**DESHUTES RIVER WATERSHED**

- **SHORELINE LENGTH:** 4.0 miles
- **LAKE SIZE:** 0.52 square miles (330 acres)
- **BASIN SIZE:** 3.35 square miles
- **MEAN DEPTH:** 4.0 meters (13 feet)
- **MAXIMUM DEPTH:** 7.9 meters (26 feet)
- **VOLUME:** 4,617 acre-feet

**PUBLIC ACCESS:**
Washington Department of Fish and Wildlife operate one public boat launch. Also, the lakeside residents have three private access points.

**GENERAL TOPOGRAPHY:**
Lake Lawrence is north of the Bald Hills, at an elevation of approximately 421 feet above mean sea level. The lake, which is very close to the Deschutes River, normally discharges to the river via a small stream. During extreme flooding events, the river water backs up into the lake.

**GENERAL WATER QUALITY:**
Fair – Classified as eutrophic, Lake Lawrence is nutrient-rich. Uses are sometimes impaired by excessive algae and aquatic plant growth and toxic algae blooms.

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DESCRIPTION

Lake Lawrence is in the Deschutes River Watershed, approximately six miles south of Yelm and six miles southeast of Rainier, Washington. The lake has two distinct basins, a large basin on the east side (site LL1) and a smaller basin to the west (site LL2). Lake Lawrence is fed by groundwater; no surface water inlet exists. A small outlet channel discharges out of the west basin through a control structure across the floodplain to the Deschutes River. The lake is relatively shallow, with an average depth of approximately 4 meters (13 feet).

Aquatic macrophyte and algae growth is exacerbated by shallow water, high nutrient levels, warmer weather, and fluctuations in lake levels (TCPW, 2018). Since 1986, an active lake management district (LMD), has funded aquatic weed control and fisheries management activities. In the early 1990s, a state grant and community-supported LMD funded a lake restoration study. Some of the recommendations from the study were incorporated into an Integrated Aquatic Vegetation Management Plan.

METHODS

In 2018, Thurston County Environmental Health (TCEH) conducted monthly monitoring at two sites from May to October. Site LL1 is in the deepest part of the larger eastern basin (Figure 1). LL2 is at the deepest part of the smaller western basin. Table 1 lists the types of data collected (Thurston County, 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.

<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>
</tbody>
</table>
| Vertical Water Quality Profile |        | 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.
Lake Lawrence 2018

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. Multiple TCEH staff members sampled Lake Lawrence during the 2018 season. The number of samplers increased sampling variability (Figures 14 and 18).

The Seasonal Kendall Test

TCEH used the Seasonal Kendall test, a highly robust, non-parametric test, to identify trends from 2009 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 2009 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. This test is more effective with long-term data sets. Less data reduces statistical confidence. Only nine sample seasons were analyzed for September because September 2017 data was not collected due to safety concerns during an algal bloom.

RESULTS

Weather Conditions

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

Table 2. Weather on Sample Day and the Average, Minimum, and Maximum Air Temperatures for Each Month

<table>
<thead>
<tr>
<th>Month</th>
<th>Weather on Sample Day</th>
<th>Monthly Weather Temperature (°C) Mean (Low/High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>Sunny and clear (24°C); 3-8 mph W wind (Gusts 16 mph)</td>
<td>15 (3/30)</td>
</tr>
<tr>
<td>June</td>
<td>Mostly to partly cloudy (20°C); 0-5 mph W wind (Gusts 13 mph)</td>
<td>16 (6/31)</td>
</tr>
<tr>
<td>July</td>
<td>Clear, (24°C); 8-10 mph W wind (Gusts 13 mph)</td>
<td>20 (7/34)</td>
</tr>
<tr>
<td>August</td>
<td>Hazy from wildfire smoke, (28°C); 4-6 mph W wind (Gusts 8 mph)</td>
<td>19 (7/34)</td>
</tr>
<tr>
<td>September</td>
<td>Sunny (18°C); 3-8 mph SSW wind (Gusts 15 mph)</td>
<td>15 (3/29)</td>
</tr>
<tr>
<td>October</td>
<td>Sunny (14°C); 0-5 mph SSE wind (Gusts 9 mph)</td>
<td>11 (0/22)</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 Lake Lawrence was thermally stratified for most of the summer (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. The shallower site (LL2) had warmer surface temperatures until September when turnover began, then LL2 temperatures were cooler than LL1.
In May, the lake was beginning to stratify. The summer sun heated the surface layer, the epilimnion. This heat was retained because air temperature remained high. The temperature difference was greater at the deeper site (LL1):

- LL1 Epilimnion Temp 20.9°C; DO 9.6 mg/L
- LL1 Hypolimnion Temp. 5.5°C; DO 1.0 mg/L

In June, three layers became readily apparent. The temperature and oxygen concentration differences between the surface layer (epilimnion) and the bottom layer (hypolimnion) were:

- LL1 Epilimnion Temp 22.0°C; DO 9.1 mg/L
- LL1 Hypolimnion Temp. 13.6 °C; DO 0.6 mg/L
- LL2 Epilimnion Temp 22.3°C; DO 9.0 mg/L
- LL2 Hypolimnion Temp. 11.7°C; DO 0.5 mg/L

The dissolved oxygen (DO) profile during thermal stratification had a clinograde curve, which resulted from excess oxygen consuming processes in the hypolimnion. The hypolimnion, cut-off from the atmosphere after stratification, lost oxygen to redox processes. The epilimnion had much higher DO because this layer gained oxygen from the atmosphere and photosynthesis (Wetzel 1983).
In July, the difference between temperature and DO in the epilimnion and hypolimnion was greater at the deeper site LL1. LL2 was more mixed, possibly due to high winds (Table 2).

- LL1 Epilimnion Temp 24.9°C; DO 9.4 mg/L
- LL1 Hypolimnion Temp. 14.6°C; DO 0.5 mg/L
- LL2 Epilimnion Temp 25.5°C; DO 9.4 mg/L
- LL2 Hypolimnion Temp. 24.3°C; DO 6.0 mg/L

In August, the difference between the surface and bottom temperature and DO remained larger at LL1 compared to LL2.

- LL1 Epilimnion Temp 24.6°C; DO 10.1 mg/L
- LL1 Hypolimnion Temp. 16.5°C; DO 0.5 mg/L
- LL2 Epilimnion Temp 24.6°C; DO 10.0 mg/L
- LL2 Hypolimnion Temp. 19.5°C; DO 0.6 mg/L
In September, air temperatures dropped, particularly after sunset. The water columns started to mix. The difference in temperature and DO at the surface and the bottom were much smaller than in August.

- **LL1 Epilimnion Temp 19.0°C; DO 8.0 mg/L**
- **LL1 Hypolimnion Temp. 17.7°C; DO 2.7 mg/L**

In October, average air temperatures continued to decline (Table 2) with the arrival of fall. Lake Lawrence 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 mixed in October, a process called turnover. The temperature differences between the epilimnion and hypolimnion was diminished at both basins. Surface DO concentration increased at both sites in October, which was correlated with an increase in productivity, as measure by the chlorophyll-a concentration.

- **LL1 Epilimnion Temp 13.3°C; DO 10.7 mg/L**
- **LL1 Hypolimnion Temp. 13.0°C; DO 7.2 mg/L**
- **LL2 Epilimnion Temp 18.9°C; DO 9.1 mg/L**
- **LL2 Hypolimnion Temp. 18.3°C; DO 6.9 mg/L**

- **LL2 Epilimnion Temp 12.7°C; DO 10.9 mg/L**
- **LL2 Hypolimnion Temp. 12.5°C; DO 5.0 mg/L**
Lake Lawrence 2018

Surface Water Temperature Trends

The Seasonal Kendall analysis for trends for 2009 to 2018 shows that surface temperature has significantly increased at both locations (Figure 6). The largest increase in temperature occurred in May (1.8°C). The magnitude of the trend toward warmer surface temperatures incrementally decreased until August (0.6 at LL2 to 0.8°C at LL1). Generally, temperature increased more at LL1 compared to LL2, particularly in July and August. No trends were detected in September and October.

![Surface Temperature Trend 2009-2018](image)

*Figure 6. Surface temperature trend (+ or -) and magnitude of change (Theil-Sen estimator) for LL1 and LL2 from 2009 to 2018. The lack of a bar means the site did not have a significant trend (p<0.05) for that time period.*

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 and nutrient pollution 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).

Water Color and Transparency

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. Water color was recorded as #3 every month, except in June when LL1 was #6 and LL2 was #7 (Figure 2 and 7).

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 LL1 and LL2 for 2018.

At the two sites in 2018, transparency was lowest in October (~1 meter) and highest in May (~3 meters). The average transparency was slightly higher at LL1 (2.2 meters) compared to LL2 (1.9 meters).

Figure 8 shows 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 both sites was less than the long-term average: 0.2 meter lower at LL1 and 0.4 meter lower at LL2.

Figure 7. Water color and Secchi depths for 2018.
The Seasonal Kendall test revealed a trend of reduced transparency (Figure 9) for two-thirds of the sample season at both sites. At LL1, the trend was reduced transparency: 0.2 meters in early summer and fall and 0.4 meters mid-summer. At LL2, the trend was reduced transparency from May until July and in October. The greatest loss to water clarity at LL2 over the last decade occurred in May (0.8 meters). The negative trend continued until July, but the loss was less each successive month. No significant (p<0.05) trend existed in September at either site (n=9), in June at LL1, or in August at LL2.

Figure 8. Transparency at LL1 and LL2 compared to the long-term average (LTA).

Figure 9. Transparency trend (+ or -) and magnitude of change (Theil-Sen estimator) for LL1 and LL2 from 2009 to 2018. The lack of a bar means the site did not have a significant trend (p<0.05) for that time period.
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). The ratio of chlorophyll-a to phaeophytin-a has been used as an indicator of the physiological condition of phytoplankton in the sample.

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. Phaeopigments have been reported to contribute 16 to 60% of the measured chlorophyll-a content (Marker et al., 1980).

2018 Productivity Data

In 2018, transparency at LL1 and LL2 was inversely related to productivity, as measured by the concentration of chlorophyll-a in the photic zone. Transparency was higher from May to July (Figure 7), when productivity was lower (Figures 10 and 11). Water clarity was the lowest from August to October, the most productive months for algae and cyanobacteria. Identification of phytoplankton would provide more information about productivity and phytoplankton assemblages.

Figures 10 and 11 show that the highest concentration of chlorophyll-a in 2018 occurred from August to October at both sites. Productivity was lowest in May and June. After that, chlorophyll-a levels increased each successive month. From June to September, an algal bloom with surface scum was reported. Seven samples were tested for anatoxin-a and microcystin. In addition, the lab analyzed the September 15 sample for cylindrospermopsin and saxitoxin. Microcystin exceeded the Washington State advisory level on September 25 (Appendix D).

Figure 10. Chlorophyll-a concentration and ratio of chlorophyll-a to phaeophytin-a pigments in samples collected at LL1.

At LL1, the ratio of chlorophyll-a to phaeophytin-a peaked in June and, to a smaller degree, in August. The supply of oxygen in the epilimnion ranged from a low of 8.0 mg/L in September to a high of 10.7 mg/L in October (standard deviation 0.8).
Figure 11. Chlorophyll-a concentration and ratio of chlorophyll-a to phaeophytin-a pigments in samples collected at LL2.

At LL2, the ratio of chlorophyll-a to phaeophytin-a peaked in August; the ratio was almost four times higher than the maximum concentration at LL1. The mean DO concentration in the epilimnion ranged from 9.0 mg/L in May to 10.1 mg/L in October (standard deviation 0.7).

The test for chlorophyll-a concentration trends for 2009 to 2018 indicates a significant (p<0.05) increase in chlorophyll-a:
- The greatest positive trend (6 µg/L) occurred at LL1 in October, which is typically after turnover when nutrients from the bottom mix with surface waters at this deeper basin site
- In August both sites had modest increases (2 to 3 µg/L) over the last decade
- In May, LL1 had a smaller increase (0.3 µg/L)

Figure 12 shows the magnitude of change for all significant trends.

Figure 12. Chlorophyll-a trend (+ or -) and magnitude of change (Theil-Sen estimator) for LL1 and LL2 from 2009 to 2018. The lack of a bar means the site did not have a significant trend (p<0.05) for that time period.
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 13 shows the total phosphorus (TP) and total nitrogen (TN) present in the surface waters at the two Lake Lawrence sites.

Figure 13. 2018 surface concentration of TP and TN at LL1 and LL2 sites at Lake Lawrence.

The concentration of TP in the epilimnion quadrupled at both sites in September, when the process of turnover started. Thermal stratification reduced internal loading to surface waters from May to August; changes in the phytoplankton community and external sources likely affect nutrient levels at the surface 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). The surface TP concentration was above the action level for the duration of the 2018 sample season:

- LL1 Surface Mean 0.035
- LL1 Surface Median 0.023
- LL1 Surface Std Dev 0.019

- LL2 Surface Mean 0.044
- LL2 Surface Median 0.031
- LL2 Surface Std Dev 0.025
Figure 14 displays the TP concentration, both at the surface and bottom, at the the two Lake Lawrence sites.

**Figure 14. Concentration of Total Phosphorus at the surface and bottom of Lake Lawrence in 2018.**

The mean concentration of TP (mg/L) near the bottom was:

- LL1 Mean 0.240
- LL1 Median 0.201
- LL1 Std Dev 0.161
- LL2 Mean 0.177
- LL2 Median 0.085
- LL2 Std Dev 0.184

The vertical profile graphs show that both sites exhibited a clinograde oxygen curve, starting in May and lasting until August (some mixing was evident to 3 meters depth in July at LL2). During thermal stratification, water density differences prevented the hypolimnion from mixing with upper strata. In the stagnant hypolimnion, decomposition and other redox processes consumed the oxygen supply. Phosphorus stored in the sediments was released into the water column and accumulated in the hypolimnion until the deeper water mixed with the rest of the water column in starting in September. The TP concentration in hypolimnion samples from July at LL2 and August at LL1 (during stratification) may be lower due to sample collection higher in the water column.

For the period of record (1998 and 2009 to 2018), the TP concentration (mg/L) at LL1 was:

- LL1 Surface Mean 0.035
- LL1 Surface Median 0.027
- LL1 Surface Std Dev 0.021
- LL1 Bottom Mean 0.072
- LL1 Bottom Median 0.052
- LL1 Bottom Std Dev 0.056
Figure 15 displays the average annual concentration of total phosphorus at LL1 in 1998 and from 2009 to 2018. The surface samples for total phosphorus have been above the state action level (dotted purple line at 0.020 mg/L) for 91% of the period of record.

At the west basin site (LL2), the TP concentration exceeded the state action level every sample season since 2009 (Figure 16). For the period of record (2009 to 2018), the TP concentration (mg/L) at LL2 was:

- LL2 Surface Mean 0.030
- LL2 Surface Median 0.029
- LL2 Surface Std Dev 0.006
- LL2 Bottom Mean 0.102
- LL2 Bottom Median 0.071
- LL2 Bottom Std Dev 0.084
The Seasonal Kendall test (2009 to 2018) revealed significant trends of increasing TP concentration (Figure 17) in surface water at LL1:

- Slight increase in July and August (0.001 to 0.002 mg/L)
- Larger increase in October (0.016 mg/L)

At LL2, the trend was increasing TP:

- May to July increase 0.002 to 0.004 mg/L
- October increase 0.007 mg/L

At LL2 in August, the trend was negative; the TP concentration declined (0.007 mg/L). August was the only month with a significant trend in productivity at LL2 (Figure 12): chlorophyll-a trended up. No significant trends (p<0.05) were detected at LL1 in May and June, and at both sites in September (no TP data in 2017; n=9).

**Figure 17. Surface TP trend (+ or -) and magnitude of change (Theil-Sen estimator) for LL1 and LL2 from 2009 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 surface total nitrogen concentration was 0.943 mg/L at LL1 and 0.965 mg/L at LL2. Figure 18 shows the 2018 TN concentrations for the two sites at Lake Lawrence.

During stratification, the hypolimnion was anoxic; ammonia-nitrogen was released from the bottom sediments and accumulated in the hypolimnion. Stratification at LL2 was weaker than LL1. The vertical profile shows mixing to 3 meters in July at LL2. Nitrogen compounds from the hypolimnion mixed with surface waters after turnover in September and October.
Figure 18. Concentration of Total Nitrogen at the surface and bottom at LL1 and LL2 in 2018. Two bottom samples, July at LL2 and August at LL1, were collected 0.7 to 0.8 meters from the bottom – closer to the bottom of the metalimnion.

In 2018, the mean surface concentration (mg/L) was:

- LL1 Surface Mean 0.896
- LL1 Surface Median 0.863
- LL1 Surface Std Dev 0.316
- LL2 Surface Mean 1.020
- LL2 Surface Median 0.924
- LL2 Surface Std Dev 0.353

Figures 19 and 20 display the average annual concentrations for total nitrogen for 2009 to 2018 (and 1998 for LL1). The last time the LL1 mean surface concentration was above 0.800 was in 2015.

Figure 19. Average Annual Total Nitrogen at LL1 from 1998 and 2009 to 2018.
At LL2, the highest mean surface TN was in 2018 (1.020 mg/L). The last time the surface TN was near 1.0 was in 2015.

Figure 20. Average Annual Total Nitrogen at LL2 from 2009 to 2018.

The Seasonal Kendall test shows a significant (p<0.05) upward trend (Figure 21) of surface TN concentrations at both sites. In general, TN increased each month from May until October, except for a larger increase in September at LL2. No significant trend was detected at LL1 in September (n=9) and at LL2 in June.

Figure 21. Surface TN trend (+ or -) and magnitude of change (Theil-Sen estimator) for LL1 and LL2 from 2009 to 2018. The lack of a bar means the site did not have a significant trend (p<0.05) for that time period.
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 22 shows the TN to TP ratio of surface waters at the two Lake Lawrence sites. LL1 was nitrogen limited in 2016 and 2017.

**Figure 22. TN:TP at LL1 from 1998 and 2009 to 2018 and LL2 from 2009 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>
<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 LL1, the 2018 TSI results were:
- Chlorophyll-a: 56 eutrophic
- Total Phosphorus: 55 eutrophic
- Secchi Disk: 48 mesotrophic

The average of the three TSI variables is 53, which categorizes LL1 as eutrophic in 2018. Based on the concentration of chlorophyll-a, LL1 was classified as eutrophic every year that data was collected (Figure 23). For the period of record, TP and Secchi measurements resulted in a eutrophic classification less often:
- 73% of summers eutrophic due to high TP concentrations
- 18% of summers eutrophic due to low transparency
Figure 23. LL1 Trophic State Index from 1998 and 2009 to 2018.

The Mann Kendall test reveals a significant trend (p<0.05) of increasing TSI values for all three parameters at LL1; the trend from 2009 to 2018 was toward eutrophication, with higher productivity, increased TP concentrations, and reduced water clarity (Appendix C).

The TSI results for the west basin site LL2 were:
- Chlorophyll-a: 56 eutrophic
- Total Phosphorus: 59 eutrophic
- Secchi Disk: 51 eutrophic

Figure 24. LL2 Trophic State Index from 2009 to 2018

The average TSI score for LL2 was 55. Every summer since 2009, LL2 has been eutrophic based on chlorophyll-a (Figure 24). Also, LL2 has been eutrophic most summers since 2009 with regards to phosphorus enrichment and many summers due to reduced water clarity:
- 80% of summers eutrophic due to high TP concentrations
- 40% of summers eutrophic due to low water clarity

The trend over the last decade at LL2 was higher Secchi Disk TSI values, indicating a trend of reduced transparency. No significant trends were observed for chlorophyll-a and TP TSI values at LL2.
SUMMARY

Thermal Stratification and Increased Temperature Trends
In 2018, the water column at Lake Lawrence was thermally stratified from May to August. The upper layers mixed more readily at the shallower west basin site (LL2) compared to the site (LL1) in the larger, deeper basin. Turnover began in September and was essentially complete in October. The trend from 2009 to 2018 was increased temperature in surface water at both locations from May to August. In September and October, no significant trends existed.

Water Clarity and Reduced Transparency Trends
In 2018, the mean transparency was slightly higher at LL1 compared to LL2. Transparency was higher from May until July at both sites, when productivity was lower. The general trend from 2009 to 2018 was a decrease in transparency for both basins, with the greater loss of water clarity at LL2 (loss of 0.5 meter) compared to LL1 (loss of 0.3 meter).

Chlorophyll-a and Higher Productivity Trends
In 2018, the concentration of chlorophyll-a increased each month from July to October. The Seasonal Kendall test for chlorophyll-a concentration trends (2009 to 2018) indicates the largest increase in productivity over the last decade was at LL1 in October (6 µg/L), typically after turnover. Also, significant (p<0.05) increasing trends occurred at both sites in May (0.3 to 1 µg/L) and August (2 to 3 µg/L).

High Concentrations of Nutrients and Trends
Excess nutrients at Lake Lawrence contributes to eutrophication and algal blooms. The average surface TP concentration was above the action level (0.020 mg/L) for lower mesotrophic lakes in the Puget Sound Lowlands ecoregion. The Seasonal Kendall test (2009 to 2018) revealed significant upward trends for TP in surface water:
- At LL1, smaller increase in July and August and larger increase in October
- At LL2, smaller increase from May to July and a larger increase in October

At the west basin site (LL2), there was a significant decrease in TP concentrations in August in surface waters. No significant trends occurred at May and June at LL1 and at both sites in September (only nine years of data).

The average surface TN concentration was 0.9 to 1.0 mg/L in 2018. The Seasonal Kendall test shows a significant (p<0.05) upward trend of surface TN concentrations in the last decade. The upward trend TN grew each month, from May (0.03 to 0.07 mg/L) to October (0.20 to 0.24 mg/L) at both sites, except for a larger increase in September (0.27 mg/L) at LL2. No significant trend was detected at LL1 in September and at LL2 in June.

Classified as Eutrophic
In 2018, both basins of Lake Lawrence were classified as eutrophic based on an average of the three TSI variables. The trend for TSI values at LL1 from 2009 to 2018 was toward eutrophication, with higher productivity, increased TP concentrations, and reduced water clarity. At LL2, trend analysis of TSI scores indicates a reduction in water clarity. No significant trends were identified for chlorophyll-a and TP concentration at LL2.

Toxic Algae
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. From June to September 2018, volunteers reported algal blooms with surface scum. Seven samples were tested for algal toxins. Microcystin exceeded the Washington State advisory level on September 25, 2018 (Appendix D).
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 the main telephone number or sarah.ashworth@co.thurston.wa.us

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

FUNDING SOURCE:

Thurston County funded monitoring in 2018.

LITERATURE CITED


Thurston County Public Works (TCPW). 2018. Aquatic nuisance weed control prescription: Lake Lawrence, Thurston County.


Appendices

Appendix A. Raw Data
Appendix B. Quality Assurance/Quality Control
Appendix C. Trends
Appendix D. Toxic Algae
### Appendix A. Raw data

**Table A-1 Raw data collected at site LL1 located in the larger eastern basin of Lake Lawrence.**

<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>
<th>Lake Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/23/2018</td>
<td>13:04</td>
<td>6.20</td>
<td>3.20</td>
<td>3</td>
<td>-</td>
<td>0.022</td>
<td>0.215</td>
<td>0.567</td>
<td>1.809</td>
<td>5.1</td>
<td>1.5</td>
<td>QA</td>
</tr>
<tr>
<td>5/23/2018</td>
<td>13:04</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.025</td>
<td>0.174</td>
<td>0.689</td>
<td>1.829</td>
<td>4.7</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>6/27/2018</td>
<td>13:21</td>
<td>6.40</td>
<td>3.10</td>
<td>6</td>
<td>6</td>
<td>0.021</td>
<td>0.207</td>
<td>0.535</td>
<td>0.935</td>
<td>3.7</td>
<td>&lt;0.1</td>
<td>Chlorophyll a and Phaeopigments Composite Sample collected at the following depths (meters): 1, 2, 3</td>
</tr>
<tr>
<td>7/18/2018</td>
<td>12:47</td>
<td>6.90</td>
<td>2.60</td>
<td>3</td>
<td>6.5</td>
<td>0.023</td>
<td>0.460</td>
<td>0.866</td>
<td>2.967</td>
<td>6.9</td>
<td>0.3</td>
<td>Chlorophyll a and Phaeopigments Composite Sample collected at the following depths (meters): 0, 1, 2, 3</td>
</tr>
<tr>
<td>8/15/2018</td>
<td>12:34</td>
<td>6.15</td>
<td>1.95</td>
<td>3</td>
<td>5.5</td>
<td>0.022</td>
<td>0.034</td>
<td>0.861</td>
<td>0.823</td>
<td>14.4</td>
<td>0.5</td>
<td>Chlorophyll a and Phaeopigments Composite Sample collected at the following depths (meters): 1, 3, 4</td>
</tr>
<tr>
<td>9/19/2018</td>
<td>13:35</td>
<td>6.17</td>
<td>1.40</td>
<td>3</td>
<td>-</td>
<td>0.073</td>
<td>0.057</td>
<td>1.530</td>
<td>1.460</td>
<td>19.0</td>
<td>5.6</td>
<td>fishy smell; sunny with slight wind</td>
</tr>
<tr>
<td>10/24/2018</td>
<td>13:20</td>
<td>6.14</td>
<td>1.11</td>
<td>3</td>
<td>5.5</td>
<td>0.048</td>
<td>0.108</td>
<td>0.992</td>
<td>1.440</td>
<td>29.0</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>10/24/2018</td>
<td>13:20</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.051</td>
<td>0.091</td>
<td>0.940</td>
<td>1.190</td>
<td>15.0</td>
<td>19.0</td>
<td>QA</td>
</tr>
</tbody>
</table>
Table A-2 Raw data collected at site LL2 located in the smaller western basin of Lake Lawrence.

<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>
<th>Lake Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/23/2018</td>
<td>14:06</td>
<td>5.50</td>
<td>2.90</td>
<td>3</td>
<td>5.0</td>
<td>0.031</td>
<td>0.072</td>
<td>0.799</td>
<td>0.797</td>
<td>4.0</td>
<td>1.2</td>
<td>Chlorophyll a and Phaeopigments Composite Sample collected at the following depths (meters): 0, 1, 2, 3; lots of algae</td>
</tr>
<tr>
<td>6/27/2018</td>
<td>13:56</td>
<td>6.10</td>
<td>2.30</td>
<td>7</td>
<td>5.6</td>
<td>0.032</td>
<td>0.508</td>
<td>0.568</td>
<td>2.690</td>
<td>6.9</td>
<td>1.1</td>
<td>Chlorophyll a and Phaeopigments Composite Sample collected at the following depths (meters): 1, 2, 3</td>
</tr>
<tr>
<td>6/27/2018</td>
<td>13:56</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.026</td>
<td>0.609</td>
<td>0.699</td>
<td>2.601</td>
<td>6.1</td>
<td>0.6</td>
<td>QA</td>
</tr>
<tr>
<td>7/18/2018</td>
<td>13:25</td>
<td>4.80</td>
<td>1.90</td>
<td>3</td>
<td>4.0</td>
<td>0.031</td>
<td>0.031</td>
<td>1.048</td>
<td>0.800</td>
<td>6.9</td>
<td>1.3</td>
<td>Chlorophyll a and Phaeopigments Composite Sample collected at the following depths (meters): 0, 1, 2</td>
</tr>
<tr>
<td>8/15/2018</td>
<td>12:54</td>
<td>5.50</td>
<td>1.75</td>
<td>3</td>
<td>5.0</td>
<td>0.022</td>
<td>0.247</td>
<td>0.719</td>
<td>1.808</td>
<td>17.1</td>
<td>0.1</td>
<td>Chlorophyll a and Phaeopigments Composite Sample collected at the following depths (meters): 1, 2, 3</td>
</tr>
<tr>
<td>9/19/2018</td>
<td>14:15</td>
<td>3.95</td>
<td>1.25</td>
<td>3</td>
<td>3.1</td>
<td>0.091</td>
<td>0.098</td>
<td>1.650</td>
<td>1.740</td>
<td>20.0</td>
<td>7.0</td>
<td>sunny</td>
</tr>
<tr>
<td>9/19/2018</td>
<td>14:15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.068</td>
<td>0.830</td>
<td>1.510</td>
<td>1.710</td>
<td>21.0</td>
<td>6.3</td>
<td>QA</td>
</tr>
<tr>
<td>10/24/2018</td>
<td>13:57</td>
<td>5.44</td>
<td>1.10</td>
<td>3</td>
<td>4.5</td>
<td>0.063</td>
<td>0.056</td>
<td>1.270</td>
<td>1.150</td>
<td>26.0</td>
<td>8.0</td>
<td>s sunny</td>
</tr>
</tbody>
</table>

Lake Lawrence 2018
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 Lake Lawrence sample days in 2018.

<table>
<thead>
<tr>
<th>Date</th>
<th>SPC (µS/cm)</th>
<th>ODO (% sat)</th>
<th>pH (std units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/23/2018</td>
<td>0</td>
<td>-0.13</td>
<td>0.02</td>
</tr>
<tr>
<td>6/27/2018</td>
<td>-3.3</td>
<td>-0.85</td>
<td>0.07</td>
</tr>
<tr>
<td>7/18/2018</td>
<td>2.2</td>
<td>-0.82</td>
<td>0.11</td>
</tr>
<tr>
<td>8/15/2018</td>
<td>1.5</td>
<td>-0.01</td>
<td>0.17</td>
</tr>
<tr>
<td>9/19/2018</td>
<td>0.1</td>
<td>-0.29</td>
<td>-0.05</td>
</tr>
<tr>
<td>10/24/2018</td>
<td>-0.1</td>
<td>-0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>% difference</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 Lake Lawrence was sampled, field replicates were collected for chlorophyll-a, phaeophytin-a and both nutrients (Table B-2).

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

<table>
<thead>
<tr>
<th>Site</th>
<th>Date/Time</th>
<th>Parameter</th>
<th>Sample</th>
<th>Field Replicate</th>
<th>%RSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>LL1</td>
<td>5/23/2018 13:04</td>
<td>TP surface</td>
<td>0.022</td>
<td>0.025</td>
<td>6.1</td>
</tr>
<tr>
<td>LL1</td>
<td>5/23/2018 13:04</td>
<td>TP bottom</td>
<td>0.215</td>
<td>0.174</td>
<td>10.6</td>
</tr>
<tr>
<td>LL1</td>
<td>5/23/2018 13:04</td>
<td>TN surface</td>
<td>0.567</td>
<td>0.689</td>
<td>9.7</td>
</tr>
<tr>
<td>LL1</td>
<td>5/23/2018 13:04</td>
<td>TN bottom</td>
<td>1.809</td>
<td>1.829</td>
<td>0.6</td>
</tr>
<tr>
<td>LL1</td>
<td>5/23/2018 13:04</td>
<td>chlorophyll-a</td>
<td>5.1</td>
<td>4.7</td>
<td>4.1</td>
</tr>
<tr>
<td>LL1</td>
<td>5/23/2018 13:04</td>
<td>phaeophytin-a</td>
<td>1.5</td>
<td>1.4</td>
<td>2.3</td>
</tr>
<tr>
<td>LL1</td>
<td>10/24/2018 13:20</td>
<td>TP surface</td>
<td>0.048</td>
<td>0.051</td>
<td>3.0</td>
</tr>
<tr>
<td>LL1</td>
<td>10/24/2018 13:20</td>
<td>TP bottom</td>
<td>0.108</td>
<td>0.091</td>
<td>8.5</td>
</tr>
<tr>
<td>LL1</td>
<td>10/24/2018 13:20</td>
<td>TN surface</td>
<td>0.992</td>
<td>0.940</td>
<td>2.7</td>
</tr>
<tr>
<td>LL1</td>
<td>10/24/2018 13:20</td>
<td>TN bottom</td>
<td>1.440</td>
<td>1.190</td>
<td>9.5</td>
</tr>
<tr>
<td>LL1</td>
<td>10/24/2018 13:20</td>
<td>chlorophyll-a</td>
<td>29.0</td>
<td>15.0</td>
<td>31.8</td>
</tr>
<tr>
<td>LL1</td>
<td>10/24/2018 13:20</td>
<td>phaeophytin-a</td>
<td>9.3</td>
<td>19.0</td>
<td>34.3</td>
</tr>
<tr>
<td>LL2</td>
<td>6/27/2018 13:56</td>
<td>TP surface</td>
<td>0.032</td>
<td>0.026</td>
<td>11.3</td>
</tr>
<tr>
<td>LL2</td>
<td>6/27/2018 13:56</td>
<td>TP bottom</td>
<td>0.508</td>
<td>0.609</td>
<td>9.0</td>
</tr>
<tr>
<td>LL2</td>
<td>6/27/2018 13:56</td>
<td>TN surface</td>
<td>0.568</td>
<td>0.699</td>
<td>10.3</td>
</tr>
<tr>
<td>LL2</td>
<td>6/27/2018 13:56</td>
<td>phaeophytin-a</td>
<td>1.1</td>
<td>0.6</td>
<td>30.2</td>
</tr>
<tr>
<td>LL2</td>
<td>9/19/2018 14:15</td>
<td>TP surface</td>
<td>0.091</td>
<td>0.068</td>
<td>14.5</td>
</tr>
<tr>
<td>LL2</td>
<td>9/19/2018 14:15</td>
<td>TP bottom</td>
<td>0.098</td>
<td>0.830</td>
<td>78.9</td>
</tr>
<tr>
<td>LL2</td>
<td>9/19/2018 14:15</td>
<td>TN surface</td>
<td>1.650</td>
<td>1.510</td>
<td>4.4</td>
</tr>
<tr>
<td>LL2</td>
<td>9/19/2018 14:15</td>
<td>TN bottom</td>
<td>1.740</td>
<td>1.710</td>
<td>0.9</td>
</tr>
<tr>
<td>LL2</td>
<td>9/19/2018 14:15</td>
<td>chlorophyll-a</td>
<td>20.0</td>
<td>21.0</td>
<td>2.4</td>
</tr>
<tr>
<td>LL2</td>
<td>9/19/2018 14:15</td>
<td>phaeophytin-a</td>
<td>7.0</td>
<td>6.3</td>
<td>5.3</td>
</tr>
</tbody>
</table>
Appendix C. Trends

Trends 2009 to 2018

Lake Lawrence Site LL1

Chlorophyll-a concentration (µg/L)
Trends 2009 to 2018

Lake Lawrence
Site LL1

Secchi Depth (meters)
Trends 2009 to 2018

Lake Lawrence Site LL1

Surface Temperature (°C)

- LL1 - Surface Temperature (°C) - May
  Increasing p < 0.05
  Sen Slope 1.86

- LL1 - Surface Temperature (°C) - June
  Increasing p < 0.05
  Sen Slope 1.47

- LL1 - Surface Temperature (°C) - July
  Increasing p < 0.05
  Sen Slope 1.29

- LL1 - Surface Temperature (°C) - August
  Increasing p < 0.05
  Sen Slope 0.32

- LL1 - Surface Temperature (°C) - September
  Decreasing p < 0.05
  Sen Slope -1.06
  n=9

- LL1 - Surface Temperature (°C) - October
  No Trend p < 0.05
Lake Lawrence 2018

Trends 2009 to 2018

Lake Lawrence
Site LL1

Total Nitrogen (mg/L)
Trends 2009 to 2018

Lake Lawrence
Site LL1

Total Phosphorus (mg/L)

2016 data; surface and bottom may have been transposed; bottom was lower 0.14 mg/L. Sen slope and significance were not affected.

Increasing p < 0.05
Sen Slope 0.001

No Trend p < 0.05

Increasing p < 0.05
Sen Slope 0.002

No Trend p < 0.05

n=9

Increasing p < 0.05
Sen Slope 0.016
Trends 2009 to 2018

Lake Lawrence
Site LL2

Chlorophyll-a concentration (µg/L)
Trends 2009 to 2018
Lake Lawrence
Site LL2
Secchi Depth (meters)
Trends
2009 to 2018
Lake Lawrence
Site LL2

Surface Temperature
(°C)
Lake Lawrence 2018

Trends
2009 to 2018

Lake Lawrence
Site LL2

Total
Nitrogen
(mg/L)

LL2 - Total Surface Nitrogen (mg/L) - May
Increasing p < 0.05
Sen Slope 0.071

LL2 - Total Surface Nitrogen (mg/L) - June
No Trend p < 0.05

LL2 - Total Surface Nitrogen (mg/L) - July
Increasing p < 0.05
Sen Slope 0.077

LL2 - Total Surface Nitrogen (mg/L) - August
Increasing p < 0.05
Sen Slope 0.094

LL2 - Total Surface Nitrogen (mg/L) - September
Increasing p < 0.05
Sen Slope 0.271
n=9

LL2 - Total Surface Nitrogen (mg/L) - October
Increasing p < 0.05
Sen Slope 0.195
Trends 2009 to 2018
Lake Lawrence Site LL2
Total Phosphorus (mg/L)
Lake Lawrence 2018

Trends 2009 to 2018
Lake Lawrence Site LL1
TSI Scores

Trends 2009 to 2018
Lake Lawrence Site LL2
TSI Scores
Appendix D. Toxic Algae

Lake Lawrence Algal Toxins

- Anatoxin-a Advisory Level 1.0 µg/L
- Microcystin Advisory Level 6.0 µg/L

Data points for Anatoxin-a and Microcystin from 1/22/2010 to 12/7/2019.