Lake Sawyer Water Quality
Water Quality Monitoring Results for Water Years 2015-2016

August 2017

King County

Department of Natural Resources and Parks
Water and Land Resources Division
Science Section
King Street Center, KSC-NR-0600
201 South Jackson Street, Suite 600
Seattle, WA 98104

Lake Sawyer Water Quality
Water Quality Monitoring Results for Water Years 2015 and 2016

Prepared for:
The City of Black Diamond

Submitted by:
King County Lakes and Streams Monitoring Group
King County Water and Land Resources Division
Department of Natural Resources and Parks

The King County
Lake Stewardship Program

King County
Department of
Natural Resources and Parks
Water and Land Resources Division

Alternate Formats Available

206-477-4800 TTY Relay: 711

Acknowledgements

Special thanks to volunteer monitors Glenn Ross and Tom Bowden for their time and effort in collecting water quality data for the City of Black Diamond and King County. We would also like to thank long-time project manager Sally Abella, who retired from the King County Department of Natural Resources and Parks in October 2015. Additional thanks go to staff members at the King County Environmental Lab.

Citation

King County. 2017. Lake Sawyer Water Quality: Water Quality Monitoring Results for Water Years 2015 and 2016. Prepared by Daniel Nidzgorski, Water and Land Resources Division. Seattle, Washington.

Table of Contents

Figures

Tables

EXECUTIVE SUMMARY

The King County Lake Stewardship Program works with resident volunteers to monitor water quality and lake use, and also to maintain residents' interest in lake health. Lake Sawyer, in the City of Black Diamond, has been monitored since 1994. Beginning in 2005, monitoring of Lake Sawyer has been funded by agreements between King County and the City of Black Diamond.

Volunteer stewards monitored Lake Sawyer year-round in 2015 and 2016, with daily measurements of precipitation and lake level and weekly measurements of water temperature and Secchi depth (water clarity). Twice a month during May-October 2015 and 2016, volunteer stewards also collected water samples at 1 m depth for biological and chemical analyses (e.g. chlorophyll, nitrogen, phosphorus). In May and August, additional measurements and samples were collected at mid-depth and 1 m above the lake bottom. These lake profiles help characterize conditions throughout the water column when the lake is thermally stratified.

Lake Sawyer continued to be categorized as mesotrophic-oligotrophic, with moderate algal productivity and water quality. Average nitrogen to phosphorus (N:P) ratios were sometimes higher than 25 and sometimes lower, indicating that algal productivity was limited by phosphorus during some periods and co-limited by both nitrogen and phosphorus during other periods. The periods of nutrient co-limitation (N:P below 25) were more favorable for cyanobacteria dominating the algal community.

In 2015, King County's Lake Stewardship Program sampled all 36 lakes in the program for cyanobacterial (blue-green algae) toxins. These toxins (microcystin, a liver toxin, and anatoxin-*a*, a neurotoxin) can cause illness or death in people and animals. Samples were collected in September and October, when cyanobacteria growth is often highest. No toxins were detected in Lake Sawyer.

Trend analyses of the long-term monitoring data found a slight decrease in chlorophyll-*a* trophic state index (TSI) values over time. While algal productivity in Lake Sawyer has been decreasing since 1994, water clarity (as measured by Secchi depth) has not shown a corresponding increase.

The long-term monitoring conducted by volunteer stewards at Lake Sawyer has built an invaluable dataset for understanding water quality and lake health over time. Continued monitoring will help grow this dataset, increasing our understanding of how the lake reacts to environmental variability and human influences. The long-term dataset makes it possible to conduct statistically robust tests for trends, as well as to detect any potentially detrimental changes that may occur in the lake. In addition, long-term monitoring provides a solid scientific basis to guide lake management decisions by identifying emergent management needs and evaluating the effectiveness of management actions.

1.0 PROGRAM OVERVIEW

The Lake Stewardship Program has been working with dedicated resident volunteers to monitor Lake Sawyer since 1994. Beginning in 2006, the City of Black Diamond has contracted with King County to continue the volunteer monitoring program on Lake Sawyer.

Specific objectives of the Lake Stewardship Program include: (1) gathering baseline data to assess long-term trends; (2) defining seasonal and water-column variability; (3) identifying potential concerns, and proposing possible management solutions when feasible; (4) educating lake residents, lake users, and policy makers about lake water quality; and (5) understanding the nature and character of the smaller lakes in King County.

Lake Sawyer was monitored year-round (Level I monitoring) to observe the hydrological balance between the lake and its watershed, as well as to characterize lake level fluctuations throughout the entire year. Volunteers measured lake level and precipitation data each day at lake-side docks. They also made weekly measurements of water temperature and Secchi depth at a mid-lake sampling station. Level I data were reported to King County each quarter, quality-checked, and uploaded to the Small Lakes Data and Information webpage (http://green2.kingcounty.gov/SmallLakes).

From May through October, Lake Sawyer also received twice-monthly monitoring and water sampling (Level II monitoring) to measure nutrient and algal concentrations. At the mid-lake sampling station, volunteers also collected water samples from 1 m depth for chlorophyll, nutrients, and other chemical analyses. These water samples were picked up by Lake Stewardship staff and delivered to the King County Environmental Laboratory. Data were analyzed and uploaded to the Small Lakes Data and Information webpage

Both Level I and Level II volunteers routinely recorded their observations of recreational lake use, algal blooms, and weather conditions that may have had an effect on measurements. Volunteers were provided with training, equipment, and ongoing technical assistance. They were also invited to attend the annual Lake Stewardship Program training workshops held each year in late April.

2.0 WHAT WE MEASURE AND WHY

2.1 Types of Monitoring

Level I monitoring measures a few key parameters year-round. **Precipitation** and **lake level** are measured daily at lake-side docks. **Water temperature** (at 1 m depth) and **Secchi depth** are measured weekly at a mid-lake sampling station located over the deepest part of the lake.

Level II monitoring is conducted twice-monthly from May through October, at a mid-lake sampling station located over the deepest part of the lake. In addition to **water temperature** (at 1 m depth) and **Secchi depth**, water samples are also collected from 1 m depth and analyzed for:

- **Chlorophyll-*a***
- **Pheophytin**
- **Total nitrogen**
- **Total phosphorus**

Twice a year, in May and August, Level II monitoring includes a **water column profile** that collects temperature measurements and water samples from 1 m depth, mid-column, and 1 m above the lake bottom. These samples are analyzed for the usual Level II parameters plus:

- Inorganic nitrogen, as **ammonia** (NH_3) and **nitrate/nitrite** (NO_2/NO_3)
- Inorganic phosphorus, as **orthophosphate** (OPO_4)
- **Alkalinity**
- **Water color** (UV254)

2.2 Parameters

Physical parameters

Precipitation and **lake level** help us understand a lake's hydrological balance and track seasonal trends and long-term changes. Relationships between precipitation and lake level reflect watershed characteristics and groundwater inputs. Precipitation is measured with a plastic volumetric rain gauge mounted in an open area. Lake level is measured using a staff plate mounted to a fixed structure such as a dock.

Secchi depth is a measure of water clarity or transparency. A 20-cm (8-in) black-and-white Secchi disk is lowered into the lake until it disappears from view. Secchi depth is shallower when there are more suspended particles in the lake, such as sediment or algae.

Water temperature can affect the growth rates of plants and algae. In addition, cooler or warmer water temperatures favor different species of fish and other aquatic organisms. Temperature measurements in a water column profile also show the extent of lake stratification. In a stratified lake, surface waters are warmer than deeper, cooler waters, which reduces mixing between the two layers.

Nutrients

Phosphorus and **nitrogen** are naturally occurring elements necessary for growth and reproduction in both plants and animals. Fertilizer, pet waste, wastewater, and other human activities can increase the concentration of these nutrients in a lake. In lakes of the Puget Sound lowlands, biological productivity is most often limited by the amount of available phosphorus in the water. Increases in phosphorus can lead to more frequent and dense algae blooms – a nuisance to residents and lake users, and a potential health threat if blooms become dominated by cyanobacteria (blue-green algae) that can produce toxins.

The **ratio of total nitrogen to total phosphorus (N:P)** indicates whether nutrient conditions favor the growth of cyanobacteria (blue-green algae). When N:P ratios are near or below 25, nitrogen is as likely to be the limiting nutrient as phosphorus. Certain cyanobacteria species can "fix" nitrogen (convert inert atmospheric N_2 into ammonia, which is biologically available), which gives them a competitive advantage over other algae when nitrogen is limiting.

Nutrients in a lake can be part of either organic or inorganic molecules. Inorganic forms of nitrogen are **ammonia** (NH_3) and **nitrate/nitrite** (NO_2/NO_3); the inorganic form of phosphorus is **orthophosphate** (PO_4). In deeper waters when dissolved oxygen concentrations are low, nutrients are found primarily in inorganic forms.

Algal pigments

Chlorophyll-*a* concentration is an indicator of the abundance of phytoplankton (algae) in a lake. Chlorophyll-*a* is a pigment necessary for algae to photosynthesize and store energy. While all algal cells contain some chlorophyll-*a*, the amount varies depending on the species. For example, some cyanobacteria have other light-catching pigments, and little chlorophyll-*a* compared to other algal types (e.g., diatoms and chlorophytes), so chlorophyll-*a* concentrations may not always correlate with the abundance of cyanobacteria.

Pheophytin is a product of chlorophyll decomposition and is generally measured along with chlorophyll-*a* as an indicator of how fresh or viable the phytoplankton in the sample are. Bottom sediments will contain a large amounts of pheophytin compared to chlorophyll-*a*, while actively-growing algae from the water column will have very little pheophytin present.

Other parameters

Microcystin and **anatoxin-*a*** are toxins produced by some species of cyanobacteria (blue-green algae). Microcystin is a liver toxin, and anatoxin-*a* is a neurotoxin. These toxins can cause illnesses in people and animals, with symptoms such as nausea and vomiting or numbness and tingling. High concentrations of cyanobacterial toxins are potentially lethal.

Alkalinity measures the buffering capacity of a lake, or the ability to resist changes in pH.

Water color is an index of the concentration of dissolved organic compounds in the water. It is measured as the absorbance of a specific wavelength of light (ultraviolet light at 254 nm) that is absorbed by many dissolved organic compounds.

Trophic State Index

The **Trophic State Index (TSI)**, developed and first presented by Robert Carlson in 1977, is a common index of a lake's biological productivity. TSI values are scaled between 0 and 100, which allows comparisons water quality over time and among lakes.

- Lakes with TSI below 40 are classified as *oligotrophic*, or low-productivity, lakes. These lakes have low nutrient concentrations and little algal growth.
- Lakes with TSI between 40 and 50 are classified as *mesotrophic*, or moderate-productivity, lakes. These have moderate nutrient concentrations and moderate algal growth.
- Lakes with TSI above 50 are classified as *eutrophic*, or high-productivity, lakes. These lakes have high nutrient concentrations and high algal growth.

A lake may fall into any of these categories naturally, depending on the conditions in the watershed, climate, vegetation, rock and soil types, as well as the shape and volume of the lake basin. Human activities such as land development, wastewater, and agricultural practices can also increase productivity, which is known as "cultural eutrophication."

TSI values are calculated using three related parameters: water clarity (Secchi depth), total phosphorus, and chlorophyll-*a.* The index assumes that higher phosphorus availability drives more algal production (and hence more chlorophyll-*a*), and more algal particles in the water decrease water clarity, and vice versa. Each parameter is used to calculate an independent estimate of the TSI.

In most cases, the three TSI estimates are very close together. Substantial divergence among the TSI estimates warrant further investigation. This divergence may be due to data errors, or it may be due to special conditions in the lake that alter the usual relationships among nutrients, chlorophyll, and water clarity. For example, high concentrations of humic compounds will cause a dark water color that also reduces water clarity, independent of algal productivity.

3.0 DATA SUMMARY

Tables 2 summarizes data from 2015 and 2016, giving the minimum, mean (average), and maximum values measured for each parameter. This includes annual summary values for Secchi and temperature, which were measured year-round as part of Level I monitoring, and May-October summary values for all parameters.

Table 2. Annual and May-October summary statistics, 2015 and 2016.

	Parameter	Minimum	Mean	Maximum
2015 Annual	Secchi depth	3.7	5.0	7.7
	Temperature	6.0	14.9	26.0
2015 May-Oct.	Secchi depth	3.8	5.0	6.0
	Temperature	15.0	21.2	25.0
	Chlorophyll-*a*	1.2	6.2	36.1
	Total Nitrogen	199.0	346.3	641.0
	Total Phosphorus	5.4	13.5	42.2
	N:P ratio	15.2	30.6	50.4
2016 Annual	Secchi depth	3.2	4.7	6.8
	Temperature	4.5	12.1	24.0
2016 May-Oct.	Secchi depth	4.3	5.8	7.5
	Temperature	16.0	20.8	24.0
	Chlorophyll-*a*	1.3	3.0	4.3
	Total Nitrogen	234.0	424.1	920.0
	Total Phosphorus	9.6	14.8	22.7
	N:P ratio	15.7	31.1	69.7

Note: Secchi depth in m. Temperature in degrees Celsius. Chlorophyll-*a*, pheophytin, total nitrogen, and total phosphorus in µg/L.

4.0 PHYSICAL PARAMETERS

4.1 Lake Level and Precipitation

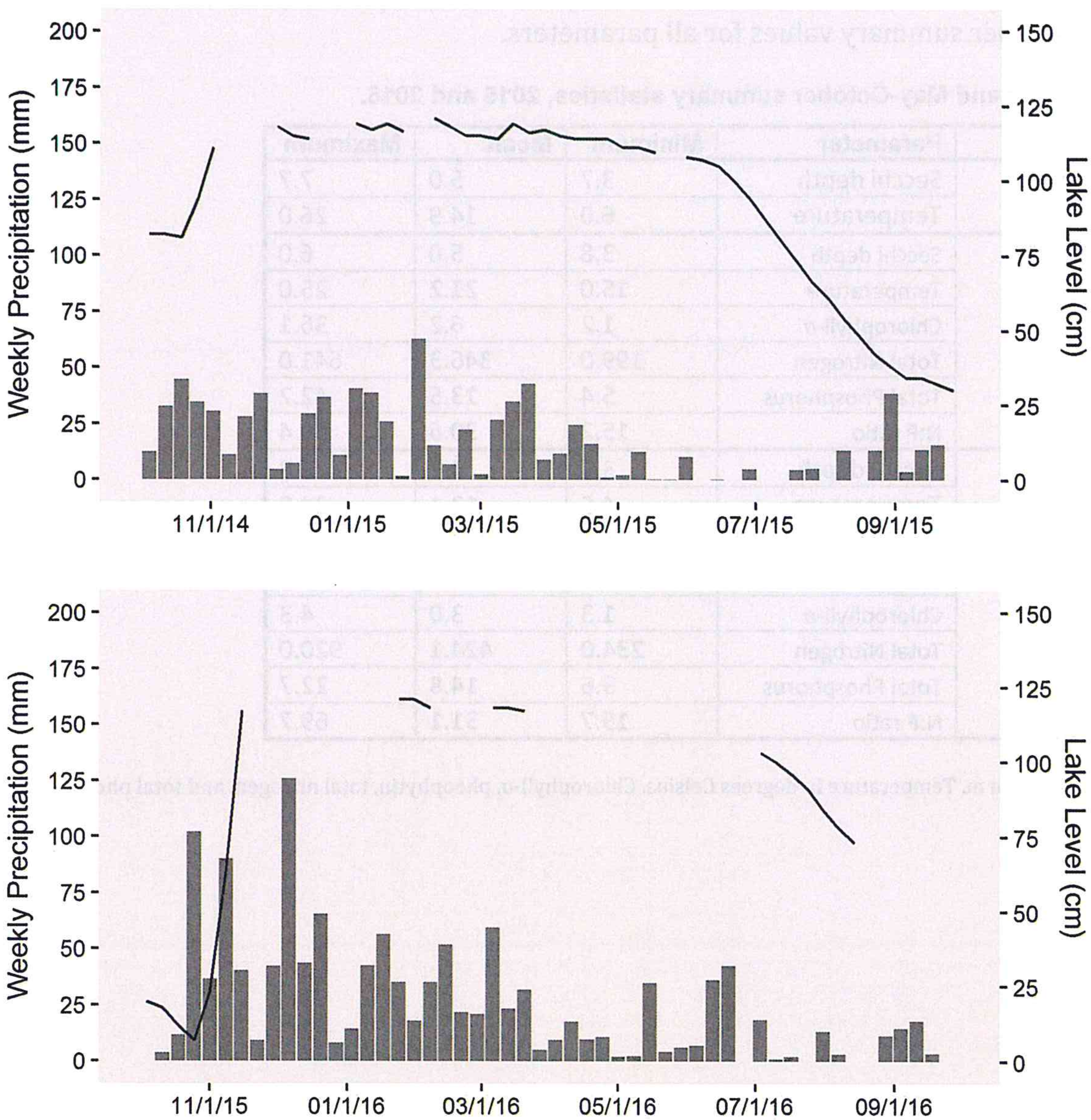

Figure 1. Weekly mean lake level (line) and total weekly precipitation (bars), water year 2015 (top) and 2016 (bottom)..

Lake level was fairly stable from December 2014 through June 2015, and then decreased substantially in July-October 2015. Lake level increased rapidly, by over 1 m, in October-November 2015.

4.2 Secchi Depth

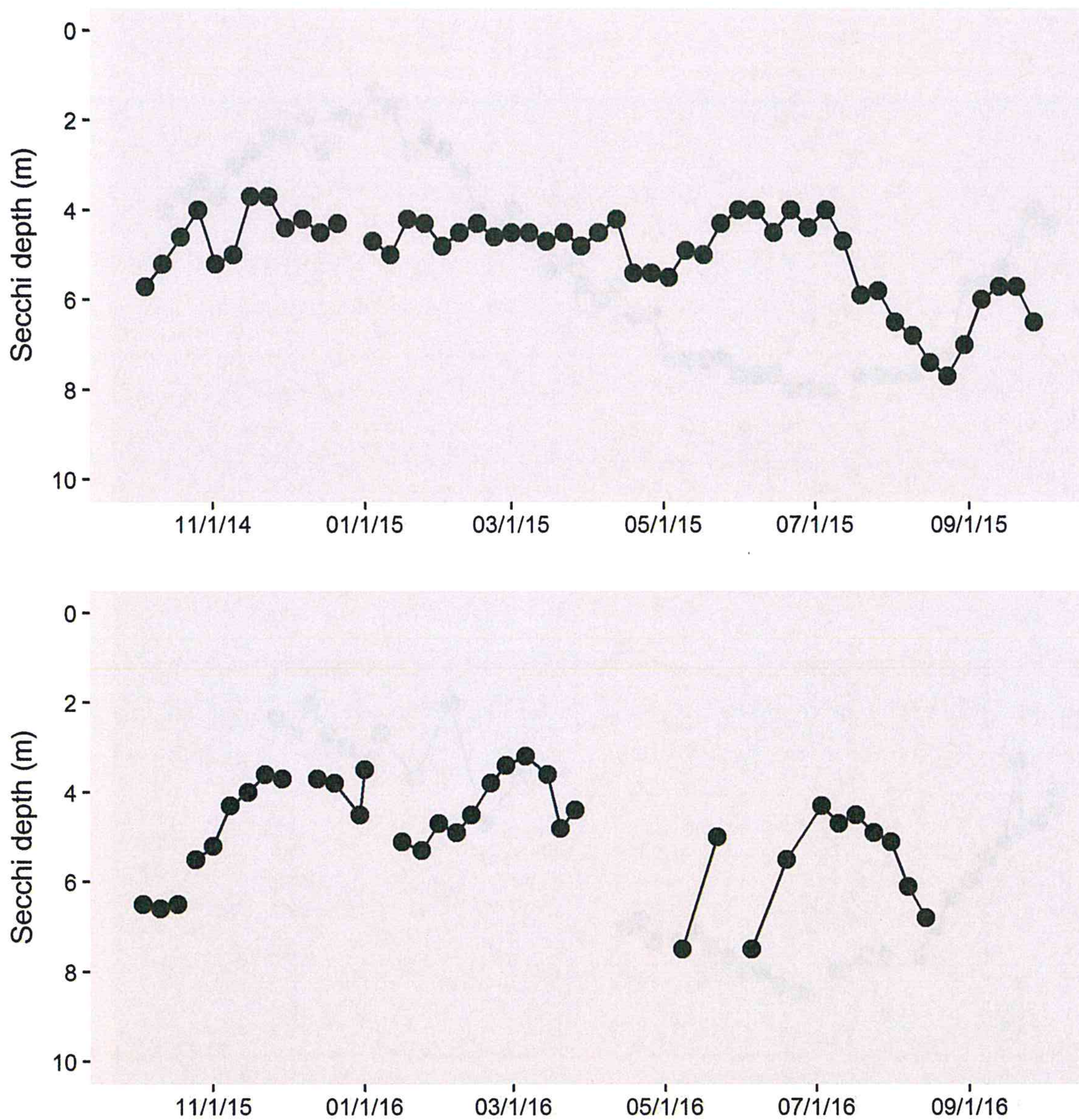

Figure 2. Secchi depth, water year 2015 (top) and 2016 (bottom). Note the inverted Y-axis.

Lake Sawyer had moderately deep Secchi depth readings throughout 2015 and 2016 (note that weekly L1 data collection ended in March 2016; later data are from twice-monthly L2 measurements). In 2015, Secchi depth readings were deepest (greatest water clarity) in the fall, and shallower in other seasons.

4.3 Water Temperature

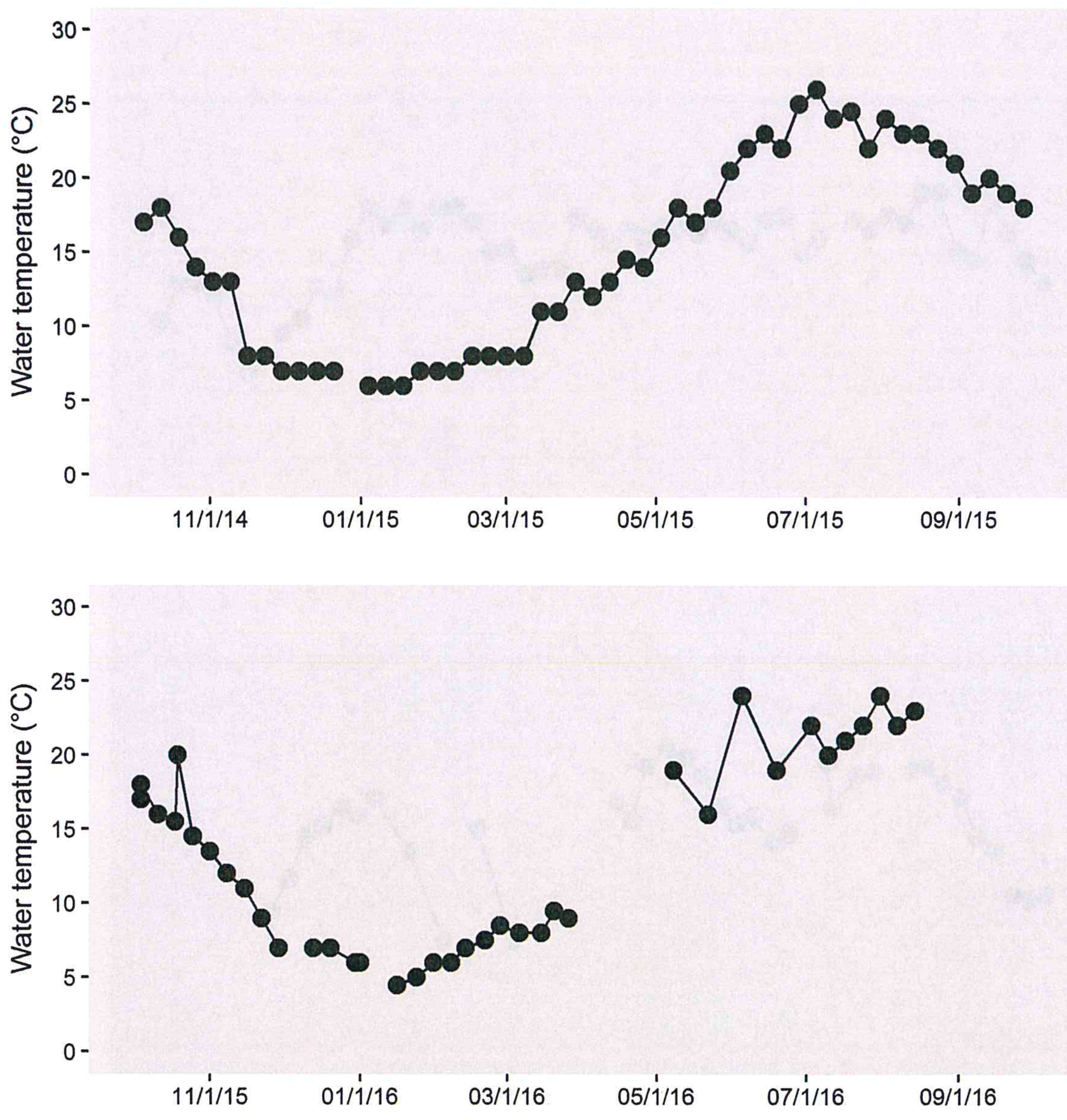

Figure 3. Water temperature at 1 m for water years 2015 (top) and 2016 (bottom).

Lake temperatures in 2015 followed a typical pattern for small lakes in the region, with cooler temperatures in the winter and spring, maximum temperatures occurring in late summer, and temperatures cooling by late September. Temperatures in 2016 appeared to follow the same pattern, though data gaps in April and September obscured some of the details (note that weekly L1 data collection stopped in March 2016; later data are from twice-monthly L2 measurements).

Average May-October water temperatures were higher in 2015 and 2016 than the previous few years. Long-term monitoring data suggest a slight increase in average temperatures, but the trend is not statistically robust.

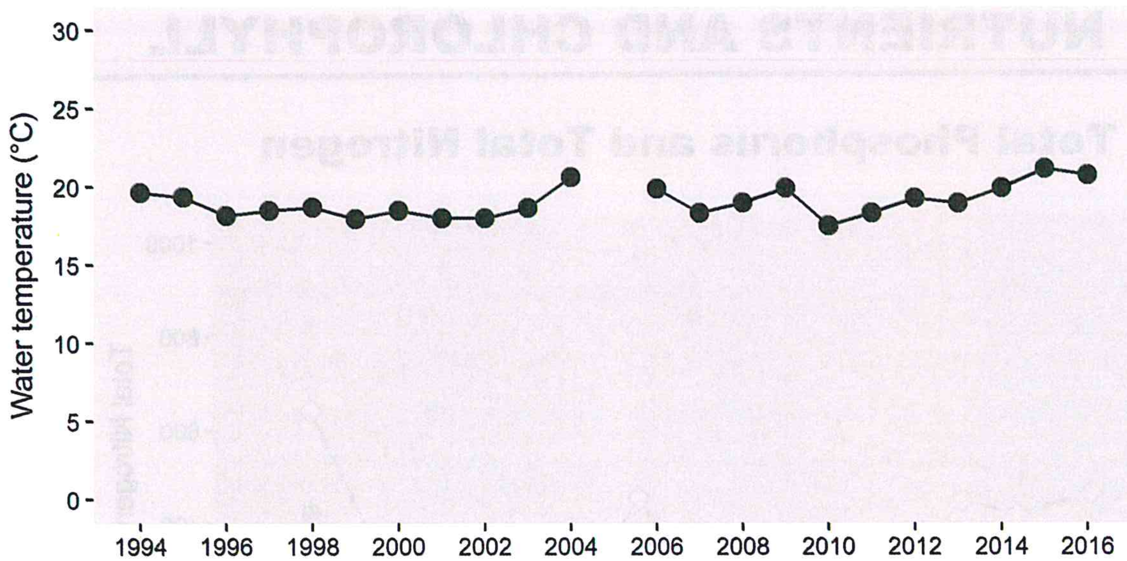

Figure 4. Average May-October water temperature at 1 m.

5.0 NUTRIENTS AND CHLOROPHYLL

5.1 Total Phosphorus and Total Nitrogen

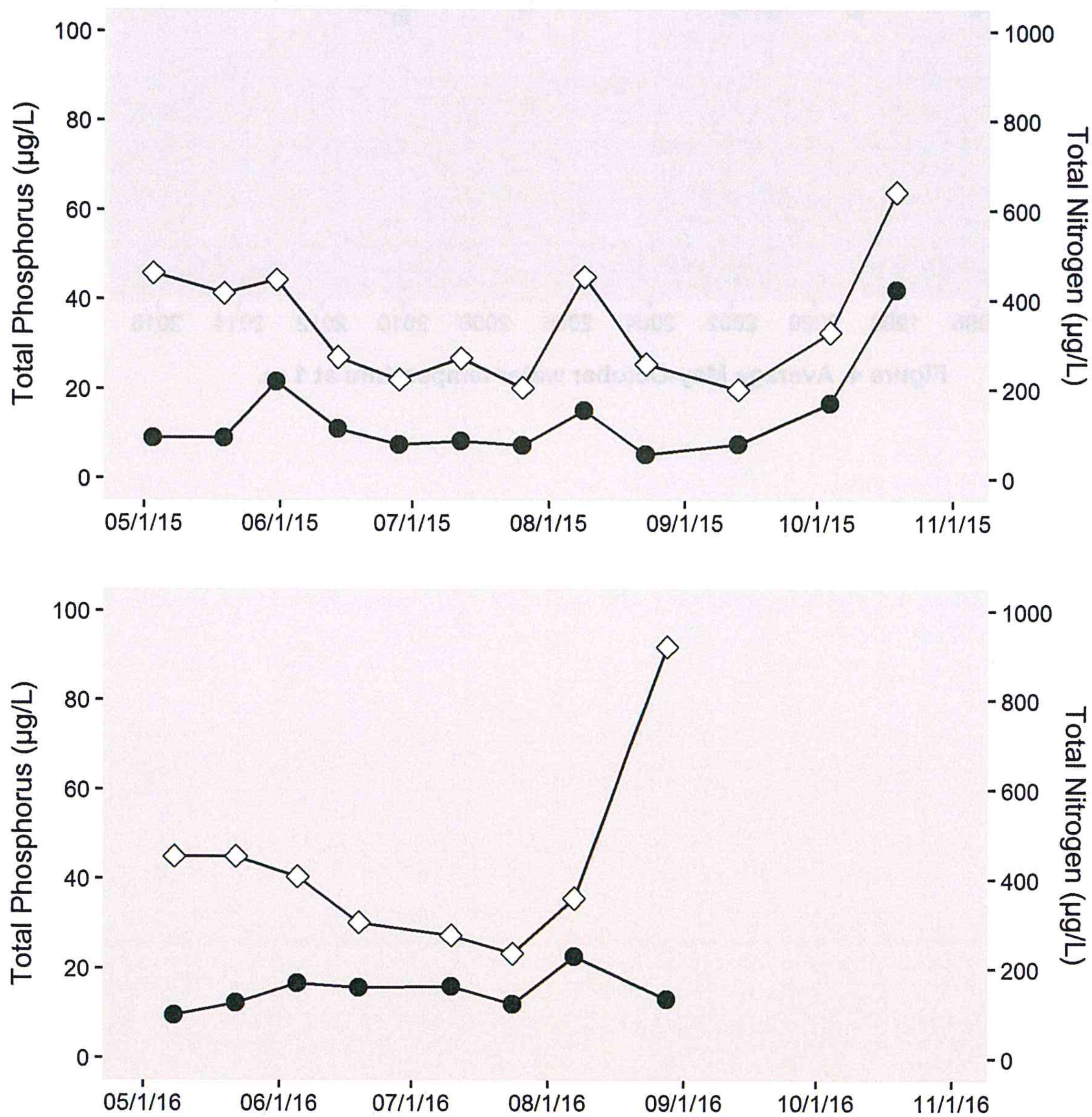

Figure 5. Total phosphorus (black circles) and total nitrogen (white diamonds) concentrations in µg/L, May-Oct 2015 (top) and 2016 (bottom).

Nutrient concentrations varied throughout the May-October monitoring period in both years, with no clear seasonal patterns.

5.2 Nutrient ratios

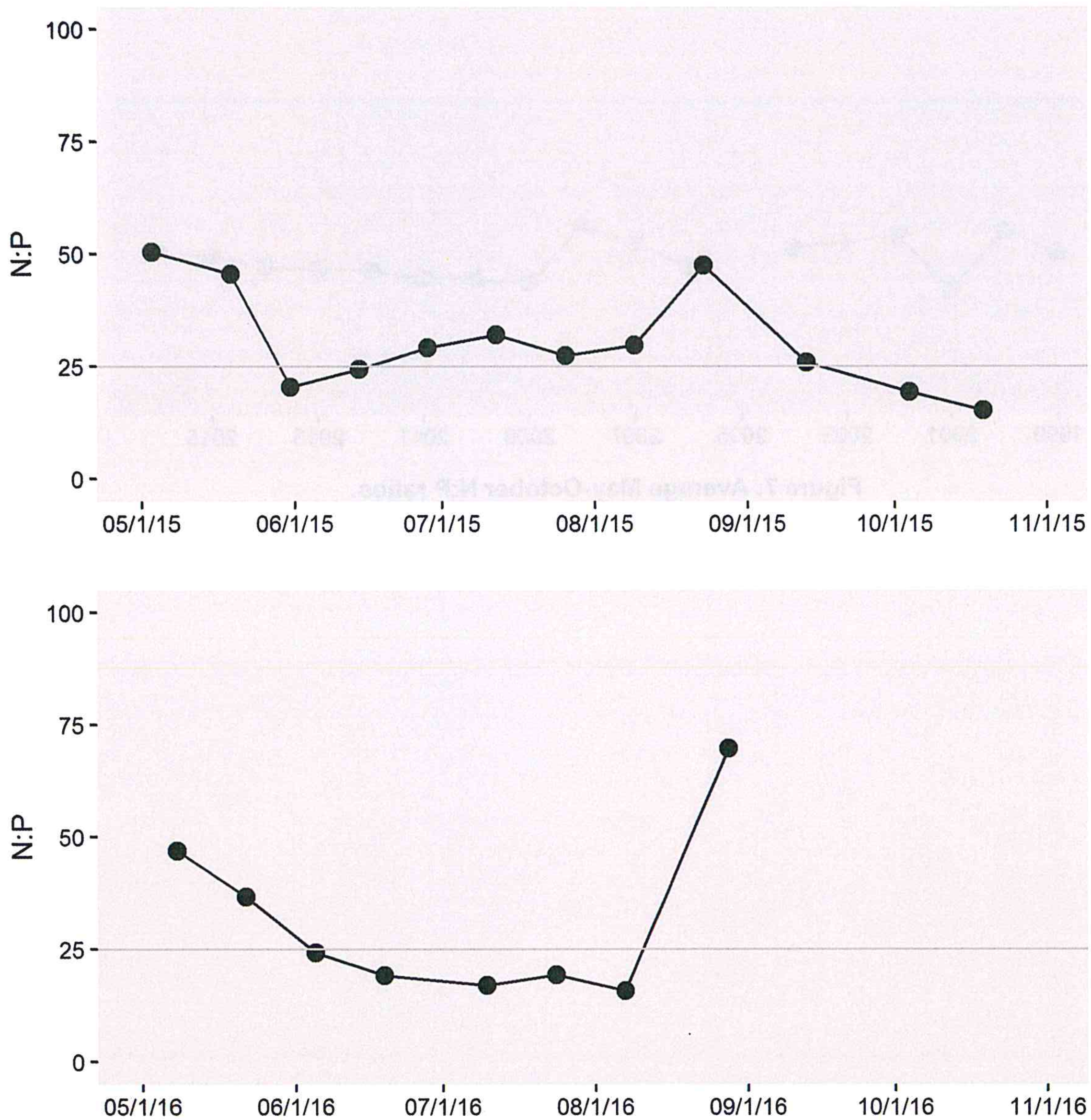

Figure 6. N:P ratios, May-October 2015 (top) and 2016 (bottom).

The ratio of total nitrogen to total phosphorus (N:P ratio) in Lake Sawyer during the May-October sampling period was higher in 2015 than 2016. While phosphorus was most often the limiting nutrient in the lake in 2015 (N:P above 25), there were times that the N:P ratio indicated co-limitation by both nitrogen and phosphorus (N:P below 25). Co-limitation was likely present throughout most of summer 2016.

The 2015 and 2016 average N:P ratios continued to increase slightly over previous years. Although there is a recent increasing trend from 2009-present, the long-term monitoring data show that this is within the range of historic variability in Lake Sawyer. Overall, there is no trend in average N:P ratios since 1999.

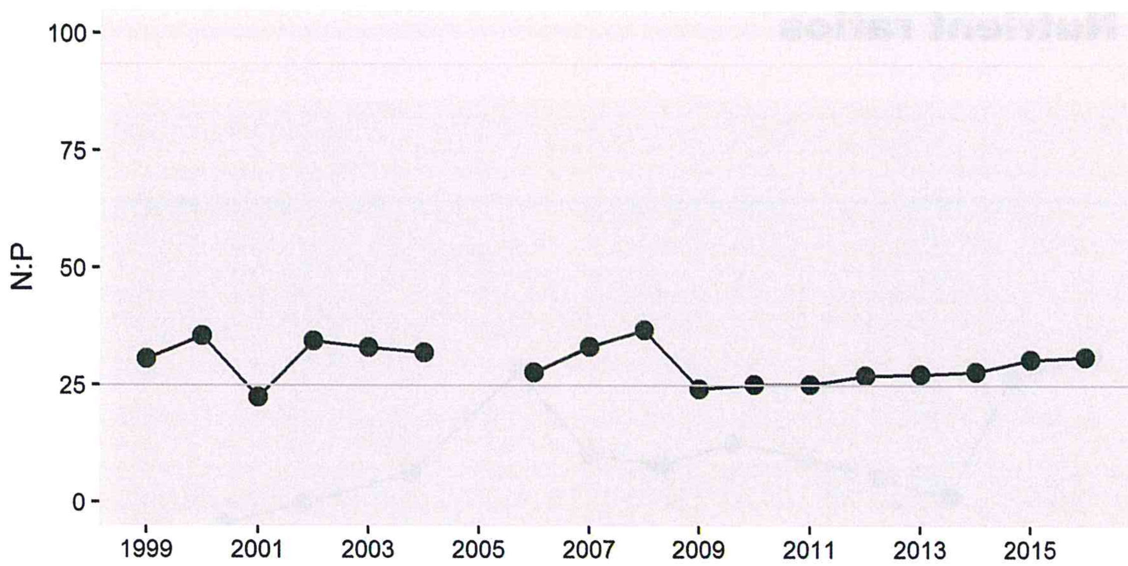

Figure 7. Average May-October N:P ratios.

5.3 Chlorophyll-*a*

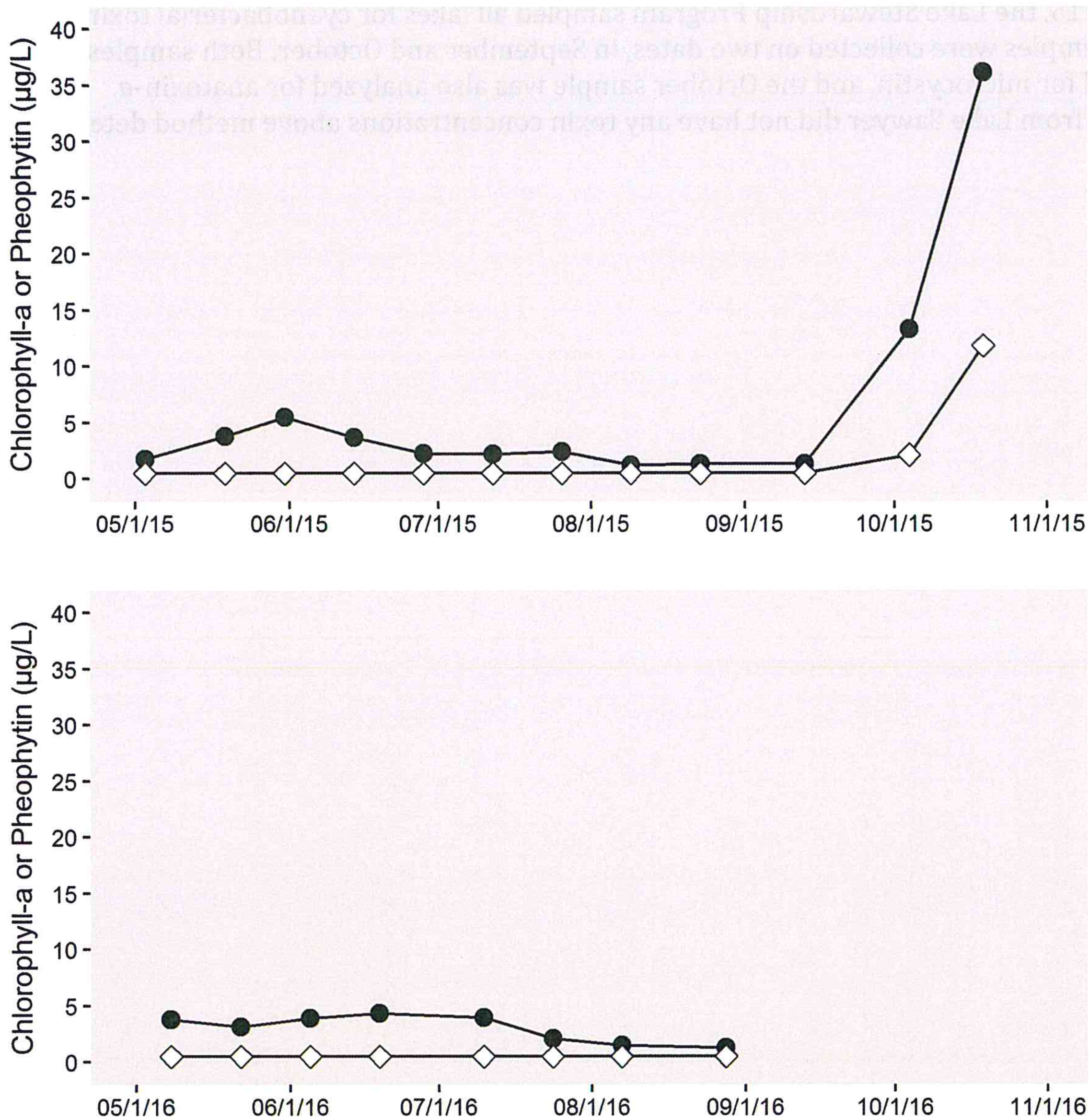

Figure 8. Chlorophyll-*a* (black circles) and pheophytin (white diamonds) concentrations, May-October 2015 (top) and 2016 (bottom).

Concentrations of chlorophyll-*a* in Lake Sawyer were low throughout summer 2015 and 2016, but increased sharply in fall 2015. Water samples were not collected in September/October 2016, so it is not known if the fall increase was also present that year. Pheophytin remained below or near detection limits all summer, indicating that the samples were fresh and stored properly.

5.4 Cyanobacterial toxins

In fall 2015, the Lake Stewardship Program sampled all lakes for cyanobacterial toxins. Water samples were collected on two dates, in September and October. Both samples were analyzed for microcystin, and the October sample was also analyzed for anatoxin-*a*. Samples from Lake Sawyer did not have any toxin concentrations above method detection limits.

6.0 TROPHIC STATE INDEX

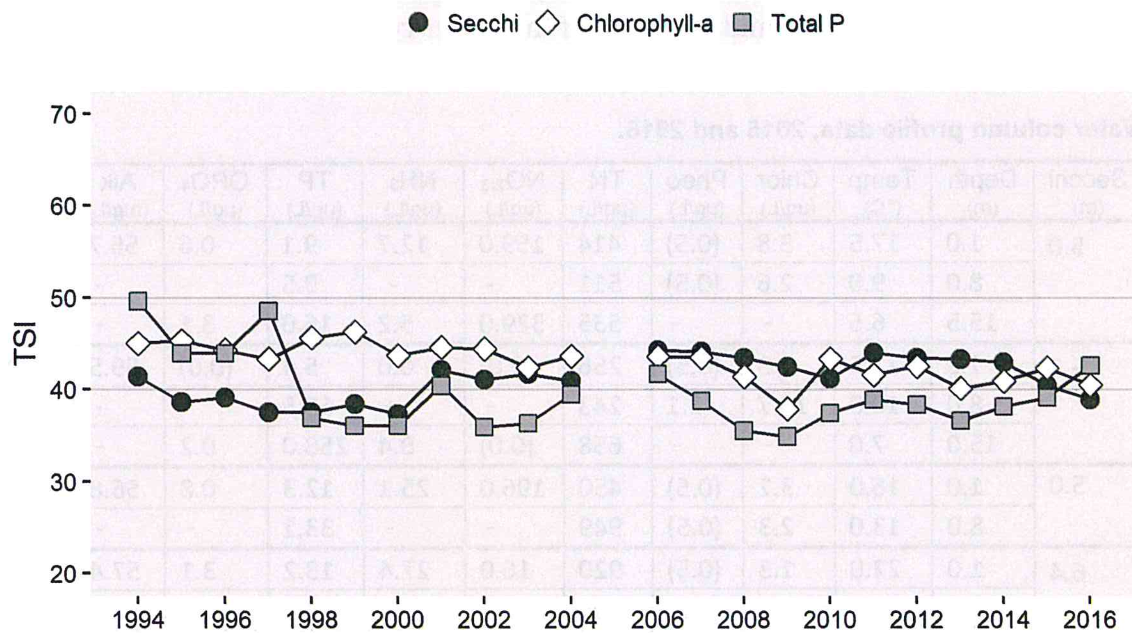

Figure 9. Average May-October Trophic State Indices.

In 2015 and 2016, all three TSI values for Lake Sawyer remained close together and within the mesotrophic-oligotrophic range. When assessing long-term trends, it is important to note that total phosphorus analytical methods changed between 1997 and 1998 (likely accounting for the apparent drop in total phosphorus TSI). We therefore only consider 1998 and later data for total-phosphorus TSI values, which do not show a discernable trend.

In contrast, chlorophyll-*a* TSI values have decreased slightly over time ($p=0.001$, $R^2=0.41$), with an average decrease of 1.5 per decade. While algal productivity in Lake Sawyer has been decreasing since 1994, water clarity (as measured by Secchi depth) has not shown a corresponding increase. Continued monitoring of Lake Sawyer will be beneficial in catching any changes that occur in the future.

7.0 WATER COLUMN PROFILE

In May and August, water was collected at the mid-lake sampling station from three depths in a water-column profile: 1 m, the middle depth of the water column, and 1 m from the lake bottom.

Table 3. Water column profile data, 2015 and 2016.

Date	Secchi (m)	Depth (m)	Temp (°C)	Chlor (µg/L)	Pheo (µg/L)	TN (µg/L)	$NO_{2/3}$ (µg/L)	NH_3 (µg/L)	TP (µg/L)	OPO_4 (µg/L)	Alk (mg/L)	UV254
5/19/2015	5.0	1.0	17.5	3.8	(0.5)	414	159.0	12.7	9.1	0.6	56.7	0.078
		8.0	9.0	2.6	(0.5)	511	-	-	9.5	-	-	-
		15.5	6.5	-	-	535	329.0	5.2	16.0	3.1	-	-
8/23/2015	5.3	1.0	22.5	1.3	(0.5)	256	(0.0)	0.0	5.4	(0.0)	59.5	0.067
		8.0	10.0	10.7	2.1	243	-	-	18.5	-	-	-
		15.0	7.0	-	-	658	(0.0)	0.4	258.0	0.2	-	-
5/22/2016	5.0	1.0	16.0	3.2	(0.5)	450	196.0	25.1	12.3	0.8	56.8	0.069
		8.0	13.0	2.3	(0.5)	949	-	-	33.1	-	-	-
8/28/2016	6.4	1.0	22.0	1.3	(0.5)	920	16.0	27.4	13.2	3.1	57.4	0.063
		8.0	-	-	20.7	404	-	-	63.7	-	-	-
		15.0	9.0	-	-	384	(5.0)	185.0	117.0	34.6	-	-

Note: Parameter abbreviations are: chlorophyll-*a* (Chlor.), pheophytin (Pheo.), total nitrogen (TN), nitrate/nitrite ($NO_{2/3}$), ammonia (NH_3), total phosphorus (TP), orthophosphate (OPO_4), and total alkalinity (Alk). UV254 is measured in absorption units. Dashes indicate parameters that were not analyzed for a given sample. Values below the method detection limit (MDL) are enclosed in parentheses and have the value of the MDL substituted.

Temperature data indicate that thermal stratification (layering of warm shallow water over cooler deeper water) was present on these sampling dates. Except for August 2016, the deeper water samples contained higher concentrations of nitrogen and phosphorus than the surface waters. This indicates that the hypolimnion (the deeper, cooler layer of water) was low in oxygen during the summer. Anoxia (lack of oxygen) in water facilitates the release of phosphorus from bottom sediments into the water, resulting in higher orthophosphate concentrations. Higher ammonia concentrations in the deep water samples also indicate anoxia.

In August of both years, chlorophyll-*a* profile data indicate that algae were present at higher concentrations in mid-depth waters. This suggests that enough light was reaching deeper waters to stimulate algal growth, or that algal species able to adapt to lower light levels were able to take advantage of higher nutrient concentrations.

The relatively low UV254 absorption measurements in Lake Sawyer indicate that the lake was fairly clear, with little coloration from dissolved organic substances. Total alkalinity in Lake Sawyer was moderate, indicating that the lake water had more buffering capacity to resist changes in pH compared to many lakes in the region.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Lake Sawyer continued to be categorized as mesotrophic-oligotrophic, with moderate algal productivity and water quality. Average nitrogen to phosphorus (N:P) ratios were sometimes higher than 25 and sometimes lower, indicating that algal productivity was limited by phosphorus during some periods and co-limited by nitrogen and phosphorus during other periods. The periods of nutrient co-limitation (N:P below 25) were more favorable for cyanobacteria dominating the algal community.

Trend analyses of the long-term monitoring data found a slight decrease in chlorophyll-*a* trophic state index (TSI) values over time. While algal productivity in Lake Sawyer has been decreasing since 1994, water clarity (as measured by Secchi depth) has not shown a corresponding increase.

The long-term monitoring conducted by volunteer stewards at Lake Sawyer has built an invaluable dataset for understanding water quality and lake health over time. Continued monitoring will help grow this dataset, increasing our understanding of how the lake reacts to environmental variability and human influences. The long-term dataset makes it possible to conduct statistically robust tests for trends, as well as to detect any potentially detrimental changes that may occur in the lake. In addition, long-term monitoring provides a solid scientific basis to guide lake management decisions by identifying emergent management needs and evaluating the effectiveness of management actions