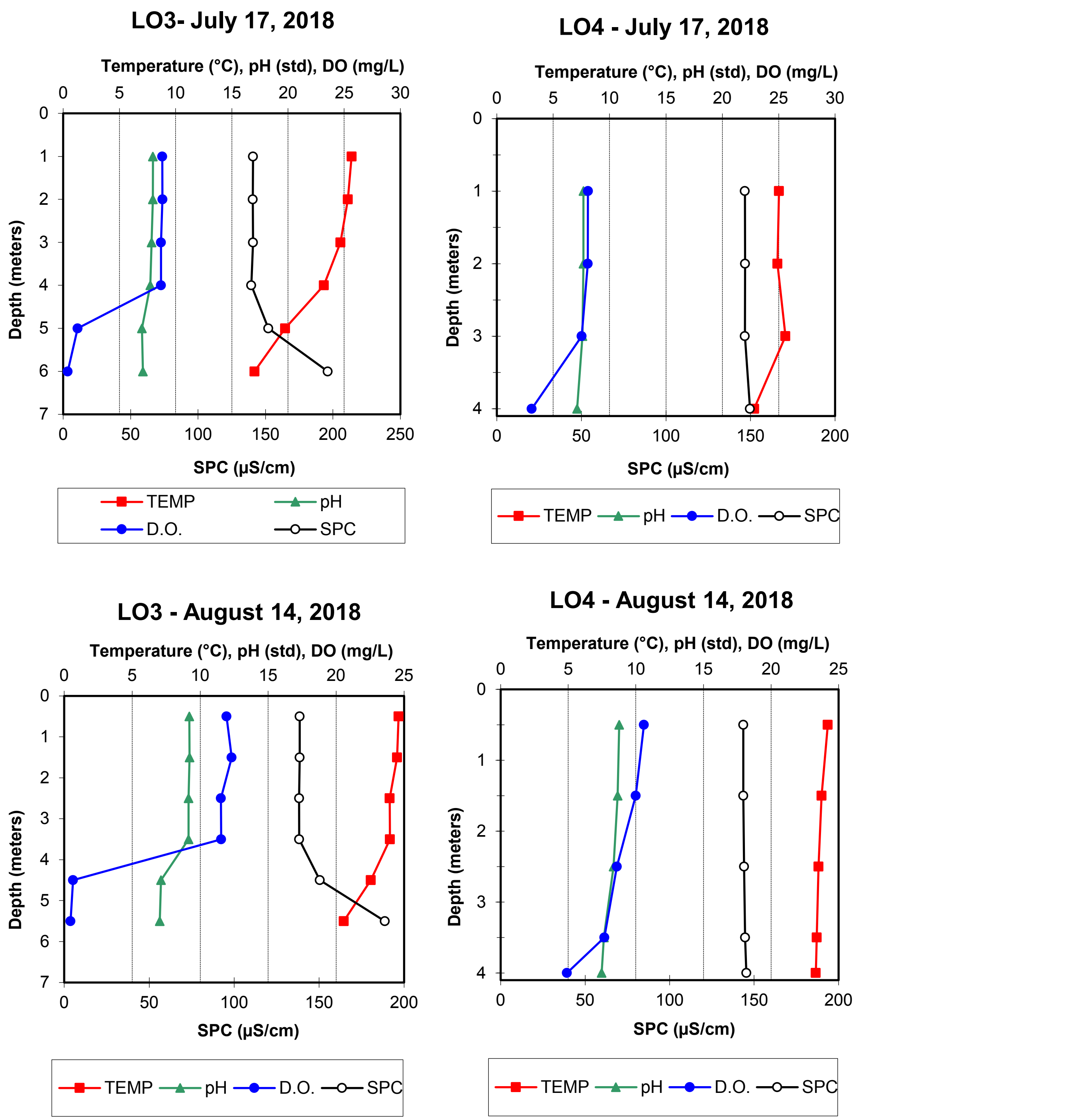

Figure 4. Vertical water quality profiles for LO3 and LO4 collected during July and August, 2018.

Three layers formed in the deeper north basin (LO3) in July and August. The summer sun heated the epilimnion. This heat was retained because air temperature remained high from May to August (Table 2). The DO profile during thermal stratification at LO3 had a clinograde curve, which results from excess oxygen consuming processes in the hypolimnion. The hypolimnion, cut-off from the atmosphere after stratification, lost oxygen to redox processes. The epilimnion, in contact with the atmosphere, had much higher DO.

- LO3 Surface – Temperature 24.6 to 25.7°C; DO 8.8 to 12 mg/L
- LO3 Bottom – Temperature 17 to 20.6°C; DO 0.4 to 0.5 mg/L

The shallower site, LO4 was more mixed, with less difference between the surface and the bottom.

- LO4 Surface – Temperature 24.2 to 25°C; DO 8.1 to 10.6 mg/L
- LO4 Bottom – Temperature 22.8 to 23.3°C; 3.1 to 5 mg/L

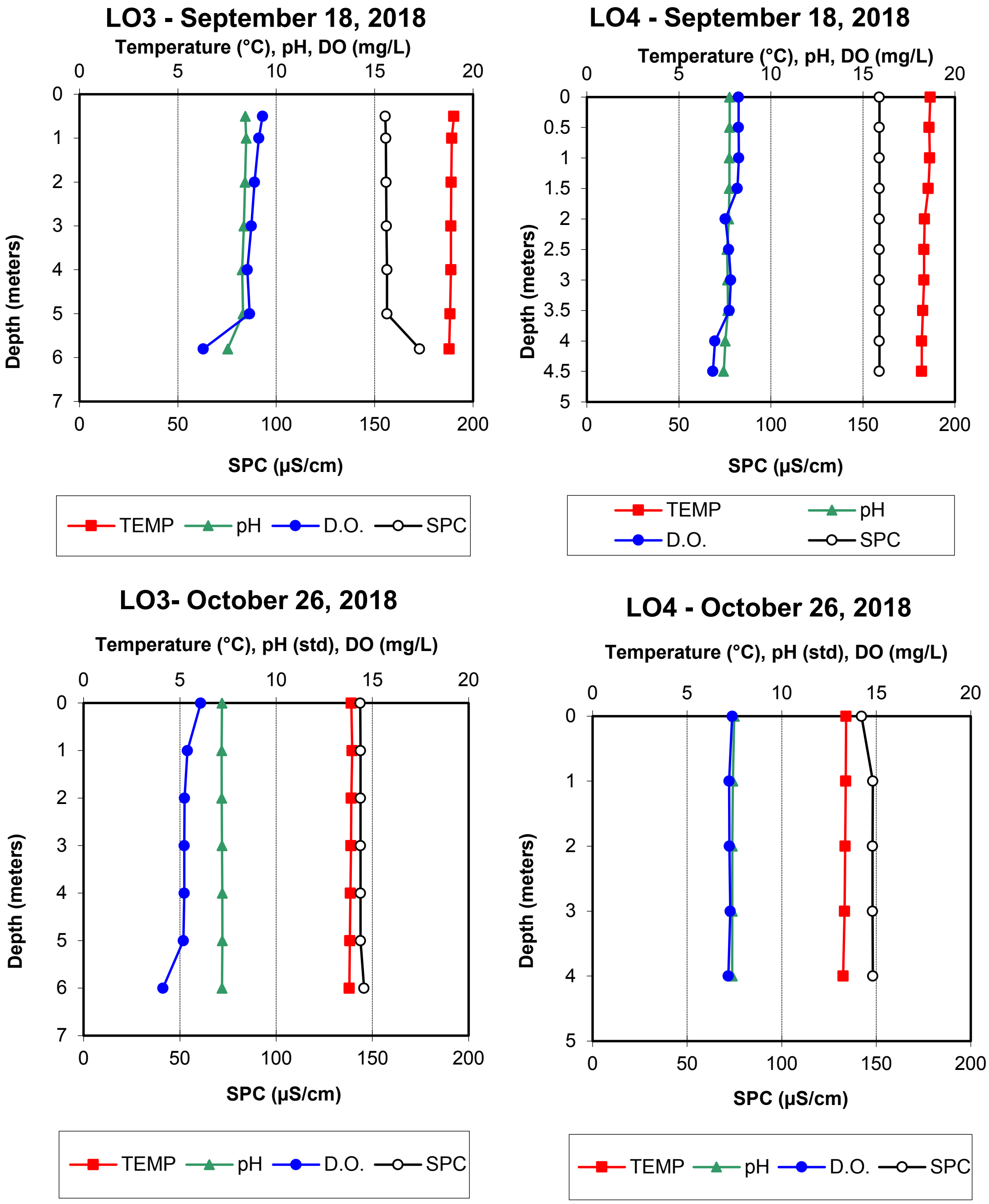

Figure 5. Vertical water quality profiles from LO3 and LO4 collected during September and October, 2018.

In September and October, average air temperatures declined. Long Lake lost more heat than it gained, especially at night. The surface water cooled, increased in density and sank. Convection currents and wind induced epilimnetic circulation. The layers began to mix in September (Figure 5), a process called turnover. By October, the temperature differences between the epilimnion and hypolimnion had been reduced at both the north and south basins (Table 3).

Table 3. Surface and bottom temperature and DO in September and October 2018.

Site	Month	Surface Temp (°C)	Bottom Temp (°C)	Surface DO (mg/L)	Bottom DO (mg/L)
LO3	Sept	19.0	18.8	9.3	6.3
LO3	Oct	13.9	13.8	6.1	4.1
LO4	Sept	18.7	18.2	8.2	6.9
LO4	Oct	13.4	13.2	7.4	7.2

Surface Water Temperature Trends

The Seasonal Kendall analysis for trends over the ten-year period from 2008 to 2018 shows that surface temperature at both locations increased 0.5 to 1.9°C from May to August. In September, the trend was decreasing temperature at both sites. There was no temperature trend in October (Figure 6).

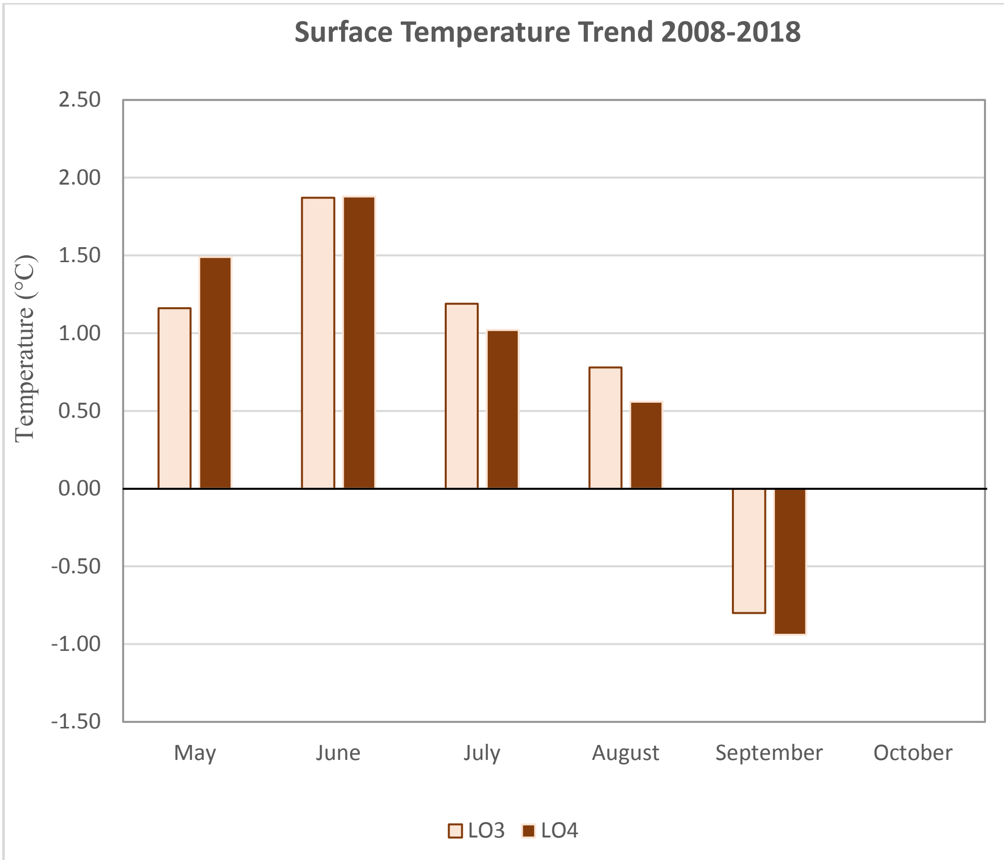

Figure 6. Surface temperature trend (+ or -) and magnitude of change (Theil-Sen estimator) for LO3 and LO4 from 2008 to 2018. The lack of a bar means the site did not have a significant trend ($p<0.05$) for that time period.

Water Color and Transparency

Water 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.

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.

Figure 7 shows the color and transparency for LO3 and LO4 for 2018.

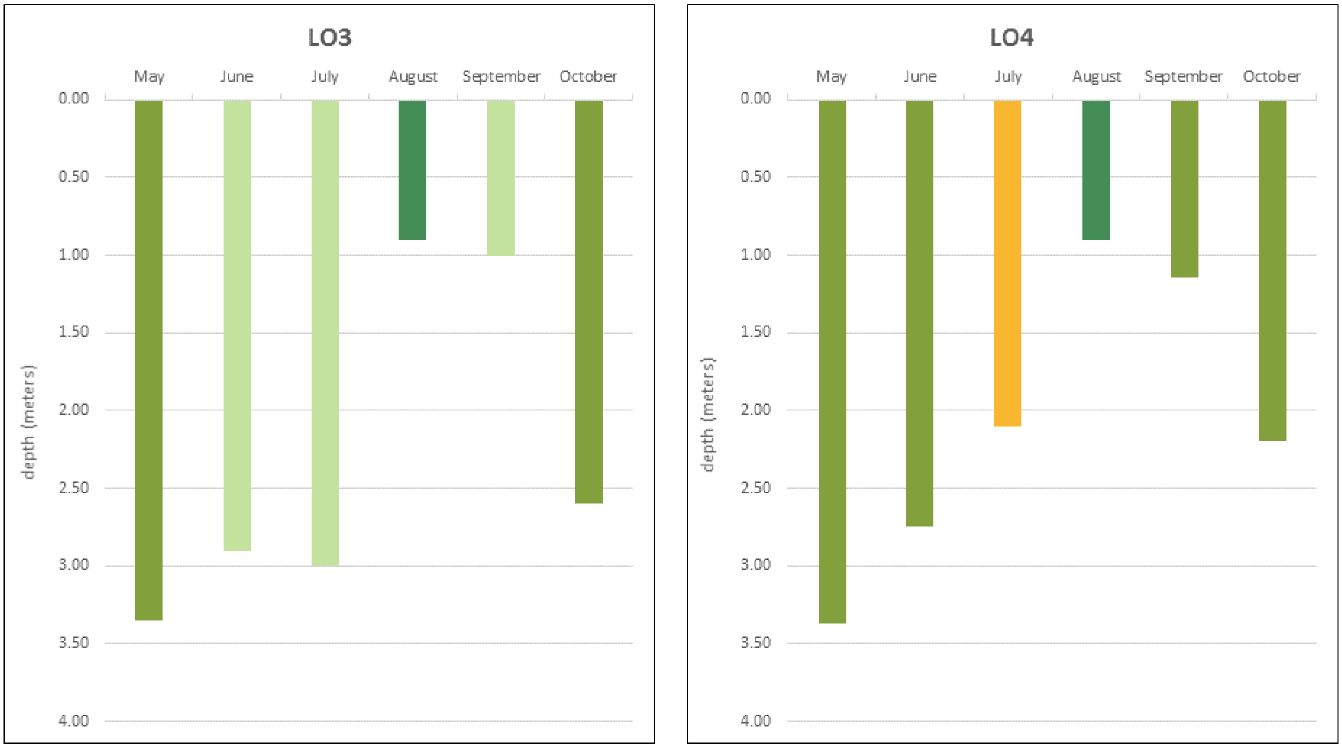

Figure 7. Water color and Secchi depths for 2018.

In 2018, both sites highest transparency was in May (3.4 meters) and lowest in August and September (0.9 to 1.1 meters). The average transparency was slightly higher at LO3 (2.3 meters) compared to LO4 (2.1 meters).

Figures 8 and 9 show the annual average transparency (Secchi depth) compared to the long-term average. Positive values reflect transparency better than the long-term average. In 2018, transparency at LO3 was 0.3 meter lower than the long-term average. At LO4, transparency was slightly higher (0.02 meter).

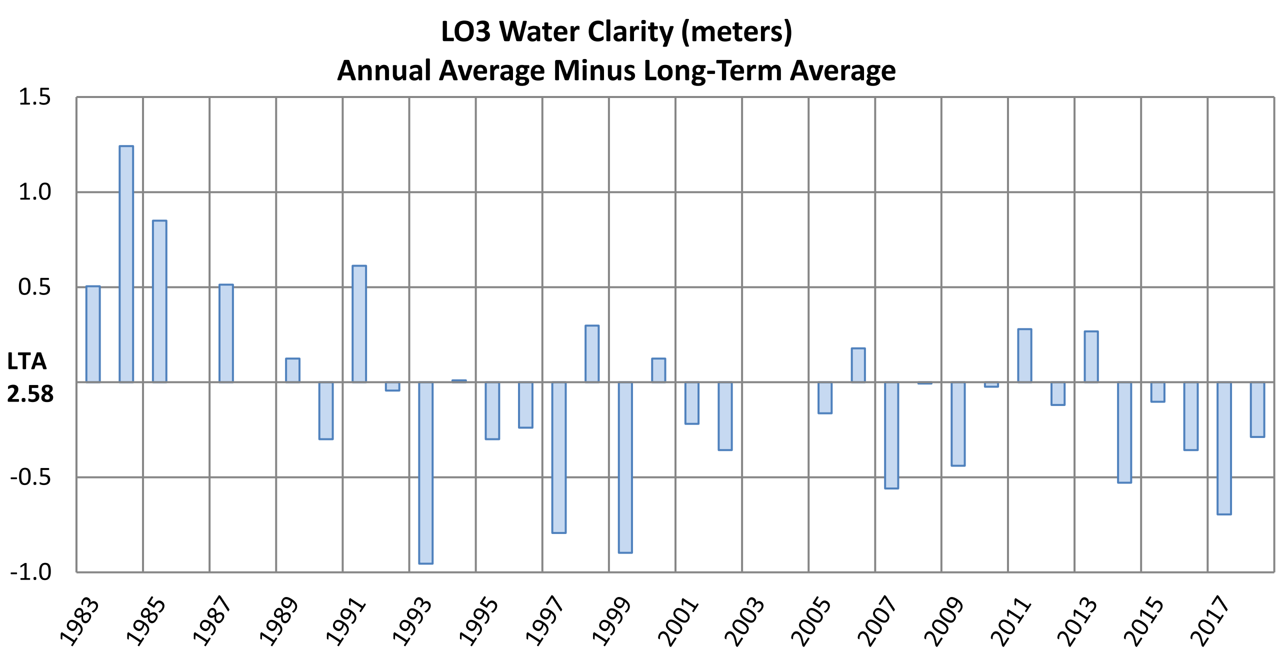

Figure 8. Transparency at LO3 compared to the long-term average (LTA).

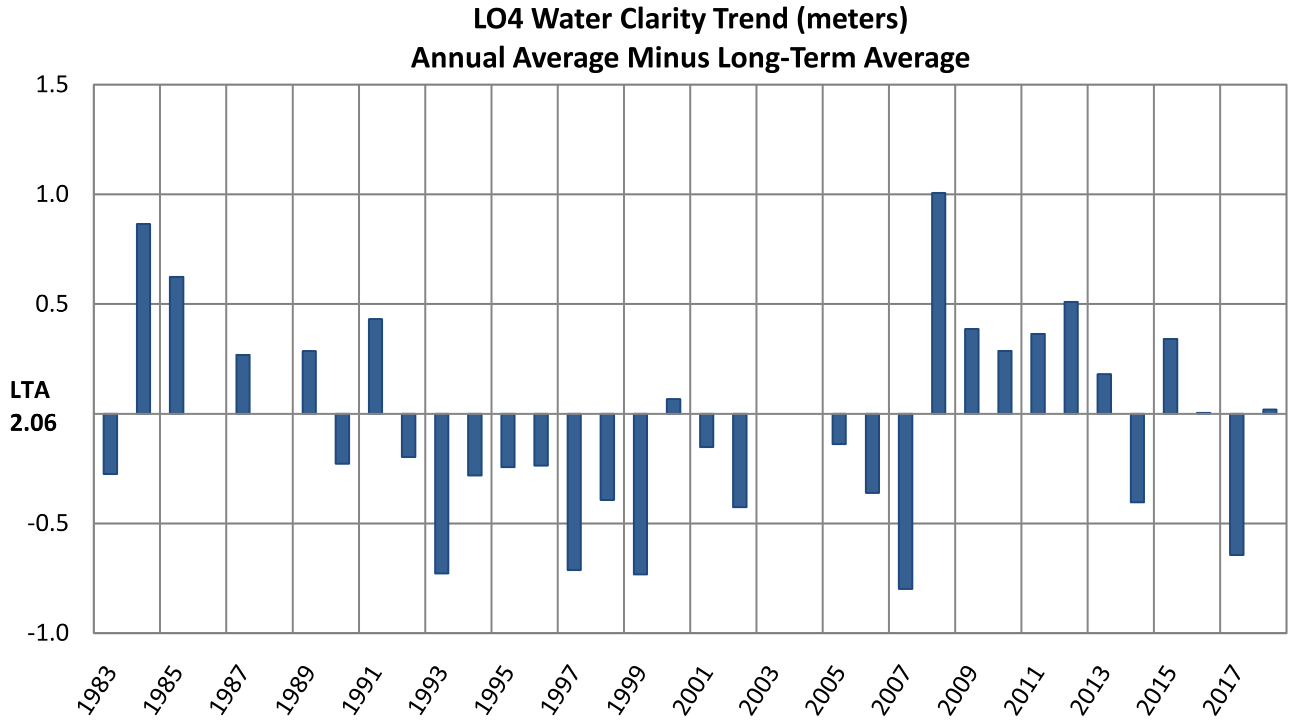

Figure 9. Transparency at LO4 compared to the long-term average (LTA).

The Seasonal Kendall test revealed a trend of reduced transparency (Figure 10) most of the summer at LO3 and from July to October at LO4. At LO3, the trend for October, typically after turnover, was improved water clarity. No trend was detected for LO4 in early summer (May and June) or LO3 in July.

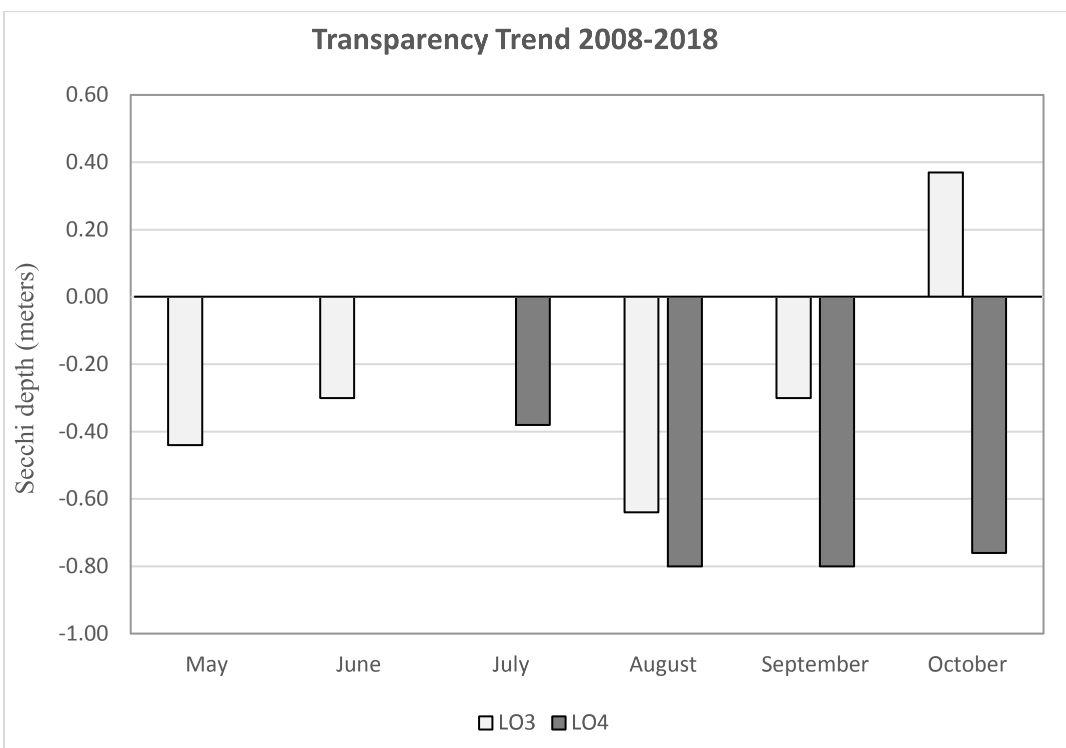

Figure 10. Transparency trend (+ or -) and magnitude of change (Theil-Sen estimator) for LO3 and LO4 from 2008 to 2018. The lack of a bar means the site did not have a significant trend (p<0.05) for that time period.

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. If present, phaeophytin 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.

2018 Productivity Data

Figures 11 and 12 show that the highest concentration of chlorophyll-a occurred in August and September at both sites. The ratio of chlorophyll-a to phaeophytin-a peaked in August at both sites, but the ratio was almost six times higher at the north basin site LO3.

Transparency at LO3 and LO4 was correlated to productivity, as measured by the concentration of chlorophyll-a in the photic zone. Transparency was greater from May to July and in October, when productivity was lower. Water clarity was the lowest in August and September, the two most productive months for algae and cyanobacteria (Figure 7). Lake color was affected by changes in the algae and cyanobacteria communities; phytoplankton identification would provide more information about productivity and phytoplankton assemblages.

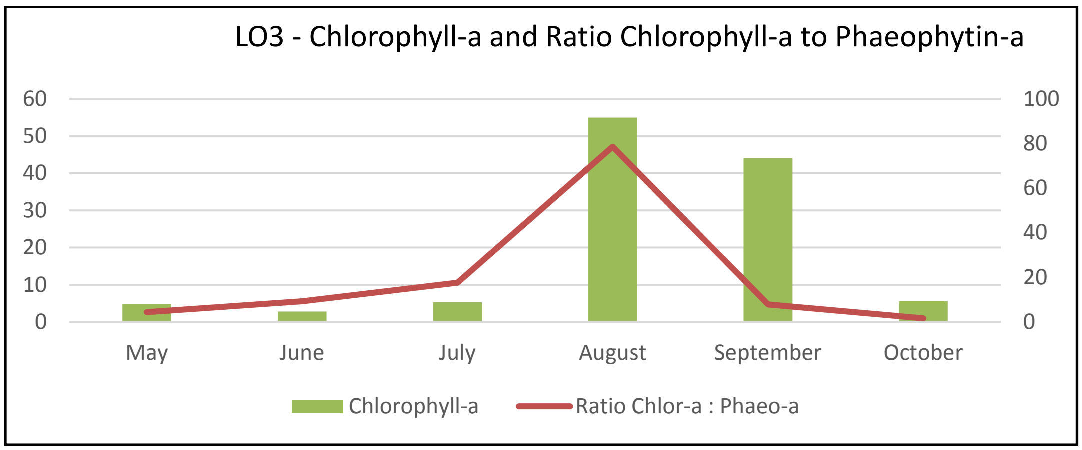

Figure 11. Chlorophyll-a concentration and ratio of chlorophyll-a to phaeophytin-a pigments in samples collected at LO3.

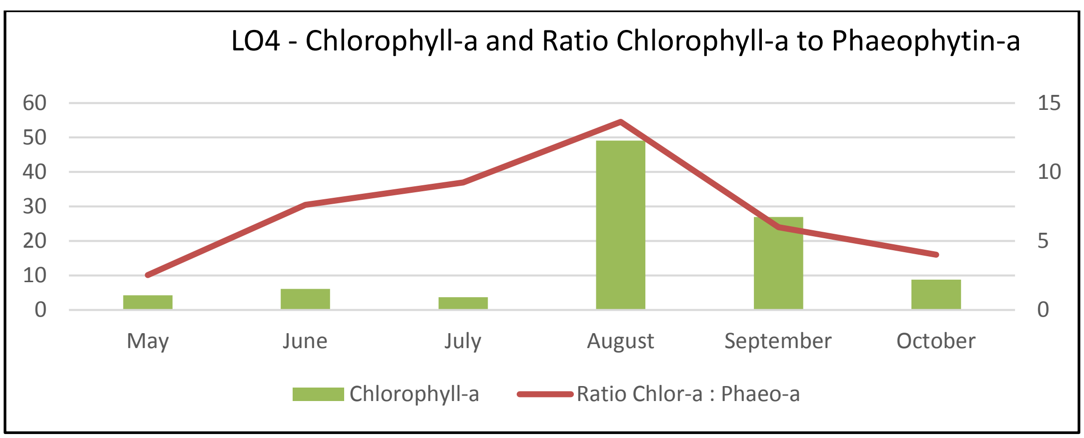

Figure 12. Chlorophyll-a concentration and ratio of chlorophyll-a to phaeophytin-a pigments in samples collected at LO4.

The Seasonal Kendall test for trends from 2008 to 2018 for chlorophyll-a concentration indicates a significant ($p<0.05$) increase (+ 10 to 17 µg/L) in chlorophyll-a concentration at both sites in August and September. A decreasing trend occurred at LO3 in October (typically after turnover), which corresponds to the trend of increased water clarity at this site in October. Figure 13 shows the magnitude of change for all significant trends.

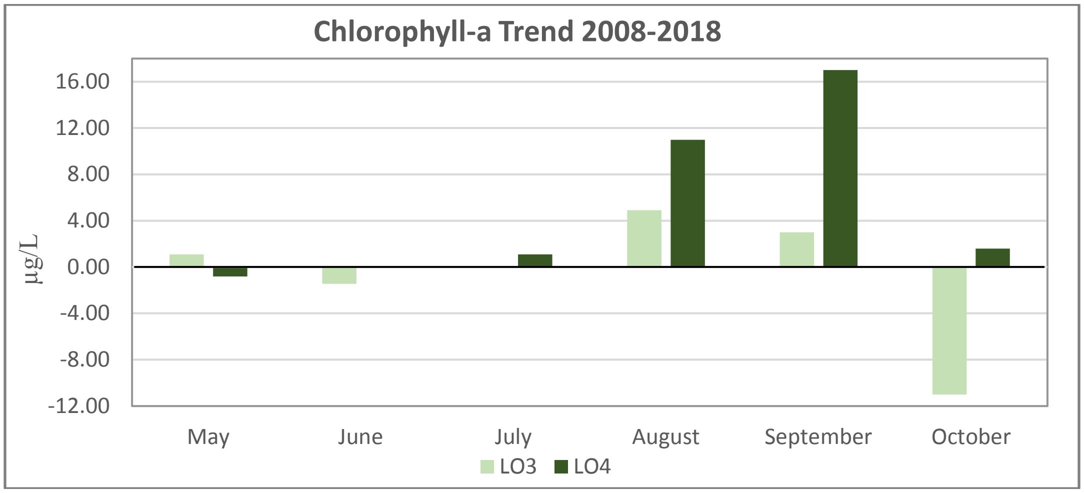

Figure 13. Chlorophyll-a trend (+ or -) and magnitude of change (Theil-Sen estimator) for LO3 and LO4 from 2008 to 2018. The lack of a bar means the site did not have a significant trend (p<0.05) for that time period.

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 14 shows the total phosphorus (TP) and total nitrogen (TN) present in the surface waters at the two Long Lake sites.

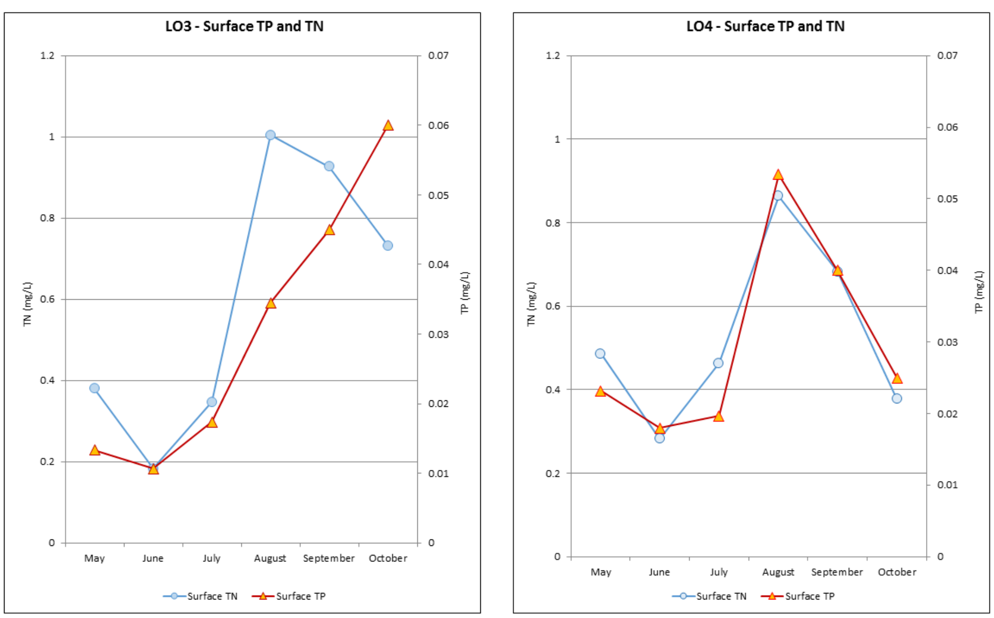

Figure 14. 2018 surface concentration of TP and TN at LO3 and LO4 sites at Long Lake.

The concentration of TP increased each successive month at LO3. Otherwise, the pattern was similar at both sites: nutrient concentrations dropped slightly in June, increased July to August, and fell again starting in September.

Thermal stratification at LO3 reduced internal loading to surface waters in July and August; changes in the phytoplankton community and external sources likely affect nutrient levels during stratification. During stratification, the concentration of TP was much higher in the hypolimnion at LO3 compared to LO4. Internal loading increased TP at the surface after turnover in September and October.

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 (Gilliom, 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). The 2018 average surface TP concentration was 0.030 mg/L at both sites.

Figure 15 displays the TP concentration at the two Long Lake sites.

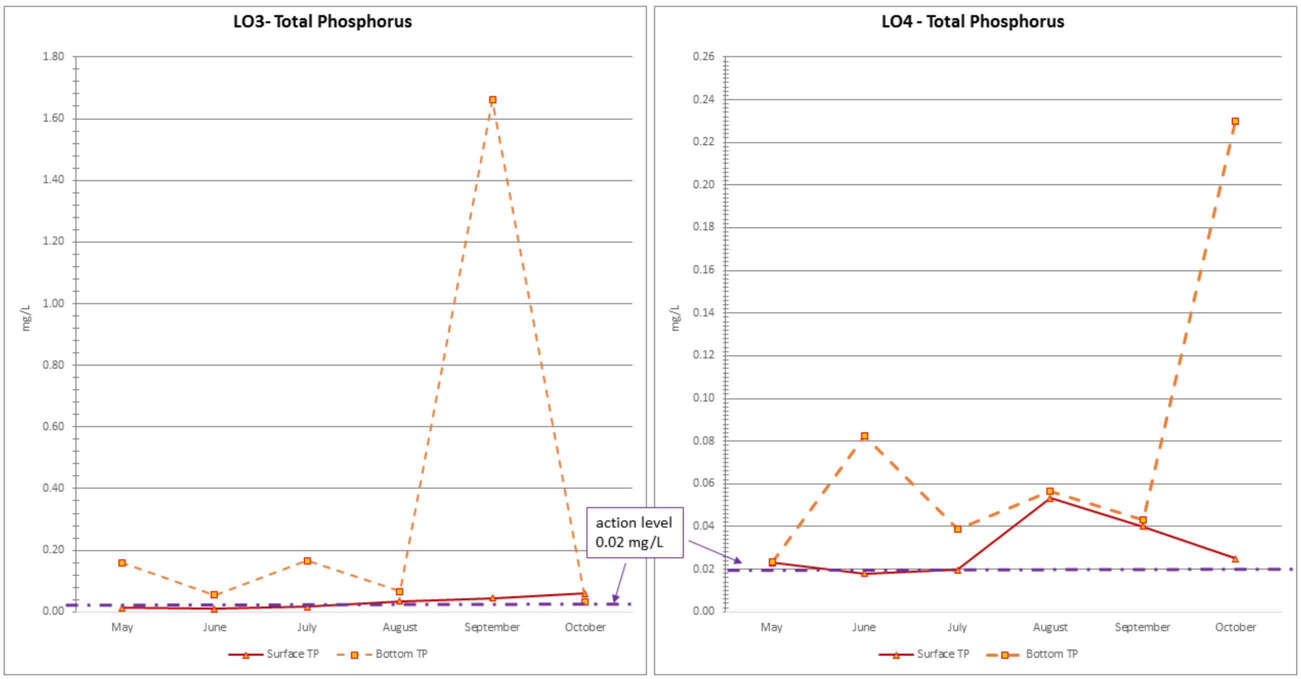

Figure 15. Concentration of Total Phosphorus at the surface and bottom of Long Lake in 2018. Note the difference in scale between the two graphs.

The concentration of TP near the bottom was much lower at LO4 (mean 0.079 mg/L) compared to LO3 (mean 0.357 mg/L). This difference is likely due to the alum treatment in 2008. The vertical profile graphs show that Long Lake exhibited a clinograde oxygen curve at LO3 in July and August. The hypolimnion was 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 the deeper water mixed with the rest of the water column starting in September.

Figure 16 displays the average annual concentration of total phosphorus at LO3 from 1981 to 2018 (mean 0.028 mg/L). The surface samples for total phosphorus have been above the state action level (green line at 0.020 mg/L) for 64% of the period of record.

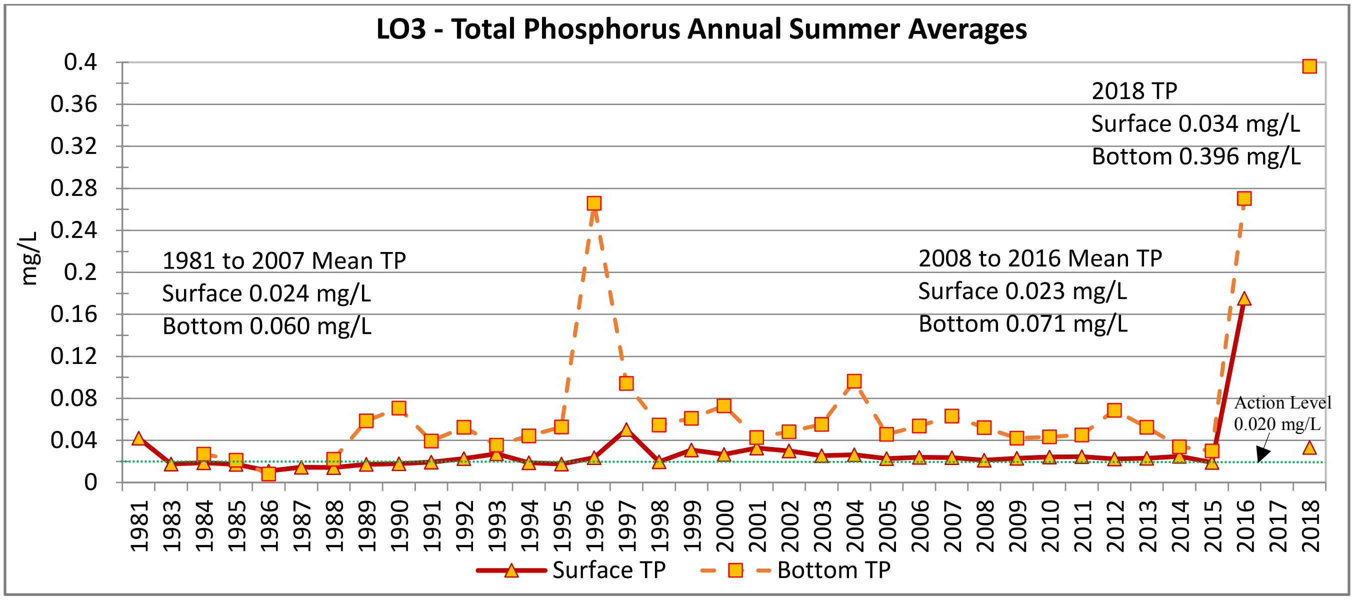

Figure 16. Average Annual Total Phosphorus at LO3 from 1981 to 2018 (TP samples were not collected in 2017).

At the south basin site (LO4), the TP concentration exceeded the state action level 69% of summers since 1983. The concentration of TP at both the surface and bottom declined in 2008 after the alum application (Figure 17). From 2007 to 2008, the surface TP concentration dropped 0.03 mg/L; the bottom concentration fell 0.07 mg/L. TP concentrations increased at the surface and bottom in 2016 and 2018 (no TP samples collected in 2017).

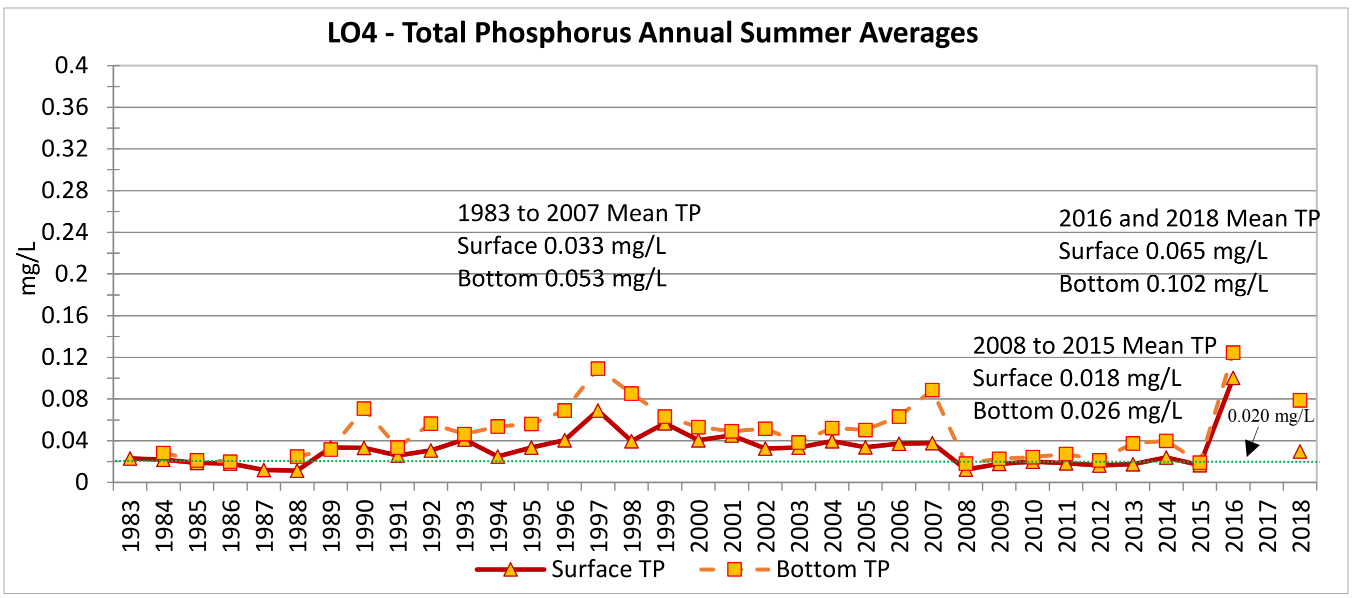

Figure 17. Average Annual Total Phosphorus at LO4 from 1981 to 2018 (TP samples were not collected in 2017).

The Seasonal Kendall test (2008 to 2018) revealed significant trends for TP (Figure 18) in surface water at LO4:

- Reduced TP concentration in June (-0.003 mg/L)
- Increased TP concentration from July to October (+0.002 to 0.008 mg/L)

At LO3, no significant trends were detected, except for a reduction (-0.002 mg/L) in July.

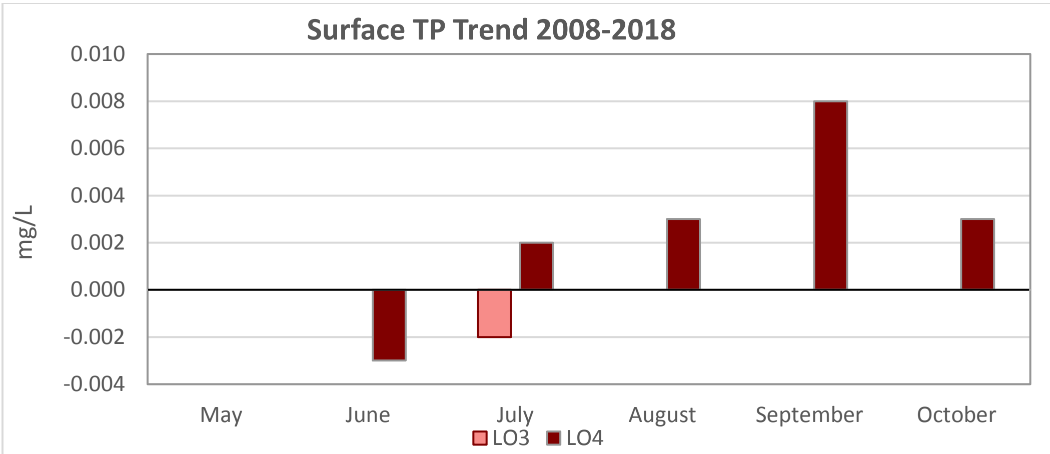

Figure 18. Surface TP trend (+ or -) and magnitude of change (Theil-Sen estimator) for LO3 and LO4 from 2008 to 2018. The lack of a bar means the site did not have a significant trend ($p<0.05$) for that time period.

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. The average total surface nitrogen concentration was 0.596 mg/L at LO3 and 0.526 mg/L at LO4. Figure 19 shows the 2018 TN concentrations for the two sites at Long Lake.

During stratification at LO3 the hypolimnion was anoxic; ammonia-nitrogen was released from the bottom sediments and accumulated in the hypolimnion. These nitrogen compounds were a source of nitrogen after turnover in September and October. Stratification at LO4 was weak from May to July. For remainder of the sampling season, the water column was relatively mixed.

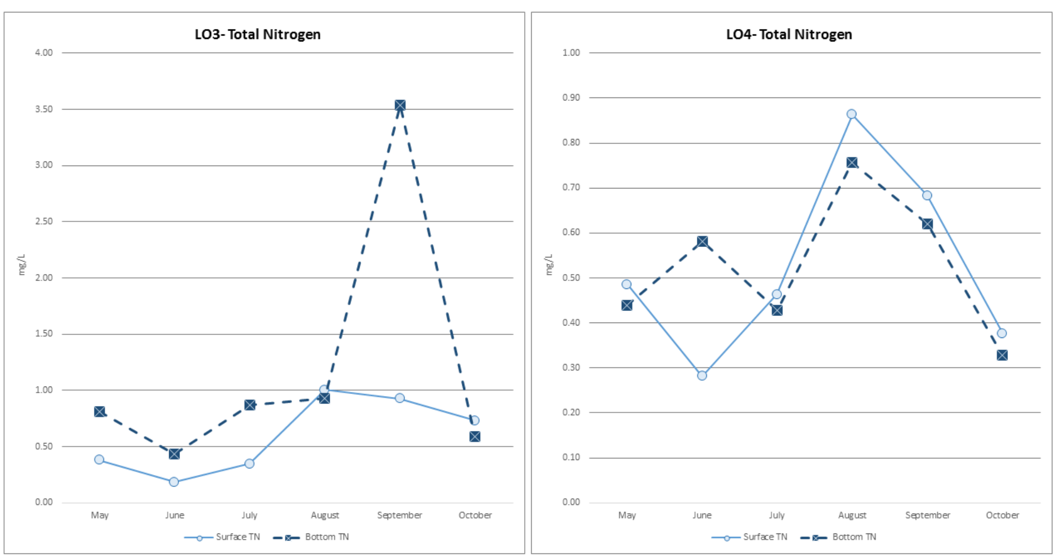

Figure 19. Concentration of Total Nitrogen at the surface and bottom at LO3 and LO4 in 2018.

Figures 20 and 21 display the average annual concentrations for total nitrogen from 1995 to 2018. The mean concentration (1995 to 2018) was:

- 0.47 mg/L at LO3
- 0.54 mg/L at LO4

In 2018 at LO3, the mean concentration of TN at the surface was 0.639 mg/L. The last time the mean surface concentration was that high was in 2001.

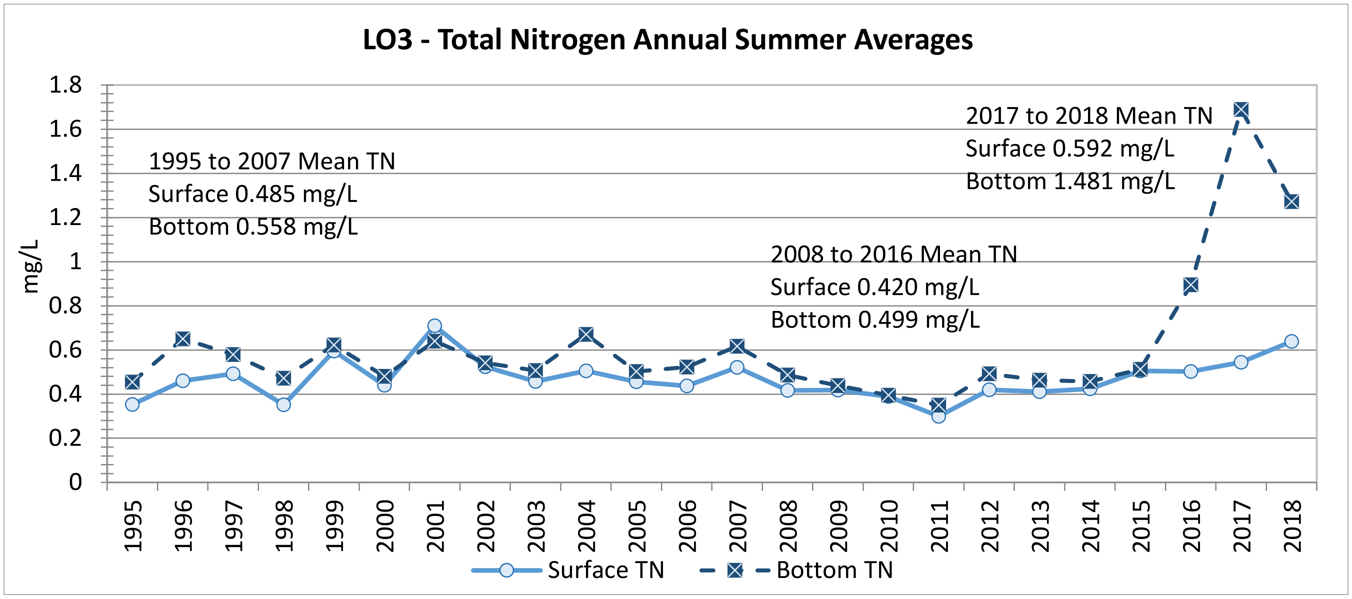

Figure 20. Average Annual Total Nitrogen at LO3 from 1995 to 2018.

In 2008, the mean TN concentration fell 0.38 mg/L at the surface and 0.53 mg/L at the bottom. The concentration of TN has gradually increased since 2008.

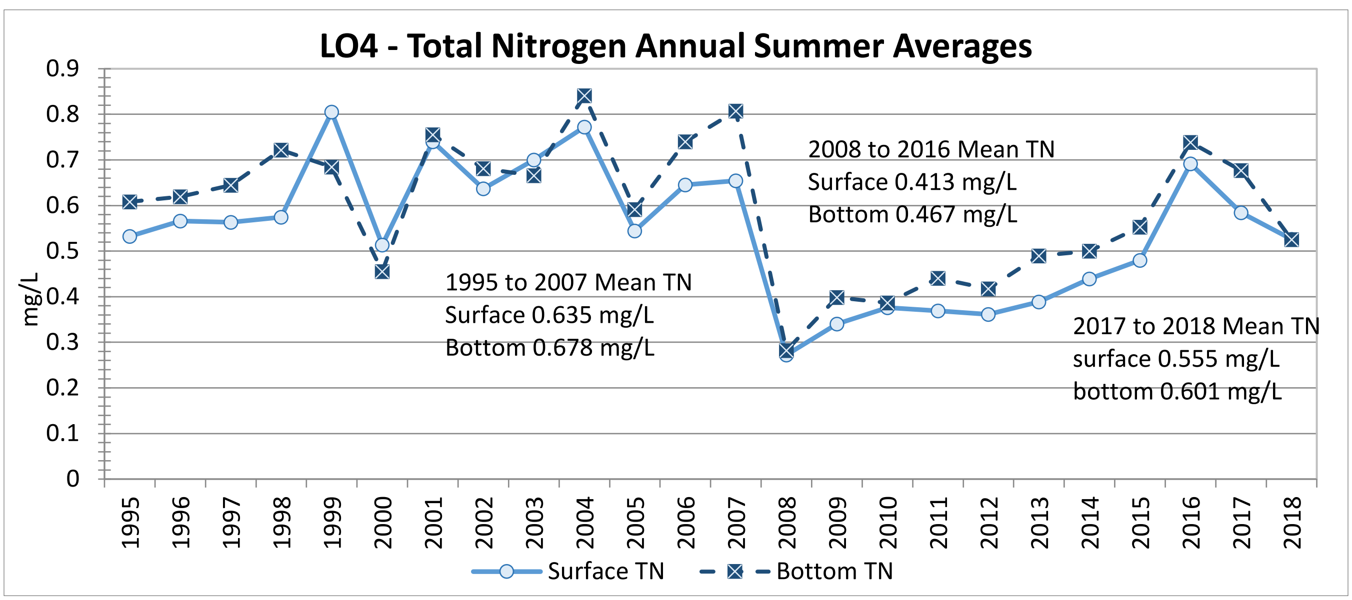

Figure 21. Average Annual Total Nitrogen at LO4 from 1995 to 2018.

The Seasonal Kendall test shows a significant ($p<0.05$) upward trend of surface total nitrogen concentrations from July to October at both sites (Figure 22). TN also increased in May at LO4. No trends were detected in May for LO3 and in June for both sites.

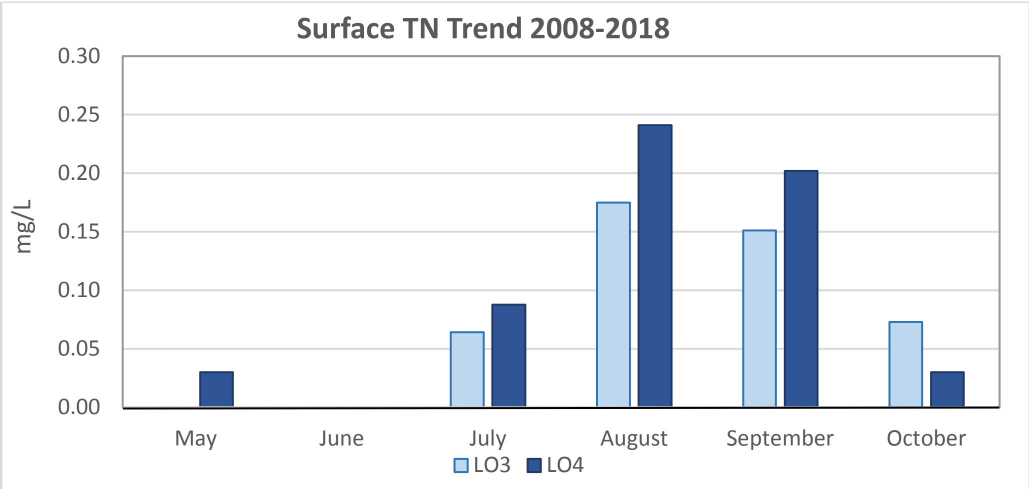

Figure 22. Surface TN trend (+ or -) and magnitude of change (Theil-Sen estimator) for LO3 and LO4 from 2008 to 2018. The lack of a bar means the site did not have a significant trend (p<0.05) for that time period.

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). Figures 23 and 24 show the TN to TP ratio at the two Long Lake sites.

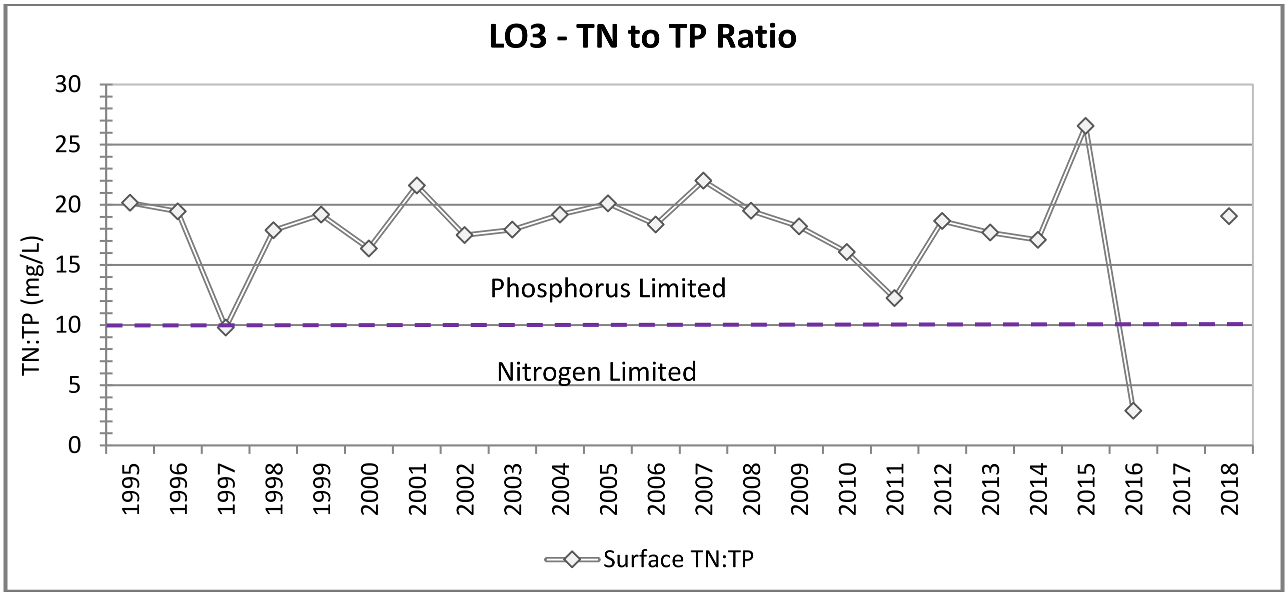

Figure 23. TN:TP at LO3 (north basin site) from 1995 to 2018. No TP samples collected in 2017.

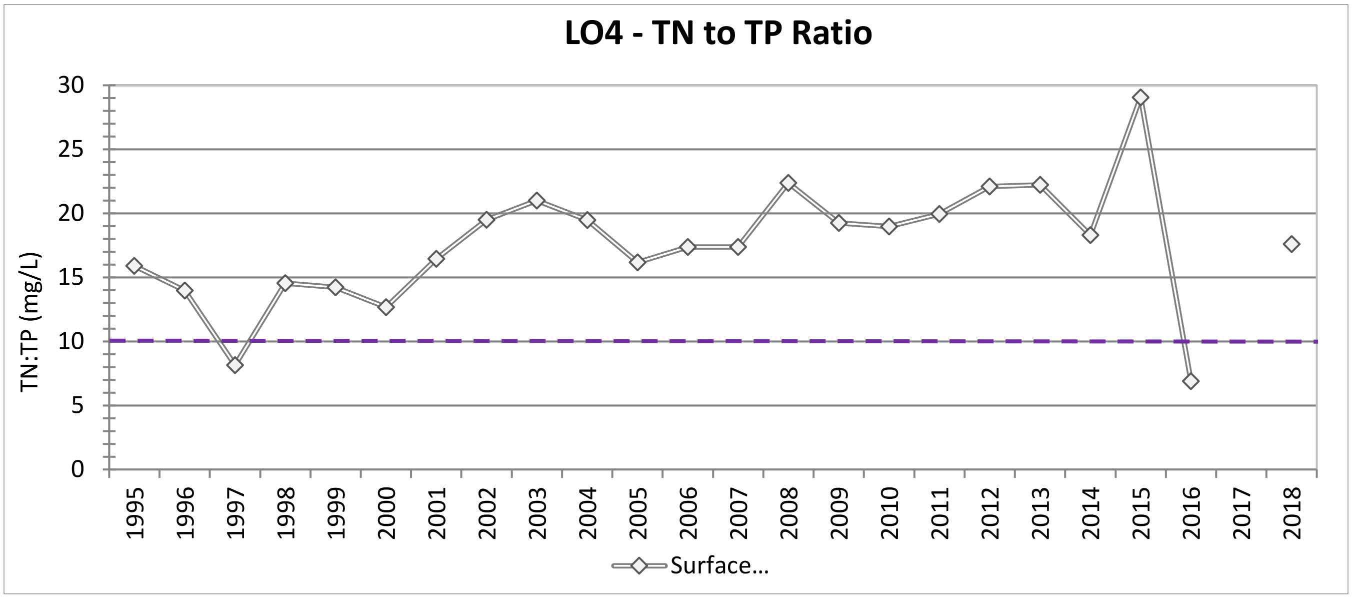

Figure 24, TN:TP at LO4 (south basin site) from 1995 to 2018. No TP samples collected in 2017.

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 4 provides the index values for each trophic classification.

Table 4. Trophic State Index variables.

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

For the north basin site LO3, the 2018 TSI results were:

- Chlorophyll-a: 61 eutrophic
- Total Phosphorus: 54 eutrophic
- Secchi Disk: 49 mesotrophic

The average of the three TSI variables is 55, which categorizes LO3 as eutrophic in 2018. Based on the concentration of chlorophyll-a, LO3 was classified as eutrophic every year that data was collected since 1983 (Figure 25). In the summer seasons since 1983, TP and Secchi measurements resulted in a eutrophic classification less often:

- 35% of summers eutrophic due to high TP concentrations
- 13% of summers eutrophic due to low transparency

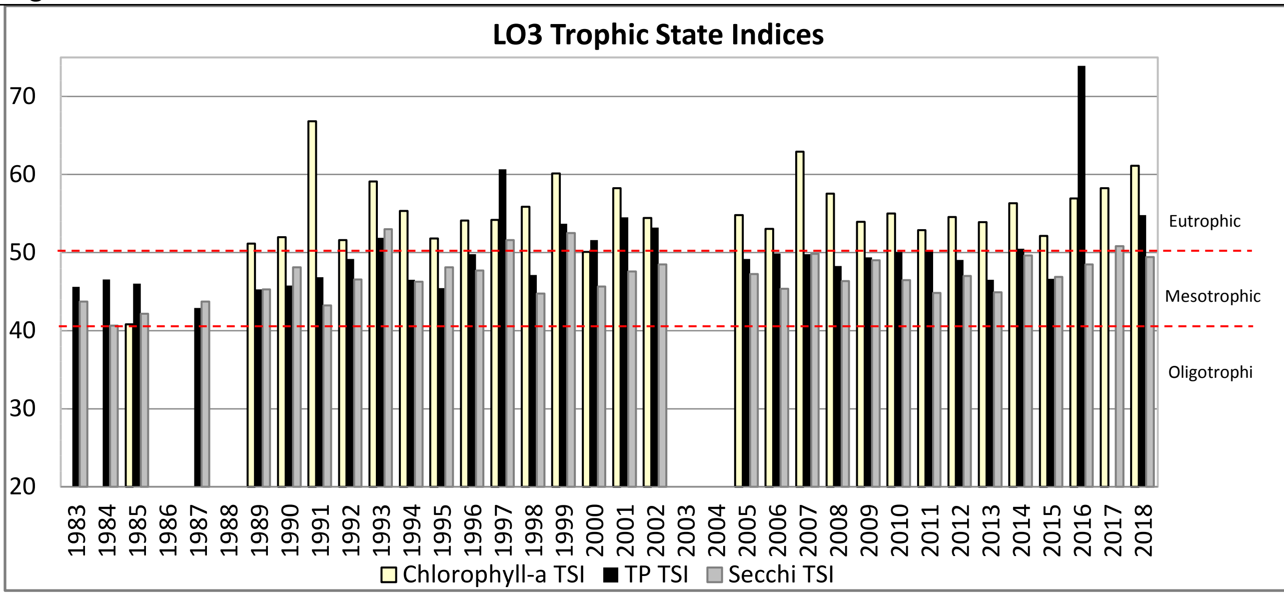

Figure 25. LO3 Trophic State Index from 1995 to 2018.

The Mann Kendall test reveals a significant trend ($p<0.05$) of increasing TSI values for chlorophyll-a concentration and transparency at LO3; the trend from 2008 to 2018 in the north basin was toward eutrophication, with higher productivity and reduced water clarity (Appendix C). No trend was detected for TP concentration at LO3.

The TSI results for the south basin site LO4 were:

- Chlorophyll-a: 59 eutrophic
- Total Phosphorus: 52 eutrophic
- Secchi Disk: 48 mesotrophic

Most (90%) summers since 1983 have been eutrophic based on chlorophyll-a (Figure 26). Also, LO4 has been eutrophic a majority of summers since 1983 with regards to phosphorus enrichment and reduced water clarity:

- 59% of summers eutrophic due to high TP concentrations
- 52% of summers eutrophic due to low water clarity

Over the last decade, the south basin (LO4) has become more eutrophic. All three TSI indicators had significant upward trends ($p<0.05$).

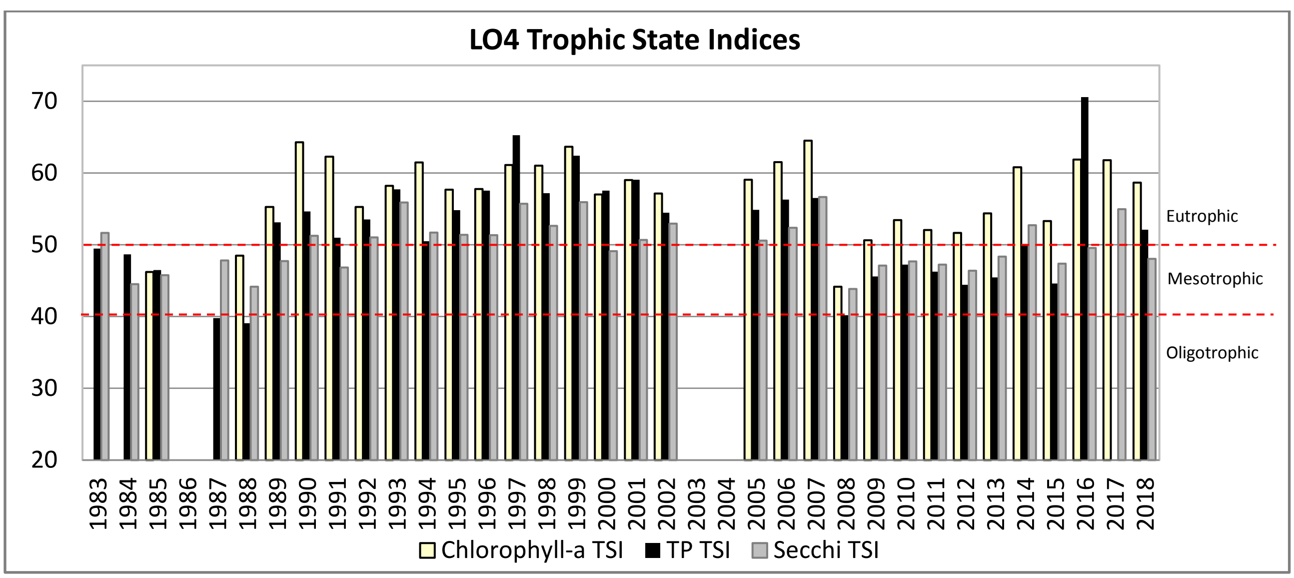

Figure 26. LO4 Trophic State Index from 1995 to 2018

SUMMARY

Thermal Stratification and Temperature Trends

In 2018, the water column at Long Lake was thermally stratified from May to August. The upper layers mixed more readily at the shallower south basin site compared to the deeper north basin site. Turnover began in September and was essentially complete in October. The trend from 2008 to 2018 was increased temperature in surface water at both locations from May to August. In September, the trend was decreasing temperature at both sites, and no trend was found in October.

Water Transparency and Trends

In 2018, transparency was higher at the north basin site than the south basin site. Transparency was greater when productivity was lower. The general trend from 2008 to 2018 was a decrease in transparency for both basins, except for the north basin in October, where the trend was increased transparency.

High Productivity in August and September

In 2018, the highest concentration of chlorophyll-a occurred in August and September at both basins. The Seasonal Kendall test for chlorophyll-a concentration indicates a significant ($p<0.05$) increasing trend at both sites in August and September from 2008 to 2018. A decreasing trend of chlorophyll-a occurred at the north basin site in October, which correlates to the trend of increased water clarity at the north basin in October.

High Concentrations of Nutrients and Trends

Excess nutrients at Long Lake contributes to eutrophication and algal blooms (sampled 139 times since 2010 for algae). The average surface TP concentration was 0.030 mg/L at both sites in 2018. This concentration is above the action level. The Seasonal Kendall test (2008 to 2018) revealed significant trends for TP in surface water at the south basin, where alum was applied in 2008:

- Reduced TP concentration in June
- Increased TP concentration from July to October

At the north basin site, no significant trends were detected, except for a TP reduction in July.

The average total surface TN concentration was 0.5 to 0.6 mg/L at both sites. The Seasonal Kendall test shows a significant ($p<0.05$) upward trend of surface TN concentrations from July to October at both sites. No trends were detected in May and June.

Classified as Eutrophic

In 2018, both basins of Long Lake were classified as eutrophic based on an average of the three TSI variables. The trend from 2008 to 2018 in the north basin was toward eutrophication, with higher productivity and reduced water clarity. No trend was detected for TP concentration at the north basin site. Trend analysis shows that the south basin has become more eutrophic over the last decade. All three TSI indicators had significant upward trends.

Human activity accelerates the rate of eutrophication through loading of nutrients from point and non-point sources. Cultural eutrophication is linked to algal blooms, degradation of water quality and biological integrity, and interference with recreational activities.

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

FUNDING SOURCE:

Thurston County funded monitoring in 2018.

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Appendices

Appendix A. Raw Data
Appendix B. Quality Assurance/Quality Control
Appendix C. Trends

Appendix A. Raw data

Table A-1 Raw data collected at site LO3 located in the north basin of Long Lake.

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)
5/22/2018	13:19	6.40	3.35	3	6.0	0.014	0.153	0.361	0.901	5.7	0.4
5/22/2018	**13:19**	**-**	**-**	**-**	**-**	**0.013**	**0.166**	**0.398**	**0.725**	**4.0**	**1.8**
6/26/2018	12:56	6.25	2.90	6	5.8	0.011	0.055	0.184	0.434	2.8	0.3
7/17/2018	13:28	6.25	3.00	6	5.8	0.017	0.166	0.347	0.869	5.3	0.3
8/14/2018	13:43	5.90	0.90	4	5.4	0.035	0.066	1.005	0.927	55.0	0.7
9/18/2018	10:47	5.90	1.00	6	5.5	0.045	1.660	0.927	3.540	44.0	5.6
10/23/2018	11:57	6.15	2.60	3	5.6	0.060	0.034	0.732	0.591	5.6	3.4
Mean Values		**6.14**	**2.29**	**-**	**5.67**	**0.03**	**0.33**	**0.56**	**1.14**	**17.50**	**1.78**

Table A-2 Raw data collected at site LO4 located in the south basin of Long Lake

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)
5/22/2018	14:15	4.34	3.37	3	4.0	0.023	0.024	0.486	0.440	4.3	1.7
6/26/2018	13:50	4.40	2.75	3	3.9	0.018	0.082	0.282	0.581	6.1	0.8
7/17/2018	12:38	4.40	2.10	7	3.9	0.020	0.039	0.464	0.427	3.7	0.4
8/14/2018	14:18	4.10	0.90	4	3.6	0.053	0.056	0.864	0.756	49.1	3.6
9/18/2018	11:10	4.51	1.14	3	4.0	0.040	0.043	0.683	0.620	27.0	4.5
10/23/2018	12:27	4.35	2.20	3	3.7	0.025	0.230	0.377	0.329	8.8	2.2
Mean Values		**4.35**	**2.08**	**-**	**3.85**	**0.03**	**0.08**	**0.53**	**0.53**	**16.51**	**2.19**

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 Long 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

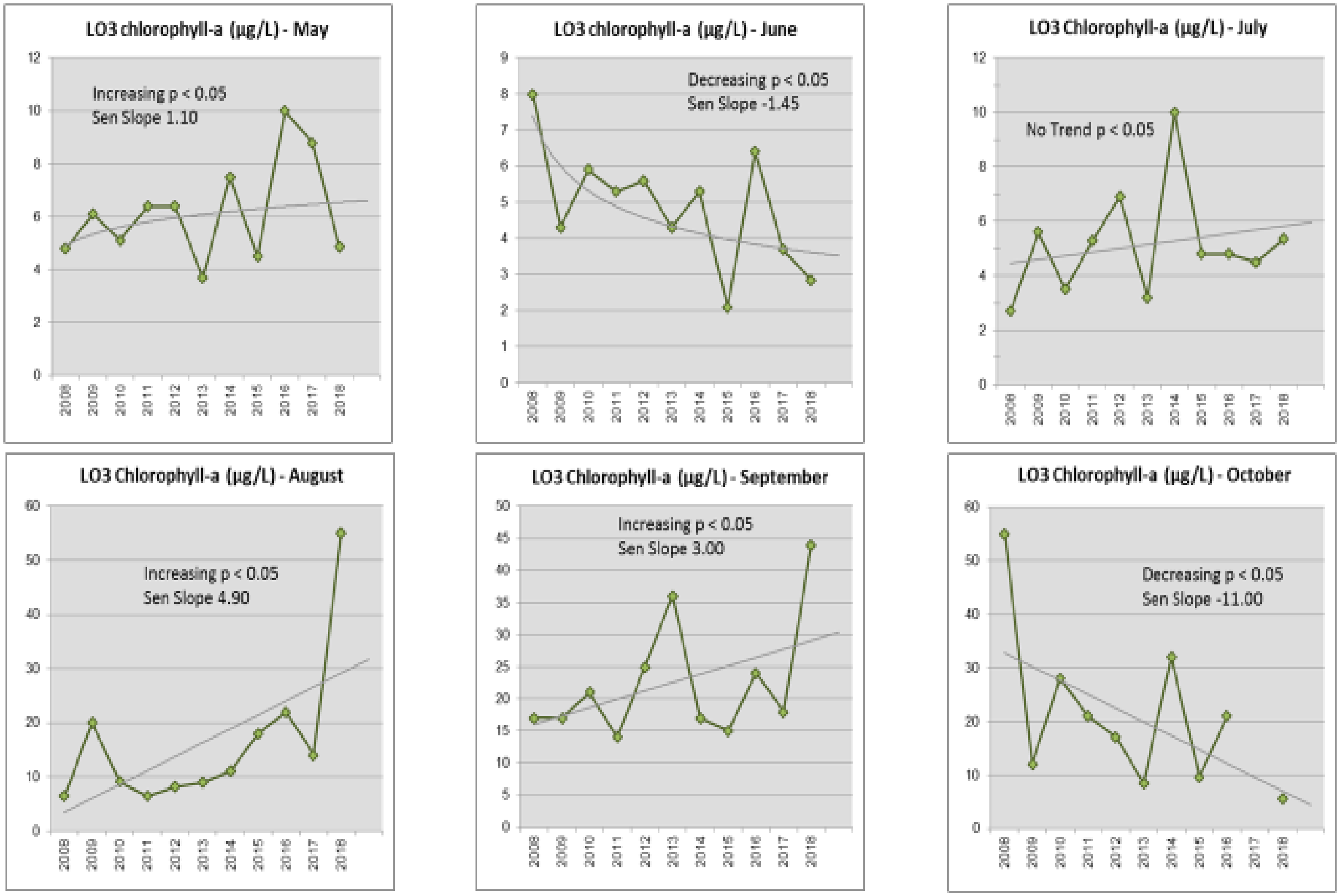
TCEH collected 10% field replicates and one blank lab sample each day. For the dates that Long Lake was sampled, field replicates were collected for chlorophyll-a and both nutrients (Table B-2).

Table B-2. Precision of field replicates collected at Long Lake in 2018.

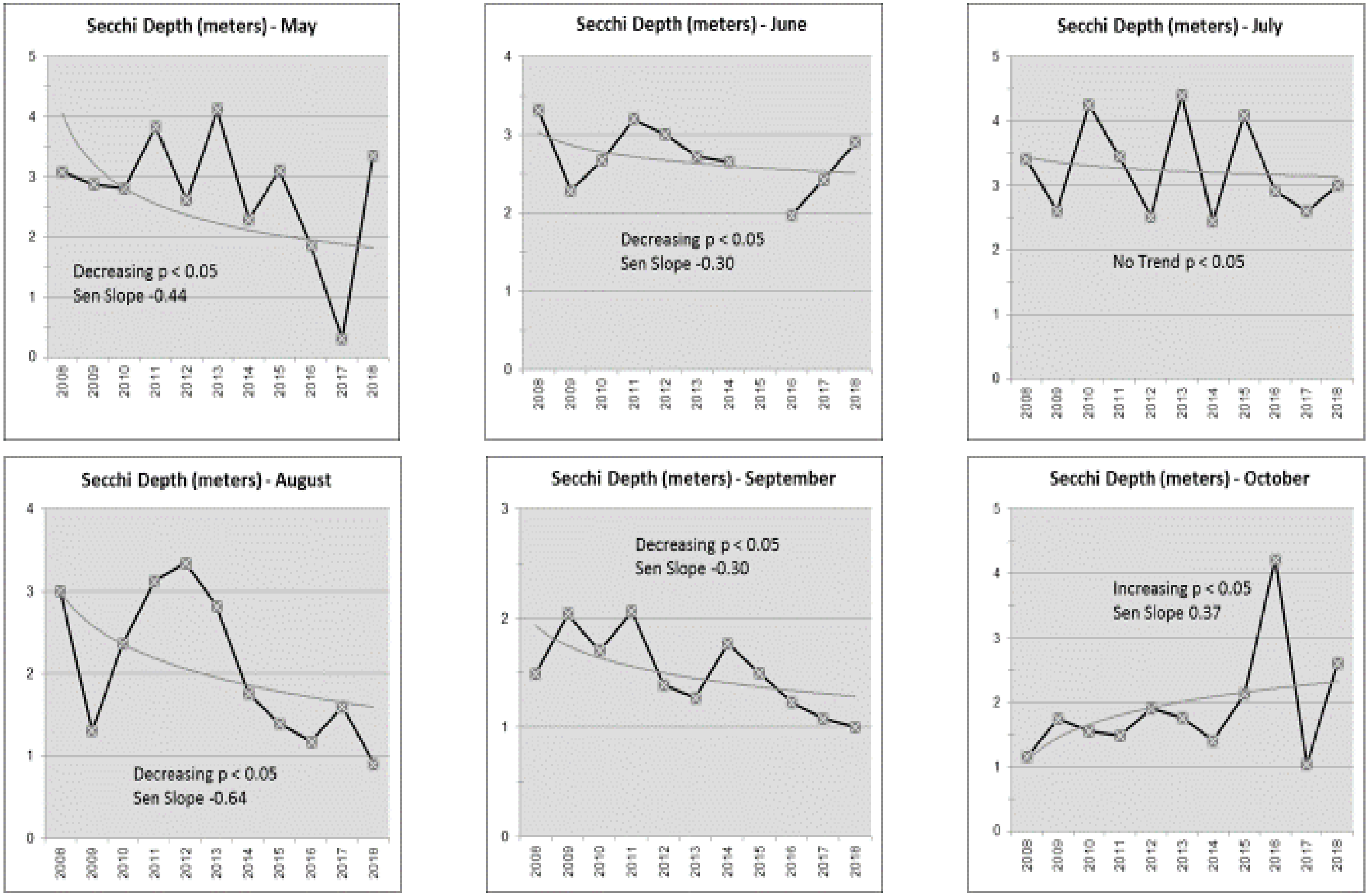
Site	Date/Time	Parameter	Sample	Field Replicate	%Relative Standard Deviation
LO3	5/22/2018 13:19	TP surface	0.014	0.013	3.7
LO3	5/22/2018 13:19	TP bottom	0.153	0.166	4.1
LO3	5/22/2018 13:19	TN surface	0.361	0.398	4.9
LO3	5/22/2018 13:19	TN bottom	0.901	0.725	10.8
LO3	5/22/2018 13:19	chlorophyll-a	5.7	4	17.5
LO3	5/22/2018 13:19	phaeophytin-a	0.4	1.8	63.6

Appendix C. Trends

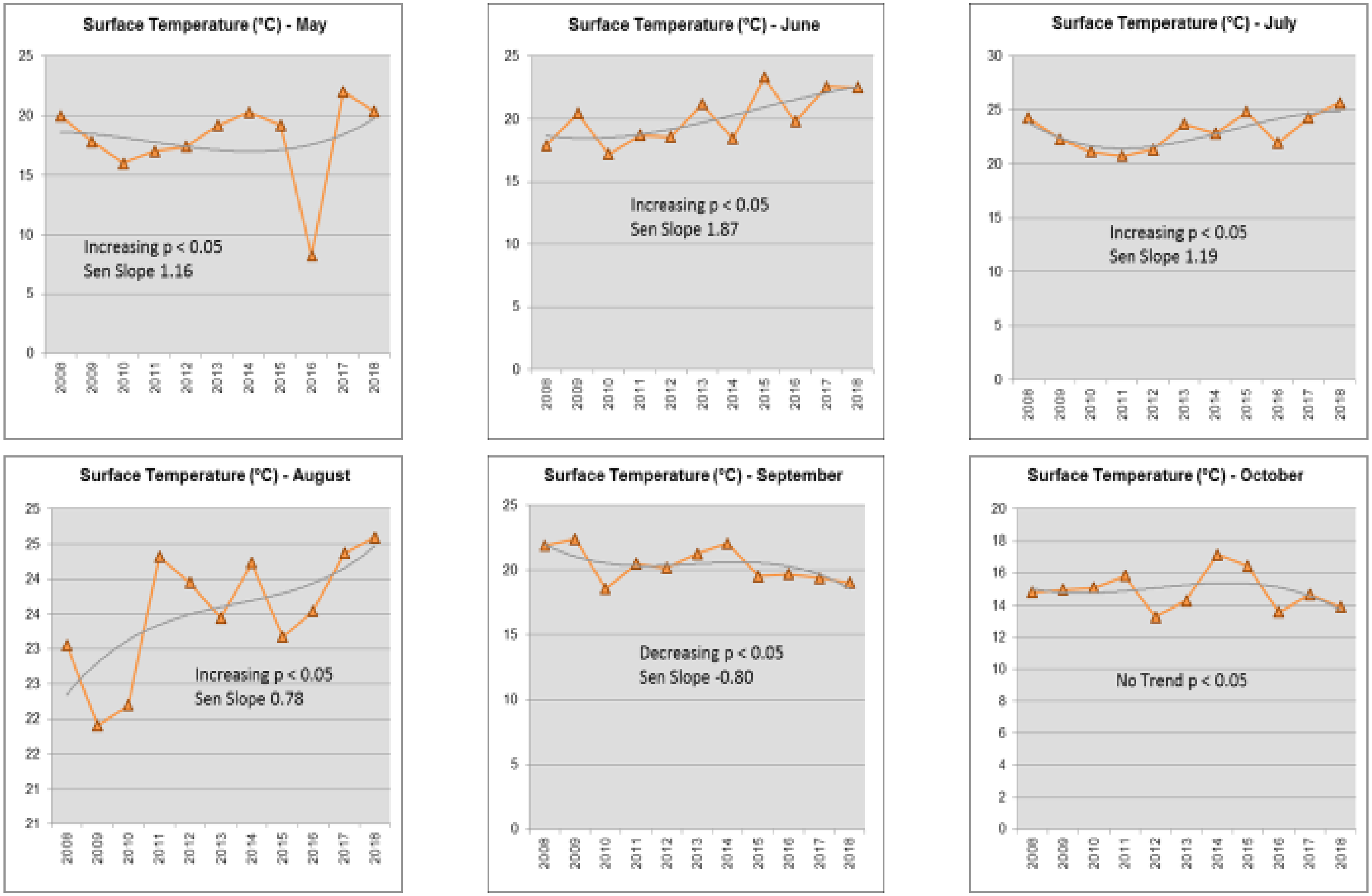
North Basin of Long Lake - Site LO3



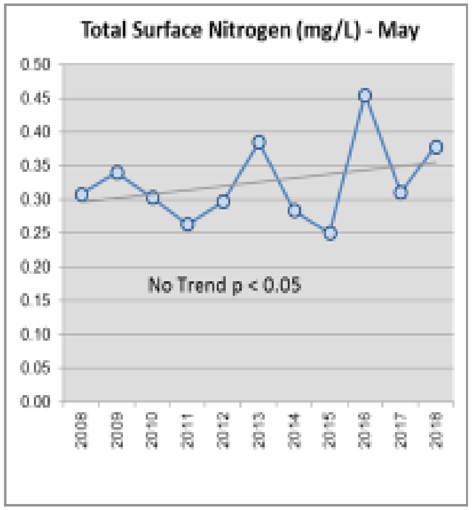
North Basin of Long Lake - Site LO3

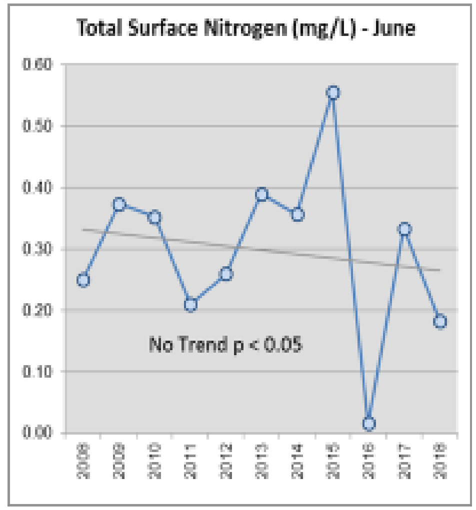


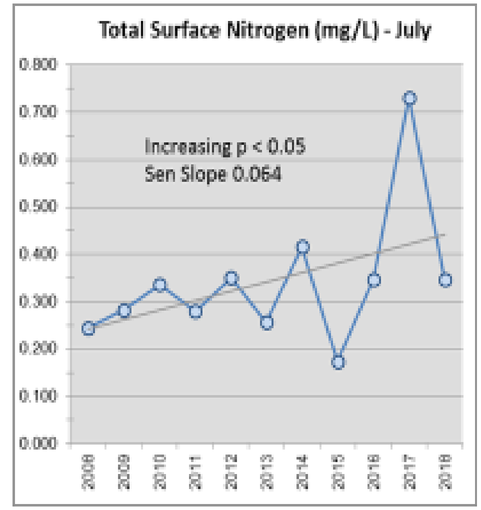
North Basin of Long Lake - Site LO3

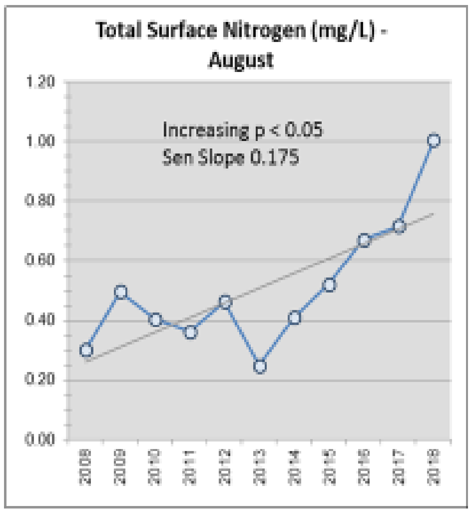


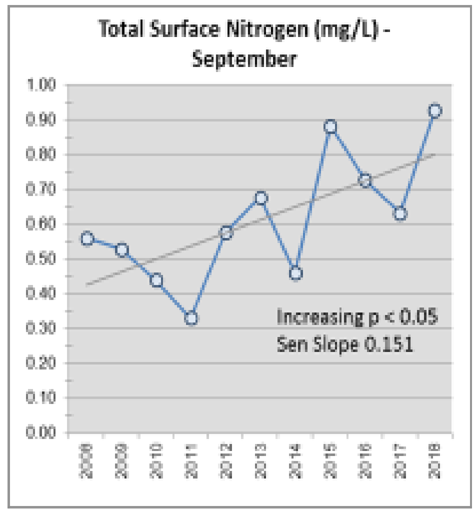
North Basin of Long Lake - Site LO3

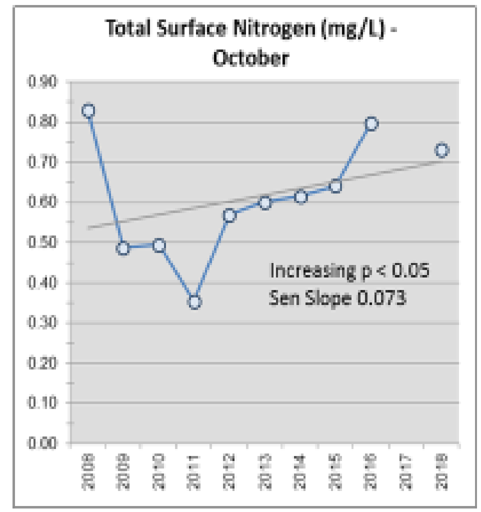






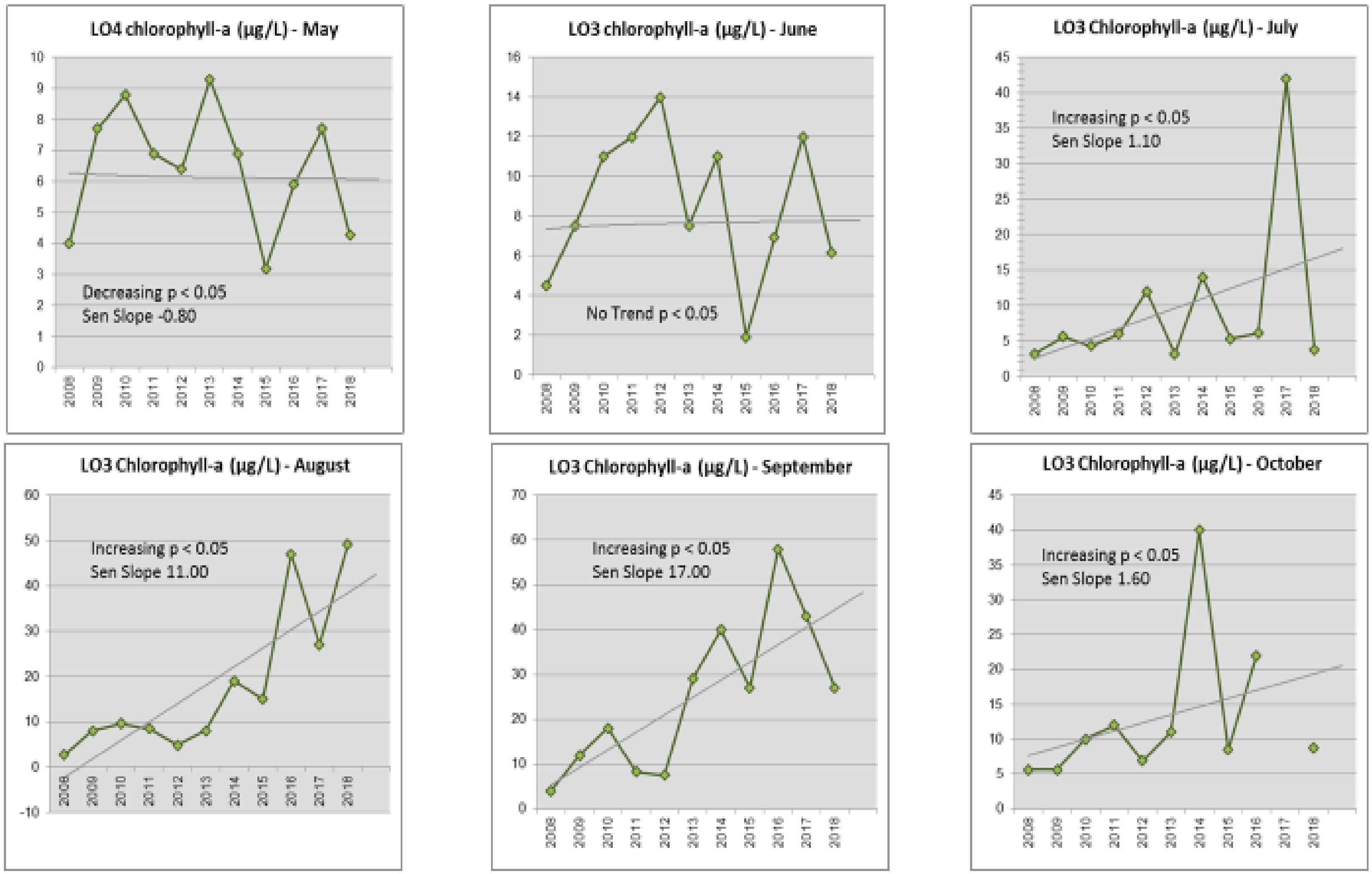




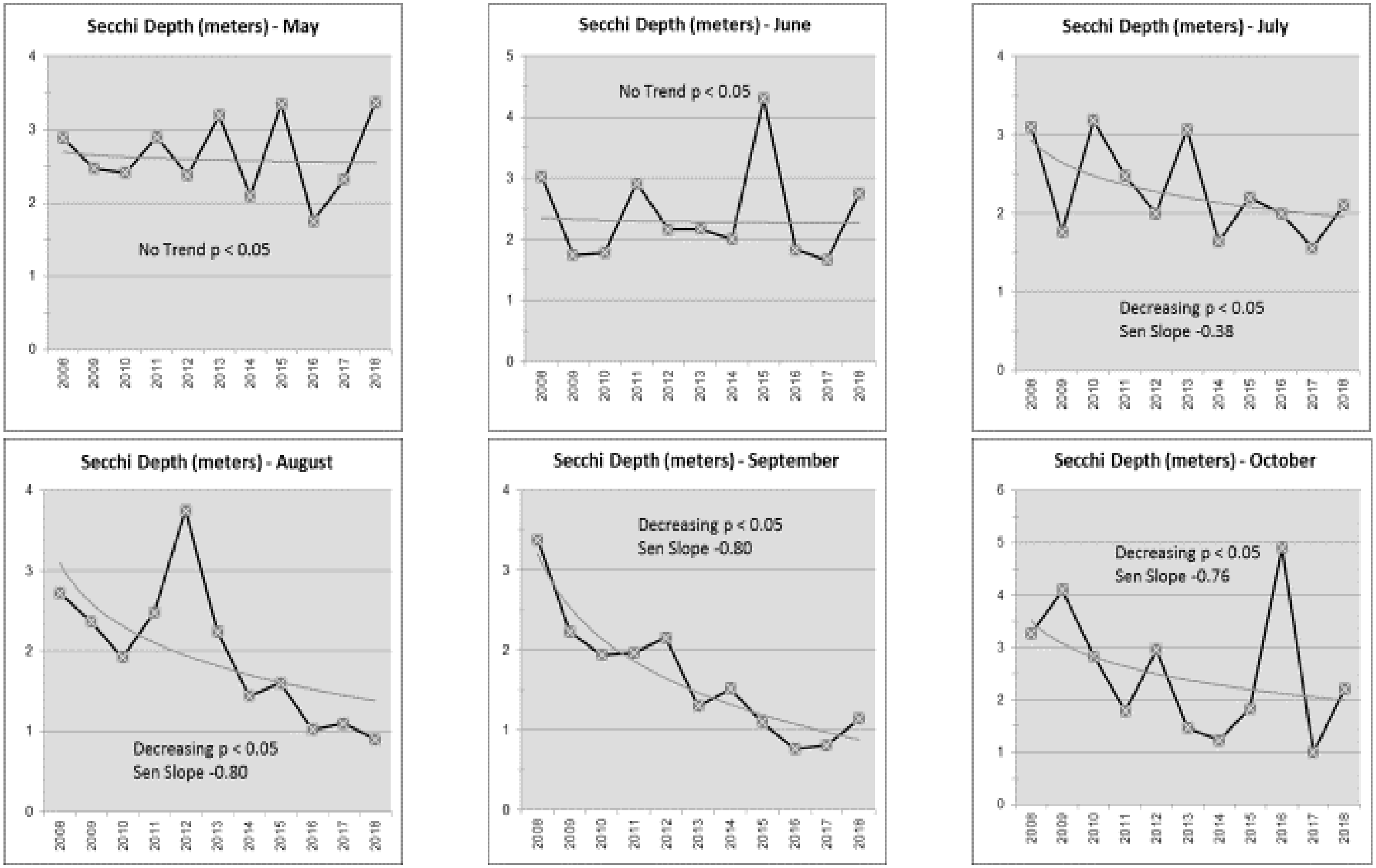


North Basin of Long Lake - Site LO3

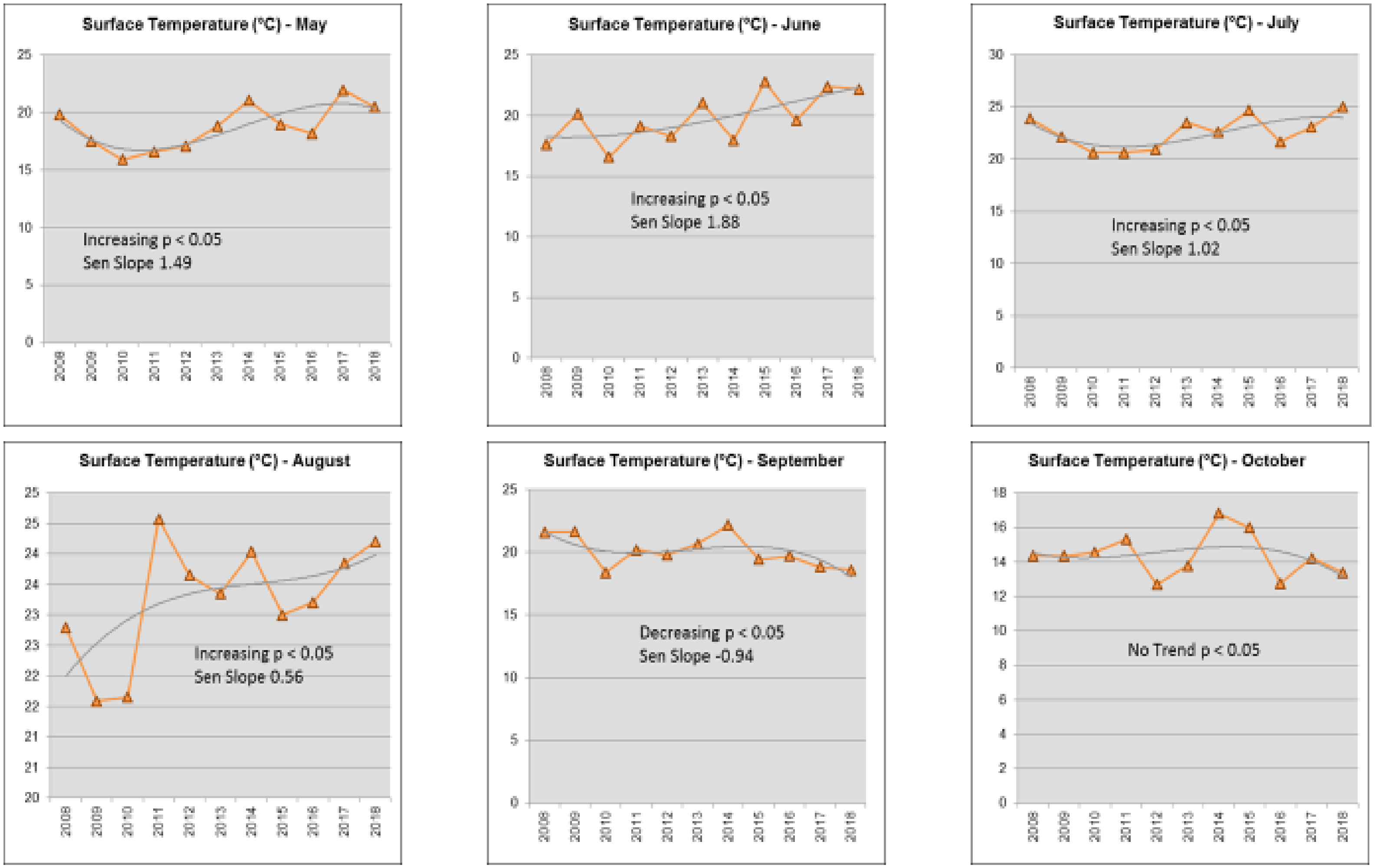
South Basin of Long Lake - Site LO4



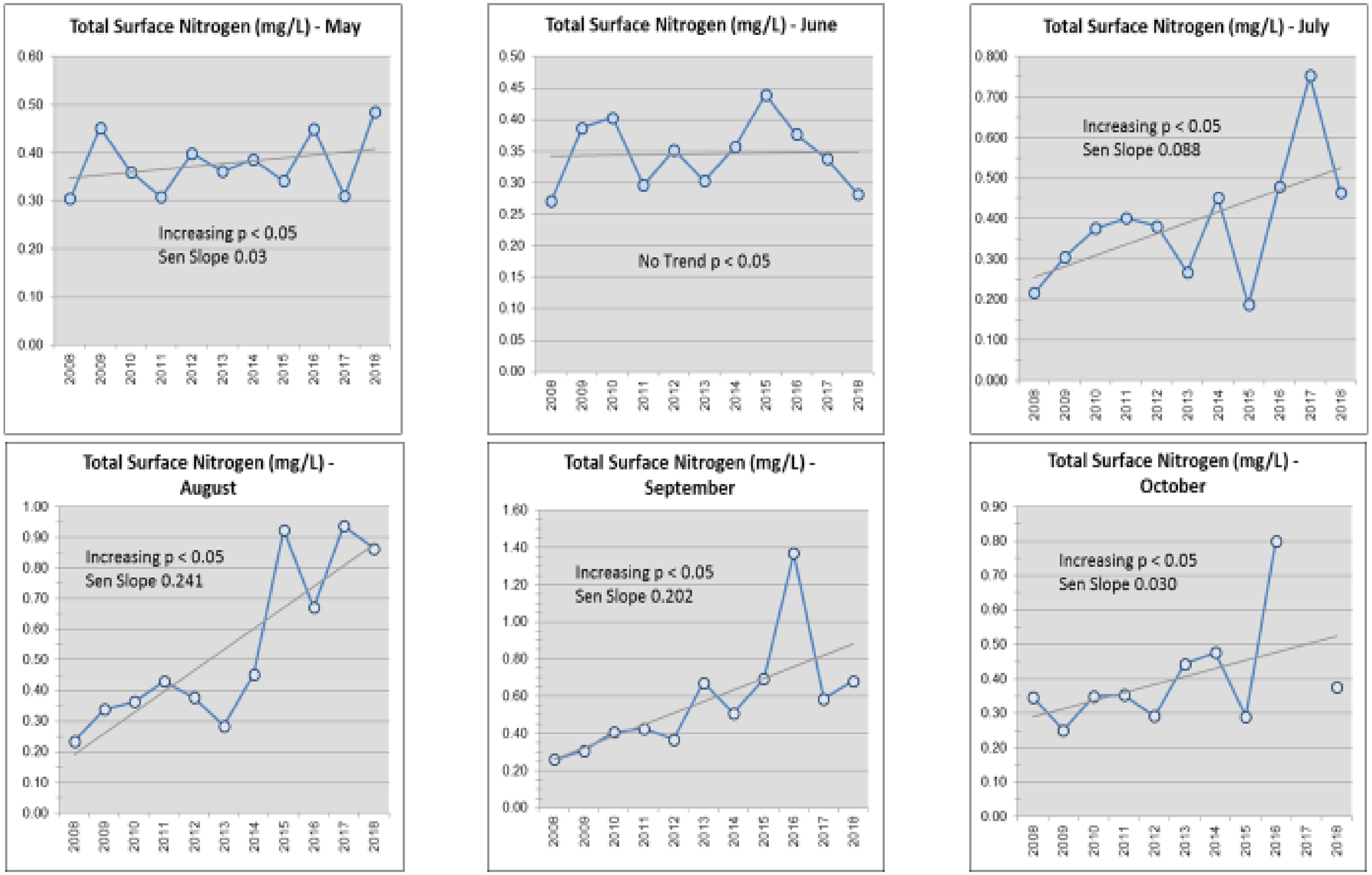
South Basin of Long Lake - Site LO4



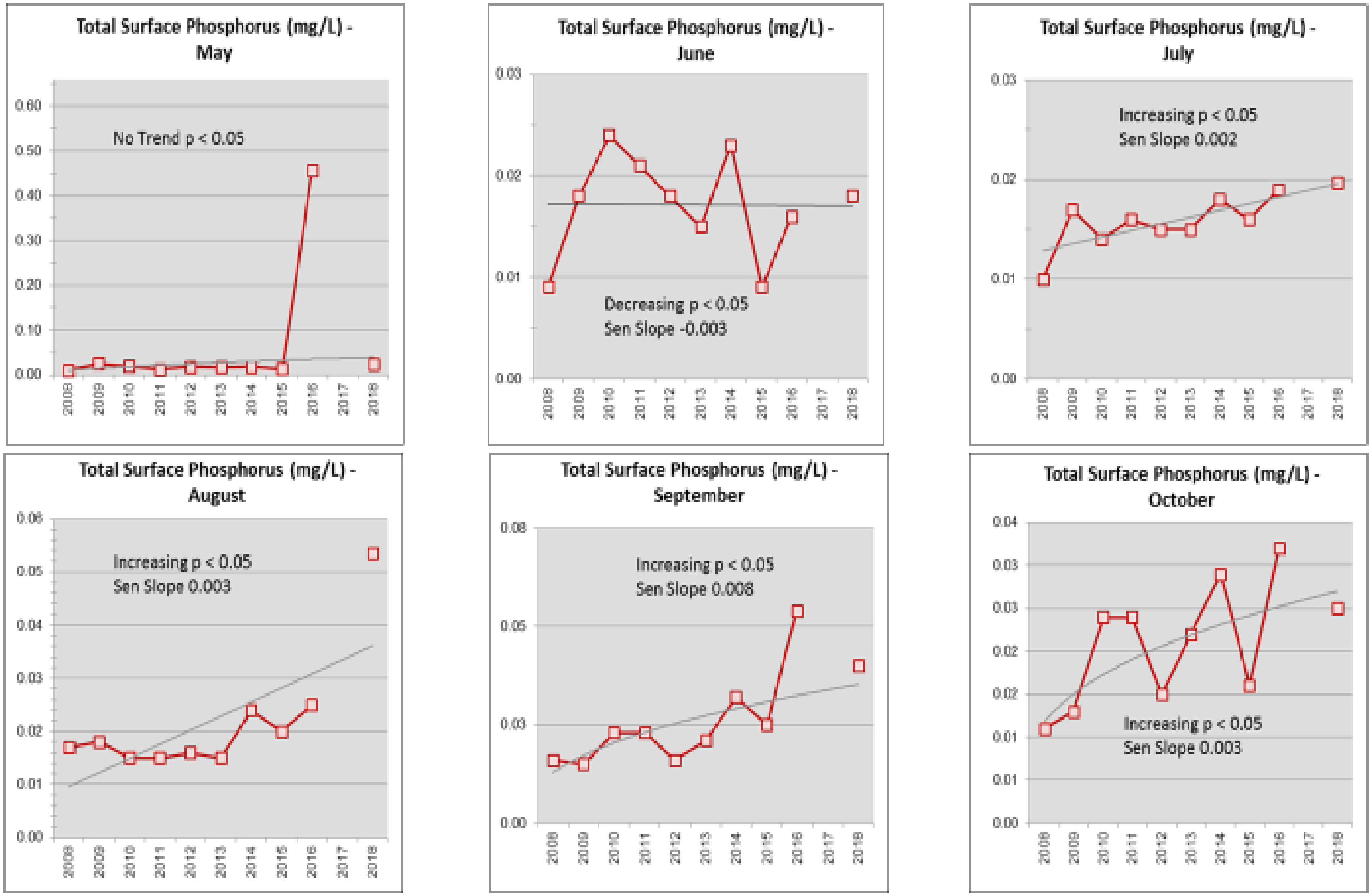
South Basin of Long Lake - Site LO4



South Basin of Long Lake - Site LO4



South Basin of Long Lake - Site LO4



TSI Trends North Basin (LO3) and South Basin (LO4) Sites of Long Lake