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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Method</th>
<th>Sampling Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transparency</td>
<td>Meters</td>
<td>Secchi Disk</td>
<td>Depth where disk is no longer visible</td>
</tr>
<tr>
<td>Color</td>
<td>#1 to #11</td>
<td>Custer Color Strip</td>
<td>Color of water on white portion of Secchi Disk</td>
</tr>
<tr>
<td>Vertical Water</td>
<td></td>
<td>YSI EXO1 Multi-parameter Sonde</td>
<td>~ 0.5 meter below the water surface to ~ 0.5 meter above the bottom sediments</td>
</tr>
<tr>
<td>Quality Profile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>mg/L</td>
<td>Grab Samples with Kemmerer</td>
<td>Surface Sample: ~ 0.5 meter below the surface Bottom Sample: ~ 0.5 meter above the benthos</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>mg/L</td>
<td>Grab Samples with Kemmerer</td>
<td>Surface Sample: ~ 0.5 meter below the surface Bottom Sample: ~ 0.5 meter above the benthos</td>
</tr>
<tr>
<td>Chlorophyll-a</td>
<td>µg/L</td>
<td>Composite of Multiple Grab Samples</td>
<td>Photic Zone</td>
</tr>
<tr>
<td>Phaeophytin-a</td>
<td>µg/L</td>
<td>Composite of Multiple Grab Samples</td>
<td>Photic Zone</td>
</tr>
</tbody>
</table>

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.

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

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.
Long Lake 2018

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

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

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

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).

![Surface Temperature Trend 2008-2018](image)

*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.
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 7. Water color and Secchi depths for 2018.

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.
Long Lake 2018

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.

![Chlorophyll-a Trend 2008-2018](image)

**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.

![LO3 - Surface TP and TN](image)

![LO4 - Surface TP and TN](image)

**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.
Long Lake 2018

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.](image)

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.
Long Lake 2018

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.

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.

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.

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

**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.

![Surface TN Trend 2008-2018](image)

**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.

![LO3 - TN to TP Ratio](image)

**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>
<thead>
<tr>
<th>TSI Value</th>
<th>Trophic State</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 40</td>
<td>oligotrophic</td>
<td>Low</td>
</tr>
<tr>
<td>41 to 50</td>
<td>mesotrophic</td>
<td>Medium</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>eutrophic</td>
<td>High</td>
</tr>
</tbody>
</table>

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
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).
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 contribute 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.

LITERATURE CITED


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.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Bottom Depth (meters)</th>
<th>Secchi (meters)</th>
<th>Water Color</th>
<th>Bottom Sample Depth (meters)</th>
<th>Surface TP (mg/L)</th>
<th>Bottom TP (mg/L)</th>
<th>Surface TN (mg/L)</th>
<th>Bottom TN (mg/L)</th>
<th>Chl a (µg/L)</th>
<th>Phae a (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>13:19</td>
<td>6.40</td>
<td>3.35</td>
<td>3</td>
<td>6.0</td>
<td>0.014</td>
<td>0.153</td>
<td>0.361</td>
<td>0.901</td>
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<td>5/22/2018</td>
<td>13:19</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.013</td>
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<td>2.90</td>
<td>6</td>
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<td>0.055</td>
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<td>0.434</td>
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<td>0.3</td>
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<td>7/17/2018</td>
<td>13:28</td>
<td>6.25</td>
<td>3.00</td>
<td>6</td>
<td>5.8</td>
<td>0.017</td>
<td>0.166</td>
<td>0.347</td>
<td>0.869</td>
<td>5.3</td>
<td>0.3</td>
</tr>
<tr>
<td>8/14/2018</td>
<td>13:43</td>
<td>5.90</td>
<td>0.90</td>
<td>4</td>
<td>5.4</td>
<td>0.035</td>
<td>0.066</td>
<td>1.005</td>
<td>0.927</td>
<td>55.0</td>
<td>0.7</td>
</tr>
<tr>
<td>9/18/2018</td>
<td>10:47</td>
<td>5.90</td>
<td>1.00</td>
<td>6</td>
<td>5.5</td>
<td>0.045</td>
<td>1.660</td>
<td>0.927</td>
<td>3.540</td>
<td>44.0</td>
<td>5.6</td>
</tr>
<tr>
<td>10/23/2018</td>
<td>11:57</td>
<td>6.15</td>
<td>2.60</td>
<td>3</td>
<td>5.6</td>
<td>0.060</td>
<td>0.034</td>
<td>0.732</td>
<td>0.591</td>
<td>5.6</td>
<td>3.4</td>
</tr>
<tr>
<td>Mean Values</td>
<td></td>
<td>6.14</td>
<td>2.29</td>
<td>-</td>
<td>5.67</td>
<td>0.03</td>
<td>0.33</td>
<td>0.56</td>
<td>1.14</td>
<td>17.50</td>
<td>1.78</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Bottom Depth (meters)</th>
<th>Secchi (meters)</th>
<th>Water Color</th>
<th>Bottom Sample Depth (meters)</th>
<th>Surface TP (mg/L)</th>
<th>Bottom TP (mg/L)</th>
<th>Surface TN (mg/L)</th>
<th>Bottom TN (mg/L)</th>
<th>Chl a (µg/L)</th>
<th>Phae a (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/22/2018</td>
<td>14:15</td>
<td>4.34</td>
<td>3.37</td>
<td>3</td>
<td>4.0</td>
<td>0.023</td>
<td>0.024</td>
<td>0.486</td>
<td>0.440</td>
<td>4.3</td>
<td>1.7</td>
</tr>
<tr>
<td>6/26/2018</td>
<td>13:50</td>
<td>4.40</td>
<td>2.75</td>
<td>3</td>
<td>3.9</td>
<td>0.018</td>
<td>0.082</td>
<td>0.282</td>
<td>0.581</td>
<td>6.1</td>
<td>0.8</td>
</tr>
<tr>
<td>7/17/2018</td>
<td>12:38</td>
<td>4.40</td>
<td>2.10</td>
<td>7</td>
<td>3.9</td>
<td>0.020</td>
<td>0.039</td>
<td>0.464</td>
<td>0.427</td>
<td>3.7</td>
<td>0.4</td>
</tr>
<tr>
<td>8/14/2018</td>
<td>14:18</td>
<td>4.10</td>
<td>0.90</td>
<td>4</td>
<td>3.6</td>
<td>0.053</td>
<td>0.056</td>
<td>0.864</td>
<td>0.756</td>
<td>49.1</td>
<td>3.6</td>
</tr>
<tr>
<td>9/18/2018</td>
<td>11:10</td>
<td>4.51</td>
<td>1.14</td>
<td>3</td>
<td>4.0</td>
<td>0.040</td>
<td>0.043</td>
<td>0.683</td>
<td>0.620</td>
<td>27.0</td>
<td>4.5</td>
</tr>
<tr>
<td>10/23/2018</td>
<td>12:27</td>
<td>4.35</td>
<td>2.20</td>
<td>3</td>
<td>3.7</td>
<td>0.025</td>
<td>0.230</td>
<td>0.377</td>
<td>0.329</td>
<td>8.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Mean Values</td>
<td></td>
<td>4.35</td>
<td>2.08</td>
<td>-</td>
<td>3.85</td>
<td>0.03</td>
<td>0.08</td>
<td>0.53</td>
<td>0.53</td>
<td>16.51</td>
<td>2.19</td>
</tr>
</tbody>
</table>
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.

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

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.

<table>
<thead>
<tr>
<th>Site</th>
<th>Date/Time</th>
<th>Parameter</th>
<th>Sample</th>
<th>Field Replicate</th>
<th>%Relative Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO3</td>
<td>5/22/2018 13:19</td>
<td>TP surface</td>
<td>0.014</td>
<td>0.013</td>
<td>3.7</td>
</tr>
<tr>
<td>LO3</td>
<td>5/22/2018 13:19</td>
<td>TP bottom</td>
<td>0.153</td>
<td>0.166</td>
<td>4.1</td>
</tr>
<tr>
<td>LO3</td>
<td>5/22/2018 13:19</td>
<td>TN surface</td>
<td>0.361</td>
<td>0.398</td>
<td>4.9</td>
</tr>
<tr>
<td>LO3</td>
<td>5/22/2018 13:19</td>
<td>TN bottom</td>
<td>0.901</td>
<td>0.725</td>
<td>10.8</td>
</tr>
<tr>
<td>LO3</td>
<td>5/22/2018 13:19</td>
<td>chlorophyll-a</td>
<td>5.7</td>
<td>4</td>
<td>17.5</td>
</tr>
<tr>
<td>LO3</td>
<td>5/22/2018 13:19</td>
<td>phaeophytin-a</td>
<td>0.4</td>
<td>1.8</td>
<td>63.6</td>
</tr>
</tbody>
</table>
Appendix C. Trends
Long Lake 2018

North Basin of Long Lake - Site LO3

Total Surface Nitrogen (mg/L) - May

No Trend p < 0.05

Total Surface Nitrogen (mg/L) - June

No Trend p < 0.05

Total Surface Nitrogen (mg/L) - July

Increasing p < 0.05
Sen Slope 0.064

Total Surface Nitrogen (mg/L) - August

Increasing p < 0.05
Sen Slope 0.175

Total Surface Nitrogen (mg/L) - September

Increasing p < 0.05
Sen Slope 0.151

Total Surface Nitrogen (mg/L) - October

Increasing p < 0.05
Sen Slope 0.073
Total Surface Phosphorus (mg/L) - May
No Trend p < 0.05

Total Surface Phosphorus (mg/L) - June
Decreasing p < 0.05
Sen Slope 0.003

Total Surface Phosphorus (mg/L) - July
Increasing p < 0.05
Sen Slope 0.002

Total Surface Phosphorus (mg/L) - August
Increasing p < 0.05
Sen Slope 0.003

Total Surface Phosphorus (mg/L) - September
Increasing p < 0.05
Sen Slope 0.008

Total Surface Phosphorus (mg/L) - October
Increasing p < 0.05
Sen Slope 0.003
TSI Trends North Basin (LO3) and South Basin (LO4) Sites of Long Lake

LO3 - TSI Chlorophyll-a
Increasing p < 0.05
Sen Slope 1.65

LO3 - TSI TP
No Trend p < 0.05

LO3 TSI Secchi Depth
Increasing p < 0.05
Sen Slope 1.59

LO4 - TSI Chlorophyll-a
Increasing p < 0.05
Sen Slope 6.58

LO4 - TSI TP
Increasing p < 0.05
Sen Slope 2.75

LO4 TSI Secchi Depth
Increasing p < 0.05
Sen Slope 1.98