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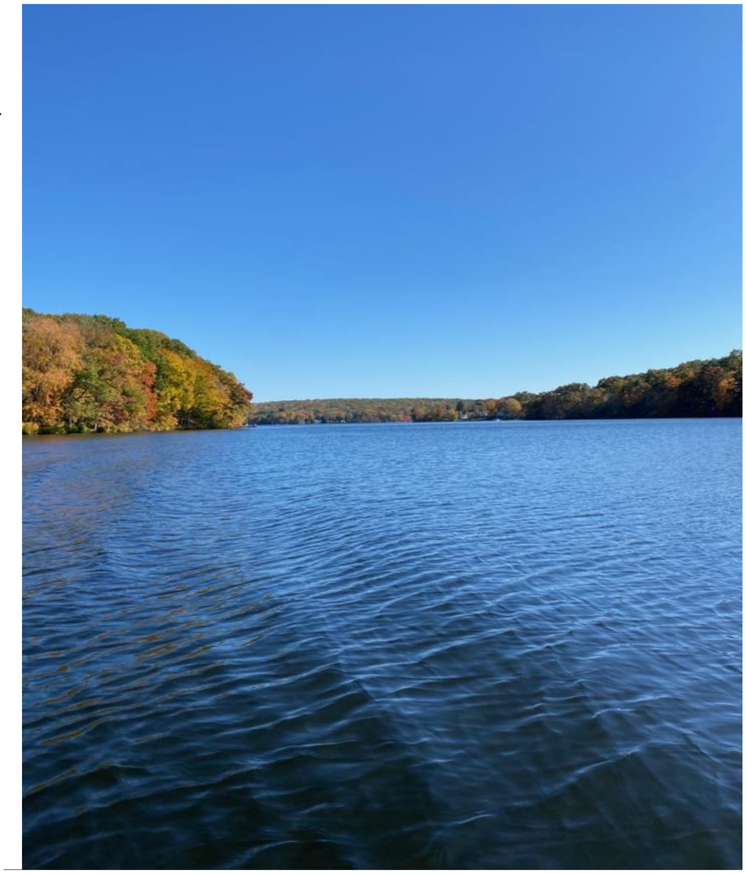
Assessment of 2022 Water Quality in Rogers Lake



With An Historical Analysis from 2005 to 2022

Prepared for
Rogers Lake Authority
119 Shore Drive
Lyme, CT 06371

Sincerely,

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1. EXECUTIVE SUMMARY

1.1 Introduction

The Rogers Lake Authority (RLA) has commissioned David Post's Lab at Yale University to conduct an analysis of water quality in Rogers Lake for 2022. This report also includes historical data on water quality since 2005, plus a few dates from 2004. Preliminary data for 2023 were included in some of the figures.

1.2 Methods

The Post Lab collected water samples at Rogers Lake starting in April and continued biweekly until mid-September, then monthly from October to November. Samples were collected on 10-14 dates per year from 2005-2022. No sampling was conducted in 2012. Water samples were collected from a single sampling site located south of Blood St. and northeast of Shore Dr. where the lake is deepest (20 m).

Water Quality Parameters Analyzed

- Temperature
- Dissolved Oxygen
- Secchi Depth Transparency
- Chlorophyll-a
- Total Phosphorus
- Total Nitrogen
- Nitrite
- Nitrate
- Orthophosphate
- pH
- Conductivity
- Chloride
- Bromide
- Fluoride
- Sulfate

1.3 Key Results

For the water parameters used by the CT DEEP to define lake trophic state, Rogers Lake is within the normal ranges for a mesotrophic lake and has been since sampling by the Post Lab began in 2005. The lake is currently in good ecological health. However, analysis of mean annual parameter values through time indicated total phosphorus and total nitrogen levels were gradually increasing, and water clarity was gradually decreasing. A summary of the mean annual values for all parameters and their general trends since 2005 can be found in Table 1.

Descriptions of each water quality parameter and more detailed results with figures can be found in Section 5 Results. A basic primer on the statistics used in this report can be found in Appendix I, with statistical results tables for the analyses in Appendices II and III.

Table 1. Mean annual values for Rogers Lake water quality parameters and their current status.

Parameter	Mean Annual Value for 2022	Status
Temperature	20.1 ± 6.56 °C	Stable
Dissolved Oxygen	8.92 ± 1.21 mg/L	Stable
Secchi Disk Transparency	2.18 ± 0.41 m	Decreasing
Chlorophyll-a	6.19 ± 4.99 µg/L	Stable
Total Phosphorus	15.52 ± 2.74 µg/L	Increasing
Total Nitrogen	0.36 ± 0.03 mg/L	Increasing
Nitrate	0.13 ± 0 mg/L	Stable
Orthophosphate	0.01 ± 0 mg/L	Increasing
pH	6.67 ± 0.32	2022 only - Normal for freshwater
Conductivity	65.2 ± 5.26 µS/cm	2022 only - Normal for freshwater
Bromide	0.12 ± 0.01 mg/L	Increasing
Chloride	12.91 ± 3.09 mg/L	Stable
Fluoride	0.09 ± 0.01 mg/L	Increasing
Sulfate	7.46 ± 2.27 mg/L	Stable

1.4 Recommendations

Continued water quality sampling is recommended to track any potential changes in the lake in the coming years, and to see if the gradual increases in total phosphorus and total nitrogen continue. While the water quality in Rogers Lake is good, and no urgent action needs to be taken, the following recommendations are suggested as general good environmental practices to reduce nutrient inputs into Rogers Lake:

- Reduction and proper timing of lawn fertilization
- Maintaining septic systems
- Using phosphate-free detergents
- Planting vegetation buffers along the shoreline
- Invasive species monitoring and spread prevention

2. INTRODUCTION

Since 2005, David Post's lab in the Department of Ecology and Evolutionary Biology at Yale University (Post Lab) has collected water samples from Rogers Lake as part of a decadal research program. Water samples were collected and analyzed to track changes in water quality and lake ecology through time.

The Rogers Lake Authority (RLA) has commissioned analyses of water quality in Rogers Lake since at least 2014. Rogers Lake is a 260-acre lake in Connecticut which borders the towns of Lyme and Old Lyme. The lake sees moderate watercraft activity in summer months and is surrounded by wooded areas and private residences. In 2022, an agreement was reached between the Post Lab and the RLA for the Post Lab to collect and analyze water samples for 2022, and to share results of samples collected since 2005.

This report will summarize findings of water samples collected in 2022 and make comparisons to samples collected from 2005-2021. The Post Lab dataset on Rogers Lake water quality spans nearly 20 years and ~200 sampling days. This data will enable the RLA to better understand long-term trends in water quality and ecological health of the lake. Preliminary data from 2023, including April through mid-July, are also included in the report. Lastly, recommendations will be provided for future water quality monitoring and management.

3. BACKGROUND

Spring turnover, summer lake stratification, and fall turnover are three lake processes that play critical roles in nutrient cycling, oxygen distribution, and overall ecological health within temperate lakes. Understanding when these events occur during the year will help in interpreting the water quality results, as they can have large impacts on some of the parameters measured.

Spring turnover occurs in Rogers Lake in March-April, when ice melts and the top layer of water is warmed to a temperature that matches the water below. At this temperature equilibrium, denser water sinks and mixes with water below resulting in turnover. During turnover, the physical and chemical properties of the lake, including temperature, dissolved oxygen, and nutrient concentrations, are generally uniform from top to bottom.

Lake stratification occurs in Rogers Lake primarily in spring and summer. As solar radiation and air temperatures increase in spring, the top layer of the lake is warmed more than during turnover. The lake begins to stratify forming distinct temperature layers:

a. The epilimnion, the warm and less dense top layer of the water column, has temperature and dissolved oxygen levels that are generally uniform. This layer is mixed by wind and the less dense warm water does not easily mix with cooler water below. The summer epilimnion in Rogers Lake is typically found from the surface down to 3-4 meters deep.

b. The metalimnion is middle layer and is characterized by sharp declines in temperature and dissolved oxygen with depth. The summer metalimnion in Rogers Lake is typically located at depths from 3-8 meters.

c. The hypolimnion, the cold and dense bottom layer, is not readily mixed with the warmer waters above. As organic matter decays and sinks to the bottom, it is decomposed in the hypolimnion by bacteria. This process consumes oxygen and because the water in this layer does not mix with warmer water from above, the hypolimnion remains oxygen-depleted until fall turnover. The summer hypolimnion in Rogers Lake is typically found at depths from 8-20 meters.

Fall turnover occurs in Rogers Lake sometime between October-December, when solar radiation and air temperatures decrease causing surface waters to cool and become denser. The dense water sinks and begins to mix with the layers below, eventually resulting in an equilibrium where the whole lake has uniform temperature, dissolved oxygen, and nutrients concentrations (similar to spring turnover).

4. METHODS

4.1 Sample Collection

The Post Lab begins collecting water samples at Rogers Lake near spring turnover (~April 1), continuing biweekly until mid-September to capture summer lake stratification, and monthly in October and November to capture fall turnover. There were 10-14 sampling dates per year from 2005-2022. No sampling was conducted in 2012. Water samples have been collected at the same location since 2005 (Figure 1). This Sampling Site is located south of Blood St. and northeast of Shore Dr. where the lake is deepest, with depths of just over 20 m.

Data for temperature, dissolved oxygen, and secchi depth were collected on-site from 2005 to 2022. Depth profiles of temperature and dissolved oxygen were generated from 0 to 14 m deep. Samples were collected every 0.5 m from 0-6 m and every 1 m from 6-14 m. Measurements were taken using YSI Digital Water Quality Meters. The secchi depth was measured using a secchi disk that was lowered into the water until the disk was no longer visible.

The epilimnion, which supports the majority of productivity and aquatic life in summer, was the focus for sampling chlorophyll-a, total nitrogen, total phosphorus, orthophosphate, nitrate, nitrite, fluoride, chloride, bromide, sulfate, pH, and conductivity measurements. Water samples were collected with a Van Dorn water sampler and transported to Yale for analysis in the Post Lab laboratories or at the Yale Analytical and Stable Isotope Center (YASIC). Chlorophyll-a, total phosphorus, and total nitrogen were measured from 2005-2022. Nitrate, nitrite, fluoride, chloride, bromide, sulfate, and orthophosphate were measured from 2014-2022. pH and Conductivity were measured in 2022 only. Equipment used to conduct the analyses and units of measure can be found in Table 2.

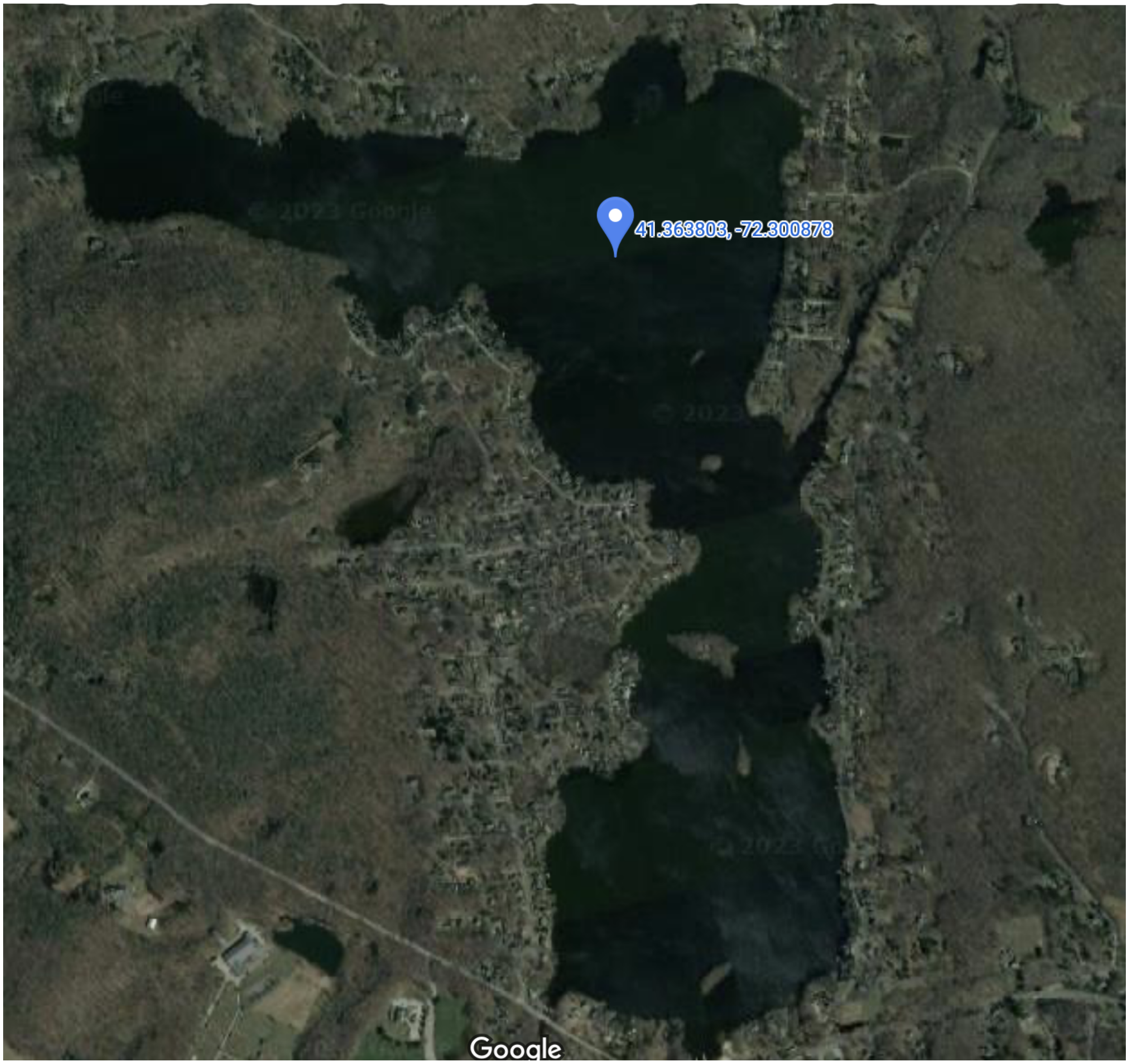

Figure 1. Photo of Rogers Lake from Google Maps showing the Sampling Site location and coordinates.

4.2 Sample Processing

Water samples collected using the Van Dorn water sampler were stored in a cooler and transported back to the laboratory. For chlorophyll-a, a 250 ml sample from each of the top, middle, and bottom of the epilimnion were run separately through Whatman GF/C glass microfiber filters to capture all algae. The filters were frozen for 7-14 days and then analyzed on a Turner Designs Trilogy Laboratory Fluorometer. Values for these three samples were then averaged to get the final chlorophyll-a value. A 250 ml aliquot of combined water samples from the top, middle, and bottom of the epilimnion was used for pH and conductivity measurements.

Another 250 ml aliquot of the combined sample was frozen for analysis of total phosphorus, total nitrogen, nitrate and nitrite, orthophosphate, fluoride, chloride, bromide, and sulfate. This sample was thawed and total phosphorus and total nitrogen analysis was conducted using an Astoria 2 Flow Analyzer. Nitrate and nitrite, orthophosphate, fluoride, chloride, bromide, and sulfate were analyzed on a Metrohm Ion Chromatograph.

Table 2. List of parameters analyzed, their unit of measure, and the equipment used to analyze samples.

Analyses	Units	Equipment
Temperature	Degrees Celsius (°C)	YSI Digital Water Quality Meter
Dissolved Oxygen	Milligrams per Liter (mg/L)	YSI Digital Water Quality Meter
Chlorophyll-a	Micrograms per Liter (µg/L)	Trilogy Laboratory Fluorometer
Total Phosphorus	Micrograms per Liter (µg/L)	Astoria 2 Flow Analyzer
Total Nitrogen	Micrograms per Liter (µg/L)	Astoria 2 Flow Analyzer
Orthophosphate	Milligrams per Liter (mg/L)	Metrohm Ion Chromatograph
Nitrate	Milligrams per Liter (mg/L)	Metrohm Ion Chromatograph
Nitrite	Milligrams per Liter (mg/L)	Metrohm Ion Chromatograph
Fluoride	Milligrams per Liter (mg/L)	Metrohm Ion Chromatograph
Chloride	Milligrams per Liter (mg/L)	Metrohm Ion Chromatograph
Bromide	Milligrams per Liter (mg/L)	Metrohm Ion Chromatograph
Sulfate	Milligrams per Liter (mg/L)	Metrohm Ion Chromatograph
Turbidity	Meters (m)	Secchi Disk
Conductivity	Micro siemens per centimeter (µS/cm)	Orapxi Salinity and Conductivity Meter
pH	pH	Orion Star A121 Portable pH Meter

***mg/L** is equivalent to parts per million (ppm). **µg/L** is equivalent to parts per billion (ppb).

4.3 Statistical Analysis

R Studio version 1.4.1717 was utilized for all data analyses and figures. In order to analyze changes in parameters across years, we calculated a **mean annual** value that was the average of all samples taken within the year and **mean monthly** values that averaged all of the samples taken within a month. For most water quality parameters, we created plots showing the change in mean monthly values throughout the 2022 sampling season, the change in mean monthly values across years within each month (providing a higher resolution look at changes in water quality), and the change in mean annual values across years.

Data from 2-3 m deep were used for temperature and dissolved oxygen to maintain consistency and avoid weather variance by sampling date. Data from samples combined from the top, middle, and bottom of the epilimnion were used for other parameters. Long-term trends were examined via linear regression for both mean annual and mean monthly values for each parameter (see Appendix I for a description of linear regression and statistical measurements used in the analysis). Additionally, depth profile plots were generated for temperature and dissolved oxygen.

5. RESULTS

5.1 Temperature

In 2022, mean monthly temperature in the epilimnion ranged from 9.55 ± 2.38 °C in April to 27.60 ± 1.67 °C in July. Spring turnover occurred in April and fall turnover occurred in November, as indicated by less temperature stratification with depth. (Figure 2). There was no significant relationship between mean monthly temperature (Figure 3) or mean annual temperature (Figure 4) and year (statistical results provided in Appendix II, Table 2.1 and Appendix III, Table 3.1).

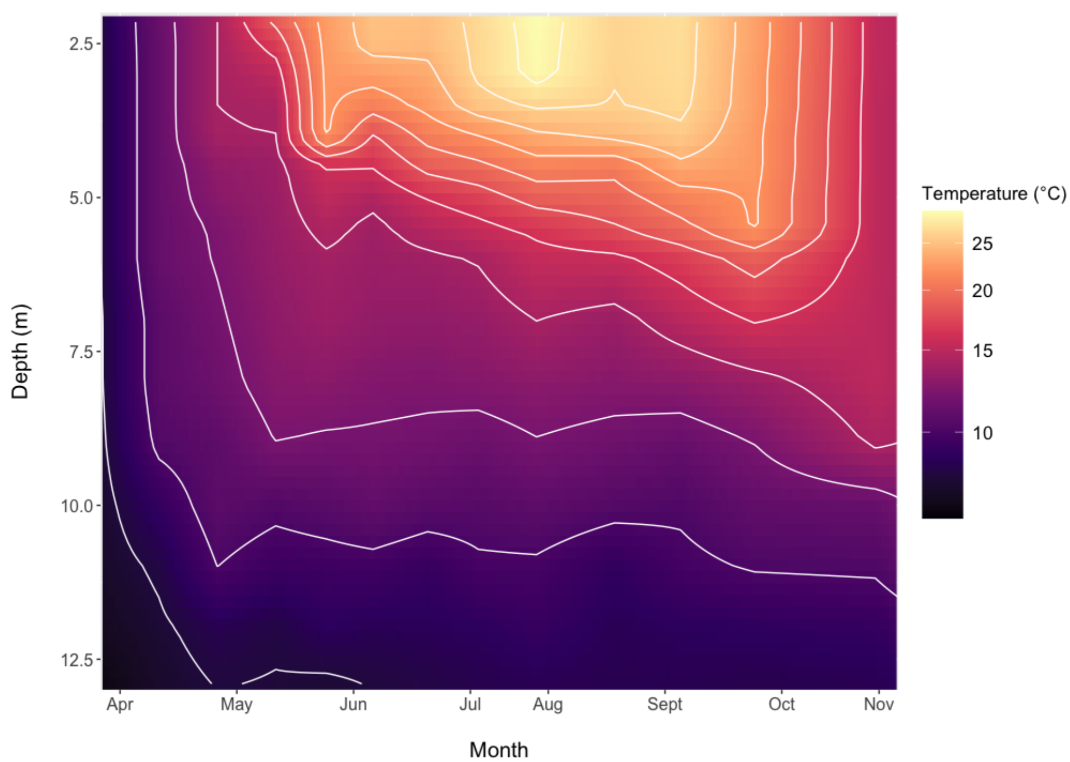

Figure 2. Temperature stratification with depth in Rogers Lake from April to November 2022.

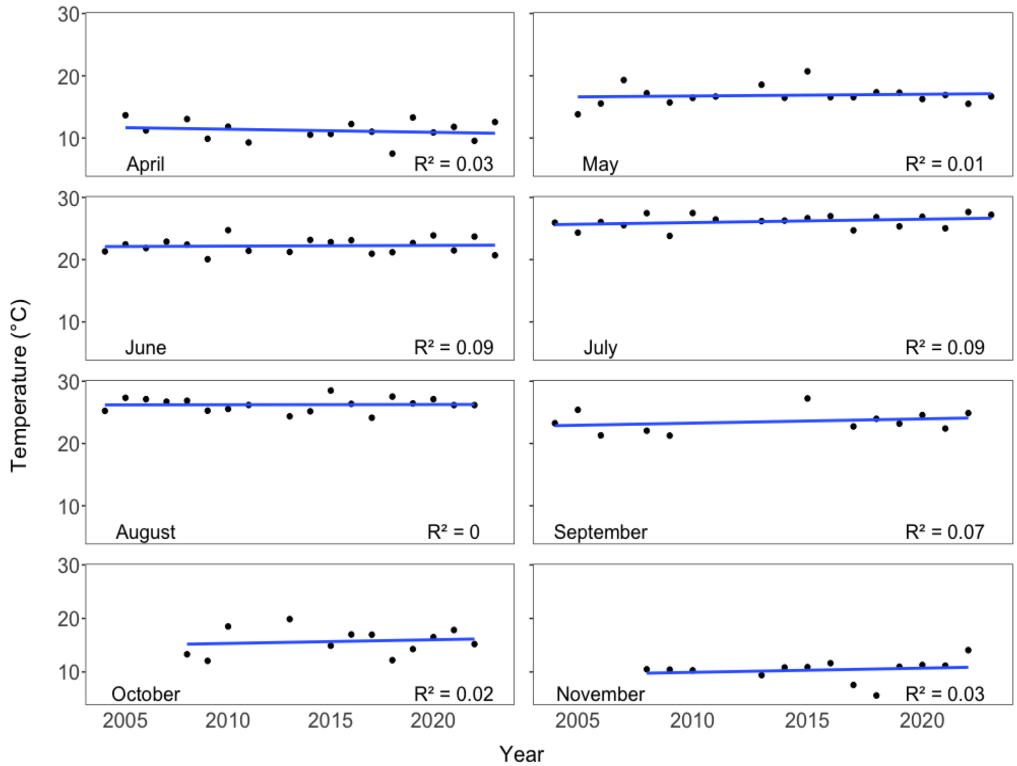

Figure 3. Mean monthly epilimnetic temperature at 2-3 m depth from 2005-2023.

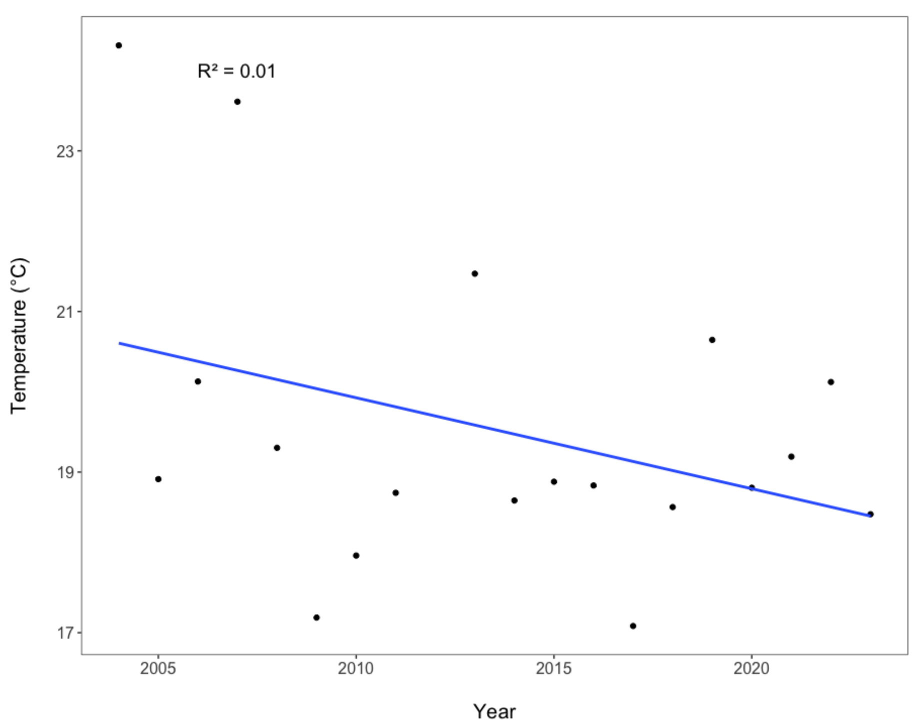

Figure 4. Mean annual epilimnetic temperature at 2-3 m depth from 2005-2023.

5.2 Dissolved Oxygen

Adequate dissolved oxygen (DO) in freshwater is critical for life and maintaining the health and well-being of the ecosystem. Low DO conditions can stress or cause death to most plants and organisms. DO values are typically lower in the summer as warmer water holds less oxygen, and higher aquatic plant and algae densities use more DO during photosynthesis.

In 2022, Rogers Lake mean monthly DO remained consistent in the epilimnion at 2-3 m deep, ranging from 7.92 ± 0.39 mg/L in July to 10.70 ± 0.43 mg/L in April (Figure 5). This range is normal for freshwater. Mean DO peaked in spring, when lake temperatures were cooler and the lake was relatively well mixed. As temperature increased and lake stratification commenced, DO decreased by approximately 2 mg/L. In early spring, high DO was observed from 0-12 m. As the lake stratified from July-October, depths of greater than 6 m became oxygen-depleted. Oxygen-depletion is common in deeper waters of freshwater lakes that have moderate to high productivity in summer as bacteria consumes oxygen during decomposition of organic matter that has sunk to the bottom.

As with water temperature, mean monthly (Figure 6) and mean annual (Figure 7) DO has remained relatively stable overall in Rogers Lake. However, 2004, 2019, and 2021 values were abnormally low. Causes are unknown but one possibility may be herbicide treatments for aquatic vegetation, combined with warm water temperatures led to increased oxygen demand as plant matter decomposed (Appendix II, Table 2.1 and Appendix III Table 3.1).

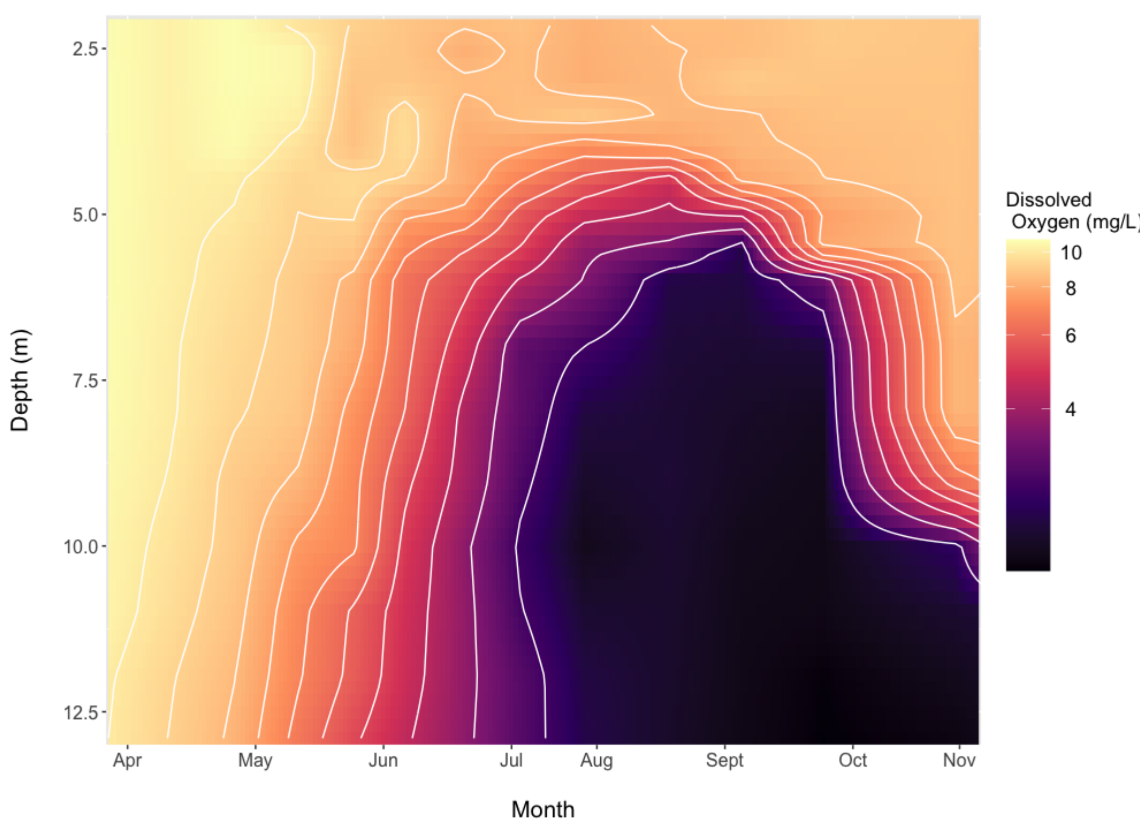

Figure 5. Depth profile of dissolved oxygen in Rogers Lake from April to November 2022.

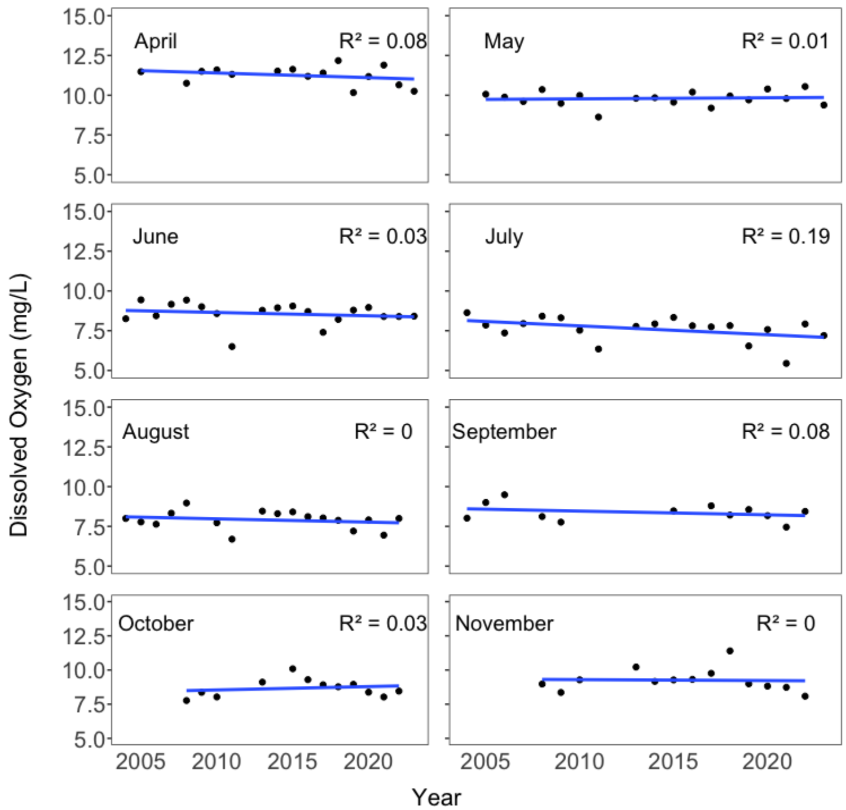

Figure 6. Mean monthly epilimnetic dissolved oxygen at 2-3 m depth from 2004-2023.

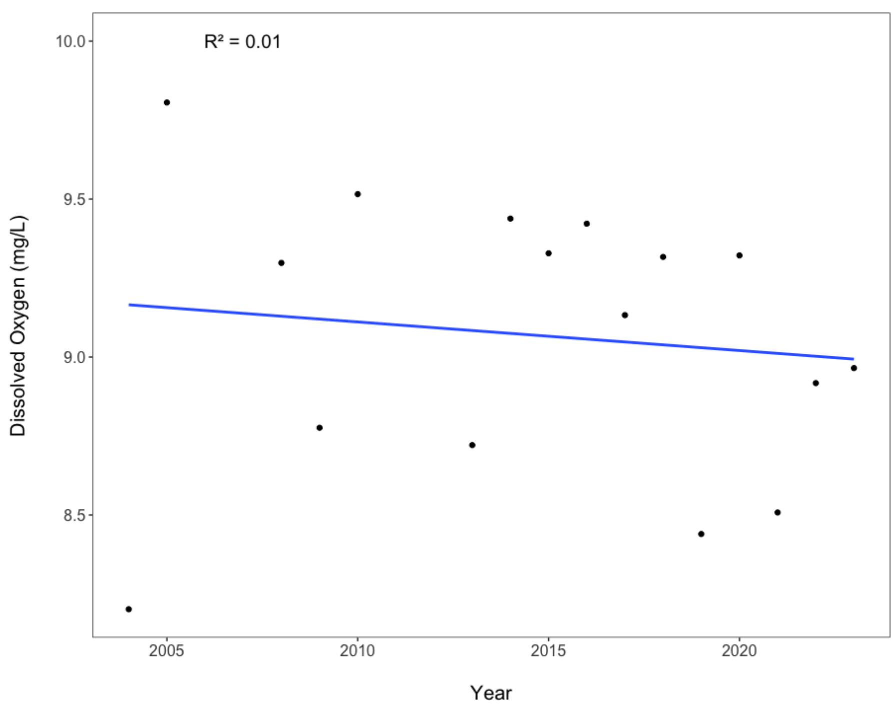

Figure 7. Mean annual epilimnetic dissolved oxygen at 2-3 m depth from 2004-2023.

5.3 pH

pH influences a wide array of biological, chemical, and ecological processes within a lake. These include the solubility and cycling of nutrients, the buffering capacity of the water, and the overall health of the ecosystem. Generally, the pH range observed in most freshwater ecosystems falls between 6 and 8 during summer months but can fluctuate during spring and fall turnover[4].

Rogers Lake pH in 2022 in the epilimnion was 5.7 during the first week of April, increased to 6.3-6.5 in May, and stabilized at 6.8-6.9 for the remainder of the summer (Figure 8). It decreased to 6.4 in November as the lake began to mix. Overall, these values are typical for freshwater. The low pH observed in Rogers Lake in April was likely caused by turnover. Spring turnover can lead to a decrease in pH due to the release of carbon dioxide and redistribution of nutrients from the deeper layers. As the lake stabilizes and the water layers become more stratified, pH levels gradually adjust back to a more typical range, which was observed in Rogers Lake in the summer. The Post Lab did not measure pH prior to 2022.

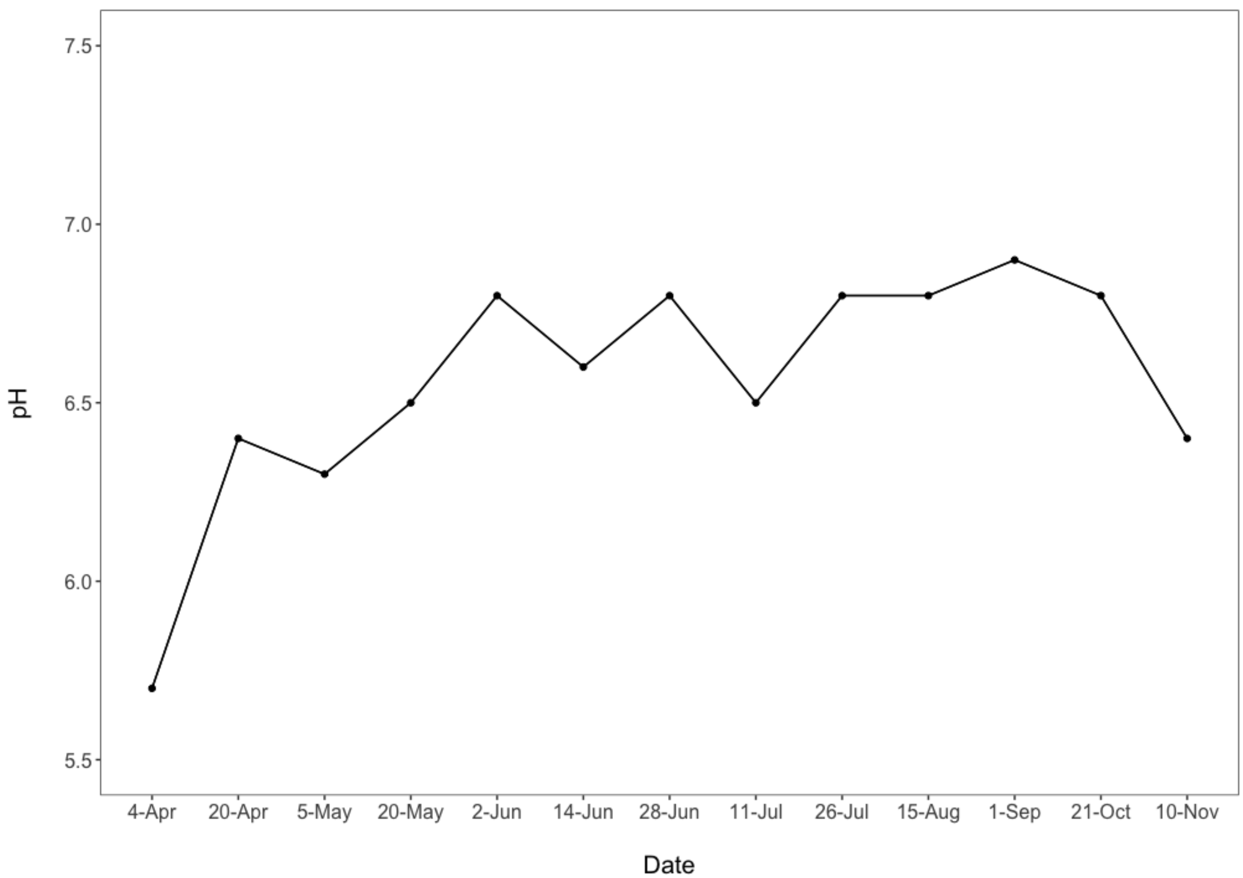

Figure 8. Change in Rogers Lake epilimnetic pH from April to November 2022.

5.4 Conductivity

Lake conductivity is the measurement of the electrical conductivity of the water. Conductivity measurements provide insights into the presence of dissolved ions, salts, pollutants, nutrients, and other substances.

Rogers Lake conductivity in 2022 was 56 µS/cm during the first week of April, increased in May, and stabilized at 68-69 µS/cm for the remainder of the summer (Figure 9). It decreased to 59 µS/cm in October and 55 µS/cm in November as the lake began to mix. These values for Rogers Lake are in range for similar lakes in the region. The observed fluctuations throughout the year are typical, and likely the result of rainfall, temperature changes, and lake mixing. The Post lab did not measure conductivity before 2022.

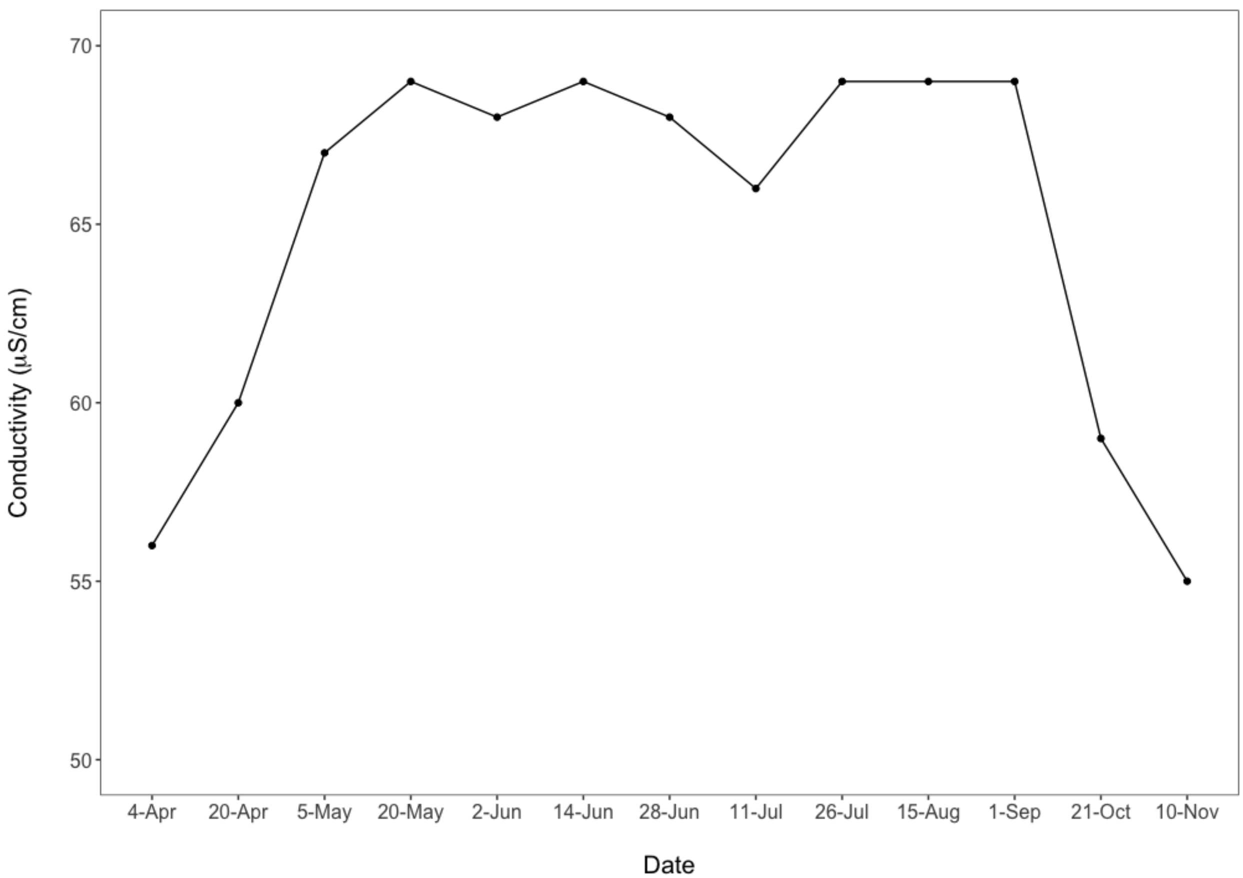

Figure 9. Change in Rogers Lake epilimnetic conductivity from April to November 2022.

5.5 Secchi Disk Transparency

The Secchi disk is a tool to measure turbidity (clarity) in bodies of water. It is used to assess overall water quality and the presence of suspended particles or algae. The secchi disk is lowered into the lake to a depth when it is no longer visible. This point is called the secchi depth and is measured in meters. Higher secchi depths indicate clearer water.

Mean monthly secchi depth for 2022 in Rogers Lake ranged from 1.75 ± 0 m in April and May to 2.75 ± 0.35 m in August and September (Figure 10). Mean monthly secchi depth decreased significantly with year in April through August, but not September through November (Figure 11, Appendix II, Table 2.1). Overall, mean annual secchi depth from 2005-2022 has exhibited a statistically significant gradual decrease with time, indicating a decrease in water clarity (Figure 12, Appendix III, Table 3.1). Frink and Norvell (1984) found water to be clearer in 1979 and 1980 summer surveys within Rogers Lake with secchi depths measuring 4.0 m.[6] Mean secchi depth for 2022 was 2.23 ± 0.134 m, a 1.77 m decrease from 1980.

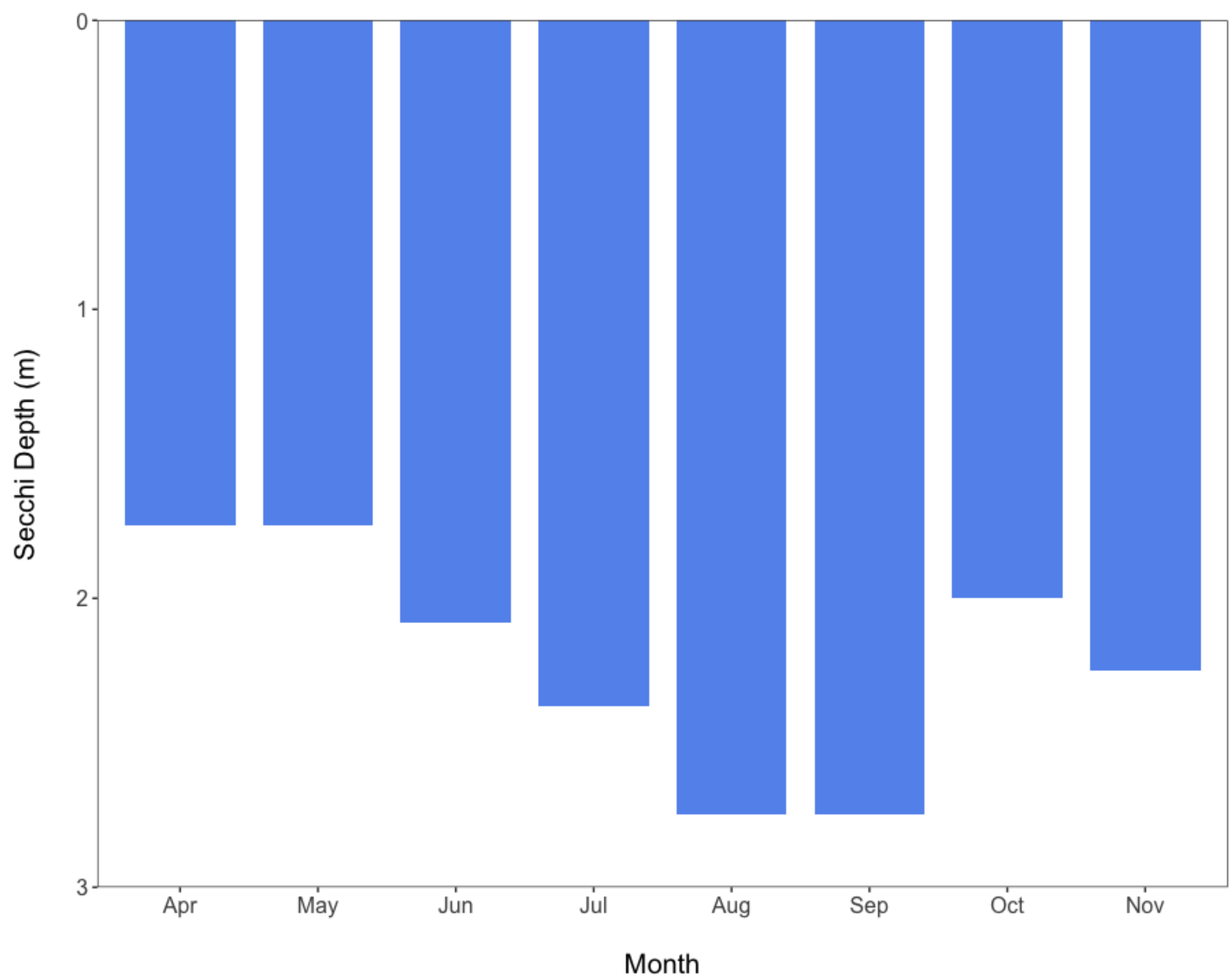

Figure 10. Mean monthly secchi depth in Rogers Lake from April to November 2022.

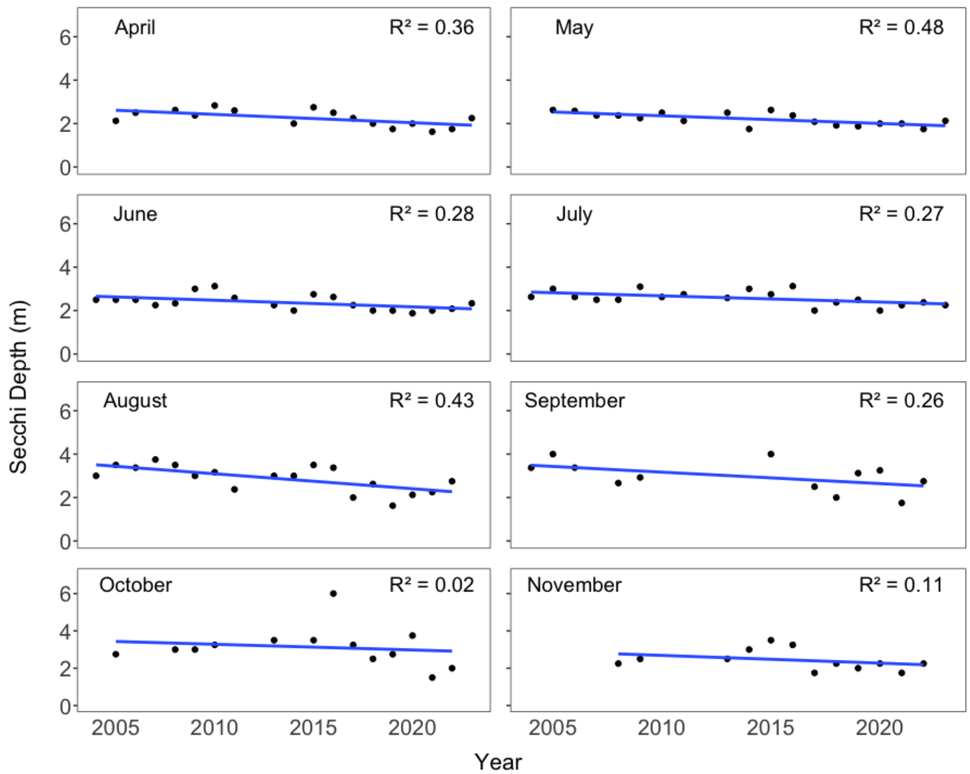

Figure 11. Mean monthly secchi depth from 2004-2023.

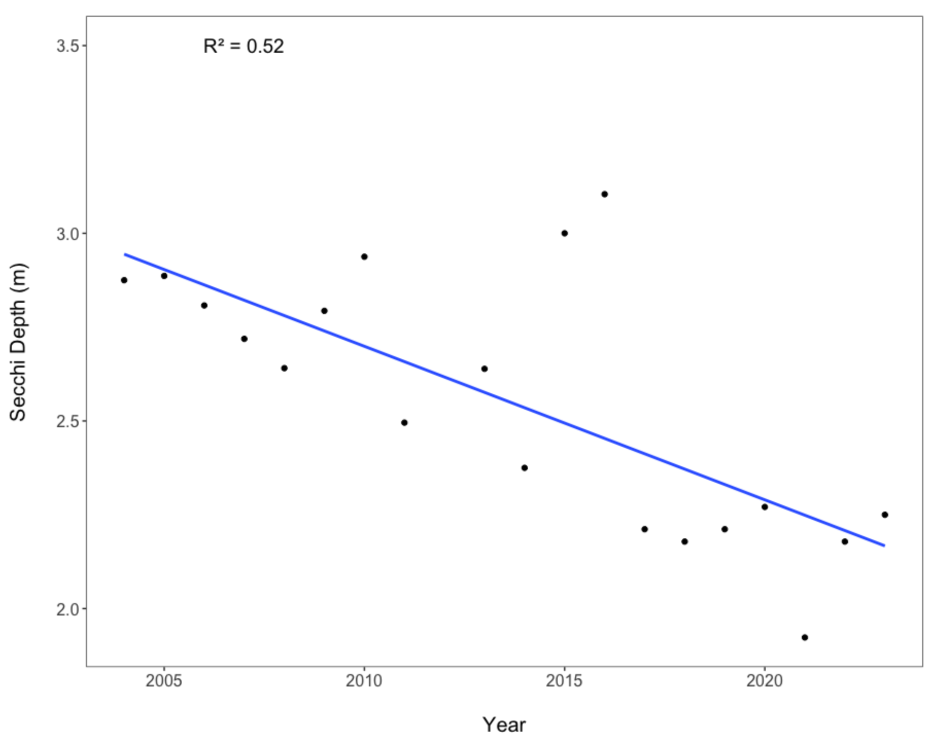

Figure 12. Mean annual secchi depth from 2004-2023.

5.6 Chlorophyll-a

Chlorophyll-a is a pigment found in aquatic plants and algae that has long been used as a standard water quality indicator in freshwater systems. Chlorophyll-a measures the amount of algal biomass present.

Mean monthly chlorophyll-a values for 2022 in the epilimnion were between 4.27 ± 0 µg/L and 10.3 ± 9.32 µg/L (Figure 13). Mean annual chlorophyll-a for 2022 was 6.19 ± 4.99 µg/L. There was a spike detected in September with values reaching 10.3 ± 9.52 µg/L. These spikes can often be the result of sampling during small algae blooms and are still well within range for mesotrophic lakes. Neither monthly (Figure 14) nor annual (Figure 15) chlorophyll-a significantly changed with time (Appendix II Table 2.1, Appendix III Table 3.1).

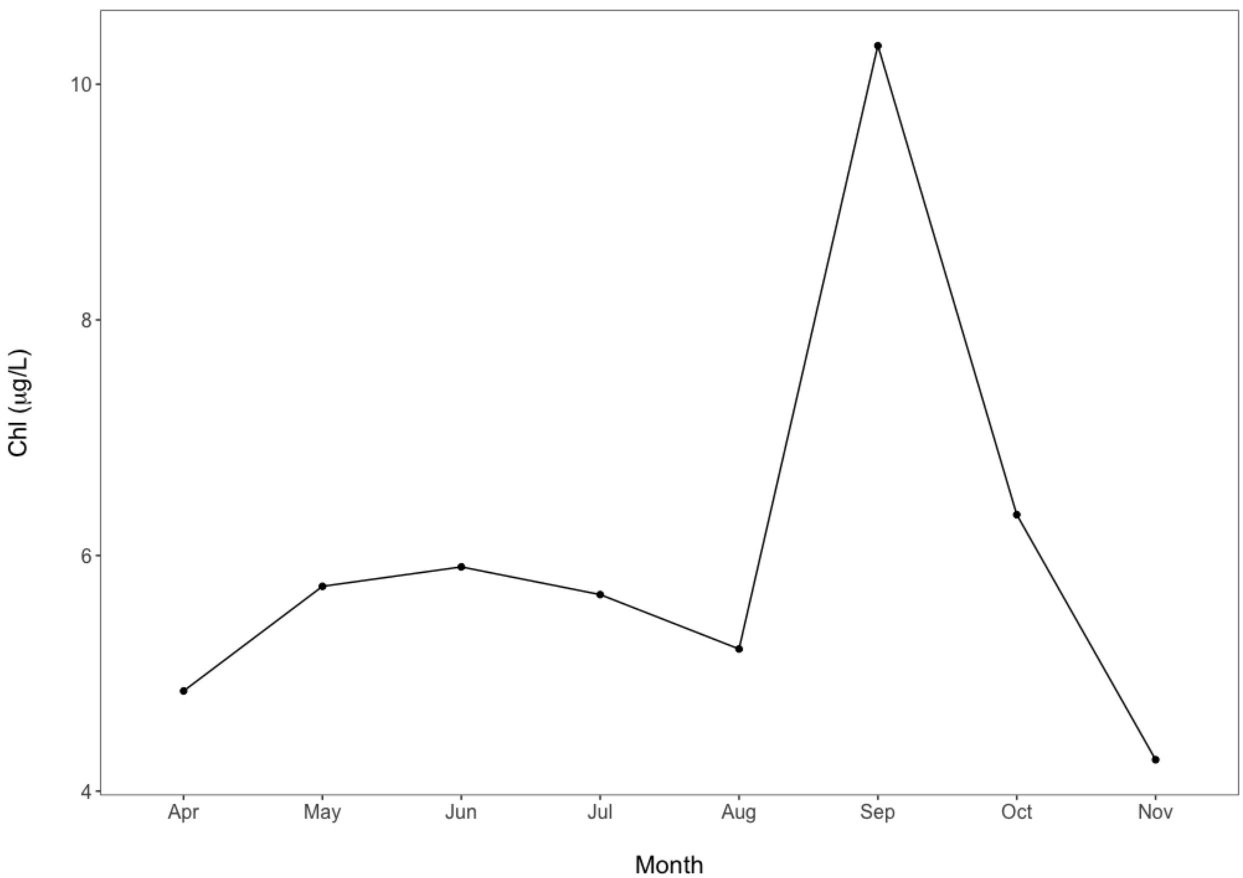

Figure 13. Mean epilimnetic chlorophyll-a (Chl) by month in Rogers Lake in 2022.

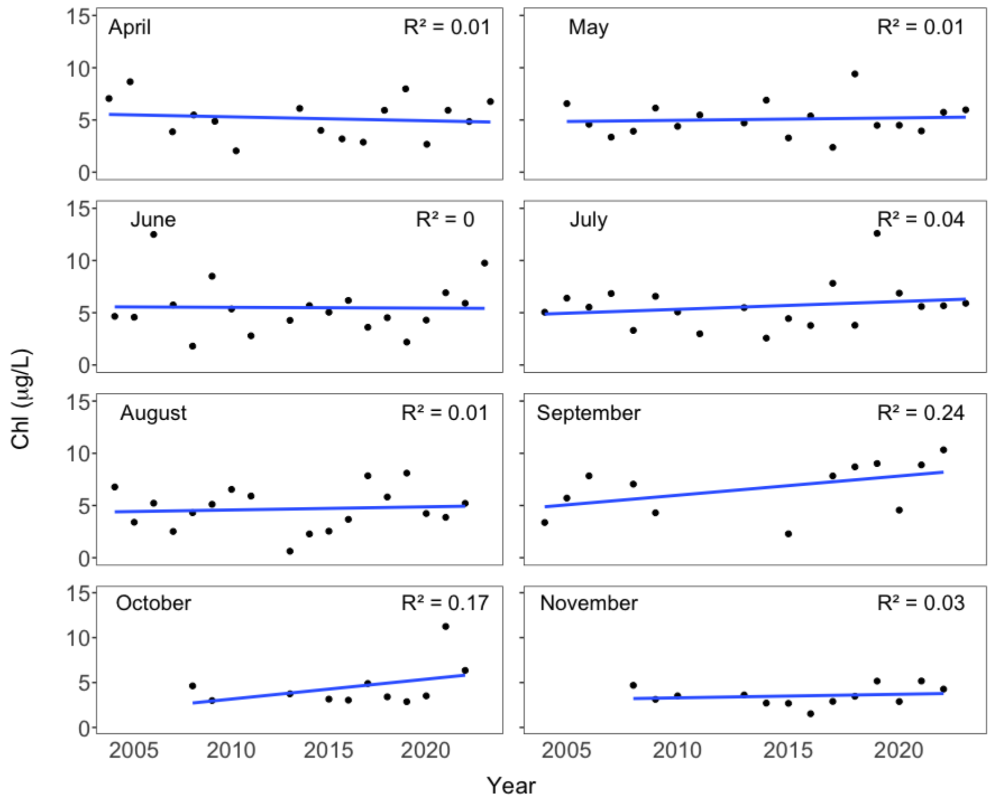

Figure 14. Mean monthly epilimnetic chlorophyll-a (Chl) from 2005-2023.

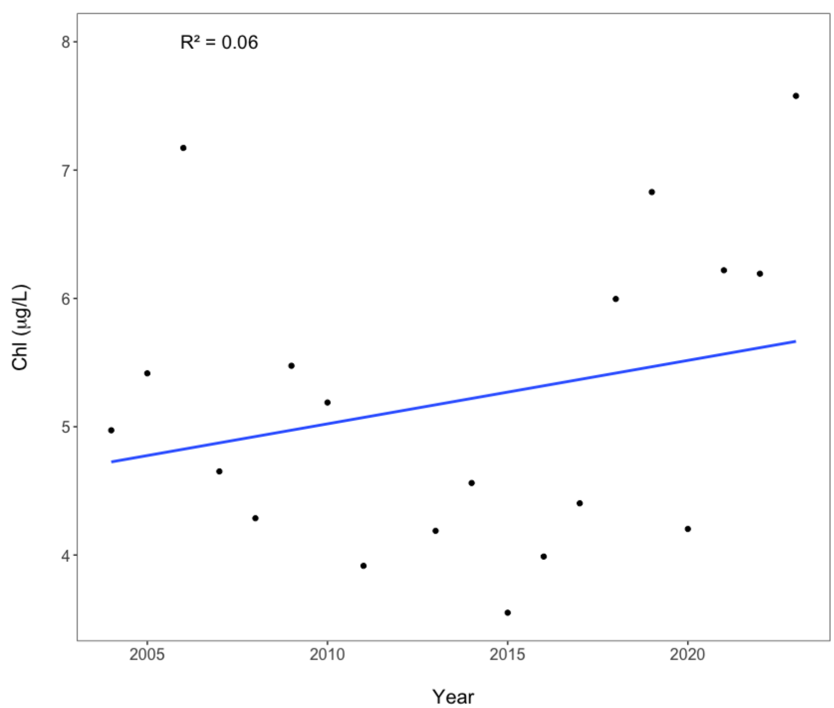

Figure 15. Mean annual epilimnetic chlorophyll-a (Chl) from 2005-2023.

5.7 Total Phosphorus and Total Nitrogen

Phosphorus and nitrogen are the primary nutrients that drive the growth of plants and algae within aquatic ecosystems, serving as essential markers for assessing the trophic status of lakes. Phosphorus acts as the predominant limiting nutrient that influences the growth of aquatic plants and algae. Total phosphorus measures all forms of phosphorus present in the water. Nitrogen is the second most important nutrient affecting aquatic plant and algal growth. Total nitrogen measures all forms of nitrogen found within the water body. Increased phosphorus and nitrogen levels can lead to eutrophication, algal blooms, oxygen depletion, fish kills, and can have severe effects on the ecological health of the lake.

Mean monthly total phosphorus for 2022 ranged from 12.81 ± 2.43 µg/L in April to 19.57 ± 1.11 µg/L in September (Figure 16). Mean monthly total phosphorus did not increase with year for any month with the exception of August (Figure 17, Appendix II Table 2.2). Mean annual total phosphorus increased at a statistically significant rate through time (Figure 18, Appendix III Table 3.1). The lowest mean annual total phosphorus recording for Rogers Lake was 10.29 ± 1.55 µg/L in 2016 and the highest recorded mean annual total phosphorus was 15.52 ± 2.74 µg/L in 2022.

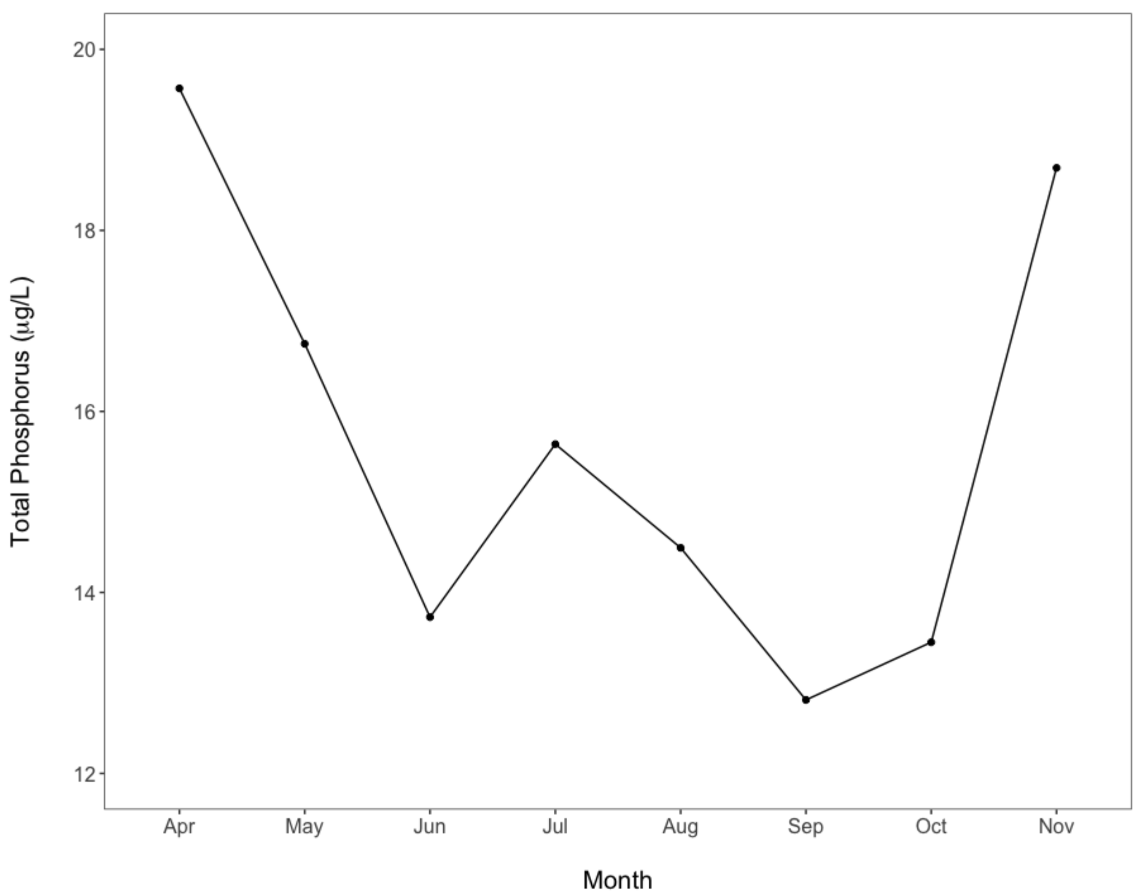

Figure 16. Mean monthly epilimnetic total phosphorus in Rogers Lake in 2022.

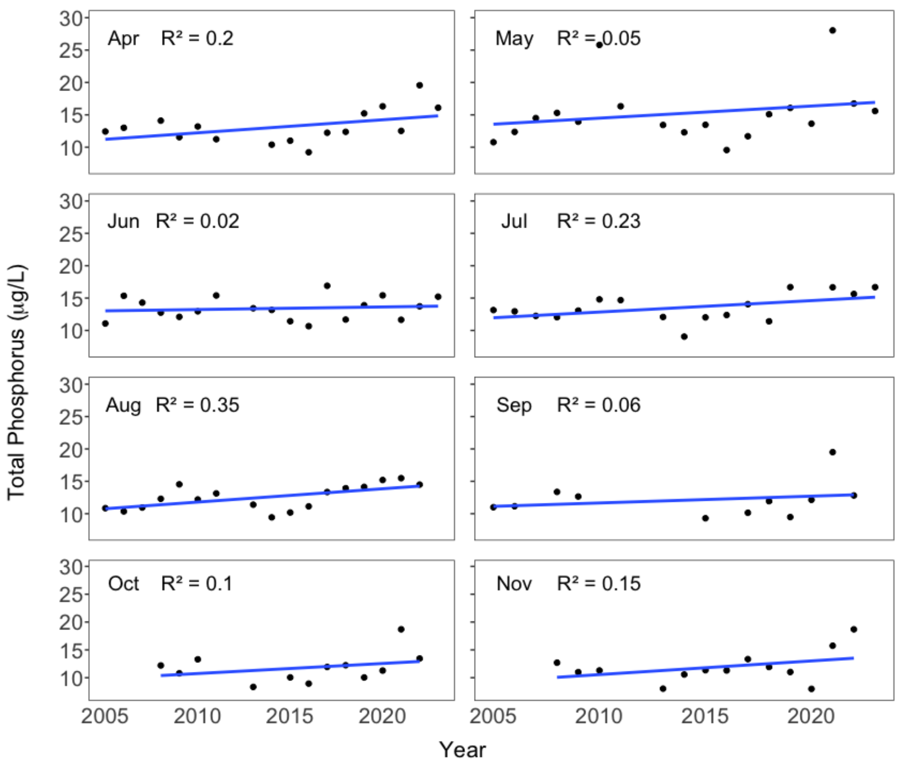

Figure 17. Mean monthly epilimnetic total phosphorus from 2005-2023.

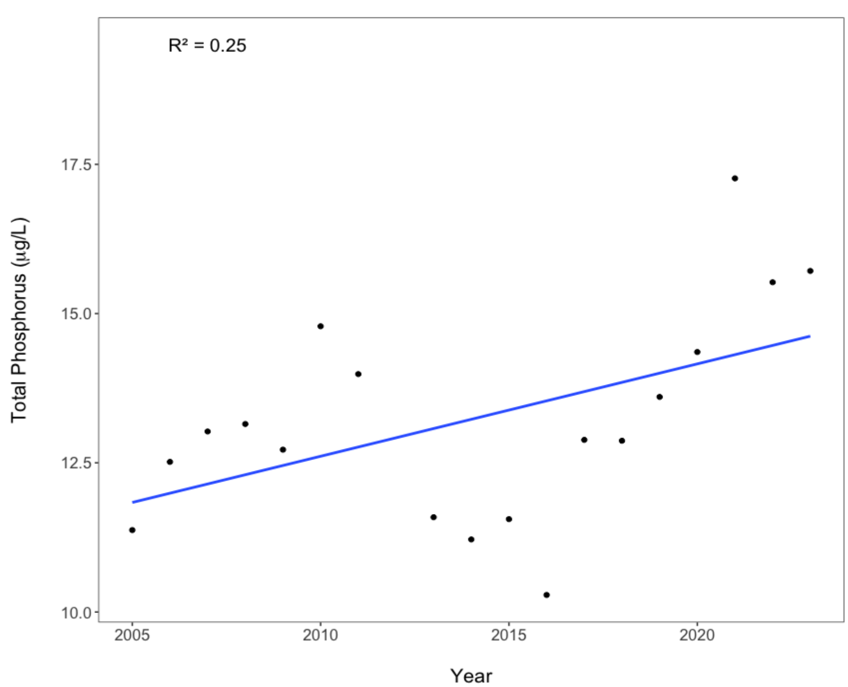

Figure 18. Mean annual epilimnetic total phosphorus from 2005-2023.

In 2022, mean annual total nitrogen was 0.36 ± 0.03 mg/L, with monthly mean total nitrogen ranging from 0.32 ± 0.04 mg/L to 0.43 ± 0 mg/L (Figure 19). Mean monthly total nitrogen increased at a statistically significant rate with year in the months of April, May, July, and November (Figure 20, Appendix II, Table 2.2). Overall, mean annual total nitrogen also increased at a statistically significant rate with time, with a 0.07 mg/L difference between 2005 and 2022 (Figure 21, Appendix III, Table 3.1).

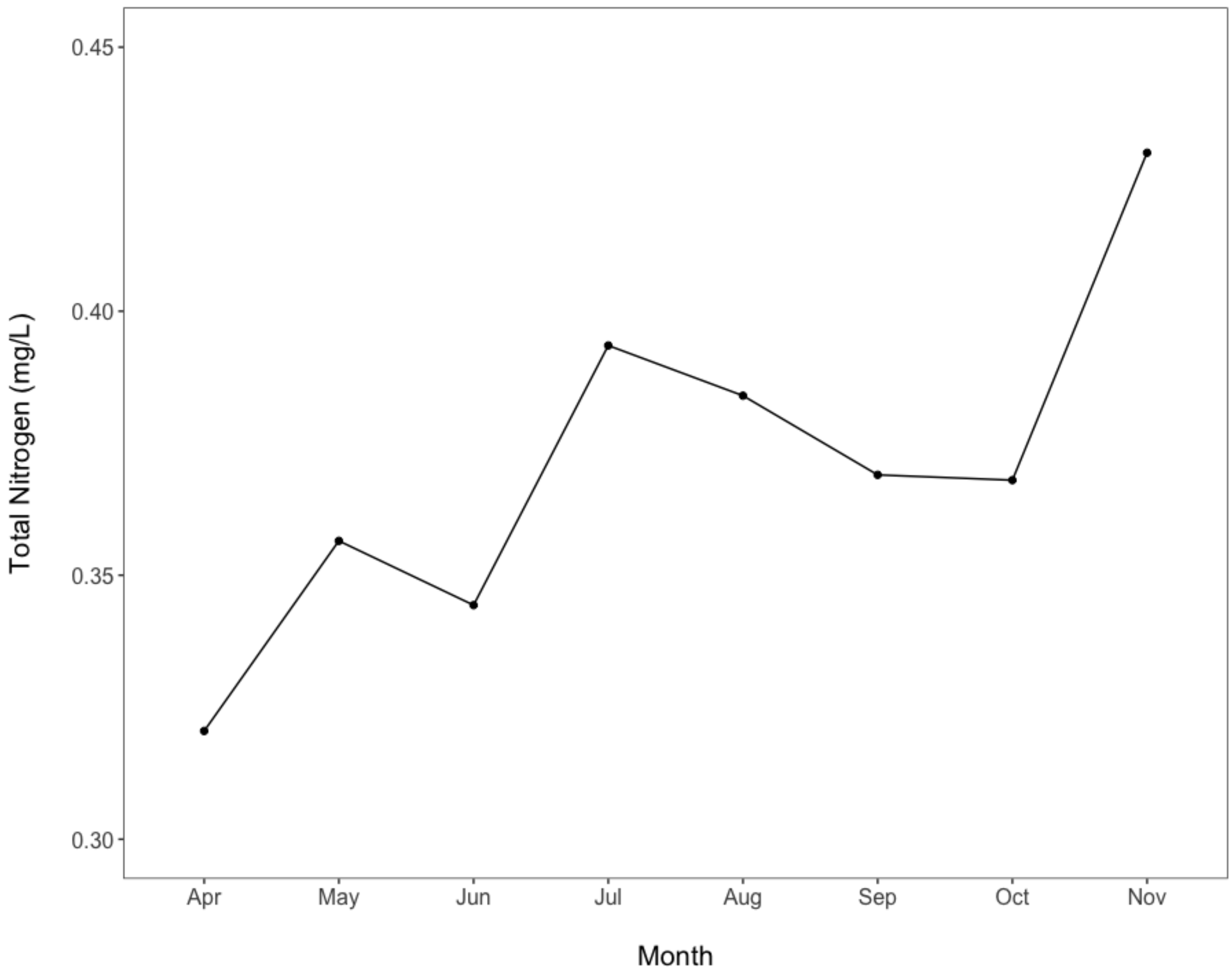

Figure 19. Mean monthly epilimnetic total nitrogen in Rogers Lake in 2022.

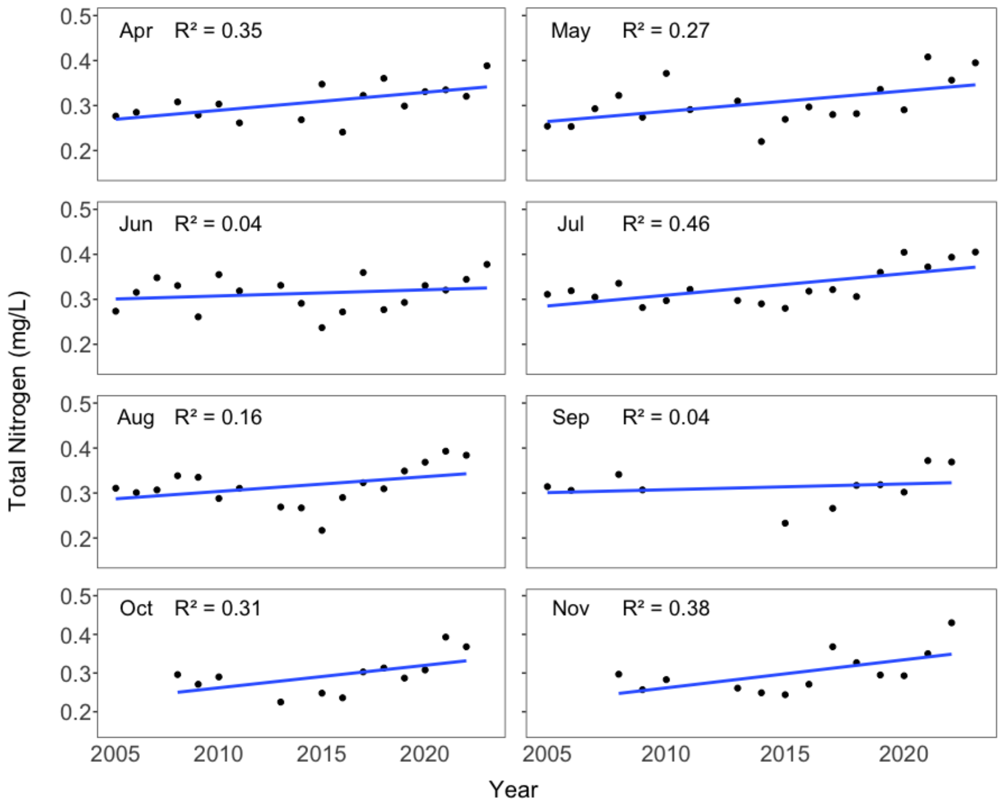

Figure 20. Mean monthly epilimnetic total nitrogen from 2005-2023.

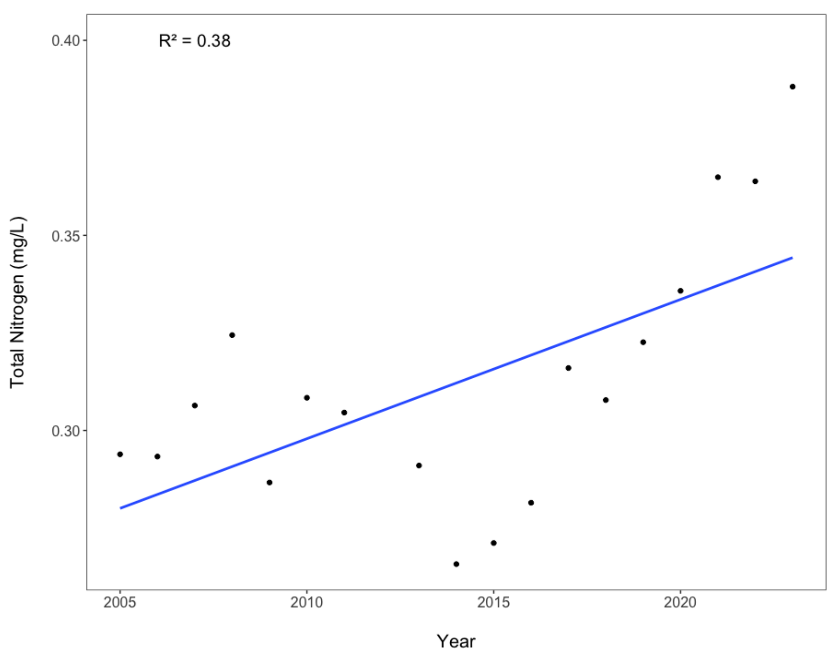

Figure 21. Mean annual epilimnetic total nitrogen from 2005-2023.

5.8 Nitrate and Nitrite

Nitrate and nitrite are used as a source of nitrogen by aquatic plants in freshwater ecosystems. High levels can lead to algal blooms. When these algal blooms die and the algae is decomposed by bacteria, it can cause a rapid depletion in oxygen.

Nitrite in Rogers Lake was below detectable limits in all samples across all years, except for October and November 2022 when it was detected in very low concentrations. Mean annual nitrate for 2022 was 0.134 ± 0.002 mg/L, with monthly means ranging from 0.132 ± 0 mg/L to 0.136 ± 0 mg/L throughout the year (Figure 22). Mean monthly nitrate (Figure 23) and mean annual nitrate (Figure 24) did not significantly change with time (Appendix II Table 2.2, Appendix III Table 3.1).

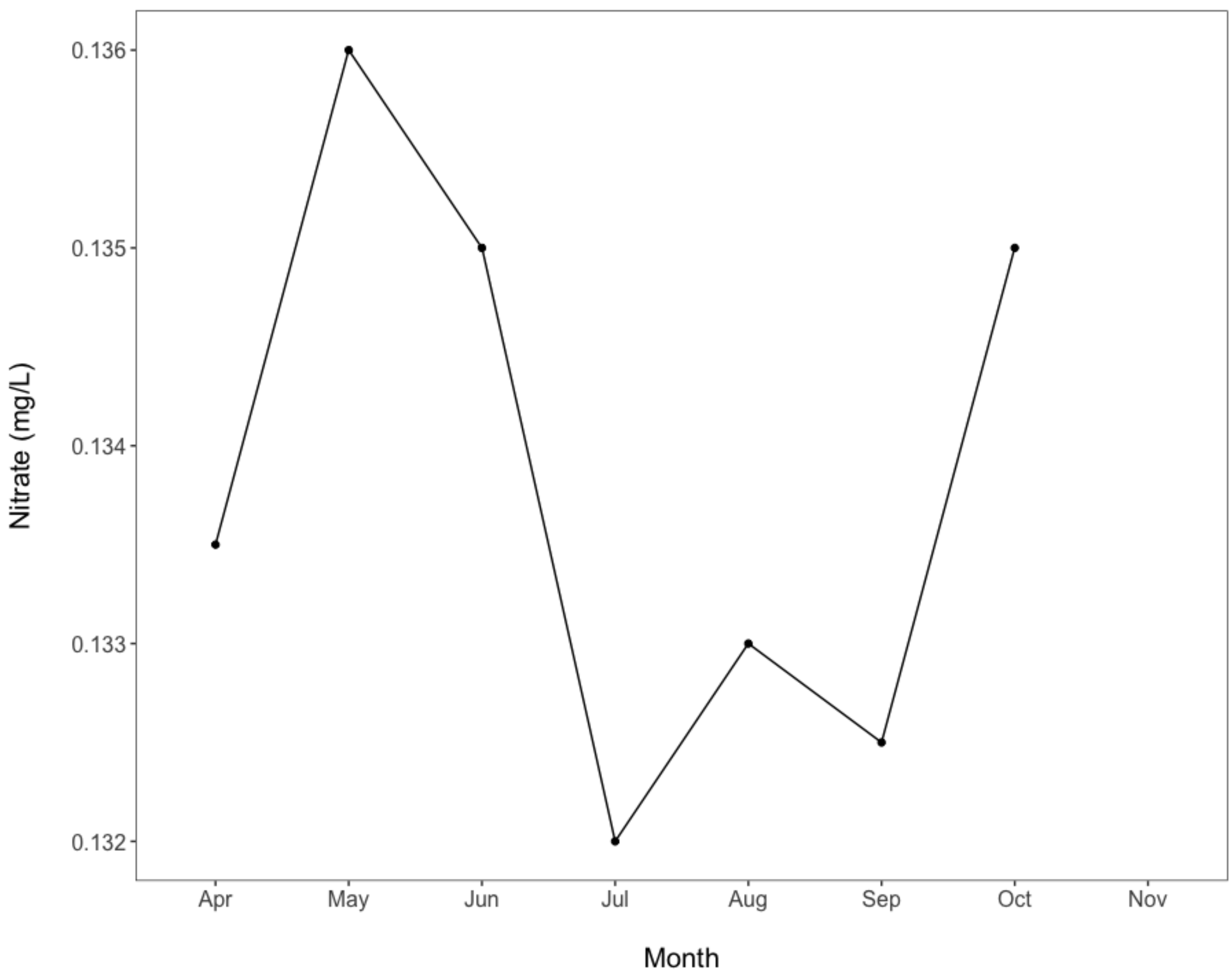

Figure 22. Mean monthly nitrate in 2022 in Rogers Lake.

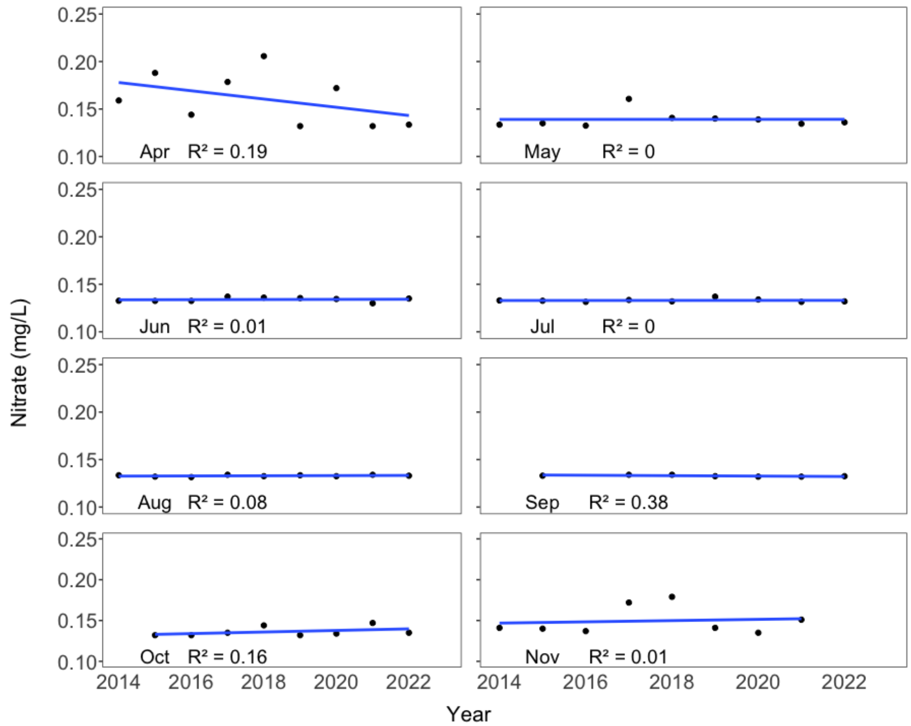

Figure 23. Mean monthly nitrate from 2014-2022.

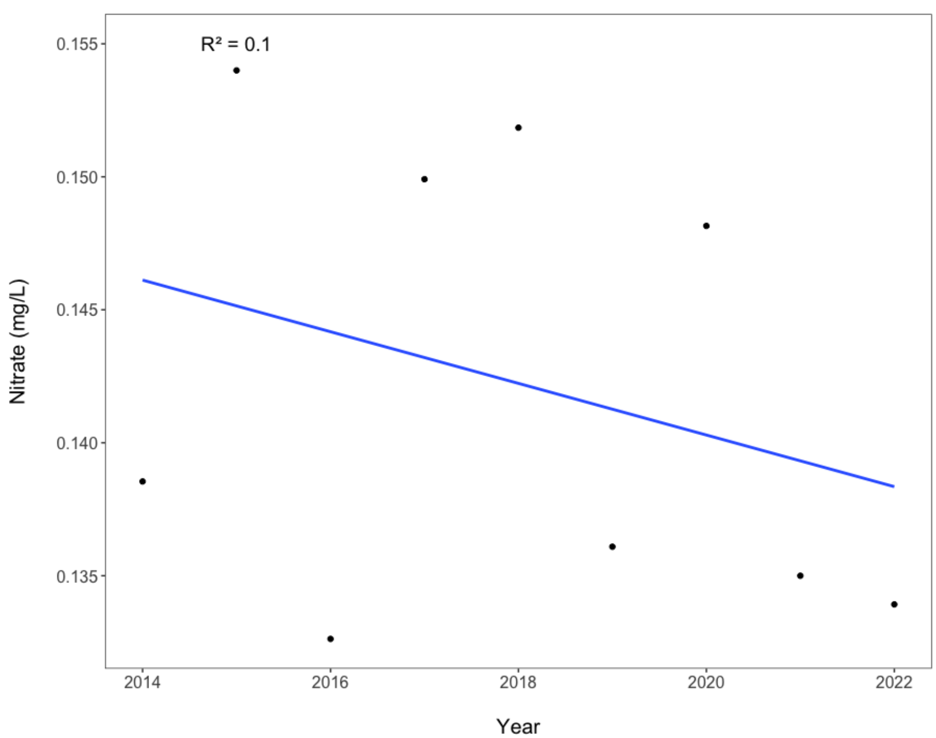

Figure 24. Mean annual nitrate from 2014-2022.

5.9 Orthophosphate

Orthophosphate, more generally known as soluble reactive phosphorus (SRP), or phosphate, is the form of phosphorus available for uptake by aquatic organisms. High bioavailable levels of phosphate can directly lead to increased plant and algal growth. Mean monthly phosphate levels in Rogers Lake in 2022 ranged from 0.021 ± 0 mg/L and 0.026 ± 0 mg/L, with an annual mean phosphate concentration of 0.022 ± 0.002 mg/L (Figure 25). When examining the relationship between mean monthly phosphate and year on a monthly basis, phosphate gradually increased in all months with time, but the relationship was only significant in October (Figure 26, Appendix II Table 2.2). Mean annual phosphate increased with time and the relationship was statistically significant (Figure 27, Appendix III Table 3.1). When comparing the highest and lowest mean annual phosphate levels from 2014-2022, the difference was approximately 0.004 mg/L.

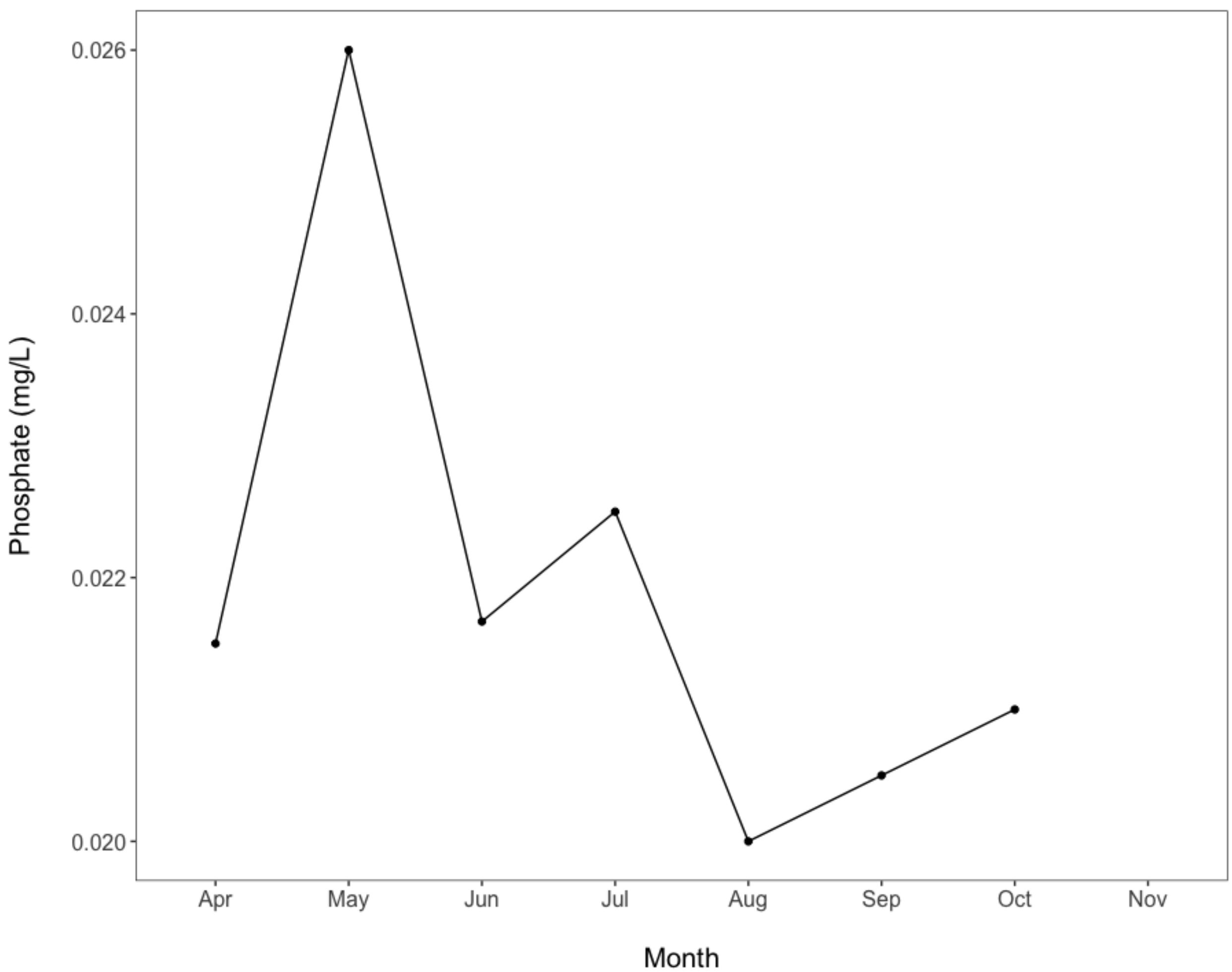

Figure 25. Mean phosphate by month in 2022 in Rogers Lake.

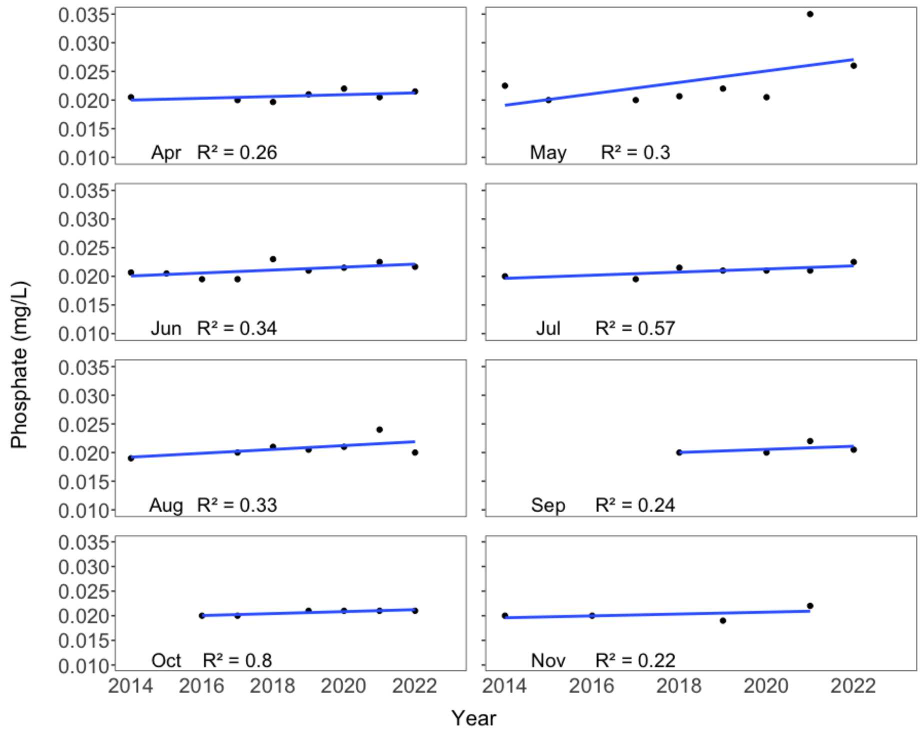

Figure 26. Mean monthly phosphate from 2014-2022.

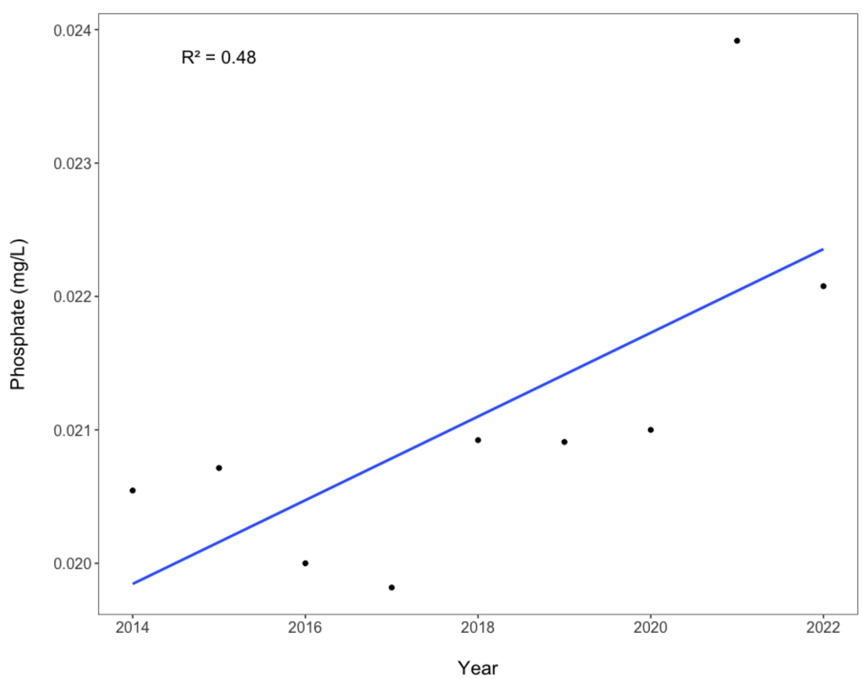

Figure 27. Mean annual phosphate from 2014-2022.

5.10 Fluoride

Fluoride is an anion of fluorine. It occurs naturally in rocks, soil, minerals, and is found in low concentrations in freshwater, where it can be used as a micronutrient by plants and microorganisms. High fluoride concentrations can have toxic effects on vertebrates including fish and amphibians. In freshwater lakes, mean fluoride levels are typically 0.2 mg/L and fluoride toxicity begins as low as 0.5 mg/L[3].

Mean annual fluoride in 2022 was 0.08 ± 0.006 mg/L, with mean monthly values ranging from 0.071 ± 0.003 mg/L in April to 0.09 ± 0 mg/L in May and again in October (Figure 28). Mean monthly fluoride levels significantly increased through time in the months of August, September, and October (Figure 29, Appendix II Table 2.3). Mean annual fluoride significantly increased from 2014 to 2022 (Figure 30, Appendix III Table 3.1). There was a 0.011 mg/L difference between the lowest concentration of 0.069 mg/L in 2016 and the 2022 annual mean fluoride concentration.

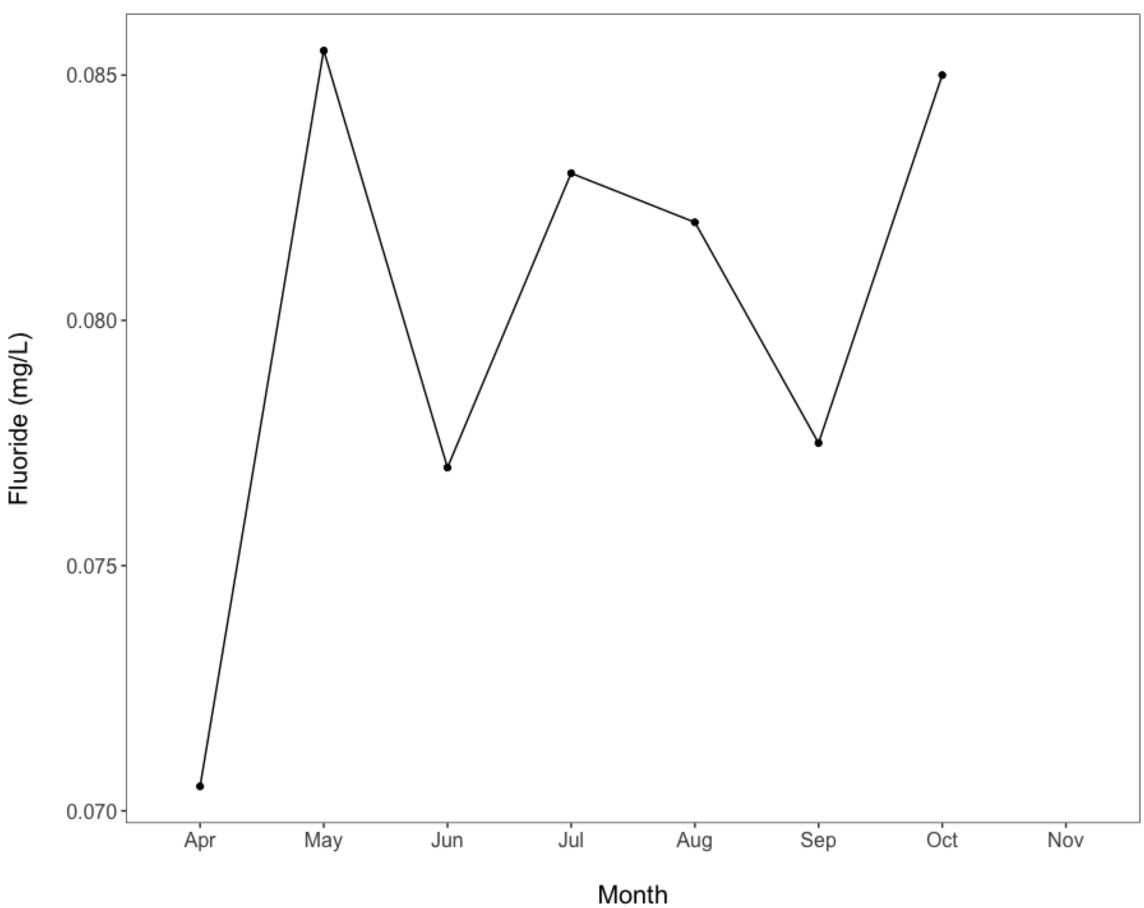

Figure 28. Mean monthly fluoride in Rogers Lake in 2022.

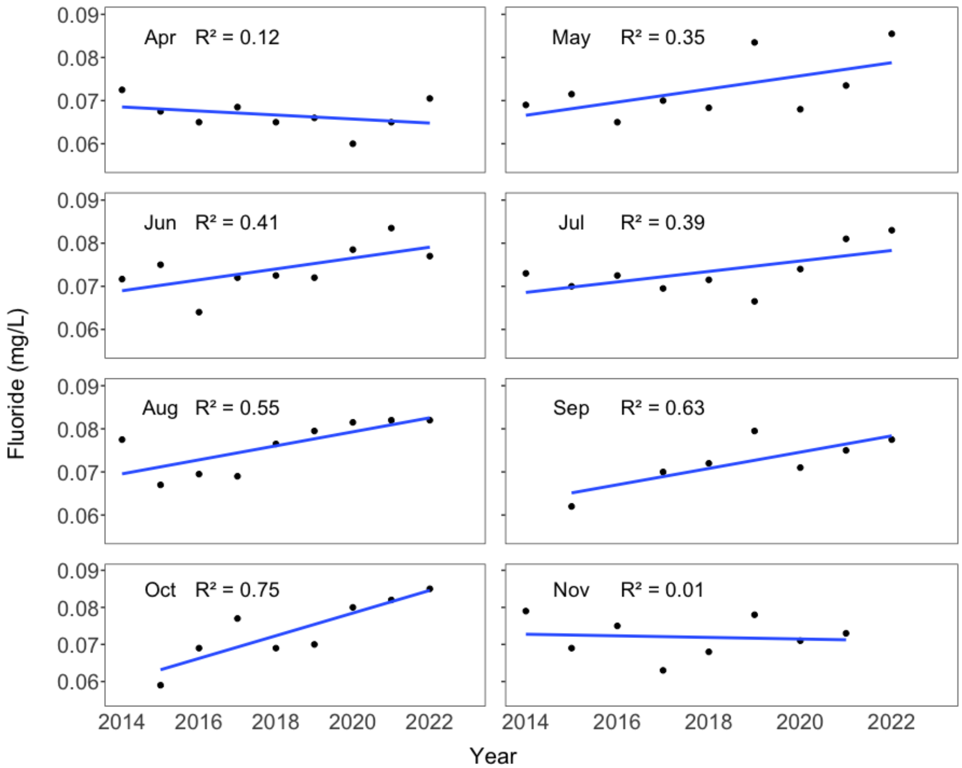

Figure 29. Mean monthly fluoride from 2014-2022.

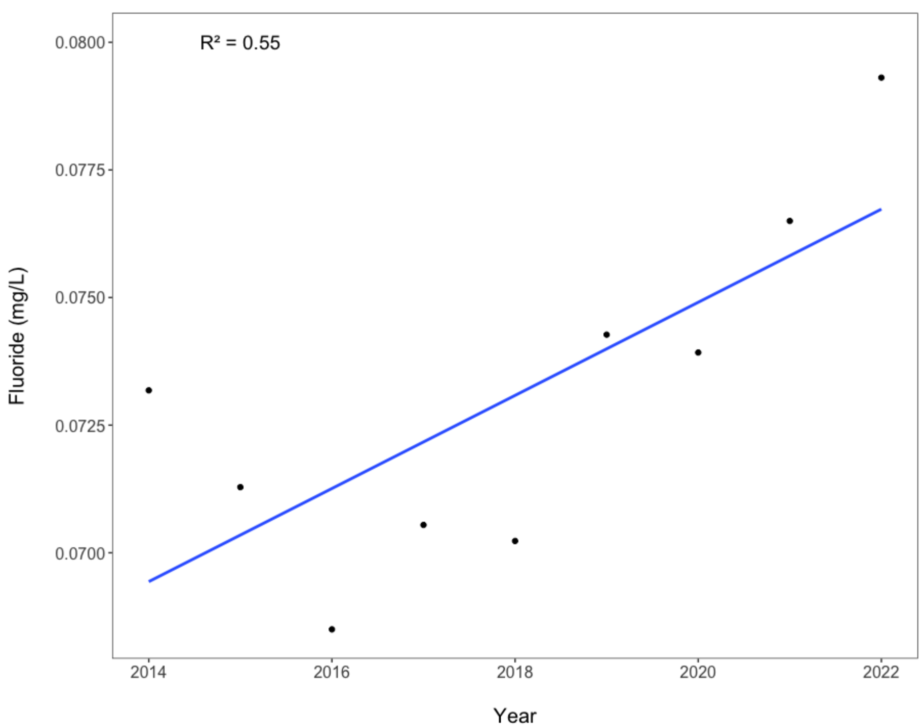

Figure 30. Mean annual fluoride from 2014-2022.

5.11 Chloride

Chloride is a chemical ion of chlorine. It is found naturally in low concentrations in freshwater. Runoff from dissolved winter road salts can cause increased chloride concentrations in lakes. Chloride above 230 mg/L for prolonged periods can be toxic to freshwater organisms[5].

Mean monthly chloride levels in 2022 were lowest in April at 7.81 ± 0.003 mg/L and increased to their highest levels in May at 18.16 ± 0.05 mg/L (Figure 31). Mean monthly chloride levels significantly decreased with year in April and November (Figure 32, Appendix II Table 2.3). Although mean annual chloride decreased from 2005 to 2022, the relationship with year was not statistically significant (Figure 33, Appendix III Table 3.1).

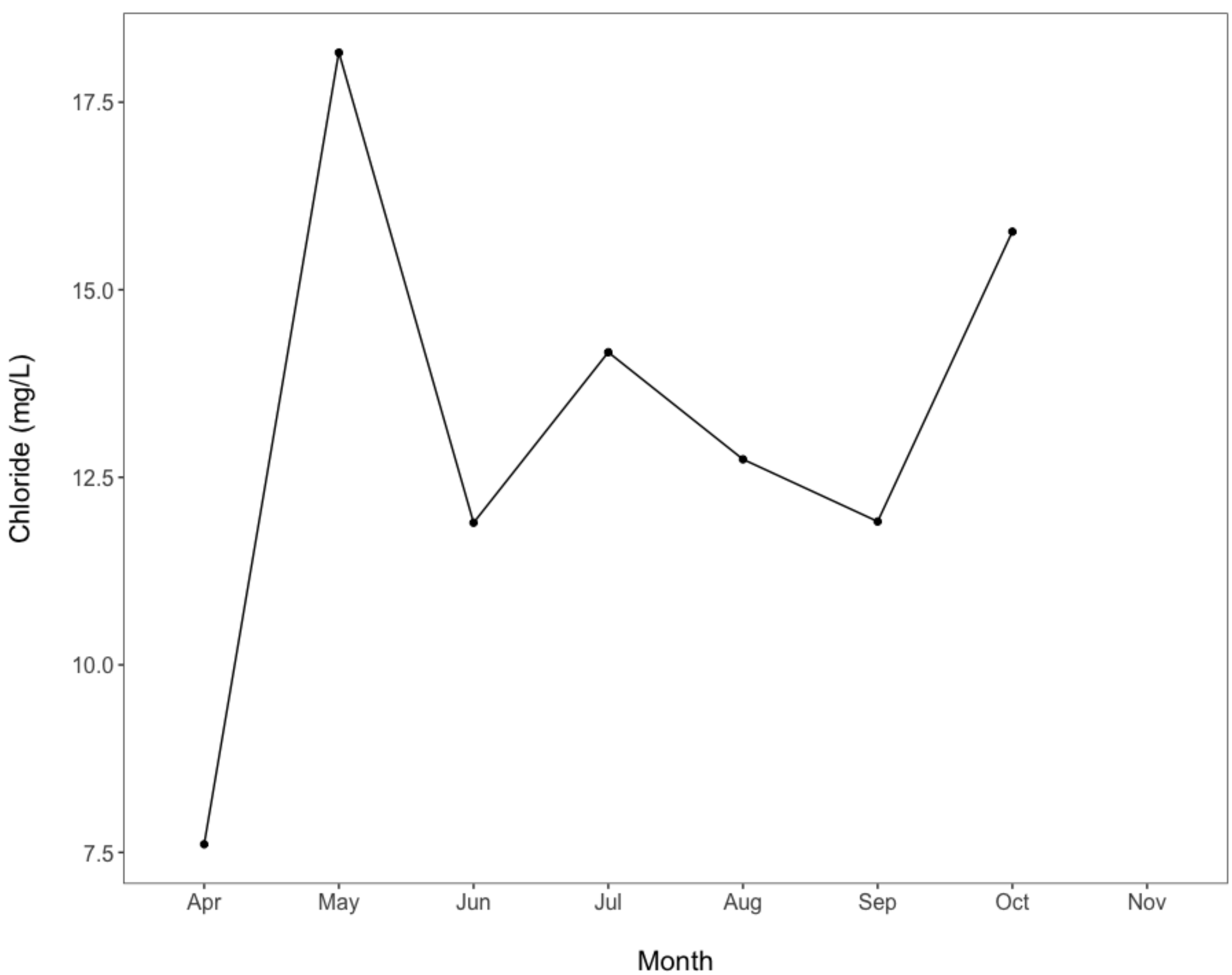

Figure 31. Mean monthly chloride in Rogers Lake in 2022.

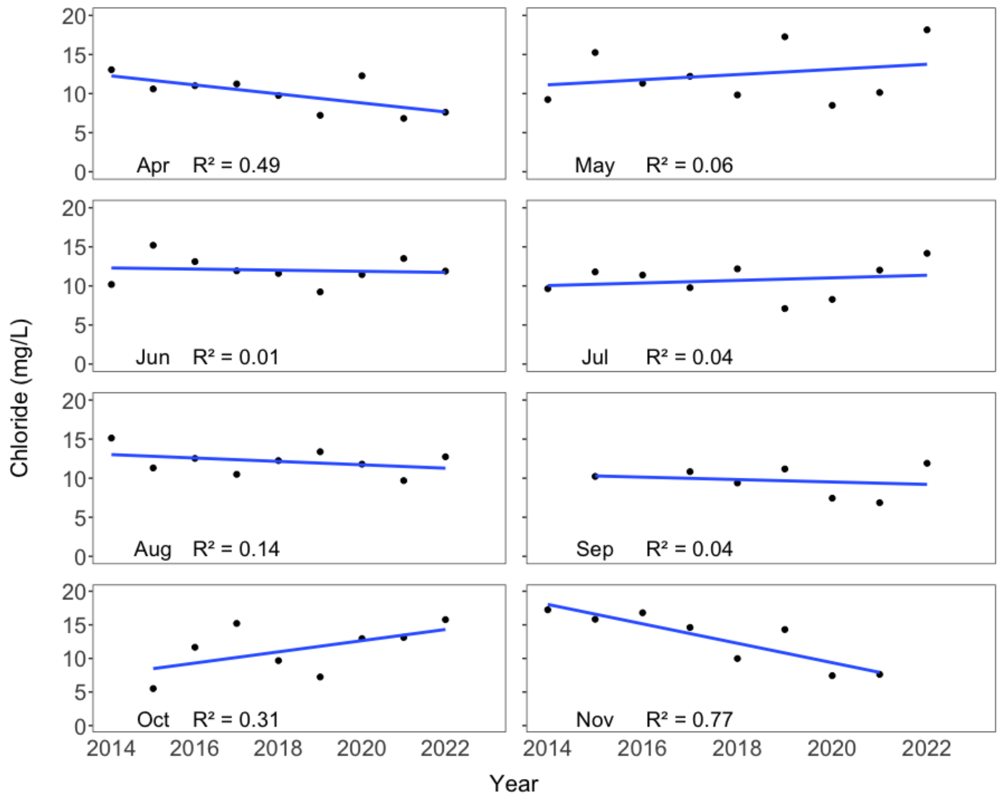

Figure 32. Mean monthly chloride from 2014-2022.

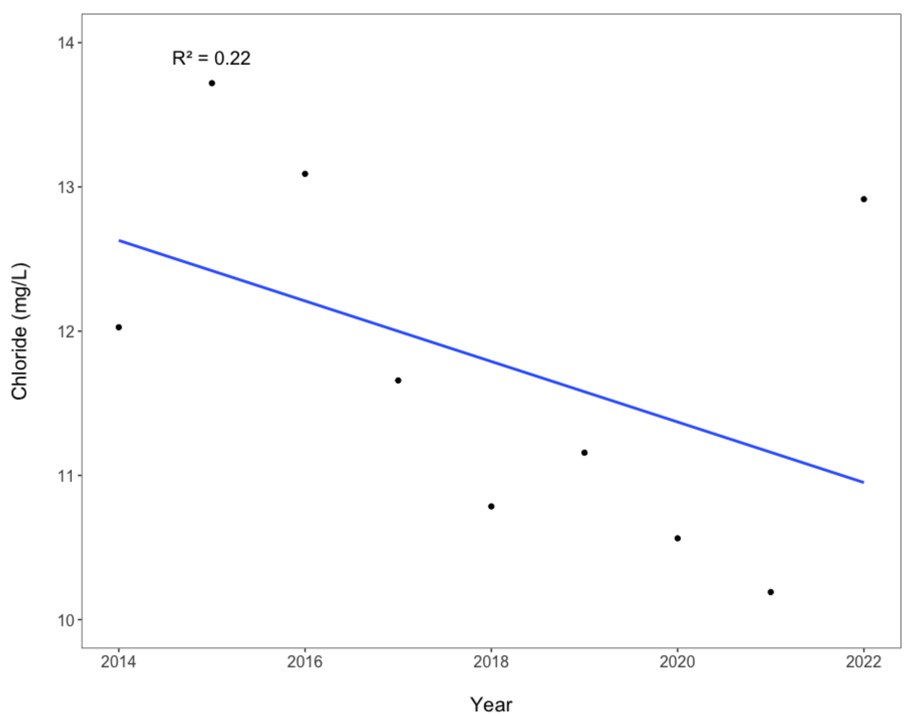

Figure 33. Mean annual chloride from 2014-2022.

5.12 Bromide

Bromide is a naturally occurring ion of bromine that is found in freshwater ecosystems, usually in very low concentrations. Its primary source in lakes is erosion of rock, but runoff from urban areas where some types of pesticides are used can cause elevated levels. Normal levels of bromide in freshwater systems are less than 0.2 mg/L[7].

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Mean monthly bromide concentrations in 2022 were lowest in April at 0.11 ± 0 mg/L and increased to their highest levels in May and October at 0.13 ± 0 mg/L (Figure 34). July was the only month where mean monthly bromide significantly increased with year (Figure 35, Appendix II Table 2.3). Mean annual bromide for 2022 was 0.12 ± 0.01 mg/L, and these levels significantly increased with time (Figure 36, Appendix III Table 3.1). However, there is only a 0.005 mg/L difference between the lowest reading in 2016 and the 2022 concentrations.

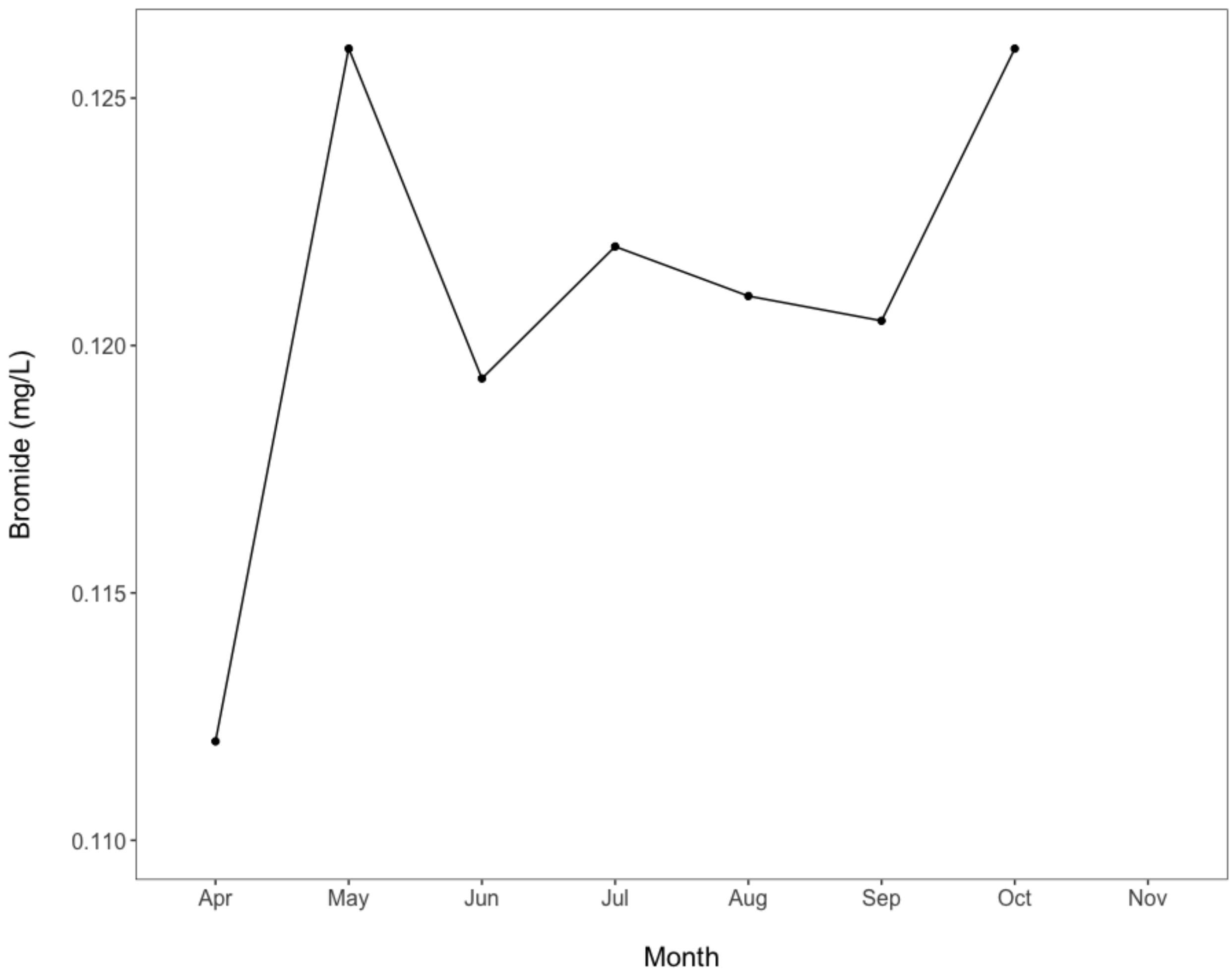

Figure 34. Mean monthly bromide in Rogers Lake in 2022.

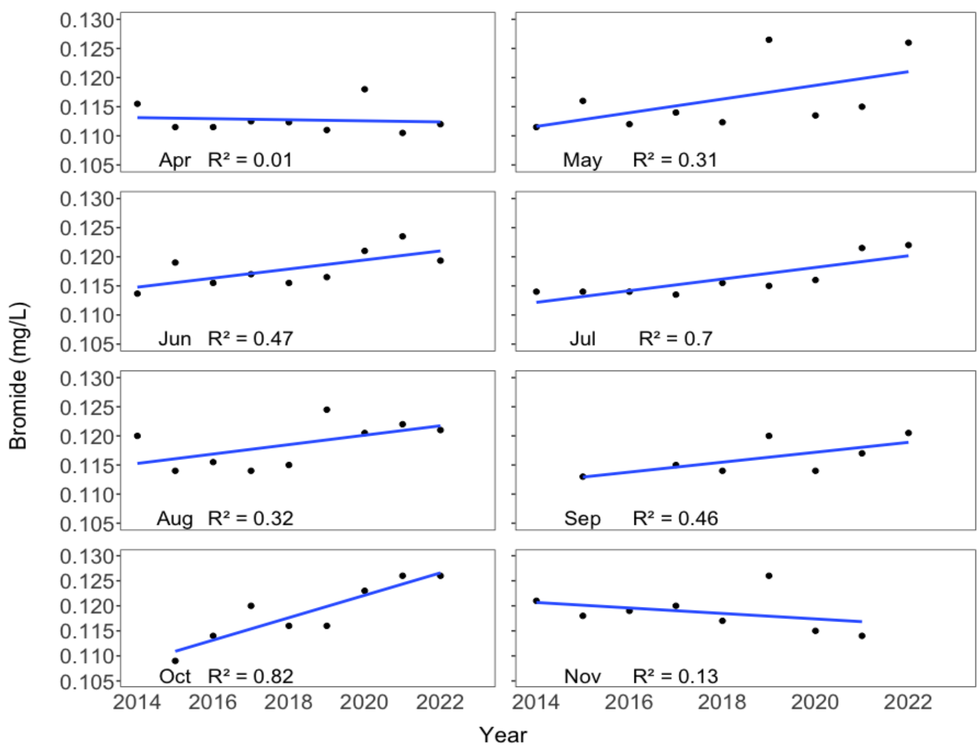

Figure 35. Mean monthly bromide from 2014-2022.

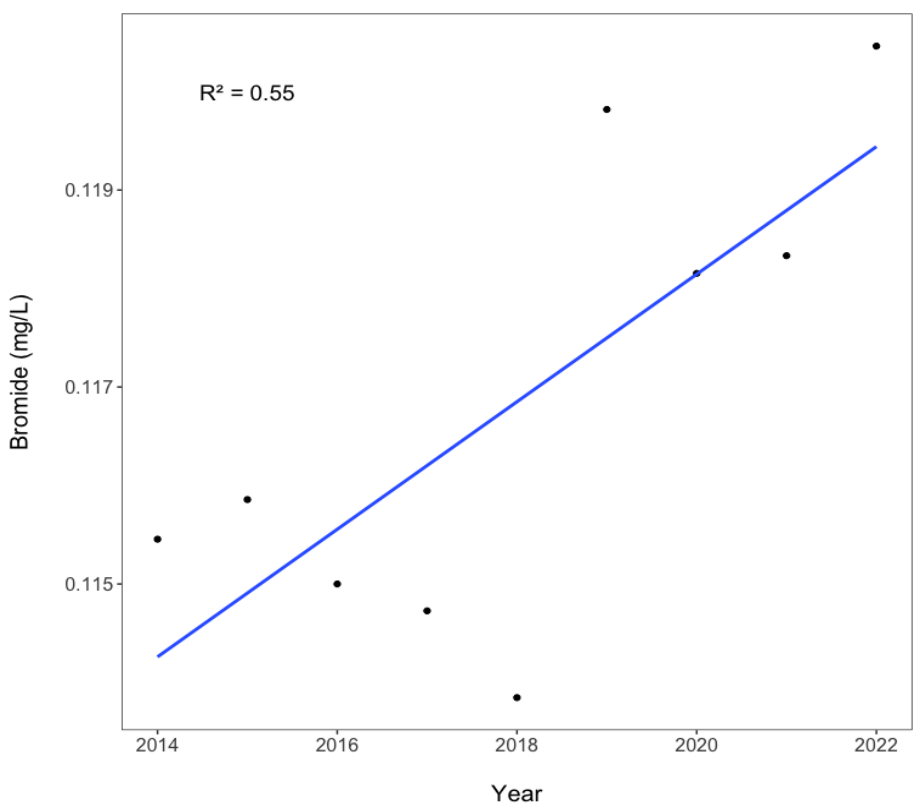

Figure 36. Mean annual bromide from 2014-2022.

5.13 Sulfate

Sulfate is a chemical ion composed of sulfur and oxygen. It occurs naturally in freshwater. High levels of sulfate are generally not toxic but can contribute to the formation of hydrogen sulfide, which can be toxic to some aquatic organisms at high levels. Typical sulfate concentrations in lakes range from 0-250 mg/L[8].

In 2022, mean monthly sulfate concentration was lowest in April at 4.7 ± 0.08 mg/L and increased to a maximum level of 10.8 ± 0.02 mg/L in May (Figure 37). Mean annual sulfate concentration in 2022 was 7.5 ± 2.3 mg/L, and there was no indication that sulfate levels were increasing with year (Figure 39, Appendix III Table 3.1). Mean monthly sulfate did increase at a statistically significant rate with year in the months of July and October, but this increase was small (Figure 38, Appendix II Table 2.3).

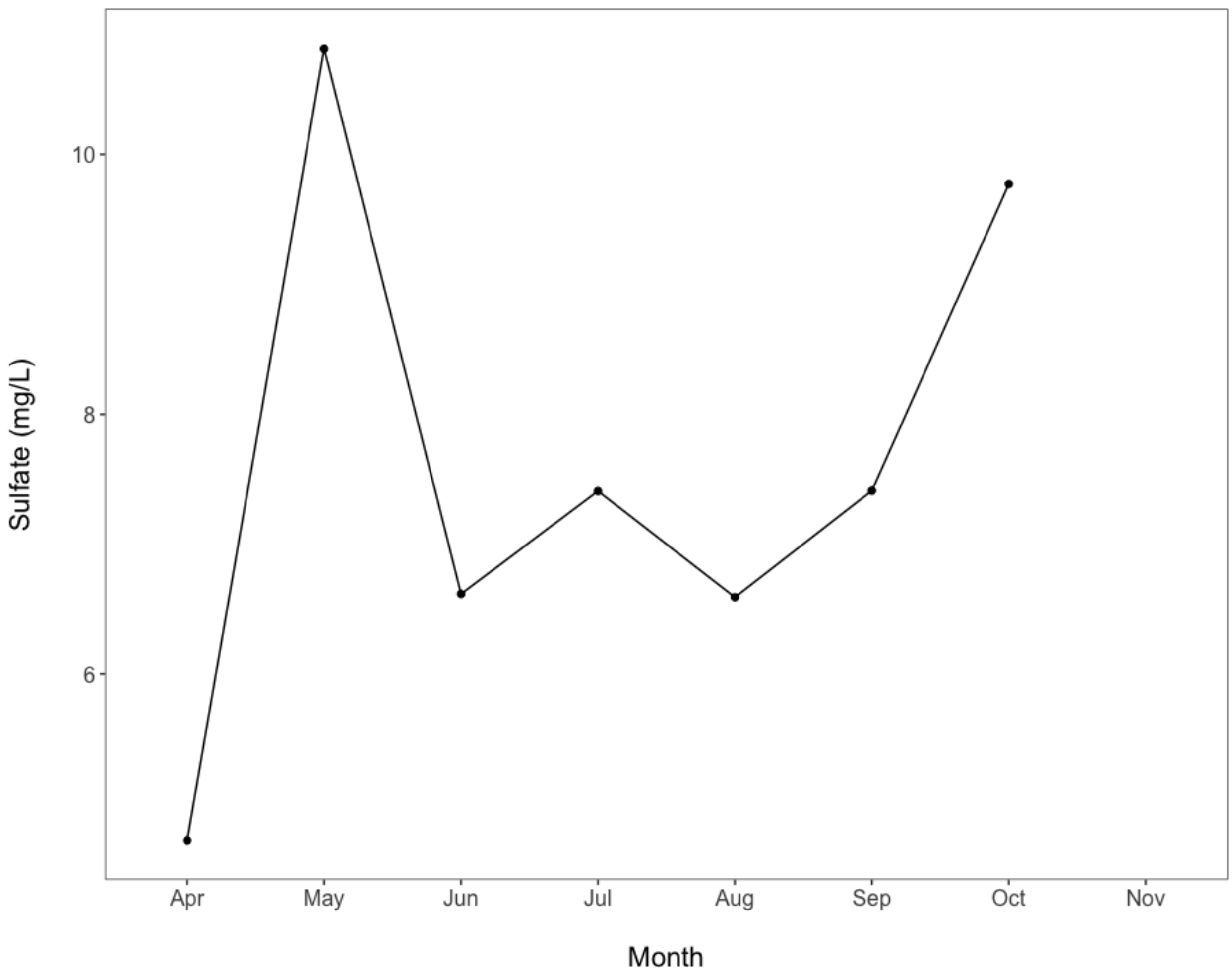

Figure 37. Mean monthly sulfate in Rogers Lake in 2022.

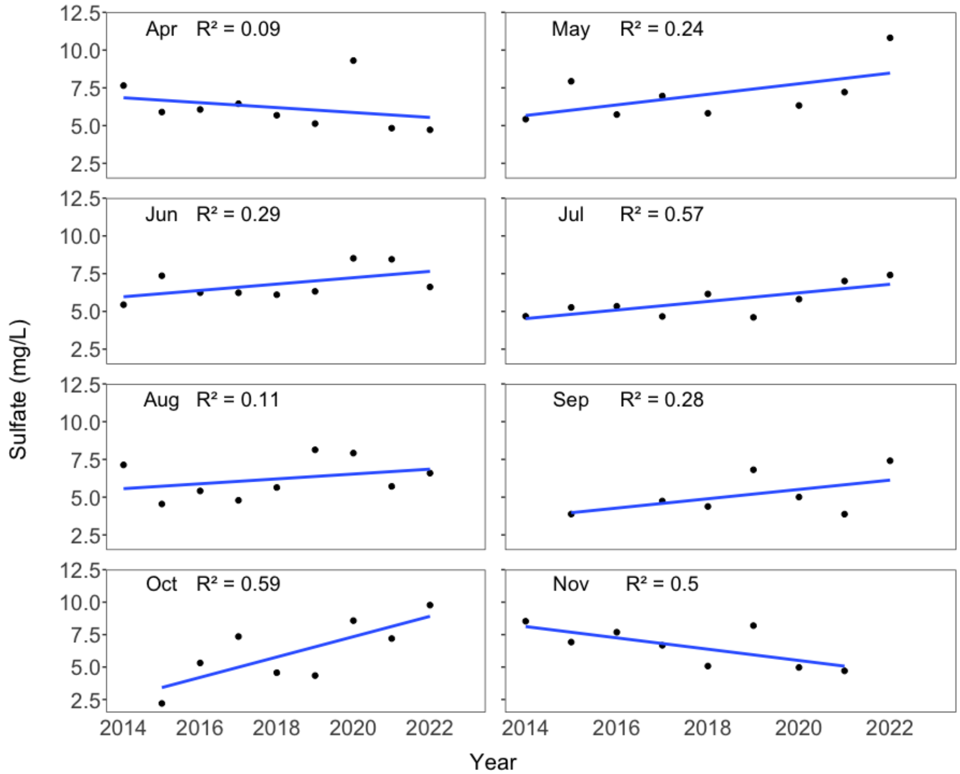

Figure 38. Mean monthly sulfate from 2014-2022.

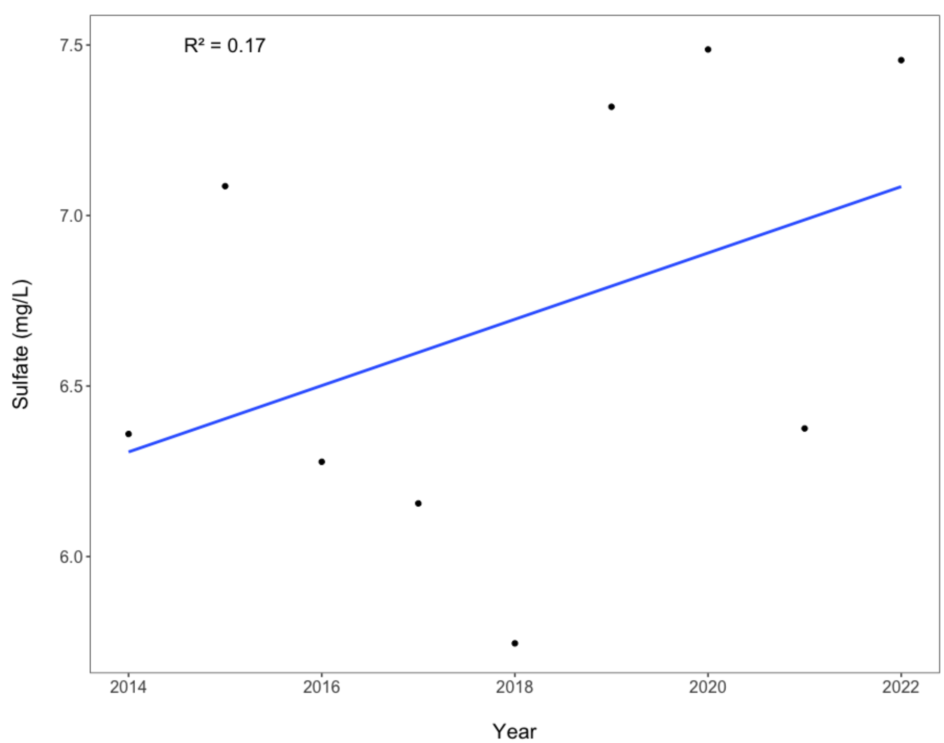

Figure 39. Mean annual sulfate from 2014-2022.

6. RESULTS SUMMARY

The Connecticut Department of Energy and Environmental Protection (CT DEEP) has established Water Quality Standards for lake nutrients[2]. Lakes are categorized by trophic state as Oligotrophic, Mesotrophic, Eutrophic, or Highly Eutrophic based on their defining ranges of total phosphorus, total nitrogen, chlorophyll-a and secchi depth transparency. Ranges and definitions for these lake states can be found in Tables 3 and 4. The measured values for these four parameters for Rogers Lake since 2005 all fall within the ranges of a Mesotrophic lake. Table 5 contains the mean annual values for all water quality parameters and their trends through time. For the purpose of this report, parameters that did not change *statistically* significantly with year were referred to as "stable".

Table 3. Parameters and defining ranges for the trophic state of lakes in Connecticut[2].

Category	Total Phosphorus (µg/L)	Total Nitrogen (mg/L)	Chlorophyll-a (µg/L)	Secchi Disk Transparency (Meters)
Oligotrophic	0-10	0-0.2	0-2	6+
Mesotrophic	10-30	0.2-0.6	2-15	2-6
Eutrophic	30-50	0.6-1.0	15-30	1-2
Highly Eutrophic	50+	1.0+	30+	0-1

Note: Defining ranges for total phosphorus and total nitrogen are for spring and summer. Chlorophyll-a and secchi disk transparency are for mid-summer.

Table 4. Definitions of each trophic lake state[2].

Category	Definition
Oligotrophic	Water is low in plant nutrients and with low biological productivity characterized by the absence of macrophyte beds.
Mesotrophic	Water is moderately enriched with plant nutrients and with moderate biological productivity characterized by intermittent blooms of algae or small areas of macrophyte beds.
Eutrophic	Water is highly enriched with plant nutrients and with high biological productivity characterized by occasional blooms of algae or extensive areas of dense macrophyte beds.
Highly Eutrophic	Water is excessively enriched with plant nutrients and with high biological productivity, characterized by severe blooms of algae or extensive areas of dense macrophyte beds.

Table 5. Mean annual values for Rogers Lake water quality parameters and current status.

Parameter	Mean Annual Value for 2022	Status
Temperature	20.1 ± 6.56 °C	Stable
Dissolved Oxygen	8.92 ± 1.21 mg/L	Stable
Secchi Disk Transparency	2.18 ± 0.41 m	Decreasing
Chlorophyll-a	6.19 ± 4.99 µg/L	Stable
Total Phosphorus	15.52 ± 2.74 µg/L	Increasing
Total Nitrogen	0.36 ± 0.03 mg/L	Increasing
Nitrate	0.13 ± 0 mg/L	Stable
Orthophosphate	0.01 ± 0 mg/L	Increasing
pH	6.67 ± 0.32	2022 only - normal for freshwater
Conductivity	65.2 ± 5.26 µS/cm	2022 only - normal for freshwater
Bromide	0.12 ± 0.01 mg/L	Increasing
Chloride	12.91 ± 3.09 mg/L	Stable
Fluoride	0.09 ± 0.01 mg/L	Increasing
Sulfate	7.46 ± 2.27 mg/L	Stable

7. RECOMMENDATIONS

Rogers Lake is currently in good ecological health and can be classified as a Mesotrophic lake. Most parameters measured were stable through time. However, total nitrogen, total phosphorus, and orthophosphate levels are gradually increasing, and water clarity is gradually decreasing, suggesting that Rogers Lake may slowly transition to a eutrophic state if trends continue.

Lake eutrophication is a natural process, but human activities can accelerate this process by adding nutrients to the lake through runoff from fertilizers, land-use changes, leaking septic systems, and erosion or soil disturbances. The RLA can maintain or improve water quality by following a few general good environmental practices for homeowners surrounding the lake, including: judicious and appropriately timed lawn fertilizers application, properly maintaining septic systems, using phosphate-free detergents, and planting vegetation buffers around the lake. In addition, there are several invasive species inhabiting Rogers Lake, including: freshwater jellyfish (*Craspedacusta sowerbi*) (personal observation), Asian clam (*Corbicula fluminea*) (personal observation), curly-leaf pondweed (*Potamogeton crispus*), variable-leaf watermilfoil

(*Myriophyllum heterophyllum Michx.*), and fanwort (*Cabomba caroliniana*)[1]. Invasive species pose a significant threat to ecosystem health and recreational opportunities in Rogers Lake. Efforts to educate the public on invasive species spread prevention and boat inspections should be continued and expanded to help prevent additional invasive species from entering the lake.

Bromide and fluoride concentrations in the lake also increased with time, but both concentrations were very low and no action is recommended.

Continued water quality sampling is recommended to track potential changes in the lake in coming years, and to see if the trend of small increases in phosphorus and nitrogen concentrations continue.

8. PRELIMINARY 2023

As of the issuance of this report, Rogers Lake water samples have been collected from April to July 2023. Total phosphorus and total nitrogen have continued to slightly increase. Mean annual total phosphorus for 2022 was 15.52 ± 2.74 µg/L and as of July 2023 it is 15.71 ± 1.68 µg/L. Mean annual total nitrogen for 2022 was 0.36 ± 0.03 mg/L and as of July 2023 it is 0.39 ± 0.02 mg/L. An updated water quality report and analysis for 2023 will be supplied to the RLA by 12/31/2023.

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Appendix I. Basic Statistics Guide

This report uses basic statistical analyses to examine how water quality parameters are changing with time. We have included a brief explanation of key statistical terms in order to facilitate interpretation of the results.

Linear regression

Linear regression is a way to understand and predict how one variable changes as another variable changes. It provides a simple way to understand and quantify relationships between two variables using a straight line. Linear regression is a foundational concept in statistics and data analysis, often used for making predictions and understanding patterns.

R^2

R-squared, often called the "coefficient of determination," gives an idea of how well a statistical model (like a linear regression model) fits the data points. It is a number between 0 and 1. Higher values mean the model explains more of the variation in the data, while lower values mean it explains less. Values from 0 to 0.3 represent a poor fit, 0.4 to 0.60 a moderate fit, and 0.70 to 1 a strong fit of the model to the data.

β (beta)

In linear regression, β (beta) represents the slope or the change in the dependent variable (y) for a one-unit change in the independent variable (x). It explains how much the dependent variable is expected to change when the independent variable changes by one unit, while keeping other variables constant. In simpler terms, β shows the relationship and direction of change between the variables in a straight-line equation.

p-value

A p-value helps us figure out if research results are meaningful or due to chance. A low p-value suggests real significance, while a high one implies randomness. In this report, a threshold of $p < 0.05$ was used to decide if results of the linear regression were statistically significant. It is important to remember that p-values are only one tool to explore the data. A statistically significant/insignificant result **may not always be biologically meaningful,** especially when the model fits poorly and the observed change in the variable of interest is miniscule**.**

Appendix II. Linear regression results for mean monthly values for all water quality parameters.

Table 2.1 Linear regression results of mean monthly temperature, dissolved oxygen, secchi depth, and chlorophyll-a with year.

Variable	Month	DF	F	R^2	β	p-value
Temperature	Apr	(1,13)	0.49	0.04	-0.06	0.50
	May	(1,16)	0	0	$3.9\ e^{-3}$	0.95
	Jun	(1,17)	0.06	0	0.01	0.81
	Jul	(1,17)	1.63	0.09	0.05	0.22
	Aug	(1,16)	0.01	0	0	0.94
	Sep	(1,10)	0.73	0.07	0.07	0.41
	Oct	(1,10)	0.18	0.02	0.07	0.68
	Nov	(1,11)	0.35	0.03	0.08	0.56
Dissolved Oxygen	Apr	(1,13)	1.14	0.30	-0.03	0.30
	May	(1,16)	0	0	$3.91e^{-03}$	0.95
	Jun	(1,17)	0.06	0	0.01	0.81
	Jul	(1,17)	1.63	0.09	0.05	0.22
	Aug	(1,16)	0	0	0	0.94
	Sep	(1,10)	0.73	0.07	0.07	0.41
	Oct	(1,10)	0.18	0.02	0.07	0.68
	Nov	(1,11)	0.35	0.03	0.08	0.56
Secchi Depth	Apr	(1,14)	7.74	0.36	-0.04	0.01*
	May	(1,16)	14.52	0.48	-0.04	0.002*
	Jun	(1,17)	6.60	0.30	-0.03	0.02*
	Jul	(1,17)	6.45	0.27	-0.03	0.02*
	Aug	(1,16)	12.3	0.43	-0.07	< 0.01*
	Sep	(1,10)	3.56	0.26	-0.05	0.09
	Oct	(1,11)	0.27	0.03	-0.03	0.61
	Nov	(1,10)	1.23	0.01	-0.04	0.29
Chlorophyll-a	Apr	(1,14)	0.21	0.01	-0.04	0.66
	May	(1,16)	0.11	0.01	0.02	0.75
	Jun	(1,17)	0.01	0	-0.01	0.94
	Jul	(1,17)	0.75	0.04	0.07	0.40
	Aug	(1,16)	0.12	0.01	0.03	0.73
	Sep	(1,10)	3.12	0.24	0.18	0.11
	Oct	(1,9)	1.88	0.17	0.22	0.2
	Nov	(1,11)	0.33	0.03	0.04	0.58

* designates statistically significant results.

Table 2.2 Linear regression results of mean monthly nitrate, total nitrogen, orthophosphate, and total phosphorus with year, divided by month.

Variable	Month	DF	F	R^2	β	p-value
Nitrate	Apr	(1,7)	1.67	0.19	0	0.24
	May	(1,7)	0	0	0	0.99
	Jun	(1,7)	0.06	0.01	0	0.82
	Jul	(1,7)	0	0	0	0.95
	Aug	(1,7)	0.62	0.08	0	0.46
	Sep	(1,5)	3.13	0.38	0	0.14
	Oct	(1,6)	1.18	0.16	0	0.32
	Nov	(1,6)	0.07	0.01	0	0.79
Total Nitrogen	Apr	(1, 15)	7.61	0.35	$4e^{-3}$	0.02*
	May	(1, 16)	5.84	0.27	$4.5e^{-3}$	0.03*
	Jun	(1, 16)	0.69	0.04	0	0.42
	Jul	(1,16)	13.48	0.46	$4.8e^{-3}$	<0.01*
	Aug	(1, 15)	2.93	0.16	0	0.11
	Sep	(1, 9)	0.39	0.04	0	0.55
	Oct	(1,10)	4.59	0.31	0	0.06
	Nov	(1,11)	6.67	0.38	0.01	0.03*
Orthophosphate	Apr	(1, 5)	1.72	0.26	0	0.24
	May	(1, 6)	2.59	0.30	0	0.16
	Jun	(1, 7)	3.63	0.34	0	0.1
	Jul	(1, 5)	6.54	0.57	0	0.051
	Aug	(1, 5)	2.44	0.33	0	0.18
	Sep	(1, 2)	0.63	0.23	0	0.51
	Oct	(1, 4)	15.51	0.80	$1.99e^{-4}$	0.02
	Nov	(1, 2)	0.56	0.22	0	0.53
Total Phosphorus	Apr	(1, 14)	3.58	0.20	0.20	0.08
	May	(1, 16)	0.90	0.05	0.19	0.36
	Jun	(1, 16)	0.28	0.02	0.04	0.61
	Jul	(1, 15)	4.43	0.23	0.18	0.05
	Aug	(1, 15)	8.13	0.35	0.21	0.01*
	Sep	(1, 9)	0.54	0.06	0.11	0.48
	Oct	(1, 10)	1.12	0.10	0.18	0.32
	Nov	(1,11)	2.0	0.15	0.25	0.18

* designates statistically significant results

Table 2.3 Linear regression results of mean monthly chloride, bromide, fluoride, and sulfate with year, divided by month.

Variable	Month	DF	F	R^2	β	p-value
Chloride	Apr	(1,7)	6.63	0.49	-0.58	0.04*
	May	(1,7)	0.47	0.06	0.33	0.51
	Jun	(1,7)	0.09	0.01	-0.07	0.78
	Jul	(1,7)	0.31	0.04	0.17	0.59
	Aug	(1,7)	1.12	0.14	-0.22	0.33
	Sep	(1,5)	0.2	0.04	-0.15	0.68
	Oct	(1,6)	2.69	0.31	0.83	0.15
	Nov	(1,6)	20.31	0.77	-1.45	<0.01*
Bromide	Apr	(1,7)	0.08	0.01	$-9.2e^{5}$	0.79
	May	(1,7)	3.09	0.31	0	0.12
	Jun	(1,7)	6.33	0.47	$7.8e^{-4}$	0.04
	Jul	(1,7)	16.47	0.7	$1e^{-3}$	<0.01*
	Aug	(1,7)	3.30	0.32	0	0.11
	Sep	(1,5)	4.28	0.46	0	0.09
	Oct	(1,6)	26.79	0.82	$2.2e^{-3}$	<0.01
	Nov	(1,6)	0.87	0.13	0	0.39
Fluoride	Apr	(1,7)	0.98	0.12	0	0.35
	May	(1,7)	3.69	0.35	0	0.1
	Jun	(1,7)	4.78	0.41	0	0.07
	Jul	(1,7)	4.42	0.39	0	0.07
	Aug	(1,7)	8.48	0.55	$1.6e^{-3}$	0.02*
	Sep	(1,5)	8.37	0.63	$1.9e^{-3}$	0.03*
	Oct	(1,6)	18.47	0.75	$3.1e^{-3}$	0.01*
	Nov	(1,6)	0.06	0.01	0	0.82
Sulfate	Apr	(1,7)	0.70	0.09	-0.16	0.43
	May	(1,7)	2.23	0.24	0.43	0.18
	Jun	(1,7)	2.84	0.29	0.21	0.14
	Jul	(1,7)	9.33	0.57	0.28	0.02*
	Aug	(1,7)	0.91	0.11	0.16	0.37
	Sep	(1,5)	1.94	0.28	0.31	0.22
	Oct	(1,6)	8.71	0.59	0.78	0.03*
	Nov	(1,6)	5.89	0.50	-0.44	0.051

* designates statistically significant results

Appendix III. Linear regressions of mean annual values for all water quality parameters.

Table 3.1 Linear regression results of all mean annual values for water quality parameters with year.

Variable	**DF**	**F**	**R^2**	**β**	**p-value**
Temperature	(1, 17)	2.58	0.13	-0.11	0.13
Dissolved Oxygen	(1,14)	0.21	0.01	0	0.65
Secchi Depth	(1, 17)	18.14	0.52	-0.04	<0.01*
Chlorophyll-a	(1, 17)	1.17	0.06	0.05	0.29
Nitrate	(1, 7)	0.74	0.10	0	0.42
Total Nitrogen	(1, 16)	10.0	0.38	$3.6e^{-3}$	<0.01*
Orthophosphate	(1, 7)	6.49	0.49	$3.1e^{-4}$	0.04*
Total Phosphorus	(1, 16)	5.25	0.25	0.15	0.04*
Bromide	(1, 7)	8.6	0.55	$6.4e^{-4}$	0.02*
Chloride	(1, 7)	1.93	0.22	-0.21	0.21
Fluoride	(1, 7)	8.43	0.55	$9.1e^{-4}$	0.02*
Sulfate	(1, 7)	1.44	0.17	0.1	0.27

* designates statistically significant results.