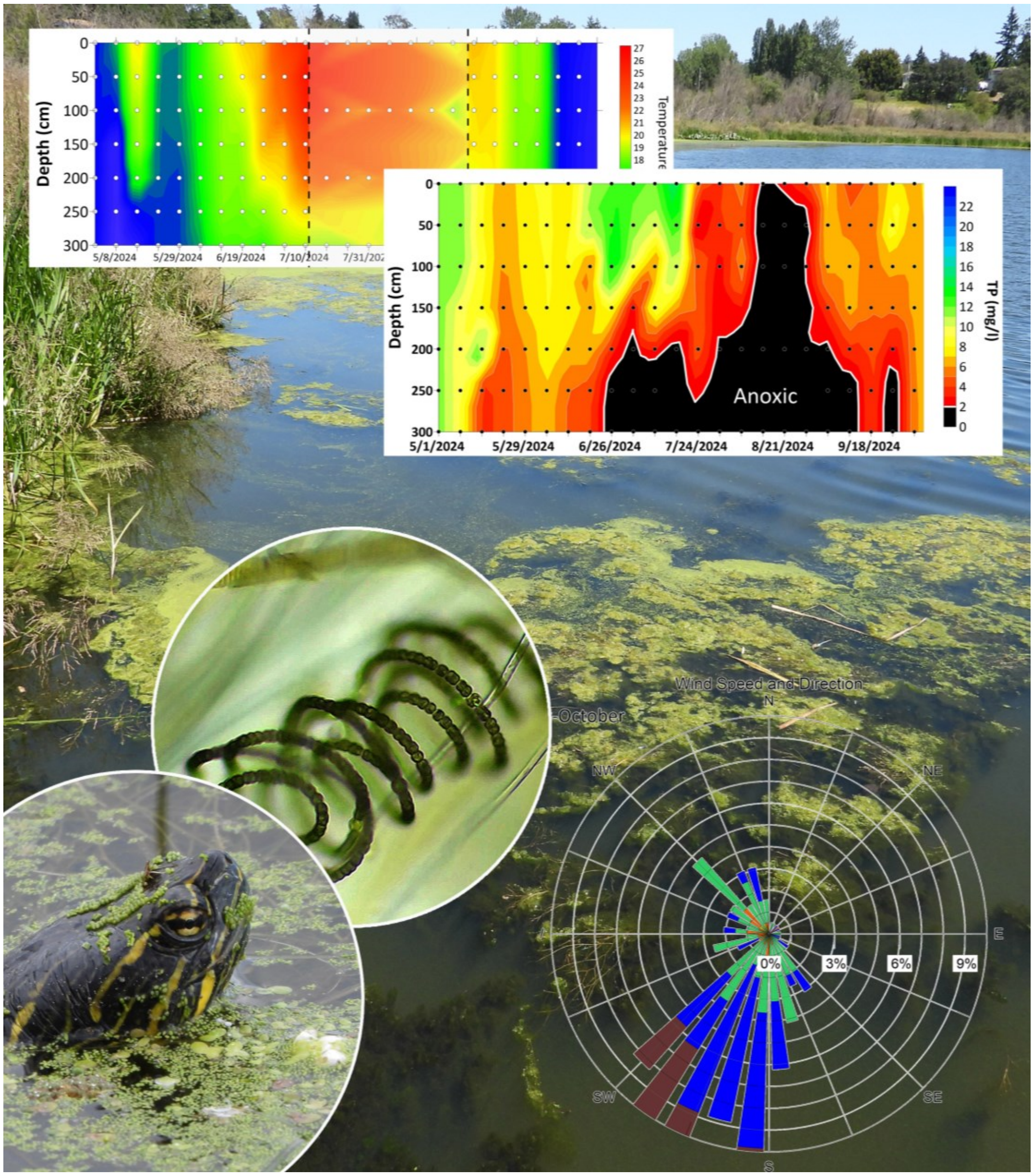
Swan Lake Water Quality Monitoring
May–October 2024



Submitted to Dr. Cara Gibson

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December 2024

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Executive Summary

This is the ninth consecutive year of water quality sampling using a consistent methodology. Key water quality parameters including dissolved oxygen, pH, temperature, oxygen reduction potential, total dissolved solids, nutrients, chlorophyll-a and phycocyanin are summarized as time-series plots and some interpretations are offered to address the inter-relationships that influence the lake conditions. Data were collected at two lake sites and the inflow creek starting in May and ending in mid-October 2024. Two dissolved oxygen loggers as well as two solar lux loggers were deployed at a 60 cm depth to provide high temporal resolution within the limited photic zone. Data were collected every 30 minutes from mid-May to mid-October. Two dominant species of cyanobacteria were observed during the course of the sampling season. *Aphanizomenon flos-aquae* were already established at the start of the sampling program in the cooler spring conditions with relatively high light penetration. This was followed by a warming of the water column and a successional transition to the more intense bloom of the species *Dolichospermum*. It was during this bloom that the lake saw dissolved oxygen levels reach their highest levels of the sampling period creating huge diurnal swings in oxygen as these organisms oscillated between oxygen production by day and respiration by night. During this bloom, the relatively high phosphorus levels were consumed through metabolic processes until they were exhausted resulting in a rapid die-off and a reduction in dissolved oxygen. Weekly water samples taken at one-meter intervals showed the dynamics of phosphorus, nitrogen, phycocyanin and chlorophyll as the lake cycled through algal bloom, die-off, decomposition and restoring forces. Contour maps of dissolved oxygen, water temperatures, phosphate and nitrates were created to help visualize lake dynamics through its various transitions. These plots give insights to the year-to-year differences. Multi-year plots are presented that compare interannual variability and a simplified dissolved oxygen seasonal pattern diagram is presented based on these data. Finally, recommendations are offered for future studies that would lead to a more comprehensive understanding of the dynamic processes at work at Swan Lake.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

This is the ninth year of monitoring Swan Lake following the steps and methods from the previous years. With the collection of water samples and water column profiles, year-to-year comparisons are providing insights into the physical, chemical and biological systems that govern the seasonal changes at Swan Lake.

The frequency of sampling a eutrophic, or at times, a hyper-eutrophic system where there are large diurnal oscillations, algal bloom states, responses to weather events and seasonal changes is an essential consideration. To achieve good temporal resolutions, two HOBO U26 dissolved oxygen loggers along with two solar lux loggers that measure light penetration were deployed. The sample interval of these loggers was set to 30 minutes. These loggers were positioned in the water column at a depth of 60 cm at both the Founders' Wharf and the boardwalk. This was complemented by weekly site visits where an array of water parameters were tested along with a series of water column profiling at depth intervals of 50 cm to the bottom. Note that there was a disruption of sampling at these lake sites for the interval of July 17–August 30. Despite this gap, another initiative measured dissolved oxygen (DO) and temperature data at a deep-water site as part of an effort to obtain Level 1 status from the BC Lake Stewardship Society (BCLSS). These data, along with the continuous HOBO DO loggers (measuring both DO and temperature at the lake sites) were used to bridge this gap.

In this report, data is presented as time series plots to examine the temporal variations of each of the measured water properties including dissolved oxygen (DO), pH, oxygen reduction potential (ORP), temperature, Secchi depth, nitrogen, phosphorus, chlorophyll-a and phycocyanin (PC) for the 2024 sampling period. These parameters are some of the key indicators of aquatic health. Although this is largely a data report, some interpretation of the factors that influence the measured parameters will be offered along with interannual time series comparisons with data spanning the years 2016–2024.

As this monitoring program is a continuation from previous years, the initial sections of this report—those that define a brief history, the physical description of the lake and its watershed, the study site selection and the water quality monitoring methodology—will be repeated as they appeared in previous years' reports with a few updates.

The water quality of Swan Lake has significant impacts on the health and biodiversity of the lake and its surrounding ecosystems. As with many urban wetlands, Swan Lake concentrates wildlife and supplies vital nursery areas, food sources and large varieties of protected habitat in the midst of an increasingly developed landscape. Additional values of this feature are far-reaching as Swan Lake gives rest to migratory birds, provides water filtration and flood control, enables aquatic transitioning for insects and terrestrial species and provides educational opportunities to observe the interactions of many natural systems.

Human impact has changed the state of the health of this lake over time. In the late 1800s and the early 1900s, people swam and fished the lake and local residents recall the lake as being clear and free from algae blooms. In 1927, a winery was constructed on Quadra Street and effluent from the winery began to have negative impacts on the water quality of the lake. Significant areas upstream of the lake introduce non-point source agricultural nutrients that follow the catchment basin via the inflow of Blenkinsop Creek. Such nutrient loading, as well as other elements from urban sources, have over time created a highly eutrophic aquatic system characterized by high turbidity, elevated phosphorus levels and at times low dissolved oxygen concentrations. During the typical dry summers of Victoria, algae blooms are common and on occasion fish kills occur where lake temperatures, dissolved oxygen, algae overgrowth and nutrient imbalances result in conditions that exceed tolerable limits for fish and a host of organisms. During these algae blooms, visitors to the walkways around the lake can at times smell a pungent odor emitted from biomats that cover large parts of the lake and shore margins. It is quite common for the western end of the lake to be completely covered in algae. As a result, the overall health and biodiversity of the wetland area is significantly impacted by these summer extreme signals that are measurable in the water quality of the lake.

Changes in lake systems can be subtle or dramatic, human induced or climatic. To better understand the processes at work within the lake and to observe temporal change, a water quality monitoring program was proposed, funded and carried out at Swan Lake measuring water parameters from the beginning of June until the end of September 2016, May to the end of September 2017, April until the beginning of October 2018, April to the beginning of October 2019, May to the end of October 2020, May to October 2021, May to October 2022, May to October 2023 and, most recently, May to mid-October 2024.

2.0 Swan Lake Watershed

The general details about the location and attributes of Swan Lake are listed below.

Swan Lake location: 48 27’47.69”N   123 22’ 21.79”W

Swan Lake watershed: Colquitz River 50 km^2 (Figure 1)

Swan Lake area: 9.3 hectares

Nature sanctuary: 48 hectares

Main inflow stream: Blenkinsop Creek

Main outflow stream: Swan Creek

Maximum depth: ~6 m (Figure 2)

Volume: ~ 317,872 m^3

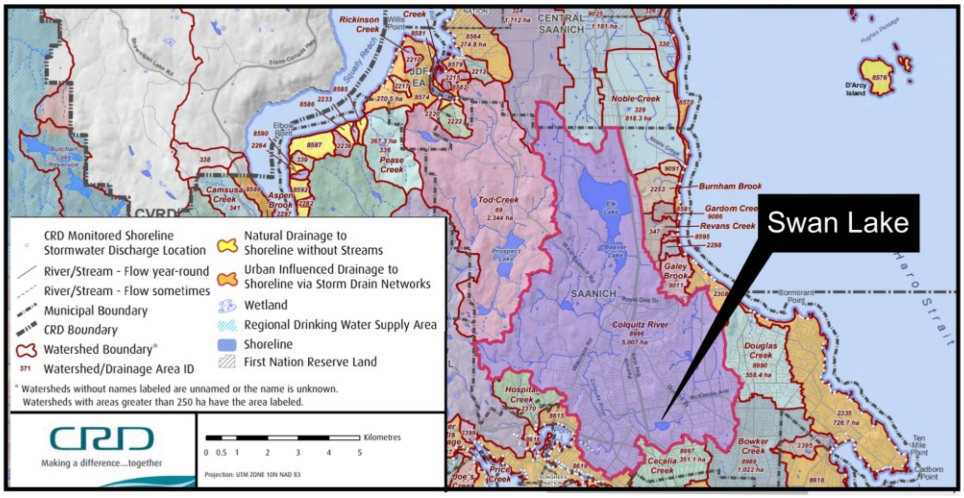


Figure 1. Swan Lake watershed boundary (source: CRD watershed maps).

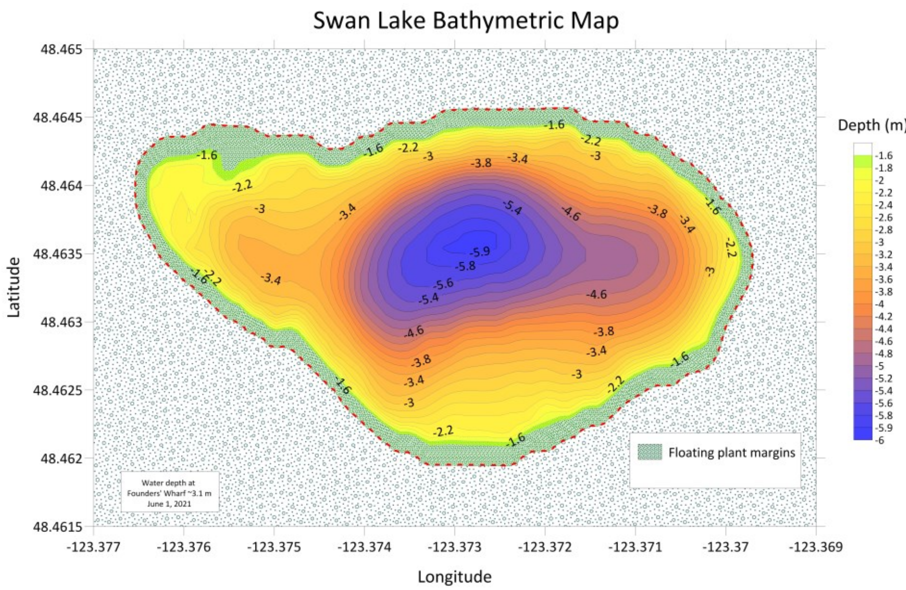


Figure 2. Swan Lake bathymetry (source: Bowen 2021).

3.0 Selection of Sample Sites

Key components to a successful sampling program are the selection of sample sites that represent a good spatial distribution of lake conditions as well as a rationale that justifies the sample site positions for profiling. In this study, two lake sites and the inflow creek were selected. In addition, a deep-water site was sampled as a separate initiative carried out by the good work of Deanie Harding, Kristen Banasch, Ben Milligan and Dylan Simpson. Some of these data were used to fill in a gap in the summer data collections. The positions of these sites are indicated in Figure 3. Each site will briefly be described and the selection rationale will be discussed.

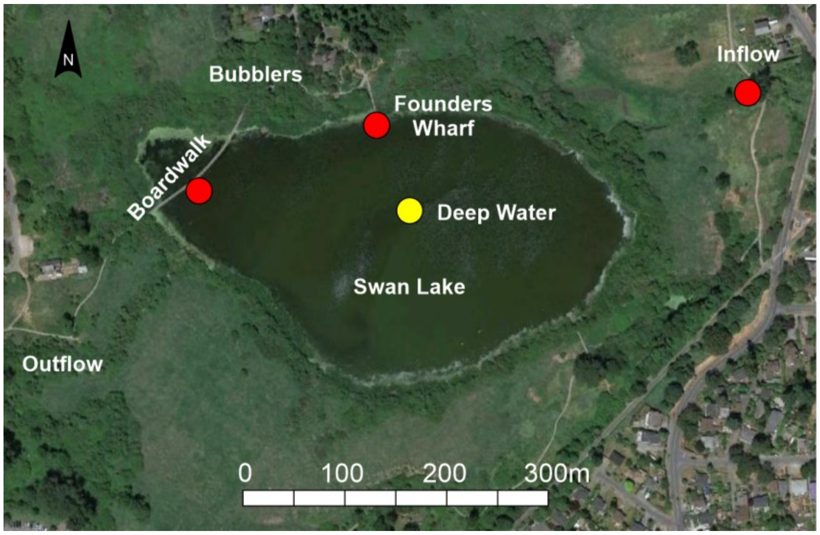


Figure 3. Water quality sample site. Red dots indicate data collected in this report and the yellow dot indicated the concurrent Level 1 data collection.

Sampling was carried out around the lake in a counterclockwise manner with the first lake site located at the Founders' Wharf. This site was at the mid-point between the inflow and outflow creeks and the wharf structure extended out from the shoreline to a water depth of approximately three metres. This site provided easy access and was a good stable platform for deploying instruments such as the Acoustic Zooplankton Fish Profiler deployed in the 2018 field season (Bowen, 2018). As will be discussed, this site is where dissolved oxygen and solar lux loggers were placed to examine diurnal cycling over several months.

The second lake site was located at the mid-point of the boardwalk. This site was away from the influence of the shore margins and was approximately 100 m from the outflow creek. Unfortunately, the dock that was located on the southeast side of the lake had been removed. This had been a key sampling site in years past as it was relatively close to where the inflow creek entered the lake. The final sample site was located at the Swan Lake trail bridge at Blenkinsop Creek, a potential input of urban and agricultural runoff carrying nutrients to Swan Lake. Elapsed field work time to complete the sampling typically was about three to four hours followed by another three hours of lab work to analyze nutrients. A complete set of sampling was done weekly from the beginning of May to mid-October with a data gap in mid-July to the end of August. The Level 1 site was selected as it was the deepest point in the lake to examine the complete water column. An anchor and surface float were placed using GPS coordinates that were taken from the deepest point from the bathymetric survey carried out in 2021 (Bowen, 2021). Weekly profiles were taken spanning a 12-week period (May–August).

Water chemistry to determine phosphorus, phosphates, nitrogen and nitrates was done in the Diversified Scientific Solutions' laboratory. Water samples were also examined under a microscope to observe abundance and succession of algal and zooplankton species throughout the May to October study period.

4.0 Methodology

Profiles were taken at each lake site at the surface and at 50 cm intervals to the bottom. These profiles were taken with two YSI handheld meters and associated probes. The YSI "Pro ODO" measured dissolved oxygen (DO) in percent saturation and mg/l of oxygen as well as water temperature. The YSI "Professional Plus," a multiparameter probe, was used to measure pH and ORP at the same intervals. In addition, a Secchi disk was used to measure water clarity, and a GoPro 4 Silver was used to acquire underwater video for visual inspection. Weekly single point 100% saturation DO calibrations were performed prior to the first set of profile measurements. The pH probe was calibrated monthly using a two-point calibration process. As the range of pH is between 6.5 and 9.5, the buffers used in the calibration were pH 7.0 and pH 10.0.

Prior to sampling, observations were noted recording weather conditions including cloud coverage, wind and wave conditions and the surface presence of duckweed, algae mats or suspended cyanobacteria. Each profile was conducted in the following manner: both DO and pH probes were suspended such that the probes were just below the surface with all parts of the probes submerged. Readings from the meters were recorded once values stabilized. This stabilization usually took about two to three minutes but there were many situations where this interval was longer especially during algal blooms. The probes were then lowered at 50 cm increments and values were recorded at each increment. The final readings were taken with the probes resting on the bottom.

Secchi depths were recorded by lowering the disk into the water column until the disk was no longer visible. Generally, each lake site had recorded Secchi depths with only a few exceptions. In some cases, where algae mats or thick duckweed were present, values could not be obtained as algae would close in immediately after the disk passed through the surface water. In these cases, a Secchi depth of zero was recorded as light penetration was significantly impeded by the algae. In the 2024 data set, there were no cases where there was 100% algae coverage at the time of testing.

Video recordings using a GoPro camera were made by lowering a two-meter pole into the water. This became a useful tool to observe the presence of fish and where in the water column the fish tended to reside. It was also useful to examine suspended algae density, water colour, bottom plant life, bottom hardness and the presence of bottom detritus.

Water samples were taken at all three sampling sites weekly. At the lake sites, a Van Dorn bottle was used for collections at water depths of 10 cm, 1 m, 2 m and 3 m depths. Before bottling, capping and labeling these water samples, several water quality parameters were measured. Two Turner FluoroSense handheld fluorometers were used to measure chlorophyll-a and phycocyanin, key indicators to quantify algal blooms. In addition, total dissolved solids (TDS), conductivity and salinity were measured. All water samples were analyzed for nutrients at Diversified Scientific Solutions' lab using a YSI 9500 photometer. Nitrogen, nitrates, phosphorus and phosphates were tested by following strict procedures using reagents and timed mixing intervals. Water samples were processed the same day in order to capture accurate concentrations with only a few exceptions where samples were processed the following day. These values were recorded for temporal comparisons.

As the diurnal cycles of DO and sunlight vary significantly over the course of the study period, two HOBO U26 DO and HOBO Lux loggers were deployed at a depth of 60 cm at both lake sites. Each logger recorded continuously with sample intervals of 30 minutes.

5.0 Data Collection

5.1 Weather

Weather data were collected from the Swan Lake weather station located on the Nature House roof. The weather station is part of a school-based weather station network that can be found at this link: (http://www.victoriaweather.ca/station.php?id=134). These data are presented below as plots and are referred to in the text as discussion points that consider the influence of climatic factors and their role in modifying lake processes. Unfortunately, not all elements of the weather station were working during this sampling season. Data for wind speed and gusts did not present reasonable data at the Swan Lake station. Maintenance of these instruments is recommended. For wind data, the weather station at Colquitz Middle school was used as this station was approximately 1.5 km from Swan Lake.

5.1.1 Air Temperature

Air temperatures (Figure 4) influence water temperature through surface contact and through the agitation of wind and waves. It is also the interface where oxygen exchange between the atmosphere and the lake can occur. Some of the surface algae have the ability to sequester atmospheric nitrogen at this air/water interface. Warming and the lengthening of daylight hours in the spring increase the metabolic rates of aquatic species and the reverse occurs as temperature and daylight hours decline in the fall. In 2024, air temperatures in most of June were generally lower than those measured over the 2017–2023 period (Figure 5). It was noted that the appearance of surface algal mats was delayed and as will be seen, the extreme DO values were relatively subdued compared to such years as 2017, 2018, 2021 (heat dome), 2022 and 2023.

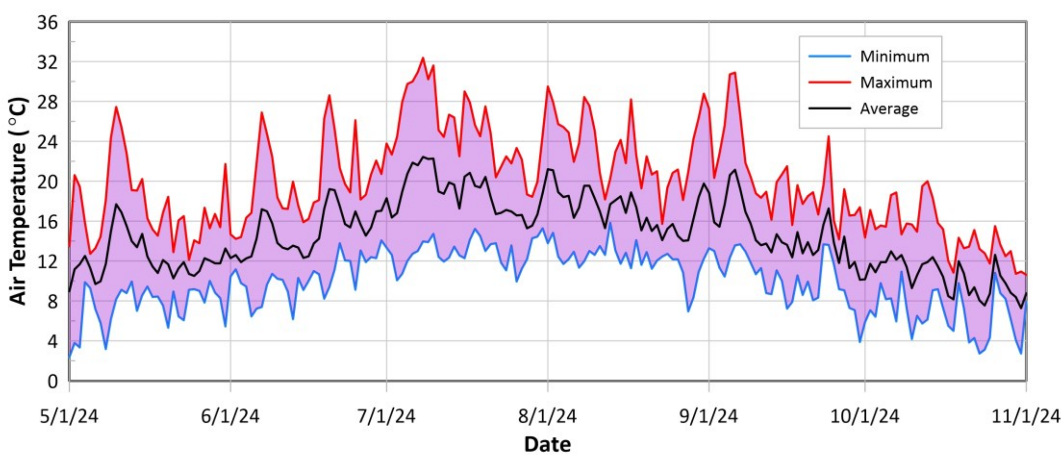


Figure 4. Air temperature.

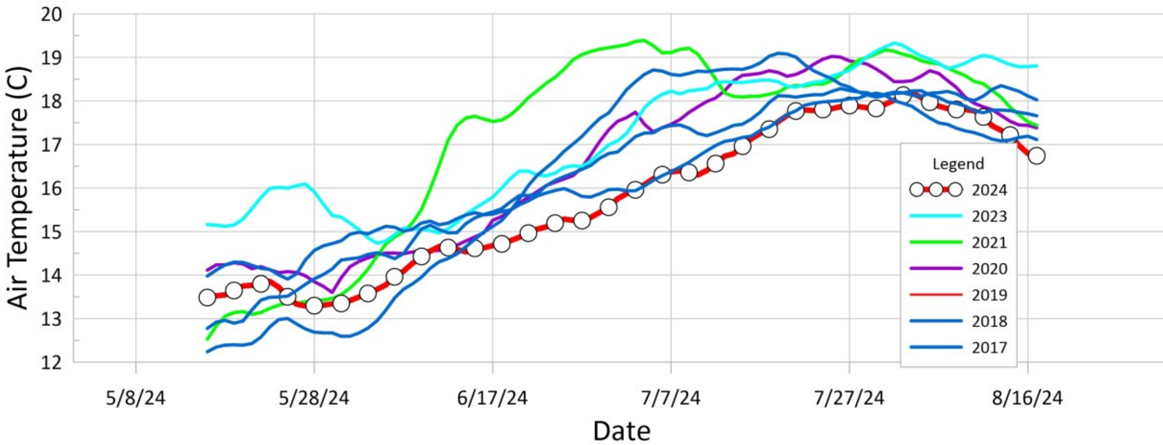


Figure 5. Relatively low temperatures in first part of 2024 study.

5.1.2 Precipitation

Rainfall (Figure 6) events can rapidly change the surface water temperature and introduce oxygen through raindrop impacts. It is also associated with low sunlight levels, reducing the photosynthetic processes. This figure represents the rain that fell within the study period.

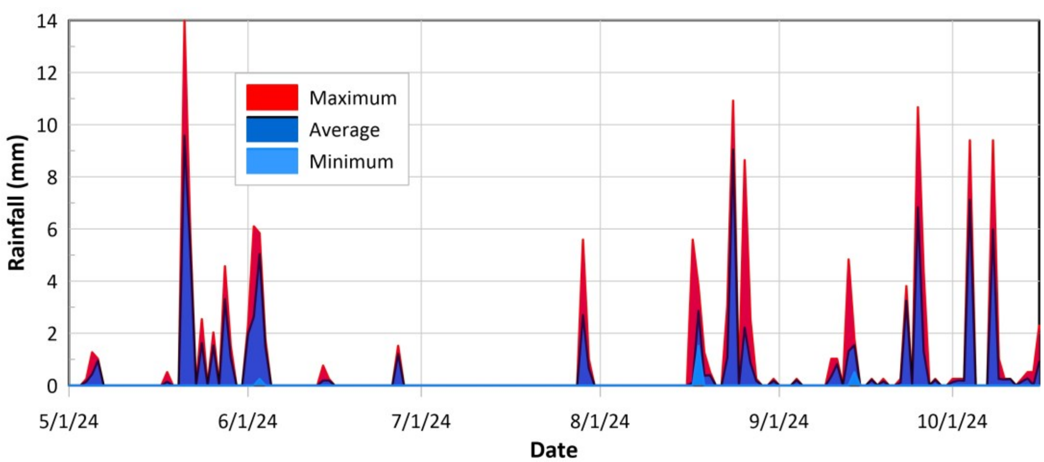


Figure 6. Rainfall.

5.1.3 Wind Speed

Unfortunately, the wind speed instrument located on the roof of the Nature House was not functioning properly during this sample season. This is a key parameter as it influences surface wave formation and the exchange of heat and orbital mixing and the atmosphere–water gas transfer exchanges such as dissolved oxygen and carbon dioxide. Wind data, however, were available from the Colquitz School weather station located approximately 1.5 km from Swan Lake and these data are reported here (Figure 7).

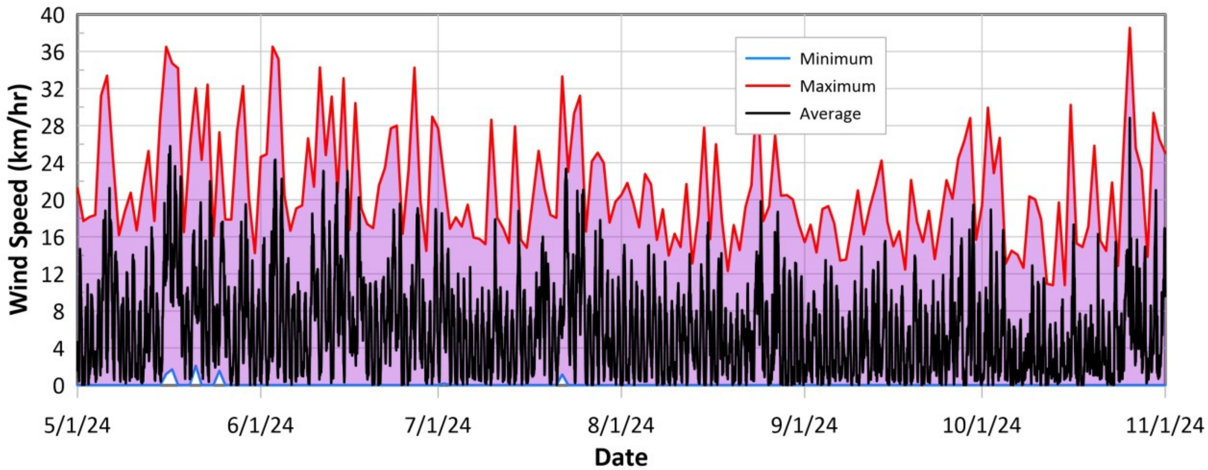


Figure 7. Wind speed from Colquitz Middle School weather station.

The predominant direction of wind along wind roses are reported in Figures 8 and 9. Each month has been plotted along with a summary plot of all wind data during the study period. Note the wind direction over the season is predominately from the southwest. This was observed most often while sampling at the Founders' Wharf where winds coming from the southwest propagated waves towards the wharf. Along with influences already mentioned, wind plays a significant role in modifying water quality at Swan Lake as they are responsible for the driving forces that move and redistribute the mobile surface algae. During calm wind conditions, duckweed and other plants such as the *Azolla filiculoides* tend to spread out over the surface of the lake typically in the months of August and September. Calm conditions were most often during the night and early morning before the influence of solar convective currents. As winds pick up, these algae are driven to the shoreline margins dynamically changing the light penetration within the water column at these affected areas.

Figure 8. Predominant wind direction.

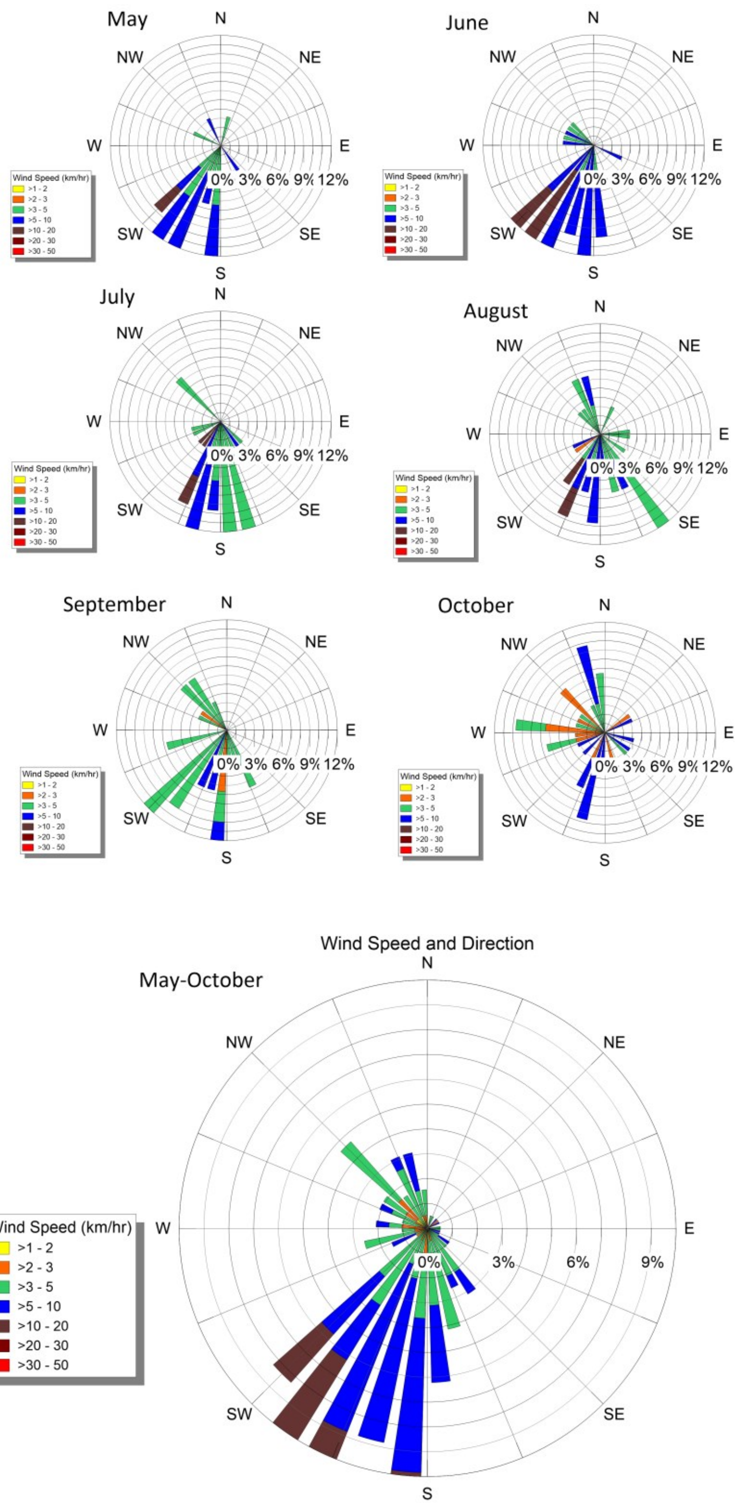


Figure 9. Wind speed and direction from Colquitz Middle School 2024.

5.1.4 Solar Insolation

As cyanobacteria and aquatic plants are dependent on solar input, solar insolation—which is a measure of solar energy—is vital to their required metabolic processes. Figure 10 displays the maximum and average solar input as measured at the Swan Lake weather station. The general curve shows the slow increase of sunlight insolation from May 1 (daylight duration 14 hr 45 min 06 sec) to its maximum on June 20, 2024 (longest day 16 hr 22 min 46 sec). This is followed by a tapering of daylight to a point on the last day of the sampling program of October 16th where the sunlight duration was only 10 hr 40 min 26 sec. The dips in the solar radiation are often associated with dips in dissolved oxygen concentrations as will be discussed with the dissolved oxygen data.

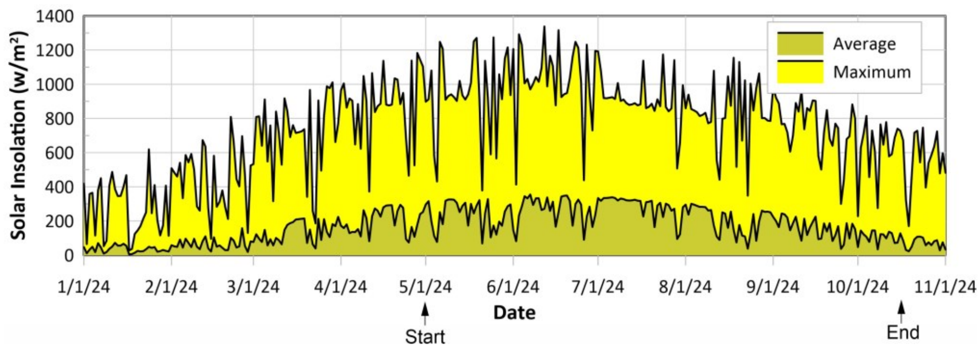


Figure 10. Solar insolation.

5.1.5 Barometric Pressure

The barometric pressure (Figure 11) is noted here as it is an important component for dissolved oxygen concentrations. The YSI ODO probe uses the barometric pressure and water temperature to calculate DO concentrations in mg/l or express DO concentrations as percent saturation. The barometric pressure is also used in calculating the water levels as the pressure sensors deployed at the bottom of the lake measure total pressure which includes the hydrostatic pressure of the weight of water above the sensor as well as the atmospheric pressure. The water depth requires the removal of the atmospheric barometric pressure.

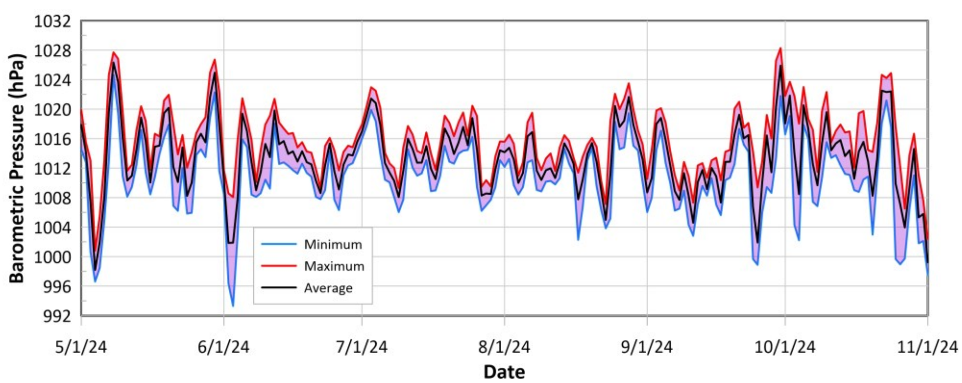


Figure 11. Barometric pressure.

5.2 Aquatic Parameters

Data collected from the various field instruments are presented in this section including the YSI optical DO/temperature probe, the YSI pH/ORP probe, the Secchi disk, the fluorometers and other water properties. Plots are included with brief discussions of interesting features. Water samples collected for nutrient analysis will be discussed in a separate section.

5.2.1 Dissolved Oxygen Profiles

As has been observed in past seasons, the DO concentrations vary significantly throughout the year. Dissolved oxygen is largely influenced by temperature, solar input, mechanical mixing, air/water interface exchanges, nutrients and biological processes including photosynthetic oxygen production and oxygen consumption through respiration. The values measured in the collected profiles are the result of complex interactions that involve various players that change through the year. Just as terrestrial plants have a seasonal succession, so too do aquatic plants or macrophytes, phytoplankton, various algal species and zooplankton. This order, depending on the species, is largely governed by nutrient thresholds, predator–prey relationships, temperature and light penetration. These successions ripple through all parts of the food web and create feedback relationships. Understanding lake processes is a comprehensive task and DO is certainly one of the most important parameters that influence many of the organisms associated with the lake. To ensure that accurate data was obtained, a new DO sensor cap was installed on the YSI DO probe this year and a two-point calibration of 0% and 100% saturation was performed at the time of installation in May 2024.

Figure 12 shows month-to-month seasonal variations of DO with respect to water depth. Note at the beginning of the study period, the DO values at the Founders' Wharf were oxygen rich with uniform concentrations of about 11.5 mg/l down to a depth of 2.5 m. Below this the DO value dropped to about half that near the bottom. The boardwalk profile showed similar DO concentration near the surface but then values tapered off with depth showing signs of stratification. By June both sites displayed stratification. During the month of July, a cyanobacteria bloom forced the top meter DO concentrations to their seasonal high along with a well established anoxic layer in the bottom one meter. It was at this time secchi depths were as low as 0.2 m. The profile recorded at the deep water site August 14, 2024 shows a collapse of DO with all values less than 1.5 mg/l. This is significant as typically the tolerance for many fish is about 2-3 mg/l and no less (Figure 13). September sees an improvement in surface DO due to green algae photosynthesis and by mid-October, the fall turn over returns the lake to well mixed conditions with improved bottom DO concentrations. This over-turn is clearly marked in the temperature profiles in the next section.

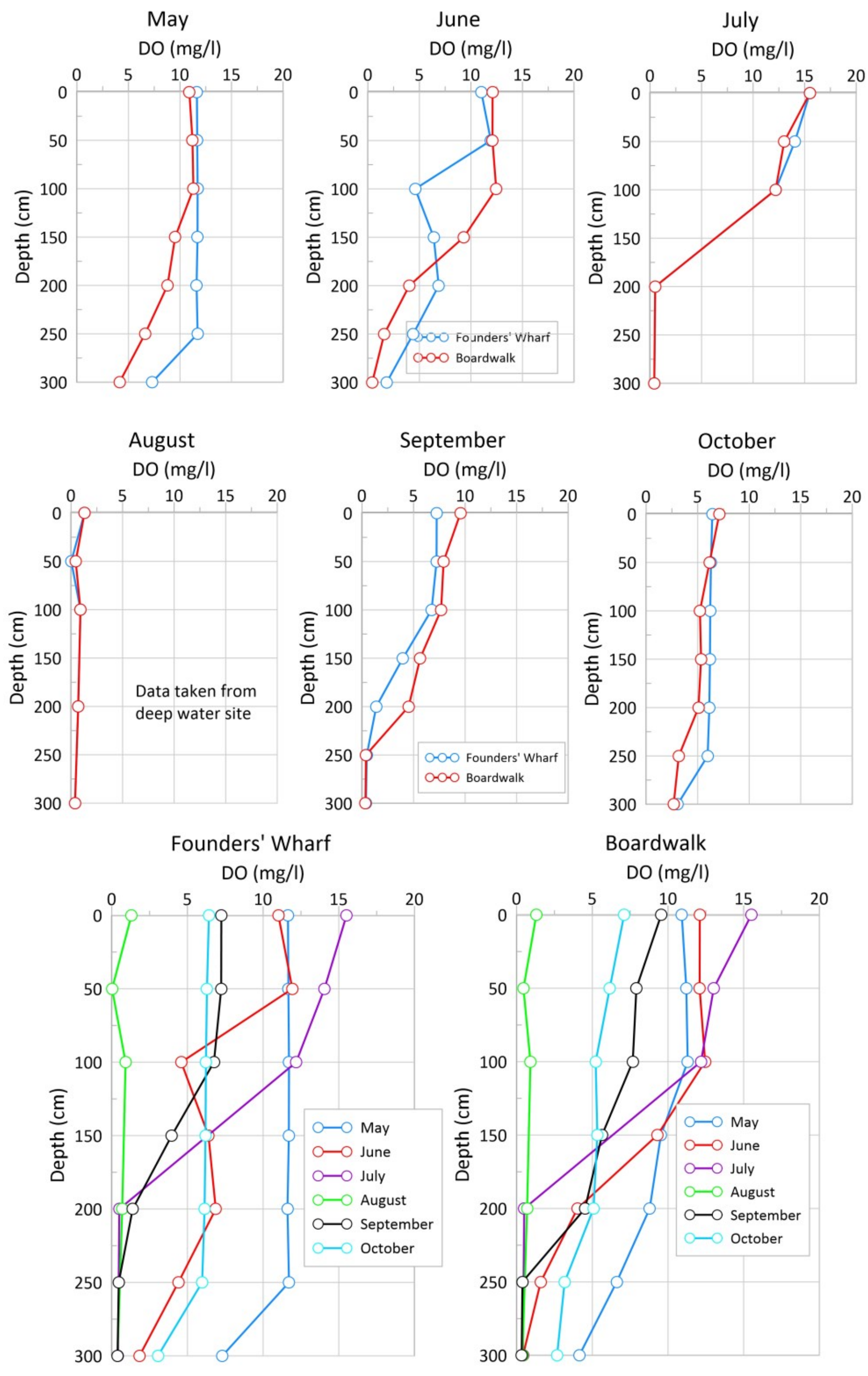


Figure 12. Monthly dissolved oxygen (DO) profiles.

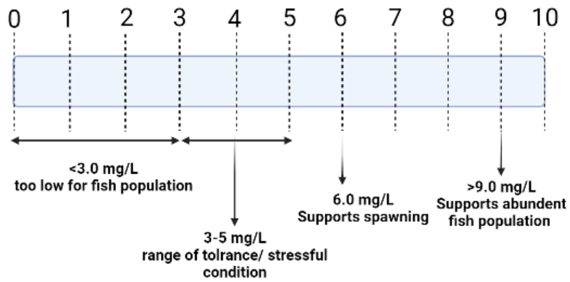


Figure 13. Dissolved oxygen range of tolerance for fish.

Time series for both the Founders' Wharf and the boardwalk were plotted for each of the site visits throughout the study period (Figure 14). Profiles were conducted weekly at the Founders' Wharf and boardwalk sites. As there was a gap in the data collection during the summer at these lake sites (July 17–August 31), data obtained from the continously recording HOBO U26 DO loggers (one at each lake site) were added. In addition, values obtained from the deep water sites were also added in to construct a continous time series plot of DO.

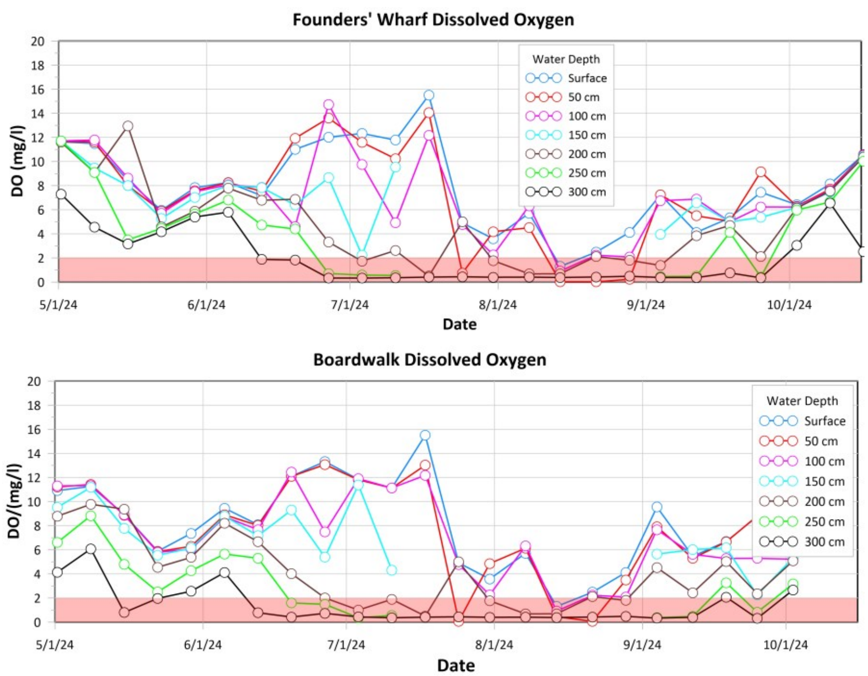


Figure 14. Dissolved oxygen time series plots for Founders' Wharf and the boardwalk sites.

From these plots, two algal blooms were noted from these profiles as well as field and microscope observations. The first was a relatively minor event dominated by the cyanobacteria *Aphanizomenom flos-aquae* (AFA). This event occurred in early to mid-May where DO levels peaked around 12 mg/l. The rains that occurred May 21st coincided with a decline in AFA and DO concentrations. By mid-June the lake had become stratified with a clear separation of DO concentrations between oxygen-rich surface waters and oxygen-depleted bottom water. As was seen in the monthly profiles, July saw the highest DO concentrations of the study period as brought on by a *Dolichospermum* algae bloom. This bloom lasted a few weeks where surface oxygen levels remained high. By the last week of July, DO concentrations dropped rapidly with an algal die-off. As will be discussed later, phosphorus cosumption may have played a role in limiting algal growth. After this decline there was a short rebound of DO followed by another dip in DO concentrations. By September chlorophyll levels began to rise in the water column which promoted photosynethetic oxygen production.

Another way to display DO data was to create a set of block diagrams that contour the DO concentrations with X as time, Y as depth and DO as the Z contours. These block diagrams are depicted in Figure 15. Note the distinct algal blooms at both sites represented by high concentrations of DO (green shading).

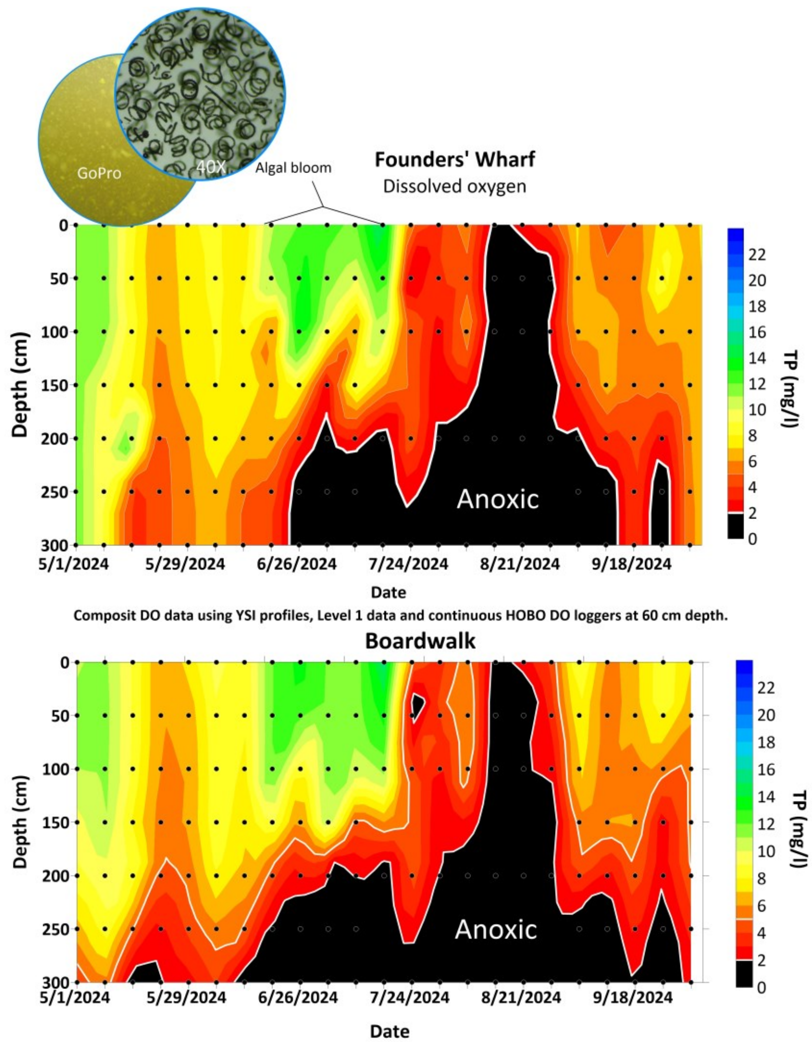


Figure 15. DO contour block diagrams of Founders' Wharf (top) and boardwalk (bottom) sites.

A similar block diagram was created based on data collected at the deep-water site (Figure 16). The deep-water site was located at the deepest point in the lake and DO and temperature data were measured down to six meters. From this contour map, it can be seen that there is a large part of the water column that is anoxic. To better appreciate the distribution of this anoxic layer, a series of plots was made to display how this anoxic layer moves towards the surface in the progression of time towards the warm summer months, limiting the volume of water where fish can thrive. Although there was good agreement between the lake sites and the deep-water site, these plots lack the spatial distribution to represent a nine-hectare lake in its entirety. As fish are mobile, there may be refuge areas where fish, although stressed, may survive.

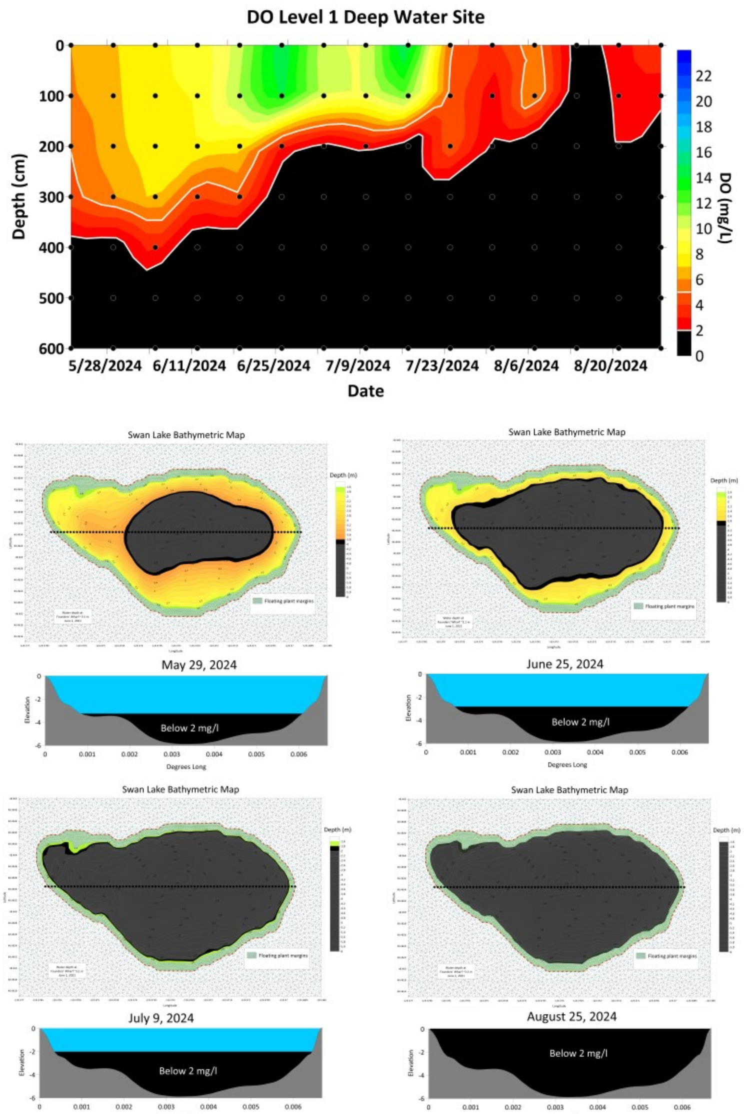


Figure 16. DO contour block diagram of Level 1 site. The bathymetric plots and cross sections show the migration of the anoxic layer.

It is important to bring into this discussion the sampling interval of this data set and the diurnal nature of DO in a eutrophic system. Note that these data were taken during daylight hours between 10 am until 2:00 pm. The solar radiation that stimulates the photosynthetic processes changes significantly from the darkness of night to the bright rays of mid-day. The DO block diagram would be significantly different if profiles were taken at night. To further examine the details of this diurnal cycle and the perturbations in the DO time series, the two DO loggers and two solar lux loggers were used to measure the relationships between DO concentrations and light penetration with a continuous sampling interval of 30 minutes. These data will be examined in more detail in the data logger section that follows.

5.2.2 Water Temperature Profiles

Water temperature profiles were assembled into a set of time series plots similar to the DO time series plots (Figure 17). During the sampling season, a maximum water temperature of 25.4°C occurred on July 17th at 60 cm depth at the Founders' Wharf site. On this same day, the highest difference between the surface and bottom water was 7.6°C (26.2°C 60 cm, 18.6°C bottom). The lowest surface water temperature this year of 14.3°C was recorded on October 16th where the water temperature throughout the water column was near uniform.

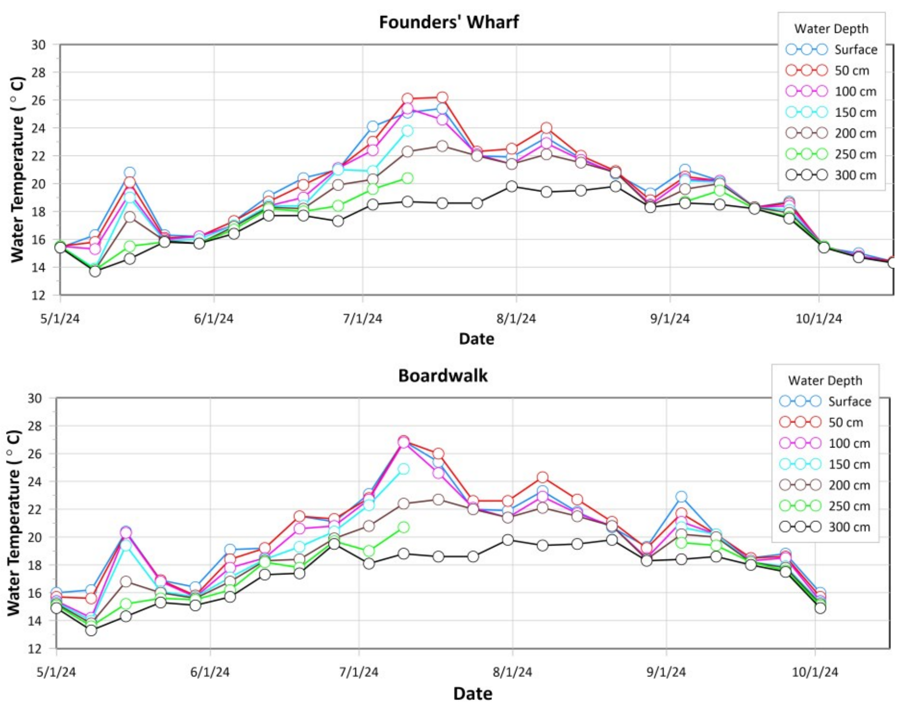


Figure 17. Water temperature time series plots for Founders' Wharf (top) and boardwalk (bottom) sites.

A contoured temperature block diagram was generated from the YSI temperature profile data and is displayed in Figure 18. Again, the datasets of the continuously sampling DO loggers and the deep-water site were blended in to create an uninterrupted time series. The dotted rectangle indicates where these data sets were added.

Swan Lake is a dimictic system that experiences two overturning events per year. The first overturn event occurred before the sample period where the stratified winter conditions were mixed to form a uniform temperature throughout the water column. Observations from April 2022 saw this winter-to-spring overturn. In this year's data, isothermal conditions were observed at the beginning of the sampling period. In the first few weeks of May, the water column began to stratify, responding to the rise in air temperatures. This was short lived as the air temperature dropped and again the lake returned to near isothermal conditions throughout the water column. This mid-May heat jet and the return to isothermal conditions can be seen in both lake sites in the temperature block diagrams.

Lake temperatures continued to rise with the summer heat and longer daylight hours. The late-summer early-fall overturn had a false start in late August as influenced by a number of days of cooler temperatures and rain events on August 26–28 and 31st. Isothermal conditions were clearly established in the first week of October.

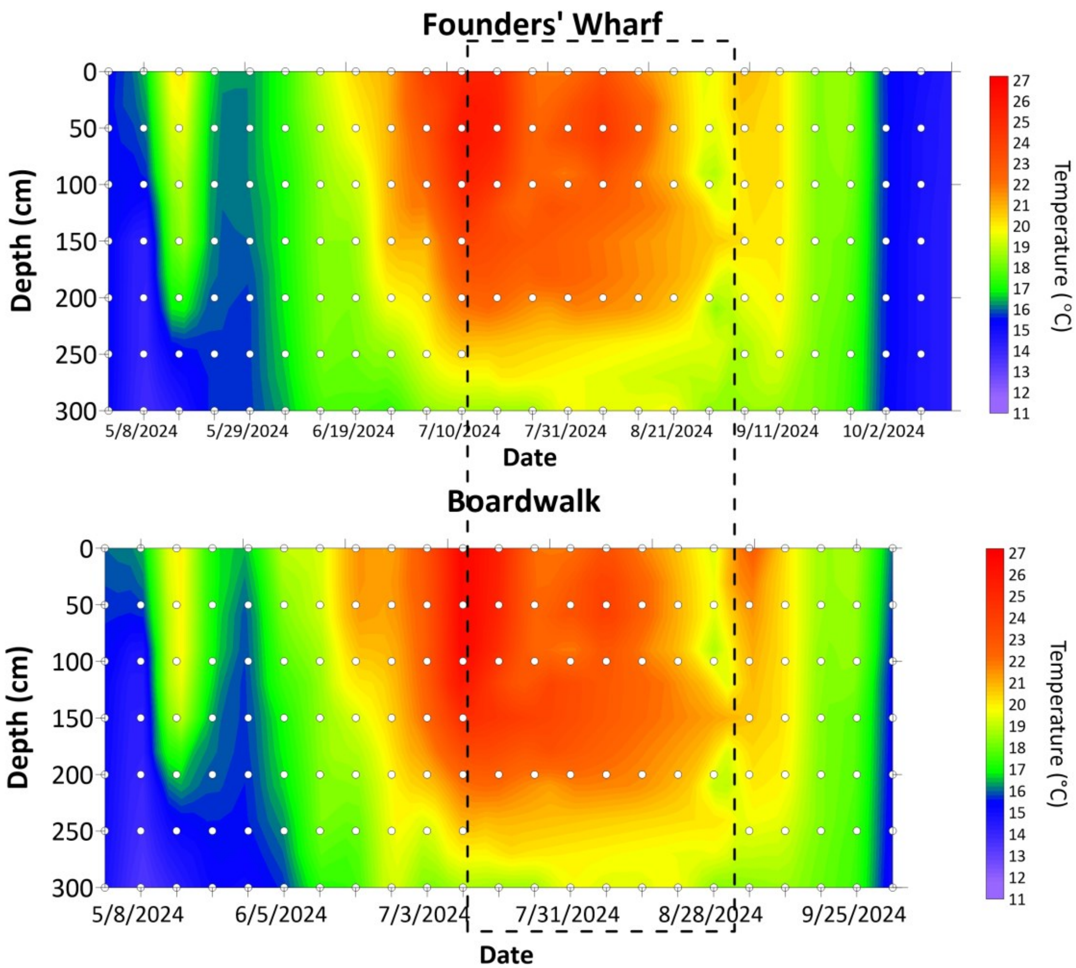


Figure 18. Contoured block diagram of water temperature and Founders' Wharf (top) and the boardwalk (bottom).

The mechanisms that trigger overturning are largely the result of thermal momentum shifts affecting water density with heating in the spring and cooling in the fall, often coupled with wind events that force mixing. Figure 19 summarizes the dimictic stages of Swan Lake.

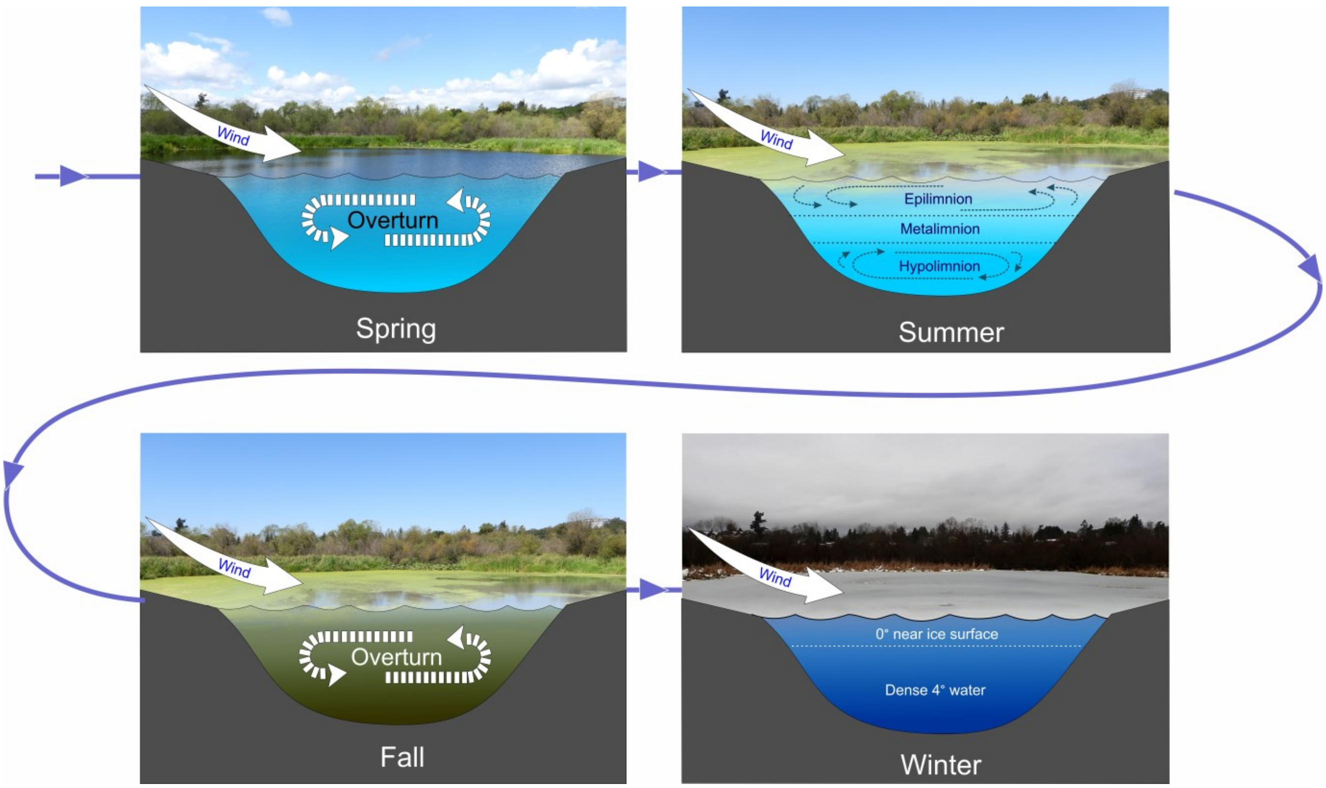


Figure 19. Dimictic stages at Swan Lake.

5.2.3 pH

The pH value uses a graduated scale ranging from 0.0 (highly acidic) to 14.0 (highly basic) with 7.0 being neutral (Figure 20). The pH scale is actually measured in millivolts and then converted to dimensionless units with the interval between units of approximately 59.16 mV at 25°C. The pH values below 7.0 are associated with the charge of the hydrogen ion H+ (acids) and pH values above 7.0 are associated with the charge of the hydroxyl ion OH-.

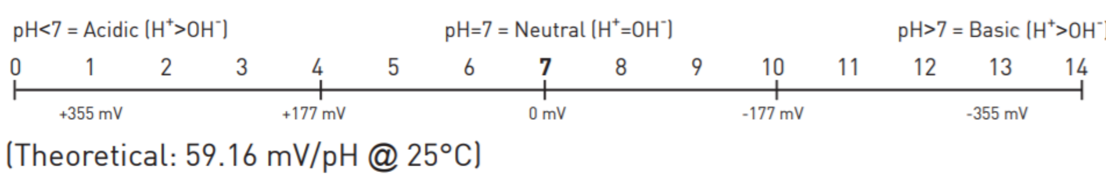


Figure 20. Graduated pH scale.

The pH is largely influenced by the photosynthetic processes at work in the lake. As noted by Andersen et al. 2017, during daylight hours, photosynthesis produces oxygen accumulations while depleting dissolved CO_2 concentration. During darkness, these same organisms respire resulting in the consumption of oxygen and the accumulation of CO_2.

To discuss pH in an aquatic setting, it is important to draw attention to available dissolved CO_2 and the respiration of aquatic plants. The two equations that govern photosynthesis are summarized as follows:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2 \qquad (1)\ (\text{Wetzel, 1983}) .$$

carbon dioxide + water -> glucose + oxygen

$$HCO_3^- + H_2O \rightarrow CH_2O + O_2 + OH^- \qquad (2)\ (\text{Pedersen et al., 2013}).$$

Note the fixation of CO_2 in equation 1 and the production of OH- in equation 2. During algae blooms where photosynthetic activities are highly active, the production of OH- tends to drive the pH level up at the surface. Lower down in the water column, where light penetration is limited, decomposing processes dominate and consume biota liberating H^+. This hydrogen ion combines with H_2O and dissolved CO_2 to create carbonic acid as describe in equation 3:

$$CO2 + H2O \rightleftharpoons H2CO3 \qquad (3)\ (\text{Talling, 2010}).$$

A new pH/ORP sensor cap was installed on the YSI Professional Plus probe and a two-point calibration was performed using buffer solutions of 7 and 10. The pH time series plots are displayed in Figure 21. Note the curves are very similar to the DO data display in Figure 12. The July bloom event is most notably detectable with a maximum pH range of about 2.4 units of pH in just three meters. Figure 22 shows the relationship of pH to DO concentrations.

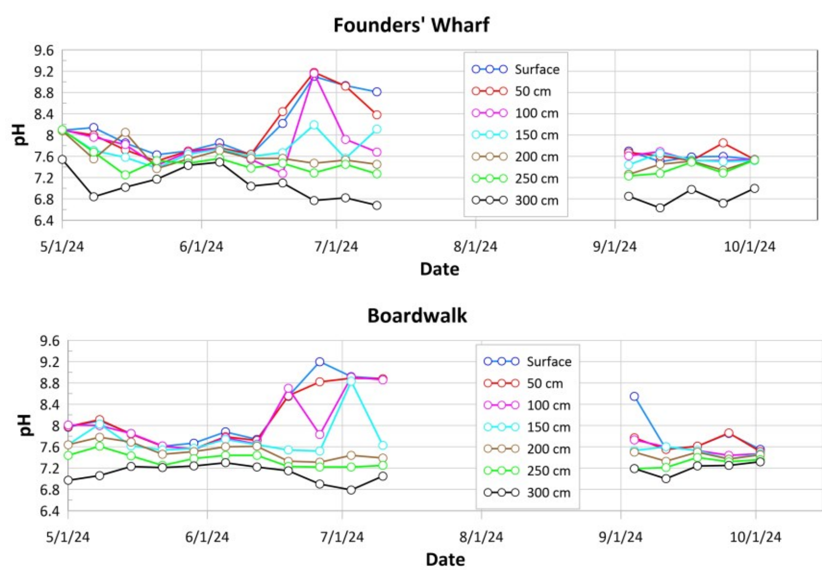


Figure 21. pH time series plots for Founders' Wharf (top) and the boardwalk (bottom) sites.

Note the near linearity between pH and DO in the 2 to 10 mg/l range. Above these concentrations this relationship is best described as exponential with a small change in DO resulting in a large change in pH. The points in this part of the curve are largely from the July algal bloom.

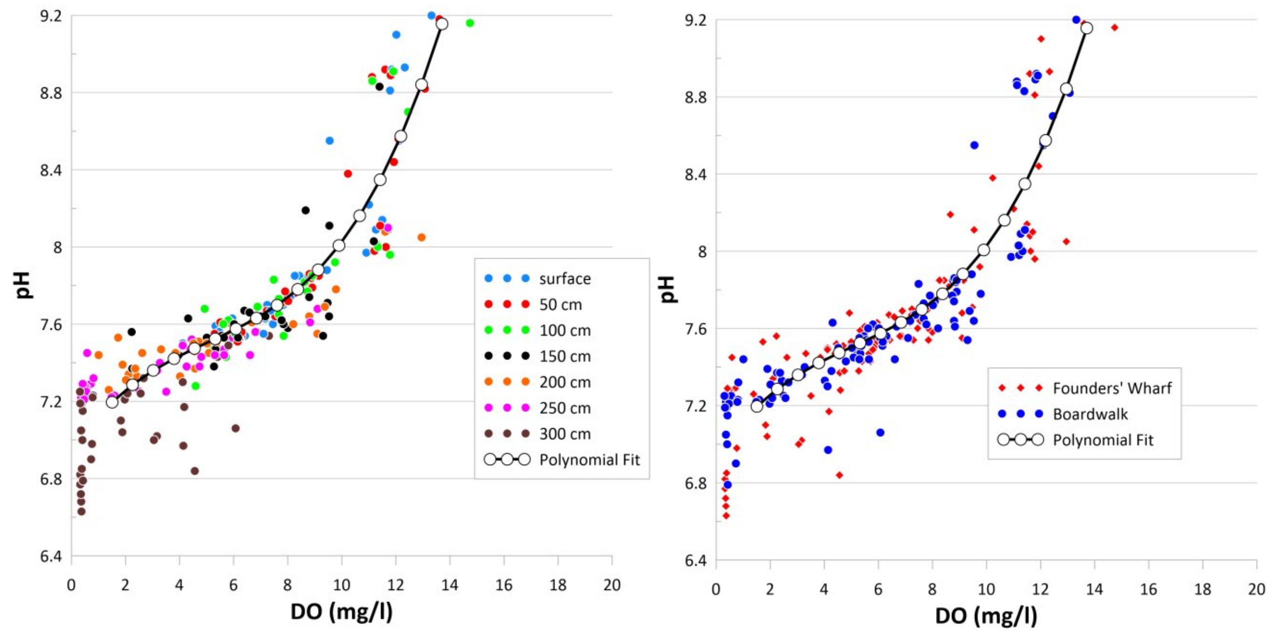


Figure 22. pH versus DO for data from both the Founders' Wharf (left) and boardwalk (right) sites.

5.2.4 Oxygen Reduction Potential

The pH probes only respond to the hydrogen activity (H^+ and OH^-) in solution. The oxygen reduction potential (ORP) is much more comprehensive in that measured values are in response to all oxidizing and reducing activity of ions in solution. The measure is, however, not specific in terms of what chemicals are reacting. The ORP is the solution's capacity for electron transfer either through oxidation (donating electrons) or through reduction (accepting electrons). This process is often referred to as REDOX reactions.

In settings where DO concentrations are high, the redox potential can be highly positive reaching values above 300–500 mV in oligotrophic lake environments. In general, the higher the ORP value, the healthier the lake. In its eutrophic state, ORP values at Swan Lake rarely get above 300 mV. As the thermocline sets up in early May, DO values stratify creating a reducing environment in the deep waters near the bottom sediments. In this anoxic zone, the redox potential tends to the negative (100 mV or less). Microbial action at the water–sediment interface where oxygen consumption is high through bacterial decomposition causes a drop in the redox potential to as low as −280 mV. At these low values, reactions occur that reduce iron and cause phosphorus to be released back into solution (Suthersan, 2001). This liberated phosphorus from the water–sediment interface provides a recycling of nutrients and aids in the recovery of DO, especially after a hypoxic event (Reynolds and Davies, 2001).

Time series plots are displayed in Figure 23. Note that the Founders' Wharf generally has a broader gradient than the boardwalk data. The Founders' Wharf surface extremes are approximately 280 mV with a plus/minus range of about 540 mV whereas the surface boardwalk extremes are nearer to 240 mV with a plus/minus range of about 460 mV. These extremes are consistent with those measured in previous years. There appears to be less REDOX activity in both the reducing processes at the benthic layer as well as the oxidizing processes near the surface in the west bay. Noted in the west bay are the high concentrations of macrophytes which may mitigate or dampen the REDOX activity.

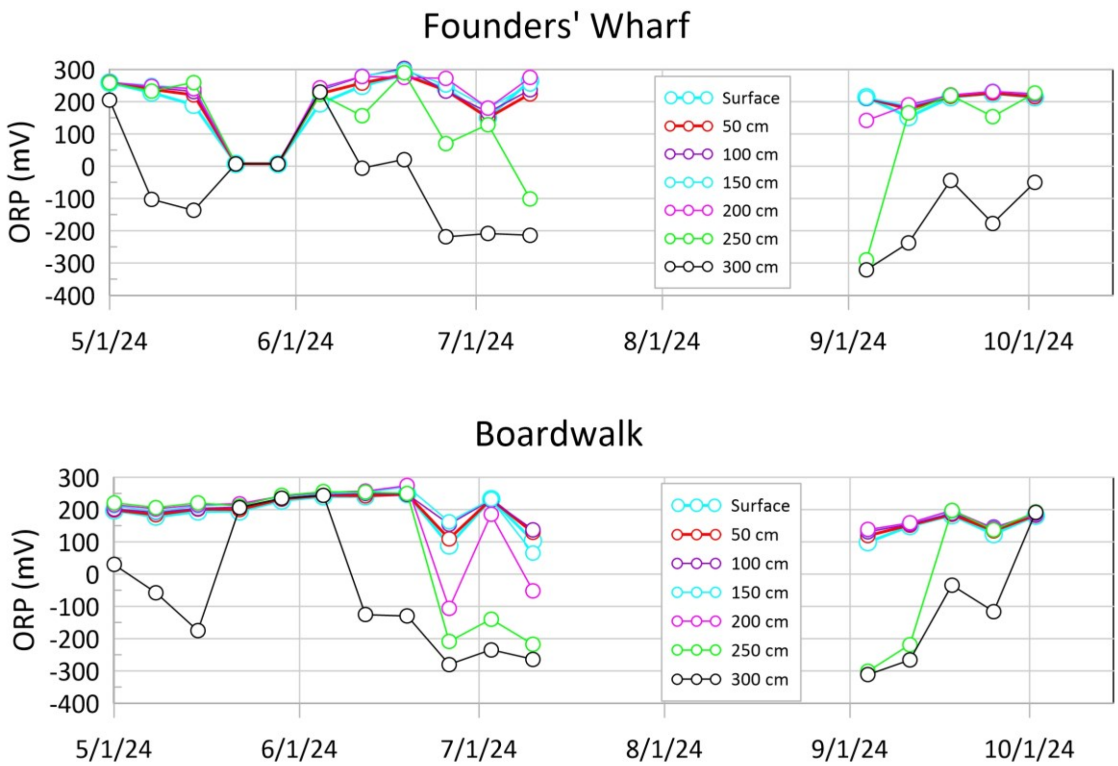


Figure 23. Oxygen reduction potential (ORP) time series plots for
Founders' Wharf (top) and boardwalk (bottom) sites.

As ORP is influenced by DO, the relative water column concentrations of DO at the two sites, surface to bottom profile data were added to give an integration of DO within the water column. Integrated data from these two sites is displayed in Figure 24. Comparing these two curves generally shows very similar results over the sample period despite the ORP amplitude differences.

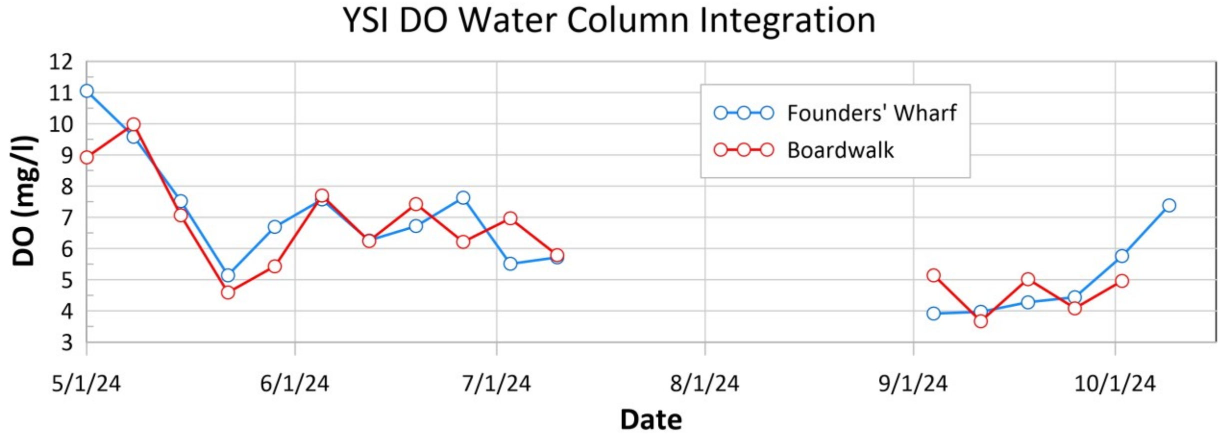


Figure 24. Integrated water column DO of both lake sites.

5.2.5 Turbidity

The turbidity of the water column was measured at each lake site visit to give an index of the clarity of the water. This parameter has both physical and biological associations and indicates the presence of both visible and microscopic organic and inorganic particles suspended within the water column.

Light penetration into the water column plays a key role in terms of heat flux and provides the necessary energy inputs for plant photosynthesis. Figure 25 shows the Secchi depths for the two lake sites. During the late July algal bloom, the Secchi depth dropped to 0.2 m—its seasonal low. This lowest point occurs about one week after the peak DO values. This low Secchi depth value was observed at a time where the DO values were rapidly declining, suggesting that the algal die-off was contributing to the higher turbidity.

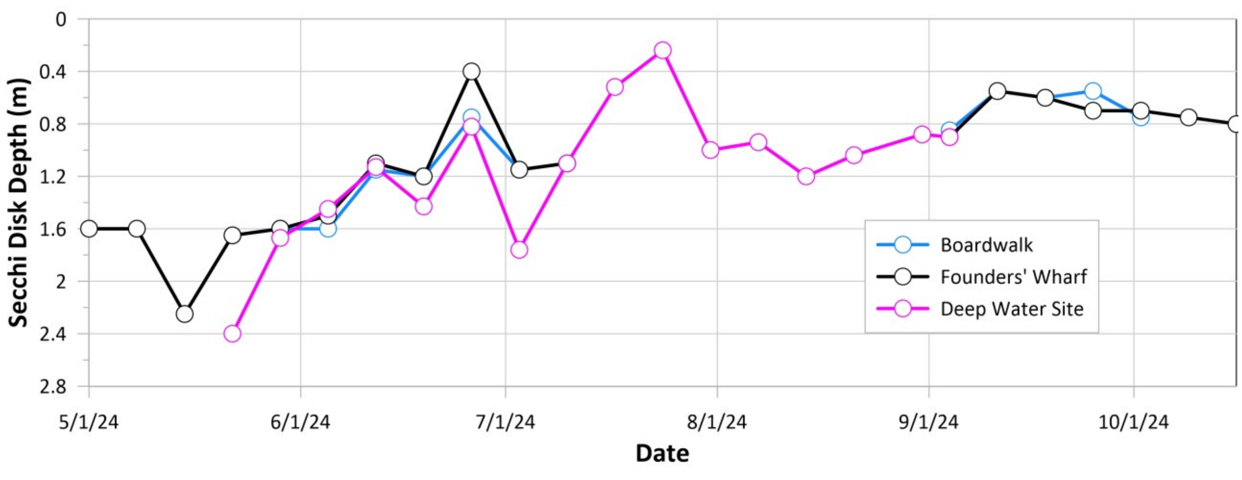
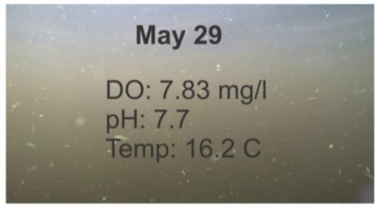


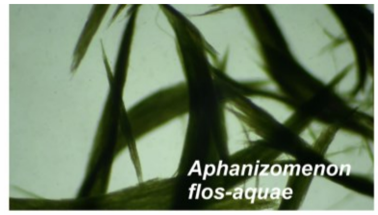
Figure 25. Secchi depth time series plots for Founders' Wharf and the boardwalk sites.

5.2.6 Water Colour and Seasonal Changes

Figure 26 displays GoPro video captures of the colour of near surface (~20 cm below surface) water as well as a representative surface photo and organism observed under the microscope. The GoPro images give qualitative insights about clarity, suspended solids such as algae and detritus, dissolved solids affecting colour hue and, to some degree, light penetration and specular light conditions. Water quality parameters are burned into each GoPro image for reference. These images, when viewed in a time series, are indicators of the complex relationships of the succession of phytoplankton, cyanobacteria, green algae and hue altering dissolved solids. The above water images display the changes in the surface algae conditions showing the algal mat growth extent along the margins. Note that it wasn't until late June that algal mats appeared this year which is a significant delay when compared to observations in 2023, 2022, 2021 and 2020 where algal mats were observed in early June. This delay may be due to the relatively cool spring. The purpose of this set of images is to try and capture the various changes throughout the study period and may be useful when examining unique water quality features.

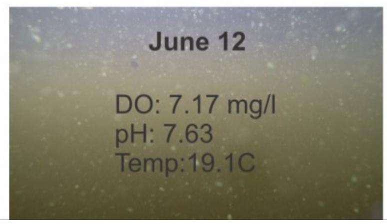
The September 11 images show the impact of the boardwalk on the distribution of surface algae. Although there are spaces between the floating elements that support the boardwalk, every year the west bay fills with dense algal mats. With the prevailing winds coming from the south-west, the boardwalk acts as a windbreak interrupting the drag forces that would move the mobile algal mats out from the sheltered bay. As the algal mats become a contiguous mass, the boardwalk acts as a retaining wall. In addition, bottom-rooted macrophytes grow to the surface in the west bay which further contributes to the prevention of the algal mats from moving.

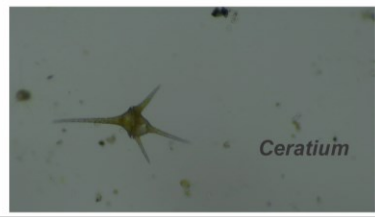

May 29
DO: 7.83 mg/l
pH: 7.7
Temp: 16.2 C

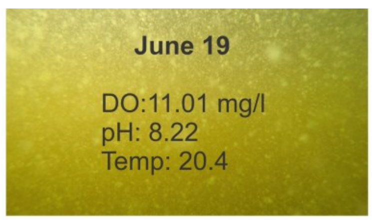

Aphanizomenon flos-aquae

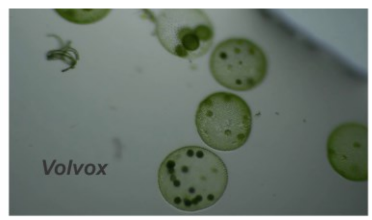

June 5
DO: 8.26
pH: 7.85
Temp: 17.3 C

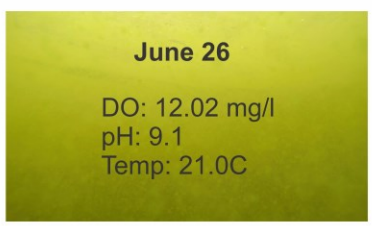

Dolichospermum

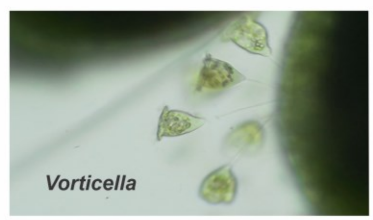

June 12
DO: 7.17 mg/l
pH: 7.63
Temp:19.1C

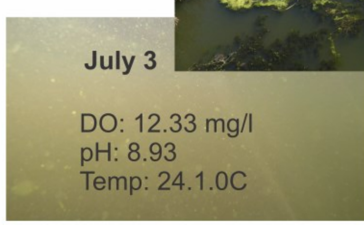

Ceratium

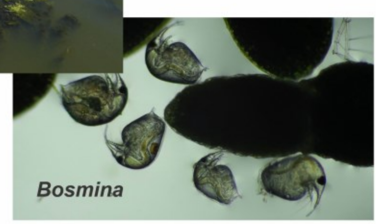

June 19
DO:11.01 mg/l
pH: 8.22
Temp: 20.4


Volvox


June 26
DO: 12.02 mg/l
pH: 9.1
Temp: 21.0C


Vorticella


July 3
DO: 12.33 mg/l
pH: 8.93
Temp: 24.1.0C


Bosmina

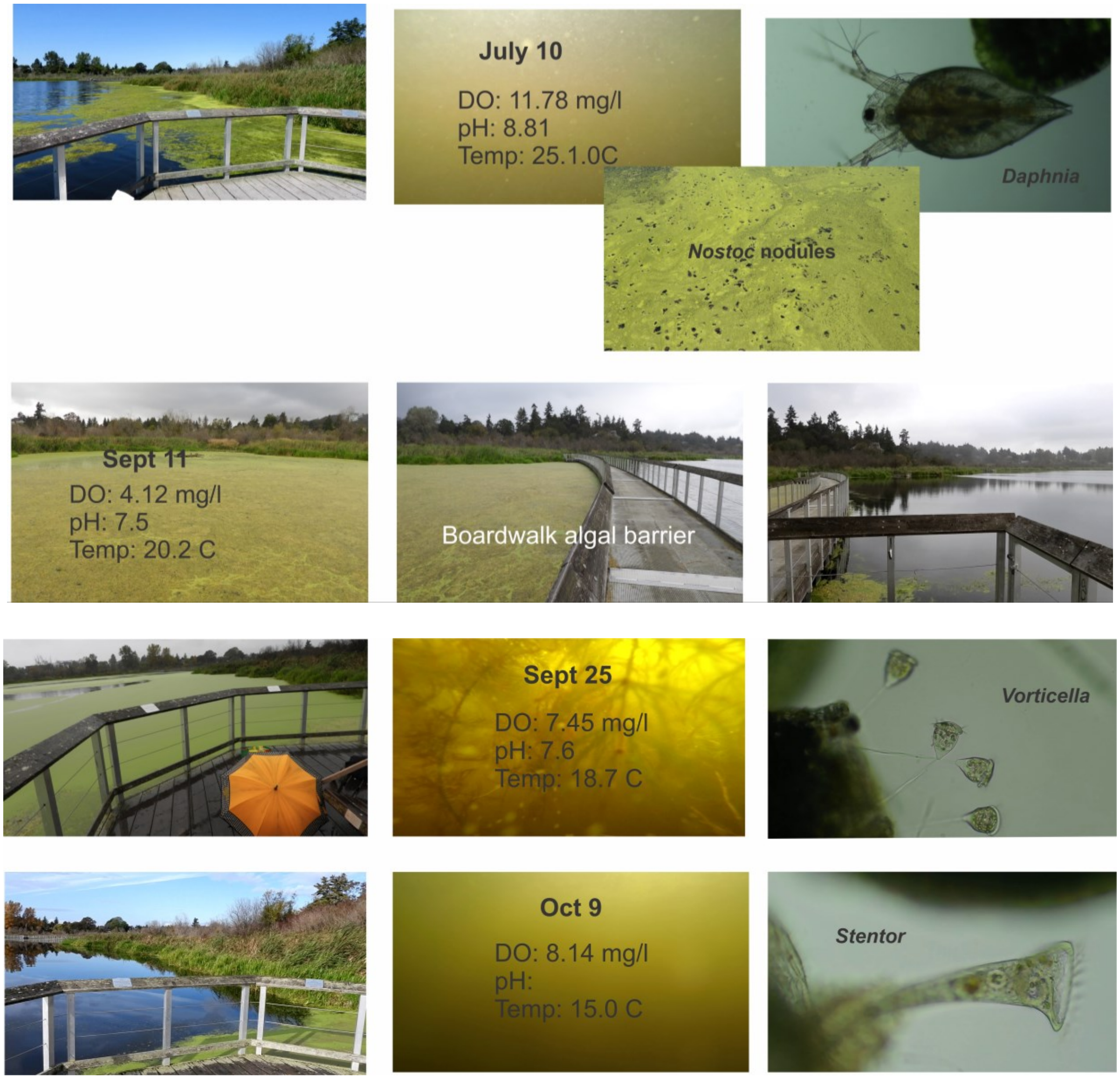


Figure 26. Time series of surface algae, water colour and microscope captures over the sampling season.

5.2.7 Chlorophyll-a and Phycocyanin

Two handheld Turner fluorometers were used to examine chlorophyll-a and phycocyanin. These instruments were useful tools to measure plant-based pigments that indicate total algal biomass. Chlorophyll-a is a broad spectrum measure of green pigment present in all plants and algae. Photosynthetic organisms use a variety of chlorophyll molecules to improve their ability to capture solar radiation. This is true of macrophytes, phytoplankton and, to a lesser extent, cyanobacteria. Cyanobacteria utilize specialized phycobiliproteins to enhance their photosynthetic efficiency. As only a few algal classes possess these pigments, measuring phycocyanin (PC), the most common of the phycobiliprotein, enables the detection of the subset of cyanobacteria within a mixed phytoplankton assemblage (Lauceri et al. 2017), Figure 27 shows the wavelengths of green algae and cyanobacteria pigments.

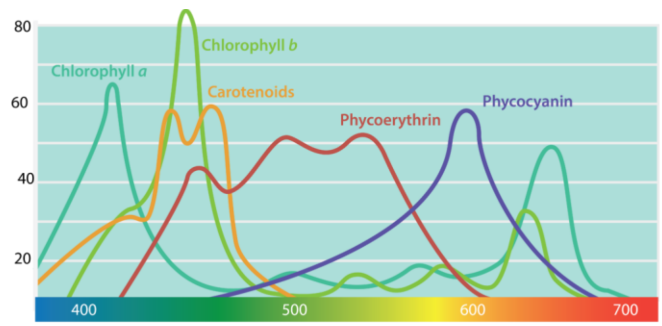
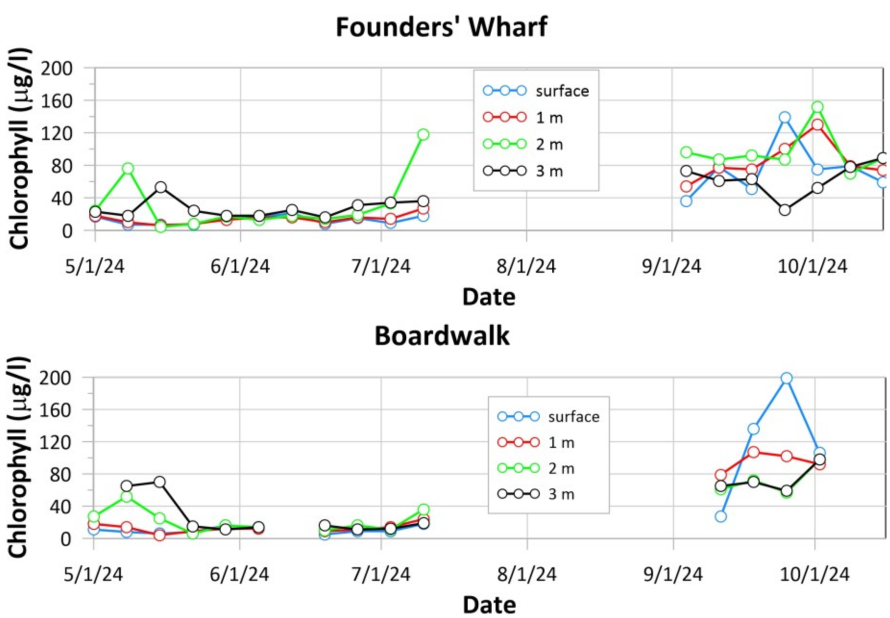


Figure 27. Wavelengths of light indicating the chlorophyll-a and cyanobacteria phycocyanin peaks.

Figure 28 shows both chlorophyll-a and PC curves for the Founders' Wharf and the boardwalk sites as taken from four depths. The phycocyanin plots show an abrupt rise in concentration of this pigment caused by the cyanobacteria bloom in the latter part of June (see Figure x DO block diagram). This coincides with the super-saturated DO levels at that time (135,4%, 12.02 mg/l). Unfortunately, the further development of this cyanobacteria bloom to its peak DO production in mid-July was not measured for chlorophyll-a and phycocyanin due to a gap in the dataset. Sampling resumed in early September where chlorophyll-a pigments dominated suggesting that the chlorophyll-a rich green algae displaced the cyanobacteria as the main mode of oxygen production.



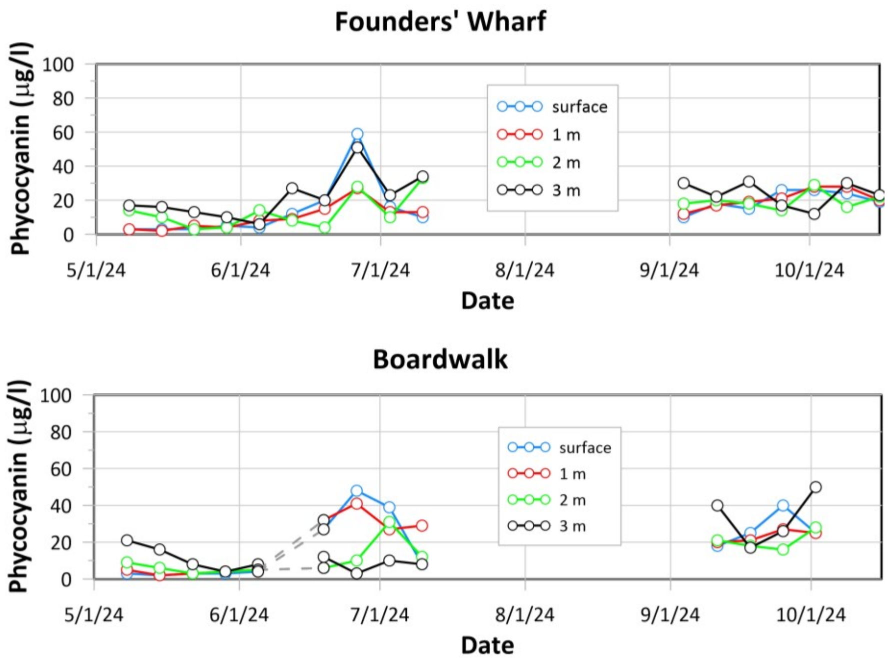


Figure 28. Chlorophyll-a and phycocyanin plots of both lake sites.

Figure 29 examines the relative ratios of PC to chlorophyll (PC/Chl). High values represent elevated cyanobacteria PC values that dominate the algal assemblage.

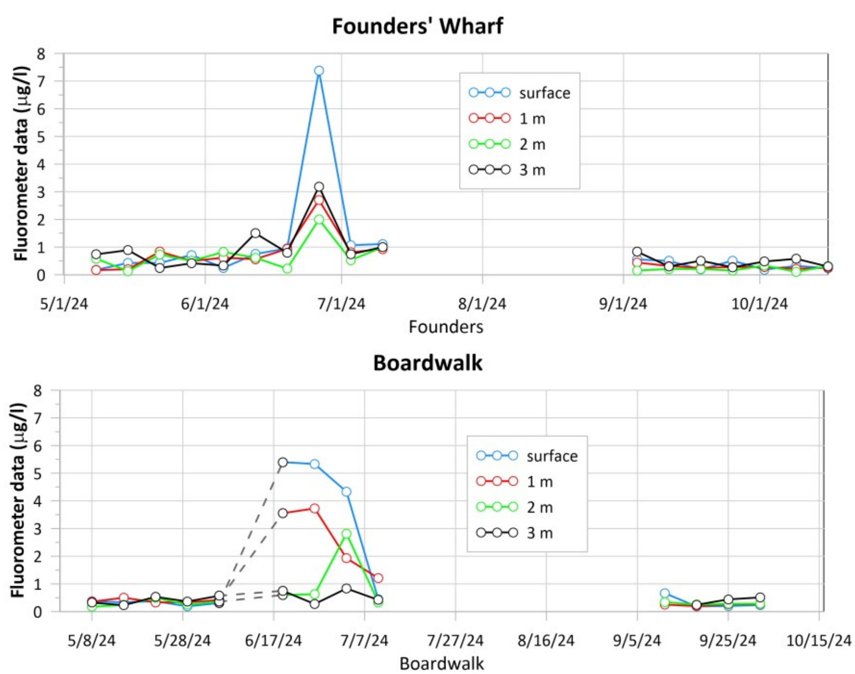


Figure 29. Ratio of Chlorophyll-a divided by phycocyanin at both lake sites.

5.3 Data Loggers

In order to examine the finer details of the diurnal cycles of DO and light penetration, two HOBO U26 DO loggers were used that sampled in phase every 30 minutes. New sensor caps were installed on both DO loggers and two-point calibrations were performed using 0% and 100% saturation. Figure 30 shows a HOBO DO logger and the HOBO lux loggers. Moorings were designed to place the DO and lux loggers in the water column at a depth of 60 cm at both the Founders' Wharf and boardwalk sites. These logger assemblies were deployed on the following dates. The first set of loggers were placed at the Founders' Wharf site on May 18, 2024 at approximately 2:52 pm. The second set of loggers were placed at the boardwalk site on May 18, 2024 at approximately 3:12 pm. Both sets of loggers were recovered on the morning of October 16, 2024.

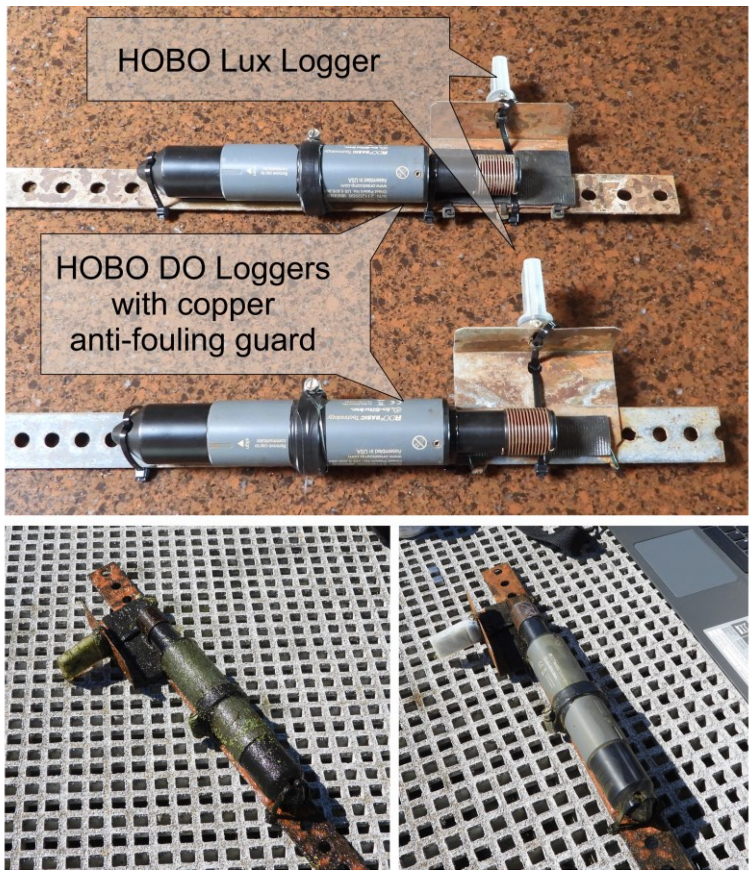


Figure 30. Dissolved oxygen and lux loggers, pre-deployment and recovery.

5.3.1 Water Temperature Time Series

Along with measuring DO and lux, water temperatures at these two sites were measured and plotted in Figure 31. The data presented here are from the two DO loggers. These curves show the influence of the diurnal cycling caused by thermal heating of the water column during the daylight hours and cooling during the night. Note the two temperatures curves are well coupled throughout the deployment period.

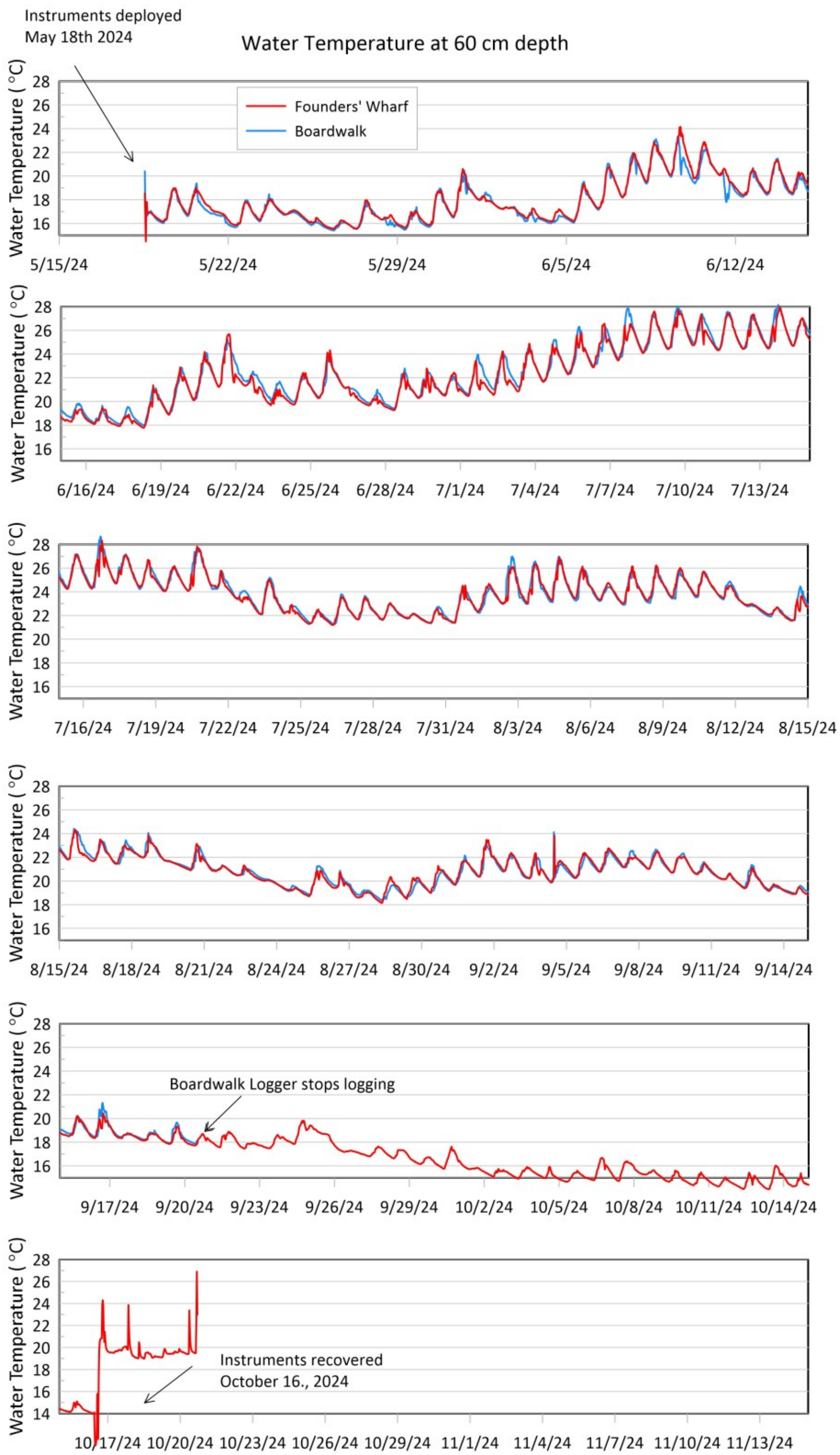


Figure 31. Water temperature time series at both sites at 60 cm depth from the HOBO DO loggers.

5.3.2 DO Time Series

The DO from both HOBO DO loggers were plotted for both the Founders' Wharf and the boardwalk sites (Figure 32). Both these loggers were deployed within the photic zone at a depth of 60 cm. Draped on top of these curves are the YSI DO probe data for 50 cm depth. There appears to be good agreement between these two types of DO sensors. The data density of the HOBO loggers measuring values every 30 minutes describe the diurnal oscilations in great detail.

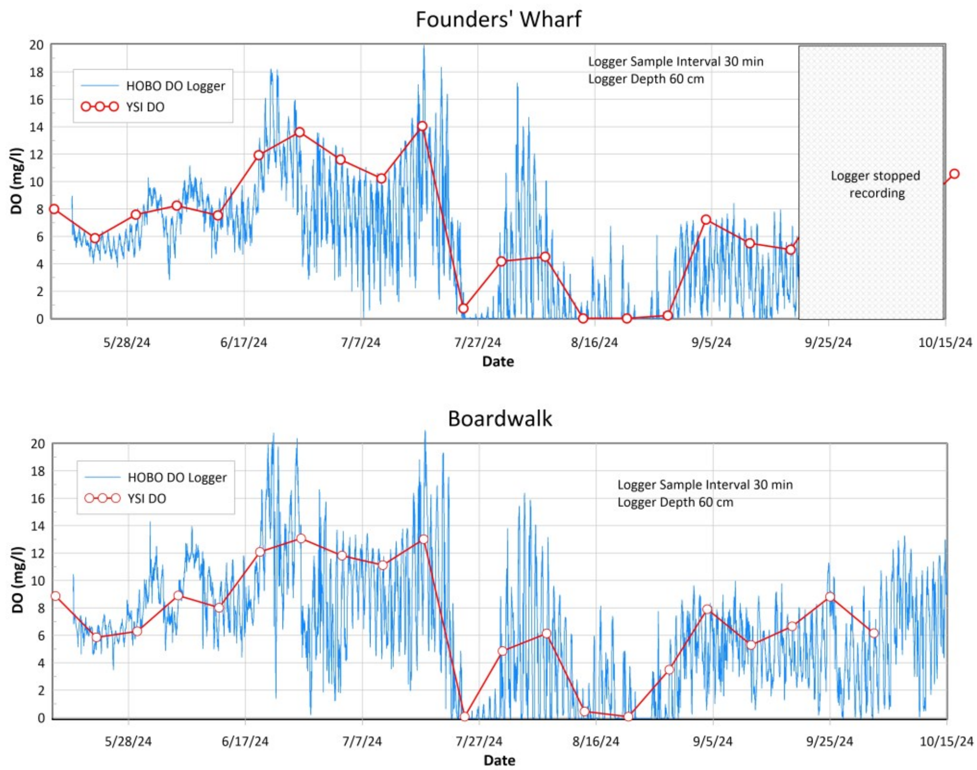


Figure 32. HOBO Dissolved oxygen logger with YSI DO probe data overlay.

The amplitude of the oscillations of the diurnal cycle indicates, to a large degree, the level of biological activity within the water column (Khan and Ansari, 2005). At either extreme, photosynthesis during the daylight hours is contributing to elevated oxygen concentrations, and darkness at the other extreme is seeing the consumption of oxygen through organism respiration. In hypoxic events from previous years, the oxygen levels had been very low (less than 2 mg/l) with a very small amplitude due to diminished biological activity. A small program was written to extract the daily minimum and maximum DO values and the average time of day that these two values occur. In Figure 33, the shaded area plots the range of the DO daily minimum and the daily maximum at the 60 cm instrument depths at both the Founders' Wharf and the boardwalk. In this text, we refer to this range as the oxygen regime. Wide bands suggest periods of high metabolic activity oscillating between DO production and DO consumption. The DO Max-Min plot shows a gradual building of this regime until the sharp die-off of the *Dolichospermum* bloom near the end of July. From the HOBO logger plots, at this depth there appears to be another metabolic peak right after the end of July dip. This activity is limited, however, just to the top 100 cm of the water column as displayed on the DO time series plot of Figure 33.

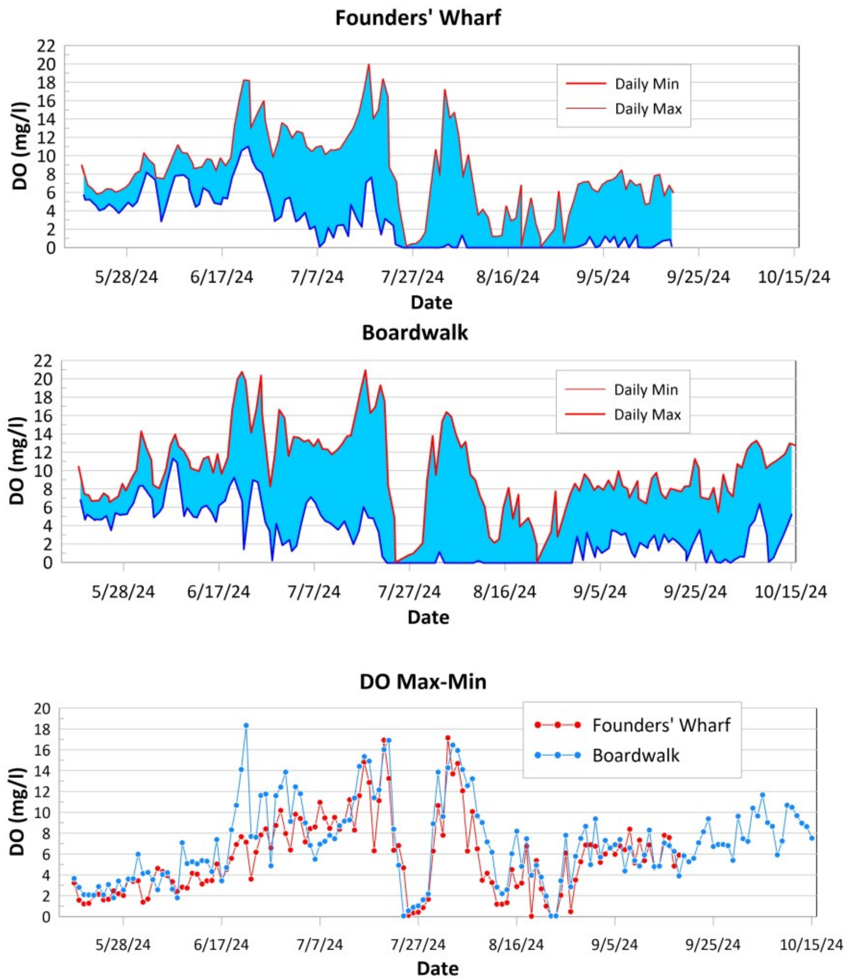


Figure 33. Dissolved oxygen regimes for the 60 cm depths at both lake sites.

5.3.3 Lux Time Series

Light plays an important role in the thermal and biological metabolic processes at Swan Lake. Light from the sun reaches the lake surface directly and through atmospheric diffusion. As light projects into the lake, it quickly attenuates with depth as it gets absorbed and scattered by particles such as algae and suspended solids. The deeper the light penetration, the deeper the potential for photosynthetic processes. The HOBO lux loggers measure lux in units of Lumens/m^2. Solar insolation as measured by the Swan Lake weather station is measured in watts/m^2. To convert the lux values into solar insolation values, a multiplier of 0.0079 was applied to the lux values. Figure 34 shows the solar insolation at the surface along with the values measured at depth from the lux loggers.

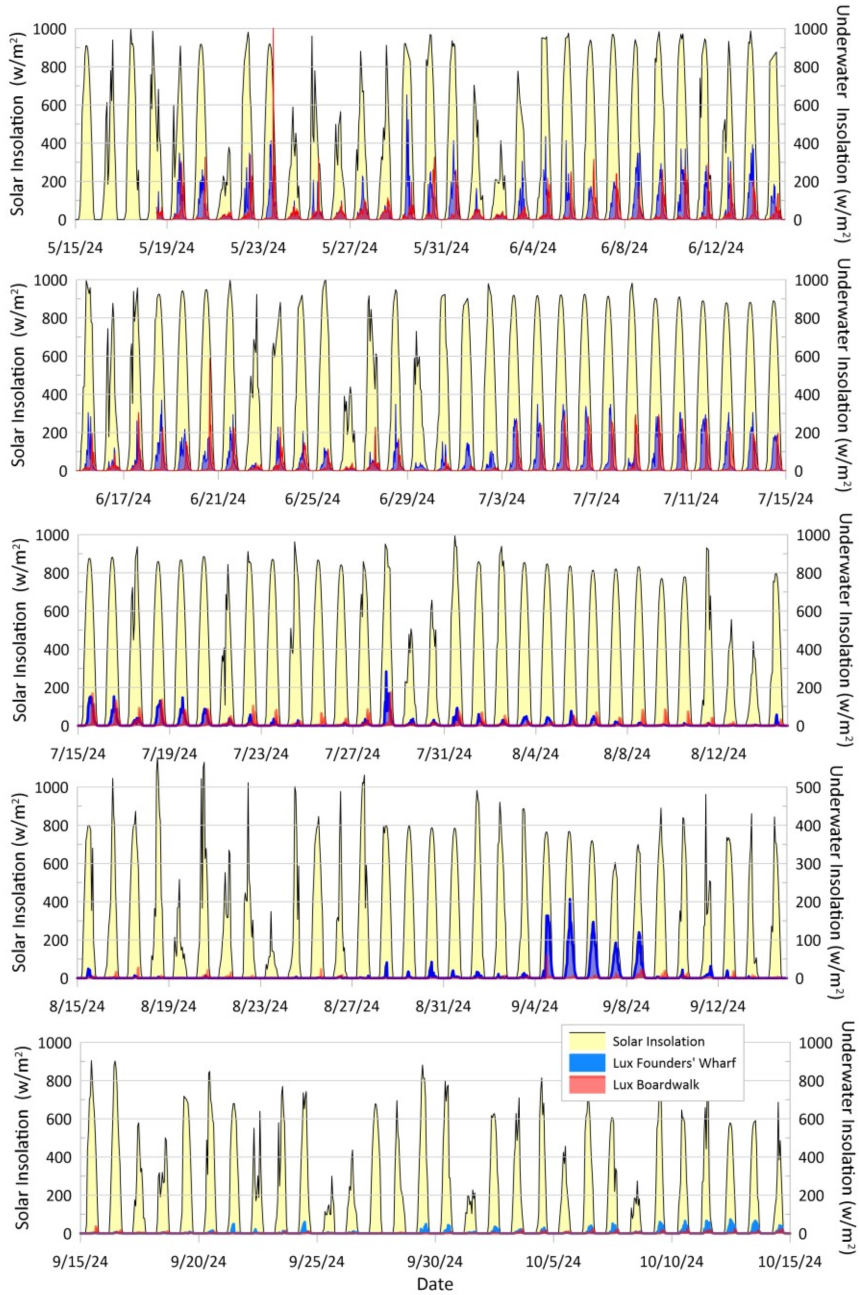


Figure 34. Solar insolation from weather station plotted with the Founders' Wharf and boardwalk lux loggers submerged at a depth of 60 cm.

The daily maximum solar insolation was calculated for the surface, the Founders' Wharf and the boardwalk lux logger data sets. These data were plotted in Figure 35. The average time of day for the maximum insolation was also calculated for each data set.

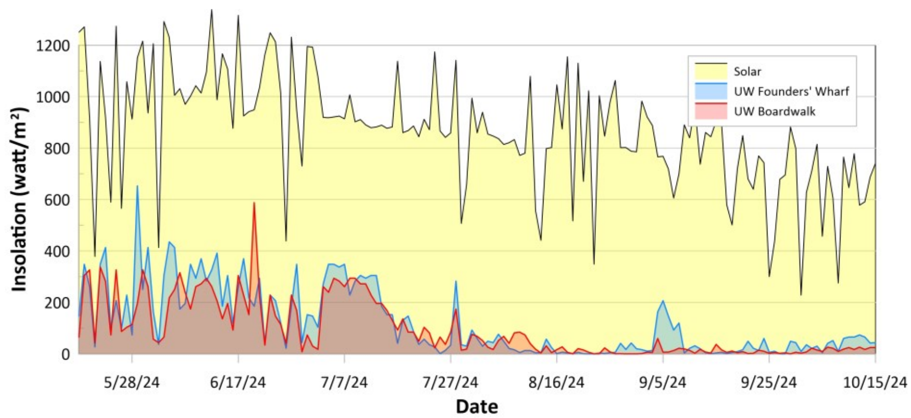


Figure 35. Daily solar maximums at surface and 60 cm depth.

The daily maximum light penetration was plotted as a percent of the total peak surface solar insolation in Figure 36. Light quickly attenuates with depth in this lake setting. There appears to be a slow decline of the light penetration as the season progresses. This shows a similar pattern to the Secchi disk depth data as turbidity degrades through the summer months.

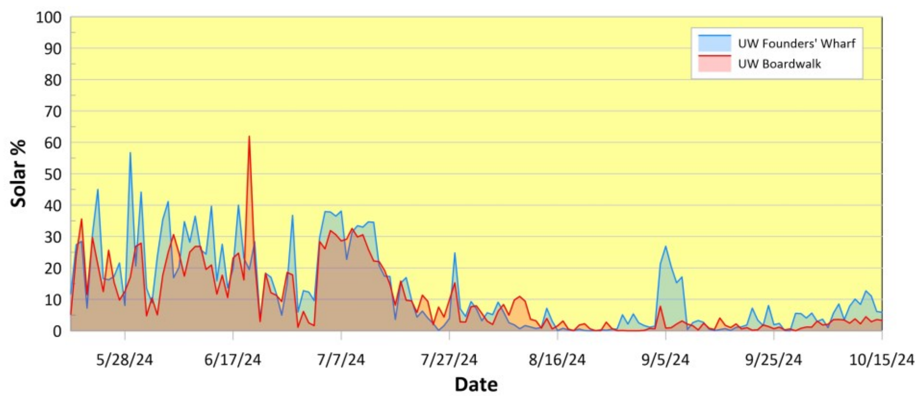


Figure 36. Percentage of surface sunlight reaching lux loggers at 60 cm depth.

Time of day details of Lux, water temperature and solar insolation are summarized in Table 1.

Table 1. Daily extremal time of day for temperature, DO and solar insolation.

Depth	Water Temperature		Average Daily Temperature Range (at 60 cm depth)	Lux	DO		Solar Insolation
	min	max		max	min	max	max
Founder's Wharf	8:52 am	2:24 pm	2.19 C	1:14 pm	7:44 am	3:46 pm	11:54am
Boardwalk	8:51 am	2:06 pm	2.05 C	3:21 pm	7:18 am	4:07 pm	11:54 am

Figure 37 shows a time of day plot depicting both the DO and Lux logger data. A curve fit was placed through the DO data showing the extreme low and extreme high DO levels at their corresponding time of day. Note the Lux logger data at the boardwalk is skewed. The position of the loggers were attached to the west side of the boardwalk. The boardwalk itself cast a shadow on the Lux logger until the sun moved high enough in the sky to illuminate the logger. Note the steep step once this angle was achieved.

The daily DO maximum at both sites was in the later afternoon well beyond the maximum light penetration. This point of interest may be related to the metabolic momentum of the organisms. The daily DO minimum required a little more analysis as there was the potential for the minumum to occur before the maximum in the morning or in the evening after the daily maximum. To average both modes would produce an incorrect average time. The histograms of Figure 37 show this bimodal distribution indicated by the red bars.

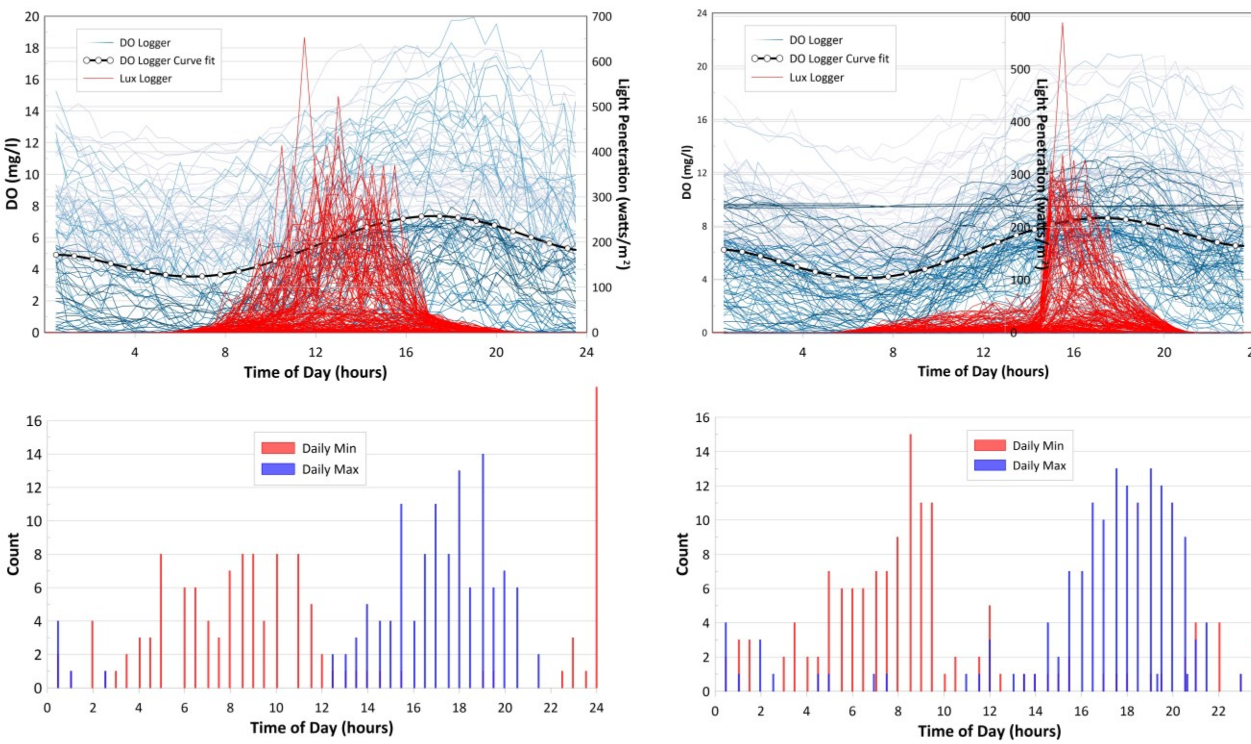
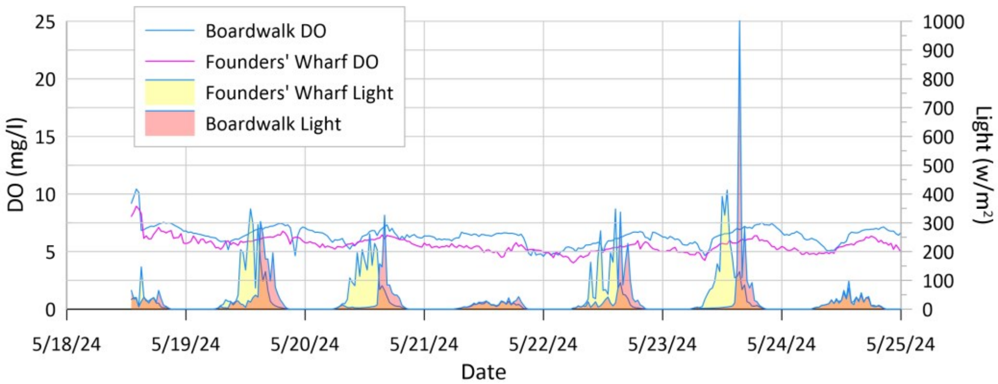
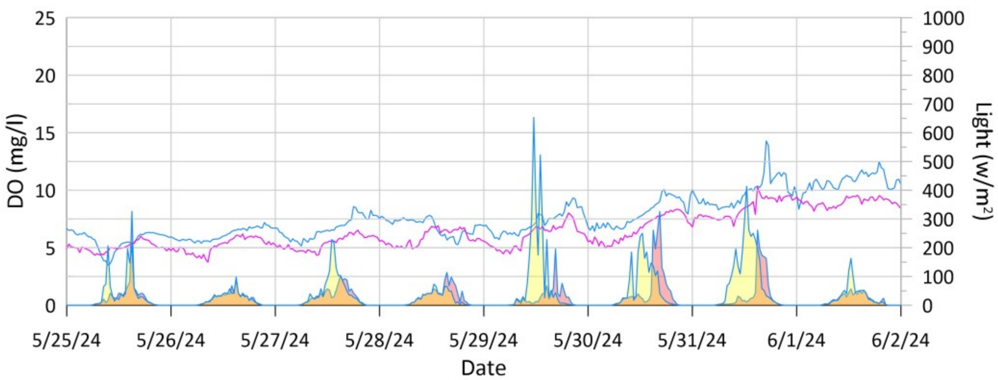


Figure 37. Time of day for DO extremes for the Founders' Wharf (left) and the boardwalk (right).

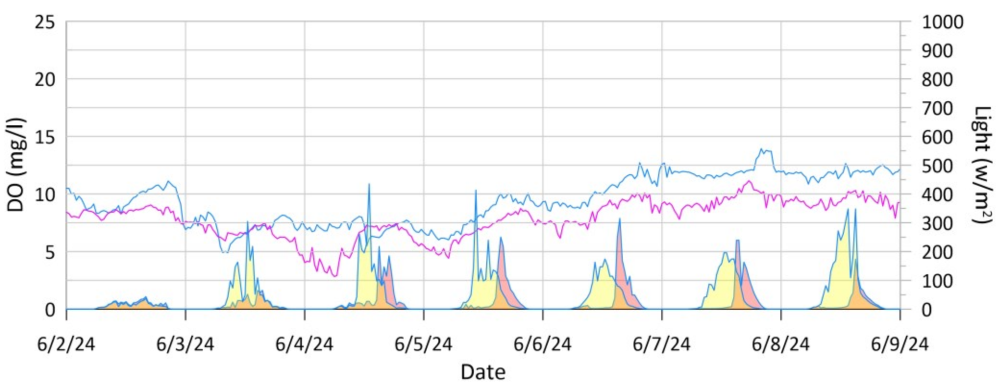
The impact on light penetration of DO production was then examined by plotting both attributes onto a comparative plot in Figure 38. The horizontal time scale was stretched out to view these features in more detail. In this plot we see the offsets of peak light to peak DO values.



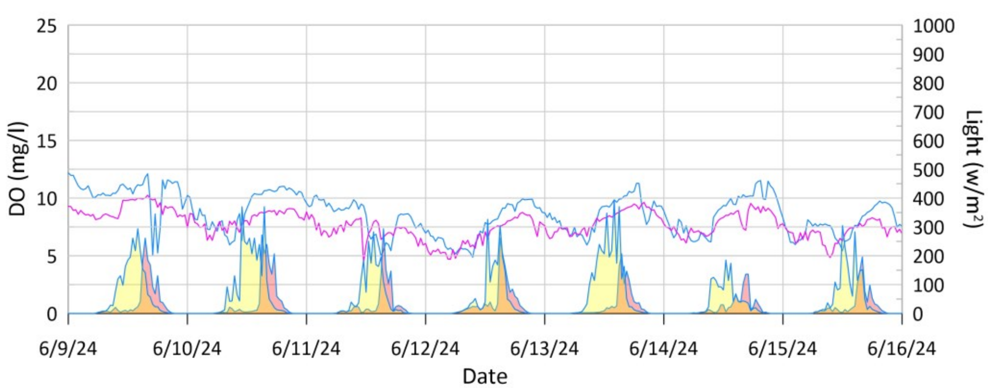
Boardwalk DO
Founders' Wharf DO
Founders' Wharf Light
Boardwalk Light
DO (mg/l)
Light (w/m²)
Date
5/18/24
5/19/24
5/20/24
5/21/24
5/22/24
5/23/24
5/24/24
5/25/24



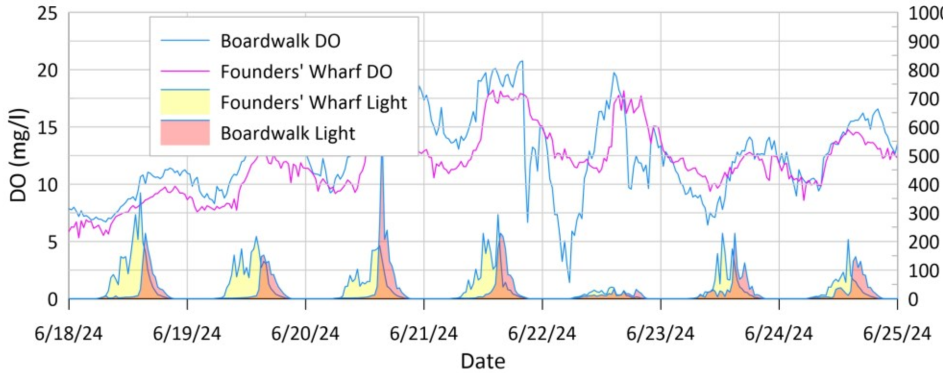
DO (mg/l)
Light (w/m²)
Date
5/25/24
5/26/24
5/27/24
5/28/24
5/29/24
5/30/24
5/31/24
6/1/24
6/2/24



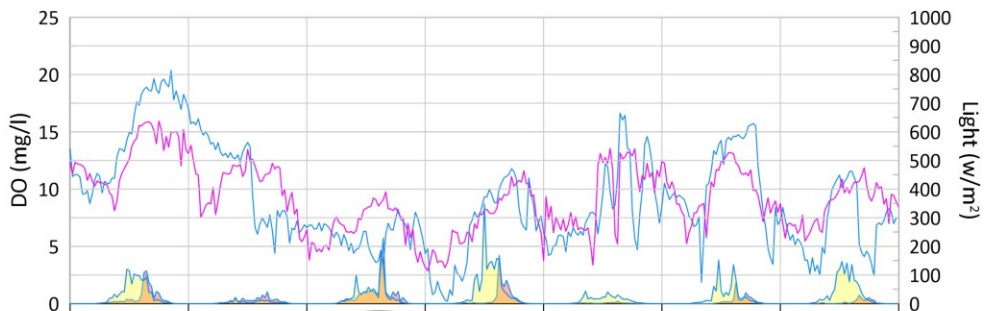
DO (mg/l)
Light (w/m²)
Date
6/2/24
6/3/24
6/4/24
6/5/24
6/6/24
6/7/24
6/8/24
6/9/24



DO (mg/l)
Light (w/m²)
Date
6/9/24
6/10/24
6/11/24
6/12/24
6/13/24
6/14/24
6/15/24
6/16/24



Boardwalk DO
Founders' Wharf DO
Founders' Wharf Light
Boardwalk Light
DO (mg/l)
Light (w/m^2)
6/18/24
6/19/24
6/20/24
6/21/24
6/22/24
6/23/24
6/24/24
6/25/24
Date



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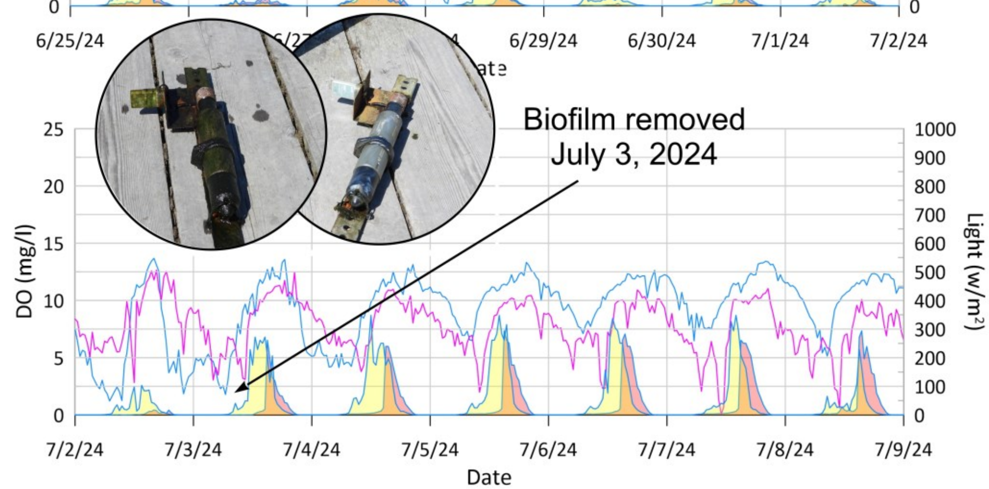

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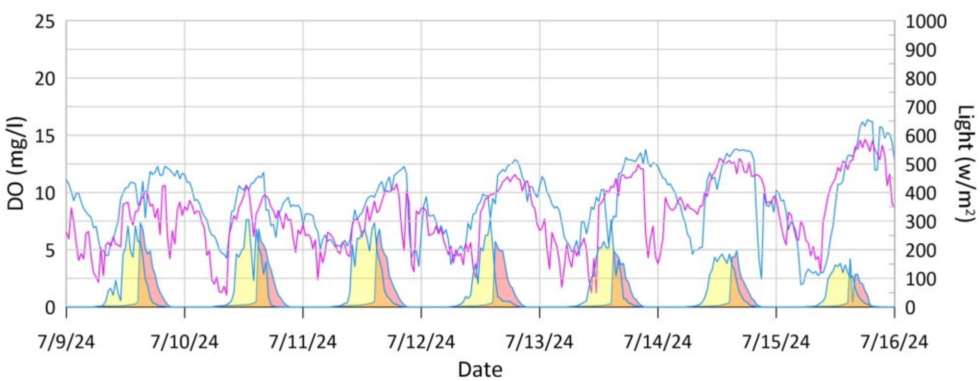

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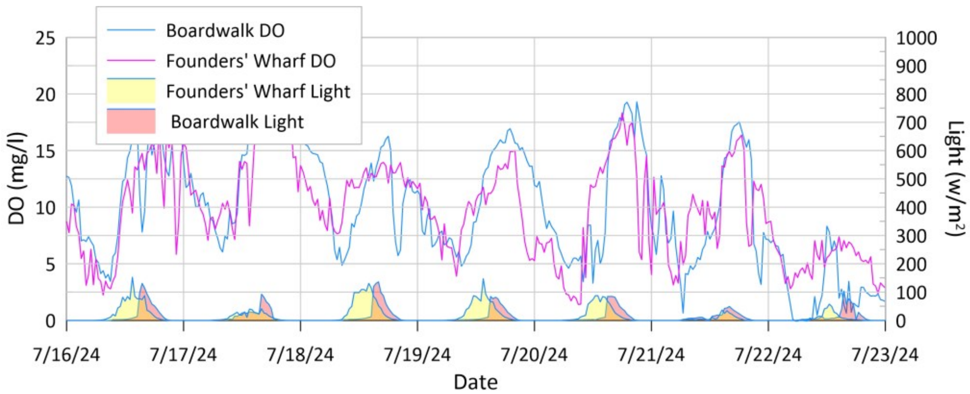
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Founders' Wharf DO
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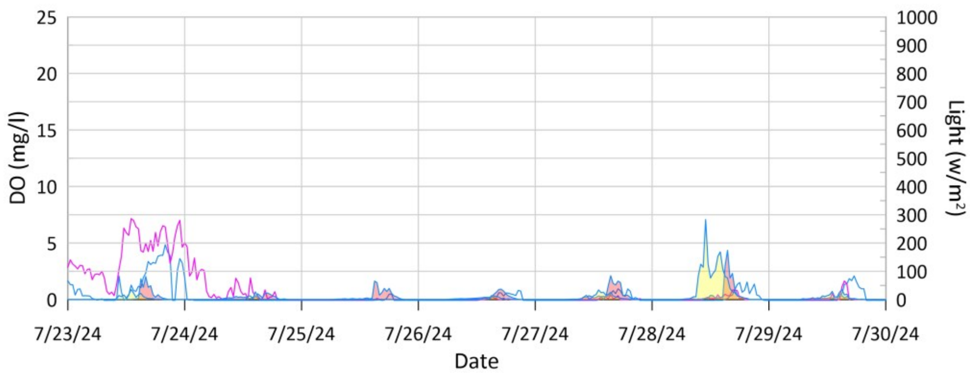
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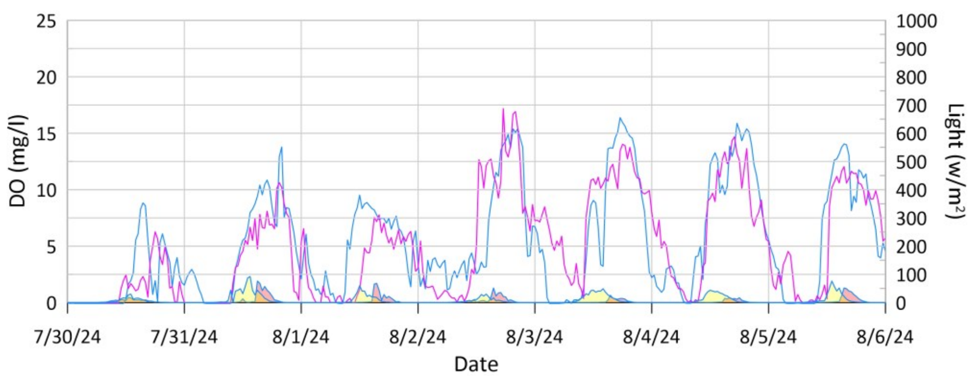
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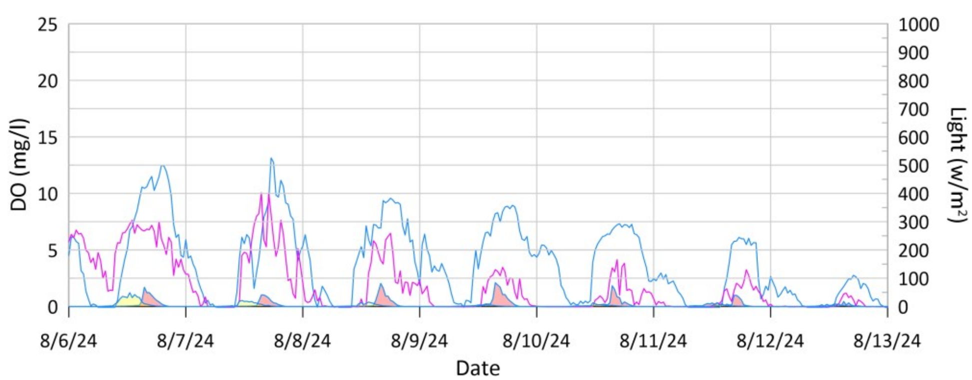
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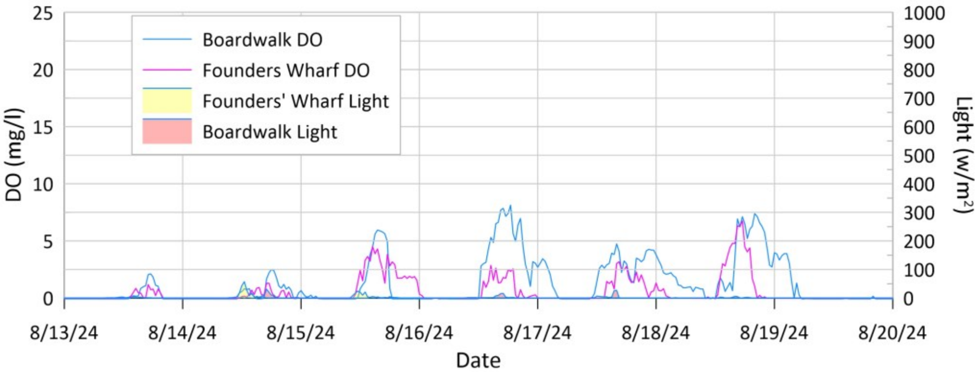
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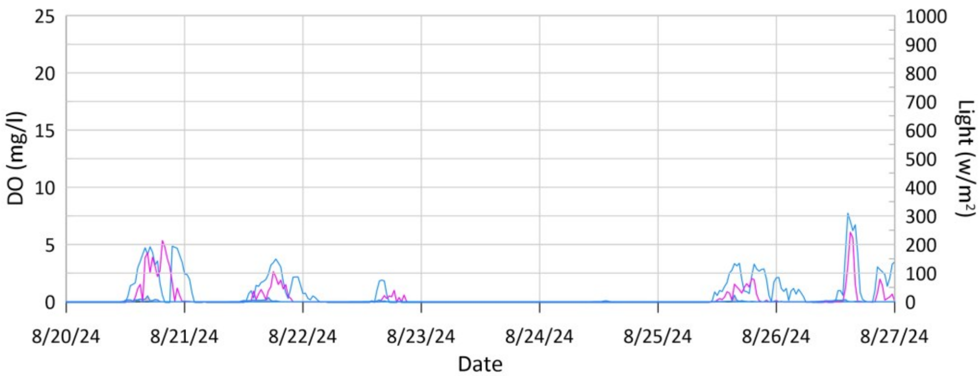
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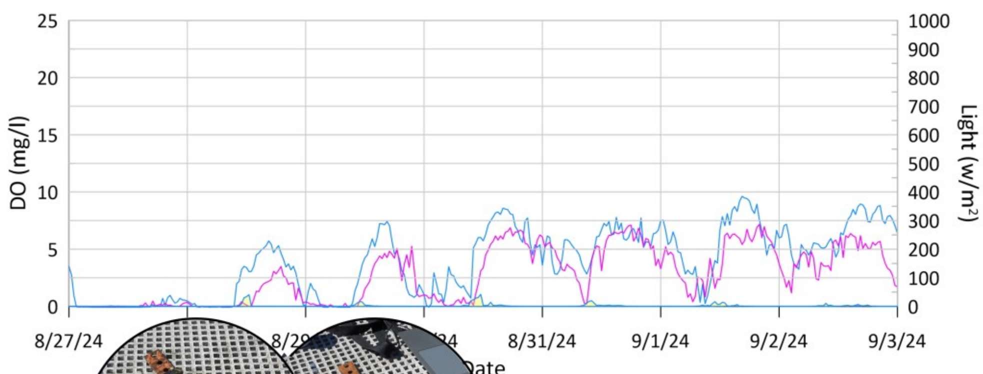
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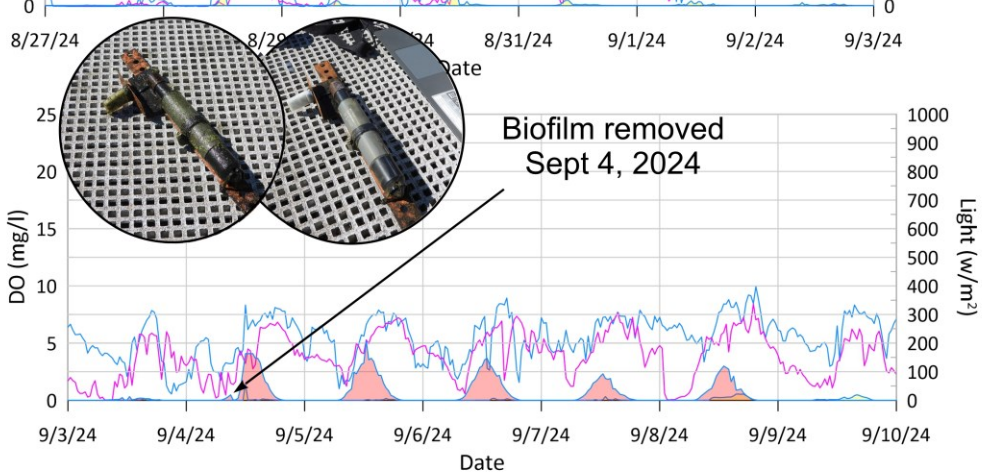
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Sept 4, 2024
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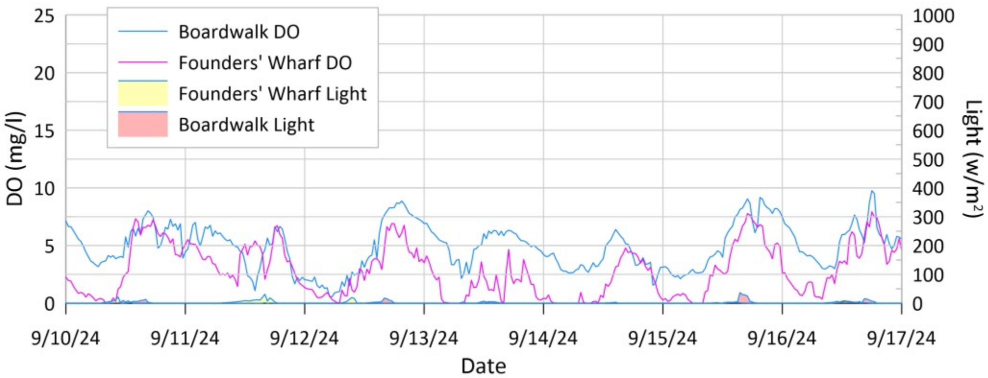
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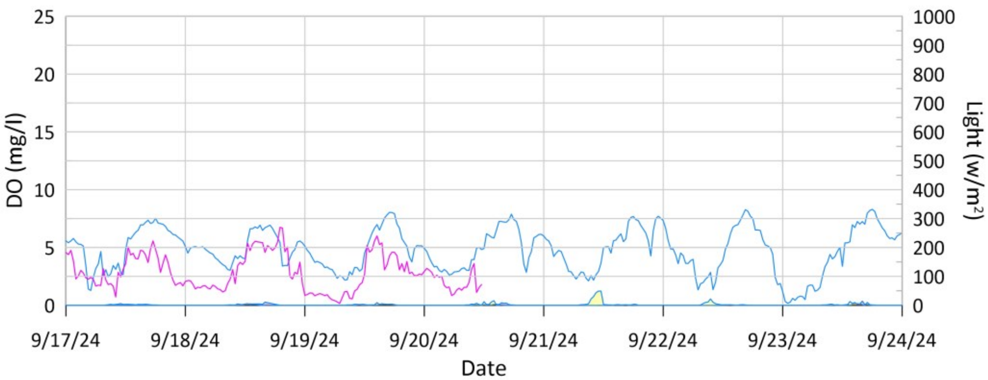
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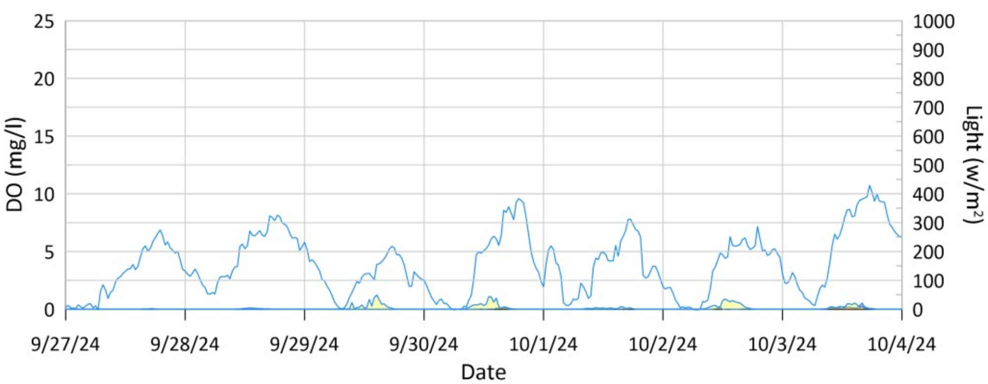
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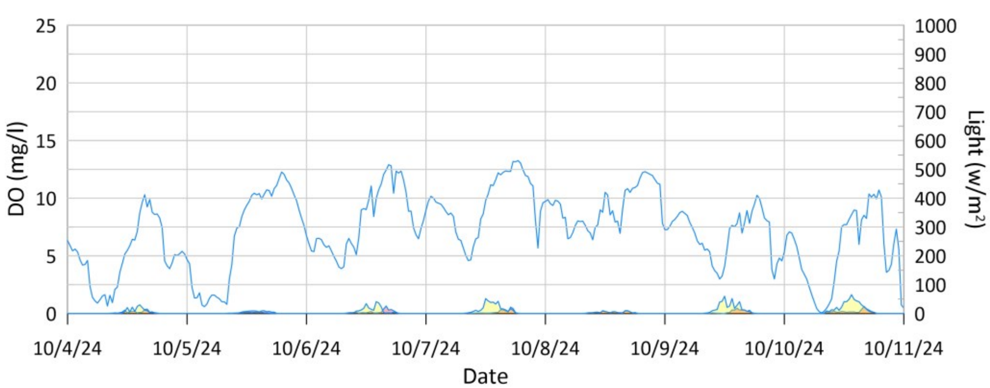
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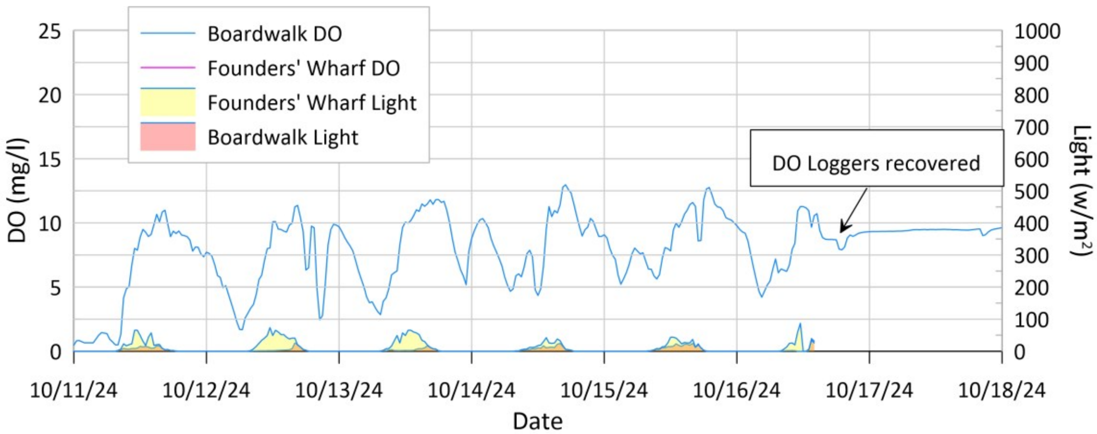

Figure 38. Comparison of DO and lux logger data.

Offsets are clearly visible between peak solar and peak DO production particularly in June in the above plots. In mid-May, light penetration is high, also observed in the Secchi disk depth, but only small oscillations in DO are observed. This is after the decline of the AFA that was visible in the early part of May. This suggests only minimal populations of photosynthetic organism activity in the latter part of May. By mid-June, the diurnal cycle of DO is well established. Biofilms accumulate on the Lux sensors over time so it was necessary to clean the sensors to get accurate measurements. This was done twice during the sampling season. Both DO and Lux loggers were removed and cleaned. A thin film of zinc cream was applied to the surfaces of the Lux loggers as an antifouling agent to reduce biofilm accumulations. The effect of this cleaning can be seen on both cleaning events of July 3rd and September 4th. From June 28—July 22, the pattern of light penetration and DO dynamics is extremely stable depicting diurnal osillations. By July 25, there are five consecutive days where light penetration is low and DO completely drops off at this 60 cm depth. This dip is clearly evident in the DO time series of Figure 14. Following this, there is a return to the regular cadence of day/night cycling with a gradual tapering of the DO amplitudes to a point in mid-August where again the lake system stuggles with irregular DO production. It is during this time that the entire water column drops to below 2 mg/l as seen at all three sites depicted in the DO block diagrams of Figures 15 and 16. From August 27 to the end of the sampling period, DO once again establishes a rythmic diurnal pattern.

5.4 Collecting Water Samples

Water samples were taken at the two lake sites using a Van Dorn bottle as well as samples taken at the surface at the inflow creek. The inflow creek site was a potential vector for external nutrient loading through the various urban and agricultural land use practices upstream. At both the Founders' Wharf and the boardwalk, samples were taken at the surface, 1.0, 2.0 and 3.0 m depths. These samples were analyzed for nutrients and biological constituents at the Diversified Scientific Solutions' laboratory using a YSI 9500 photometer and imaging trinocular.

5.4.1 Phosphorus

The phosphorus cycle is a key component to the biological processes at Swan Lake. Phosphorus is considered, in general, to be a major nutrient that leads to global lake eutrophication and algal blooms due to increasing anthropogenic sources (Reynolds and Davies, 2001 and Paerl and Otten, 2013). It is an essential nutrient for cyanobacteria, algae and aquatic plant metabolic processes. The concentration of phosphorus has detrimental effects at either extreme. As has been observed at Swan Lake, high concentrations have led to lake-wide blooms whereas low concentrations have been strongly correlated with lake-wide hypoxia such as the fish kill of 2017 where the phosphorus levels collapsed to zero in the water column accumulating at the benthic layer.

The phosphorus cycle within eutrophic lakes has been likened to a biochemical engine where the inflow streams provide the power supply (external loading from the watershed) and the legacy phosphorus deposited in the sediments (internal loading) is like the engine's battery (Dr. Sean Waters https://www.lakestoriesnz.org/insights). This analogy is useful when considering mitigation techniques to reduce phosphorus from lake systems such as cutting off the "power supply" by reducing the in-flow phosphorus to the lake.

Figure 39 illustrates the phosphorus cycling process. Generally, the input inorganic phosphorus is converted to organic phosphorus through plant assimilation. This organic phosphorus can be deposited as these plants die or be consumed by other organisms such as grazing zooplankton. In time, phosphorus is either excreted or deposited to the lakebed as these organisms die. Bacteria at the lakebed break down the organic phosphorus and through this process of decomposing rerelease inorganic phosphorus back into the water column (The Phosphorus Cycle, 2021).

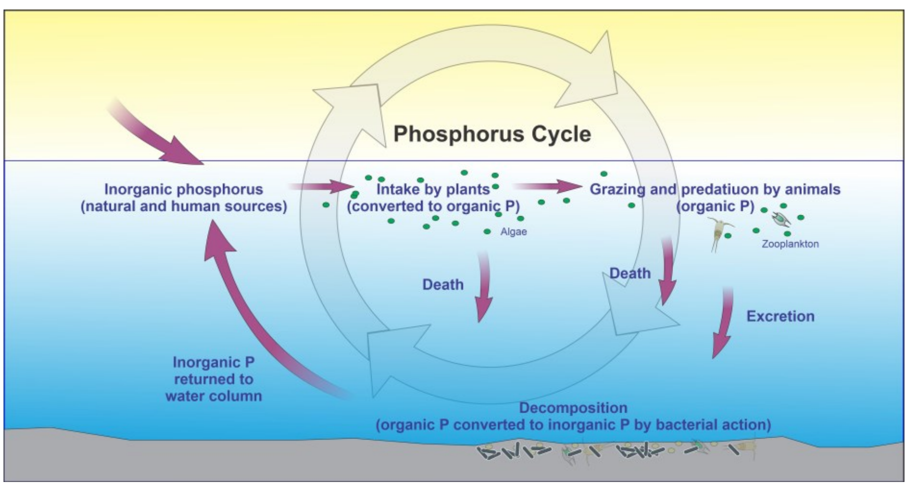

Figure 39. The phosphorus cycle.

Figure 40 shows plots of total phosphorus (TP) concentrations from the Founders' Wharf, the boardwalk and the inflow creek. Unfortunately, no samples were collected during the summer months spanning July 17–August 31.

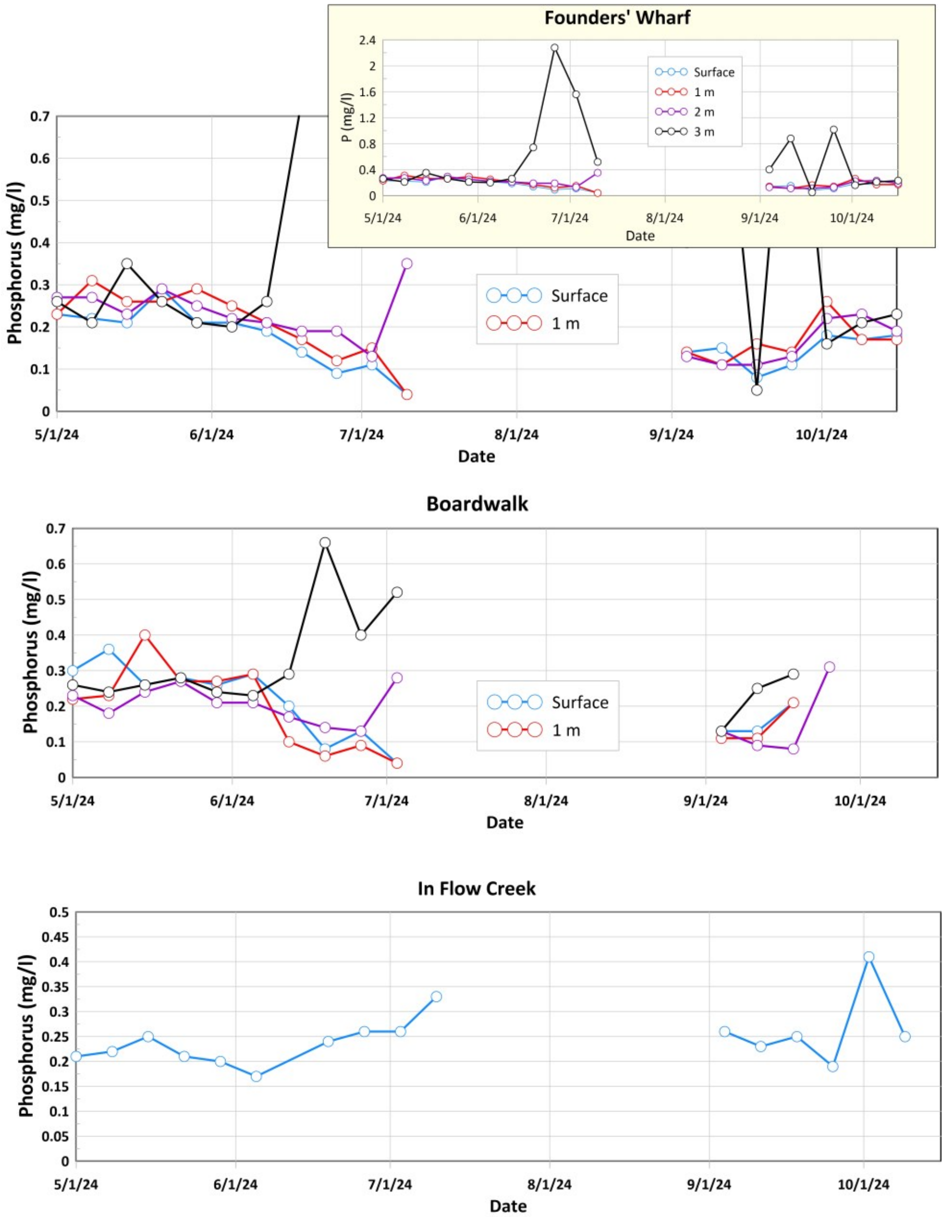

Figure 40. TP time series plots. Inset shows the high TP levels at the benthic layer (Founders' Wharf site).

The TP for Swan Lake at the beginning of the sample program was between 0.2 to 0.3 mg/l within the water column. In both lake sites, the concentrations slowly declined as the *Dolichospermum* bloom consumed this vital nutrient. By mid-June, the upper water column was now nearing its seasonal low values, and the benthic zone was becoming highly concentrated. This intensifying of nutrients at the bottom was likely due to the increasing volume of die-off from the bloom above. This process created a downward flux of TP. Despite these lower concentrations of TP in the surface waters, DO production remained high, suggesting that other nutrients may have been utilized such as nitrogen either available in solution or sequestered through fixation by the heterocyst of the *Dolichospermum*. In September and October, TP slowly returned to near spring values.

Blenkinsop Creek continues to deliver phosphorus to the lake system with concentrations that range from 0.2–0.40 mg/l. Although these values are significant in magnitude, the flow of this creek tapers to low flow conditions by late June and continues at this low discharge state with the exception of a few rain events until the fall rains again charge the creek to more significant flow rates. This creek does become a significant vector for phosphorus during the fall rain events.

A contour plot was created for both the Founders' Wharf and the boardwalk data to visualize the dynamics of phosphorus in the water column (Figure 41) throughout the study period. Each site was sliced into two segments as there was a gap in data collection between mid-July and late-August.

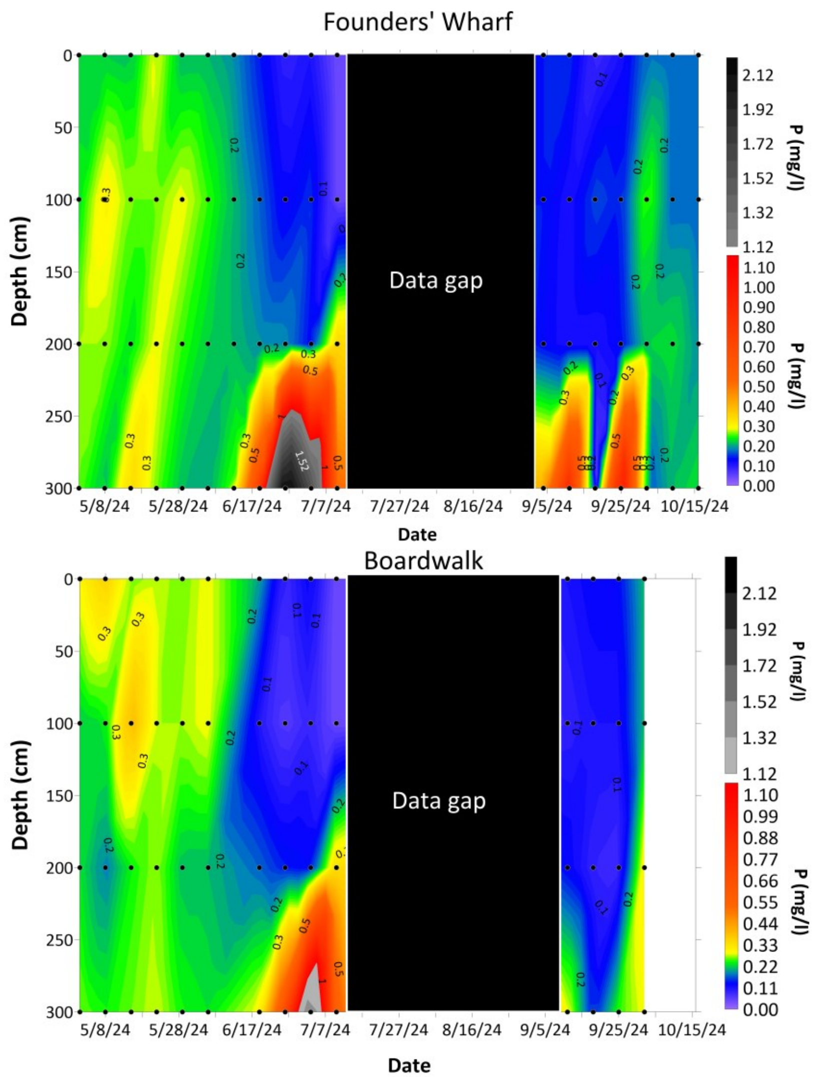

Figure 41. Phosphorus contour plot for the Founders' Wharf (top) and the boardwalk (right).

The trophic status of lakes has been divided into several distinct class-based categories based on lake parameters such as phosphorus concentrations. These states are summarized in Table 2 along with Carlson's trophic state index (see: https://www.nalms.org/secchidipin/monitoring-methods/trophic-state-equations/). Swan Lake has been referred to as a eutrophic lake but at times presents as hyper-eutrophic. For most of the study period, the 0.1 mg/l threshold is exceeded. Throughout the site visits, Secchi depths range from as high as 2.25 m to as low as 0.2 m during the *Dolichospermum* blooms (see Figure 25). The chlorophyll-a values at Swan Lake are also in the hyper-eutrophic range as they were elevated in August and measured as high as 160 µg/l (see Figure 28). From these parameters (white arrows indicating ranges), the trophic state index for Swan Lake, depending on the time of year, would range from about 53 to much higher due to the combination of high total phosphorus, high chlorophyll-a and low Secchi depths (Figure 42).

Table 2. Lake trophic status (Environment Canada, 2004 and after Carlson, 1977).

Trophic Status	Total Phosphorus (µg/l)	Total Phosphorus (mg/l)
Ultra-oligotrophic	< 4	< 0.004
Oligotrophic	4-10	0.004-0.01
Mesotrophic	10-20	0.01-0.02
Meso-eutrophic	20-35	0.02-0.035
Eutrophic	35-100	0.035-0.1
Hyper-eutrophic	>100	> 0.1

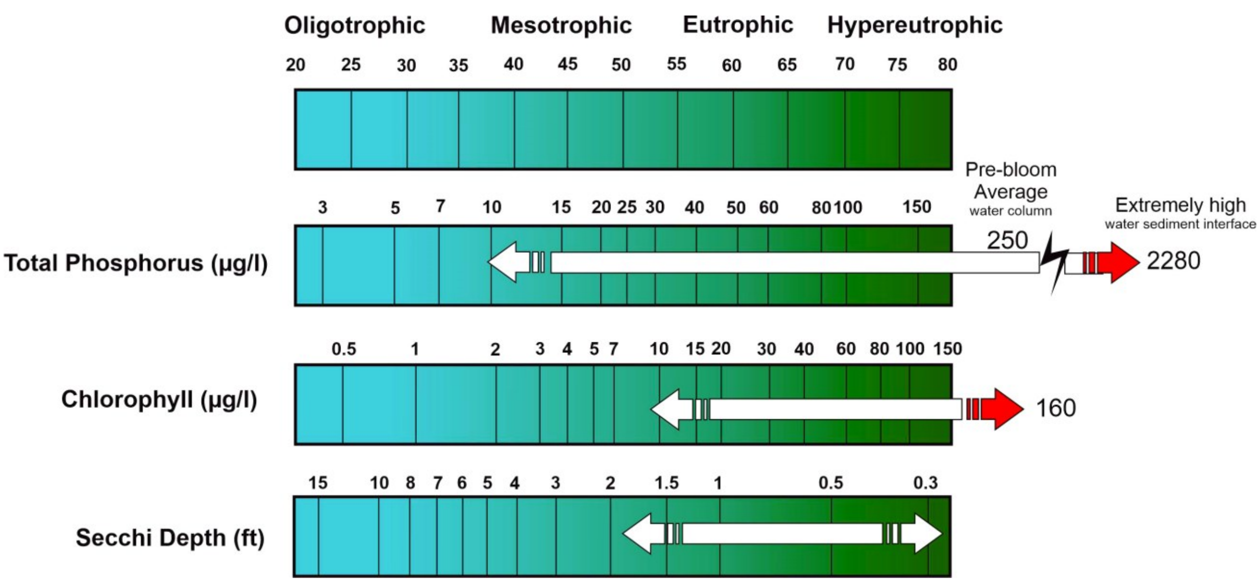

Figure 42. Trophic State Index chart with Swan Lake ranges indicated by white arrows.

Figure 43 is a simplified diagram showing the characteristics of the various tropic states of a lake. Although a eutrophic lake initially tends to be a much more productive system in terms of biomass, the biodiversity is lost as the most successful species, often invasive ones, outcompete and displace rival species. At Swan Lake, because of the shallow, warm, high nutrient concentrations, cyanobacteria can very quickly ramp up and completely inundate the water column. With such blooms, the dissolved oxygen can have extreme oscillations bordering on concentrations that are too high (causing gas bubble disease) or too low (hypoxia) for such desirable fish as cutthroat trout. With algal blooms, huge amounts of organic material form during onset. Once conditions are no longer favourable these organisms die off and form large volumes of detritus that are either suspended in the water column or drop to the bottom.

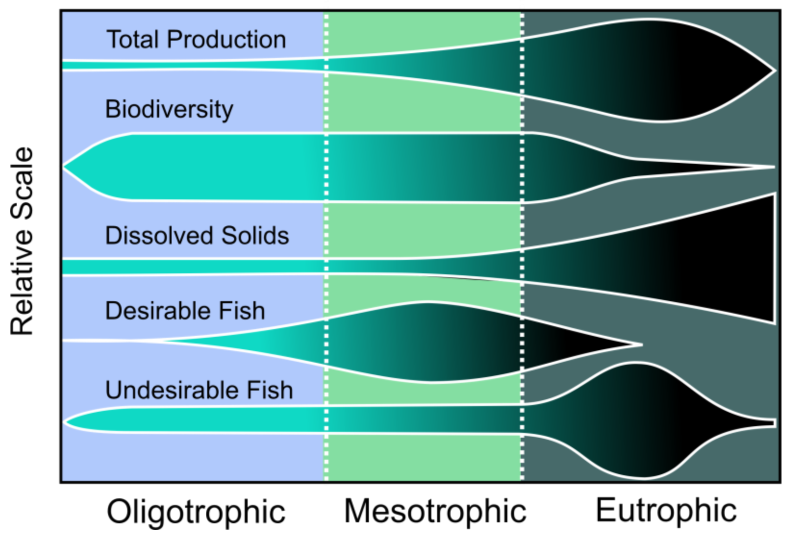

Figure 43. Diagram of lake characteristics of different trophic states (after Welch and Lindell, 1980).

5.4.2 Nitrogen

Nitrogen data in the form of nitrates were also plotted for the 2024 field season (Figure 44). In this year's data, two relatively high concentration peaks occur during the early May AFA bloom and then again for the July *Dolichospermum* bloom. These peaks of nitrates may have been influenced by both species having the ability to fix nitrogen through their specialized heterocyst cells (Kumar et al., 2010). These cells are independent from the other photosynthetic cell types in their structure. Their purpose is to sequester nitrogen from the environment to assist in the feeding of the organism. Where phosphorus concentrations begin to decline, the nitrate concentrations remain high. On July 14^{th} during the continued high DO concentrations, the inverse occurs where TP values go up and the nitrate values go down for the most part. It is uncertain as to how these curves would appear during the data gap but by September the concentrations have drop to about a quarter of the values in June.

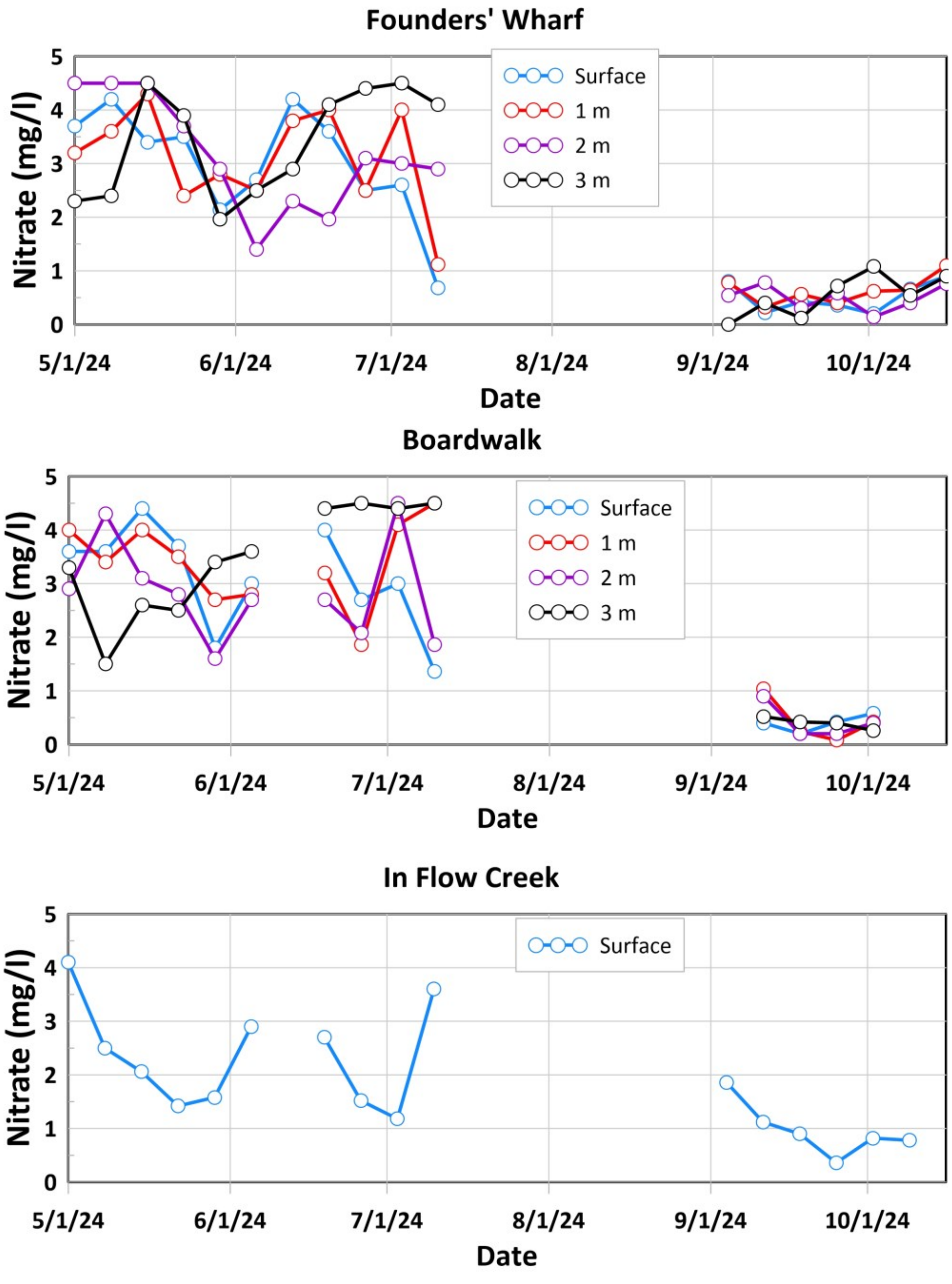

Figure 44. Nitrogen time series plots for Founders' Wharf (top), boardwalk (middle) and in flow creek (bottom).

A contour plot was also created for the nitrate concentrations (Figure 45). These contour models show the contrast of the high concentrations in the early period of the study compared to the low concentrations of the September/October period.

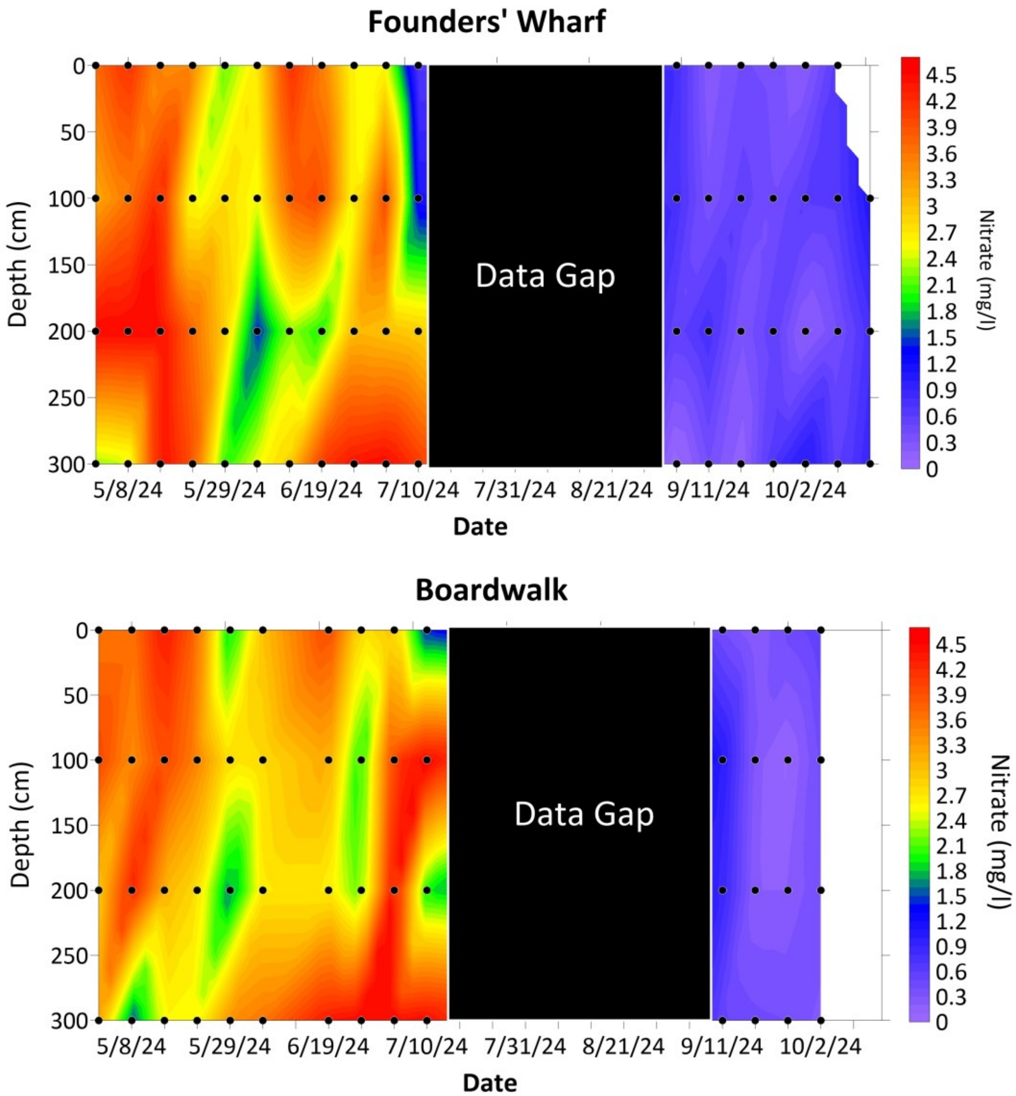

Figure 45. Nitrogen time series plots for Founders' Wharf (top) and boardwalk (bottom).

5.4.3 Turbidity

Figure 46 displays the turbidity for the two lake sites. Note both sites show a gradual upward trend as more organic materials enter the water column. These curves show a reduced turbidity trend in the September and October period as the number of suspended particles diminishes. The bottom panel of this figure shows the two integrated water column curves for these two sites. Generally, the turbidity is higher in the deeper water as organic material passes through the water column on its way to the bottom. In this deeper area, decomposing organisms are active, processing the die-off of algae and other organisms and it is here that significant nutrient exchanges occur between the bottom water and the sediments. Some of these interactions are depicted in the phosphorus cycle (Figure 39).

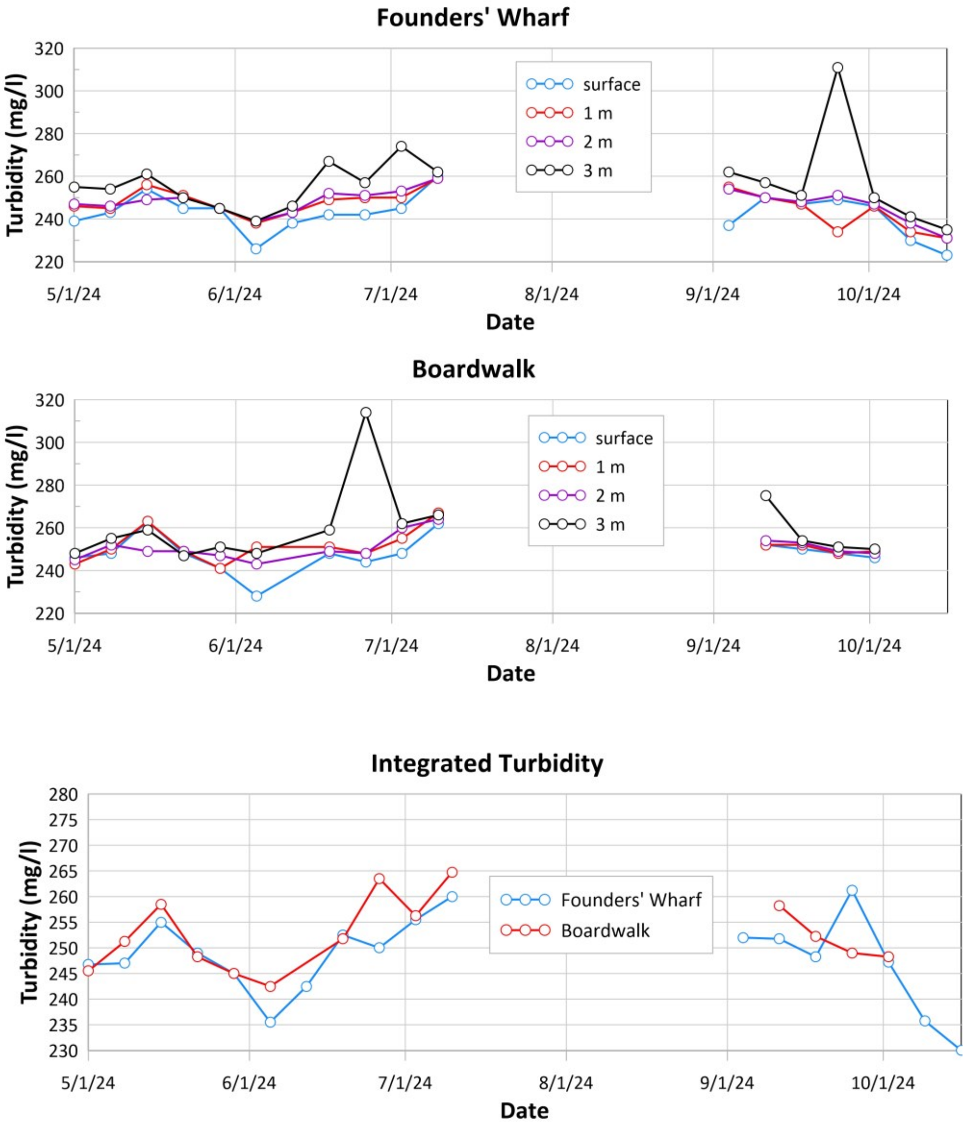

Figure 46. Turbidity data for the two lake sites along with an integrated water column summary.

5.5 Water Levels

Water levels for this year's data collection are displayed in Figure 47. The continuous red curve is taken from the barometric pressure compensated Solinst water level sensor placed on the lake bottom near the Founders' Wharf. This sensor logged data every 30 minutes. Draped onto this curve are weekly water depth measurements at the same location that verify the accuracy of the pressure sensor. Note the impact of rain events and how the water levels change based on the amount of rain. The Solinst logger was brought to the surface July 14th and downloaded. Unfortunately, when the logger was recovered in October, there was no new data and it was still in standby mode. The instrument was reset and is now continuing to log pressure and temperature over the 2024/2025 winter months.

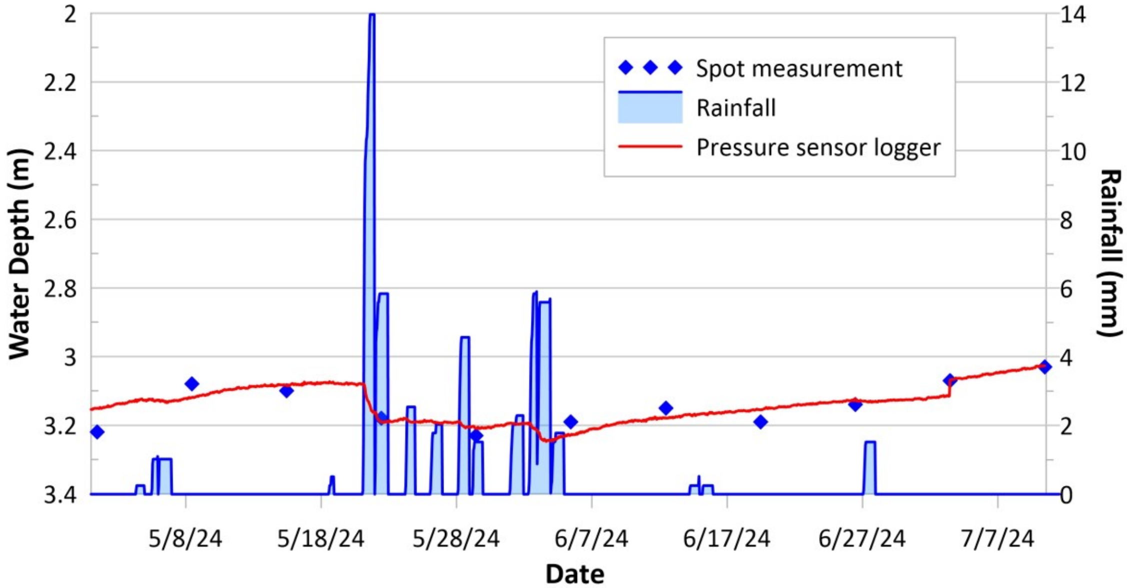

Figure 47. Water level changes comparing pressure sensor data to line measured data.

6.0 Interannual Comparisons

Swan Lake is far from existing in a steady state as it undergoes significant seasonal changes physically, biologically and chemically. These changes vary over many different time scales including minute by minute, diurnally and monthly. With nine years of data, interannual comparisons can be made to examine year-to-year variability. These comparisons are useful for detecting longer term trends and provide insights into how the system responds to different climatic influences such as drought and changes in algal blooms. Only a cursory treatment of these comparisons are offered here.

6.1 Dissolved Oxygen

Figure 48 overlays the 2024 data with previous data sampled near the surface of the Founders' Wharf. Now with several years of data, it appears that Swan Lake typically has four major dissolved oxygen events during the May to October study period with some year-to-year variability (Figure 49). This year's data shows a shift in time of these features to the left. These include two elevated DO levels due to an initial May/June bloom followed by a second more intense late July bloom. These blooms produce supersaturated DO concentrations and consume significant amounts of available phosphorus. Following these blooms a dramatic drop in DO occurs as the lake reaches its lowest point of resilience sometime in August. Weather certainly is a factor in these low oxygen periods and influences such a cloud cover, calm wind conditions and drought can provide the catalyst to tip the lake towards hypoxia and recovery. Certainly, wildfire smoke has in previous years occurred at this time, filtering the sunlight from conducting photosynthetic processes. Following the low DO concentration comes a time in October/November of recovery where restoring forces such as wind mixing, a flush of phosphorus released from benthic bacteria, cooling temperatures and precipitation again drive the DO levels to improve.

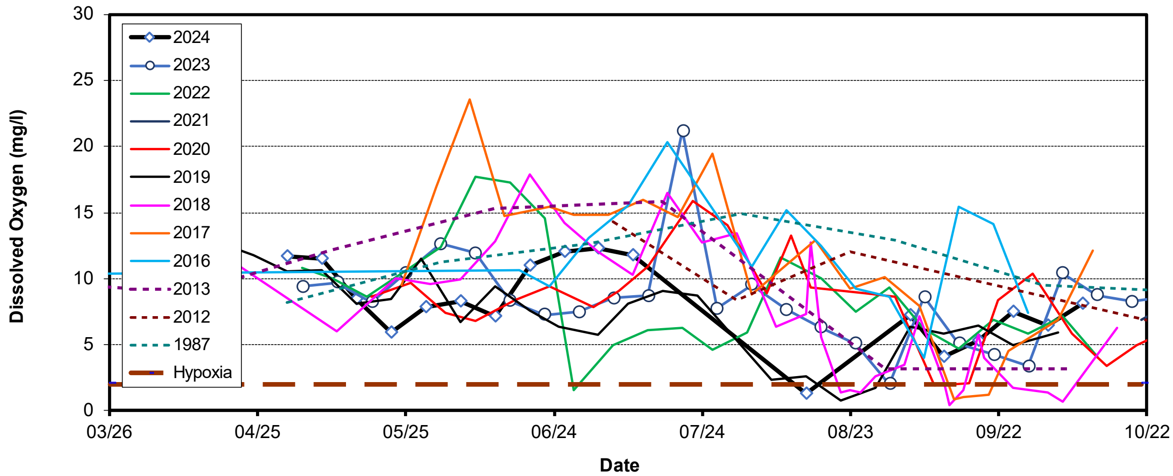

Figure 48. Interannual comparison of DO time series at Founders' Wharf.

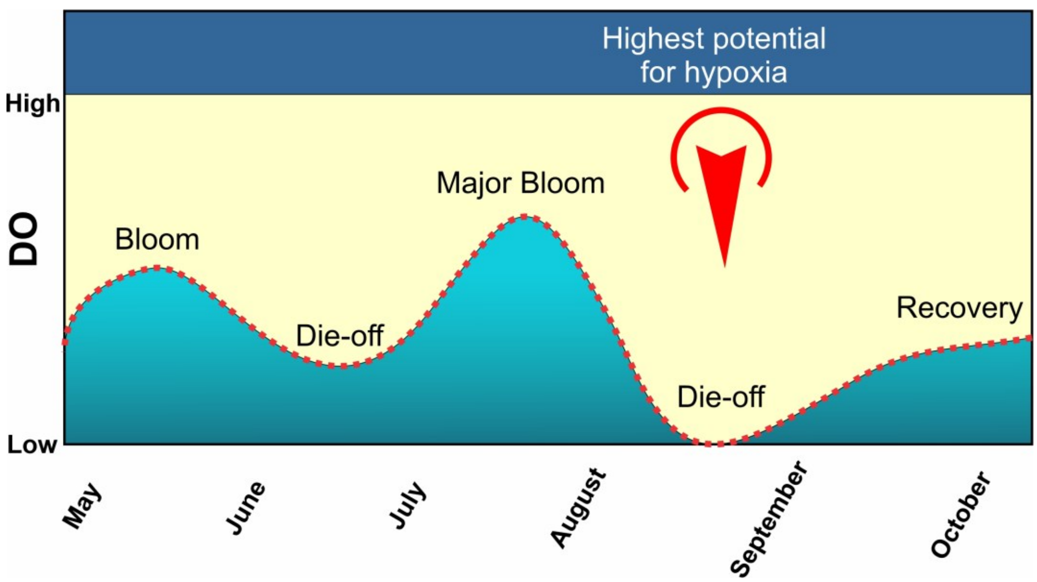

Figure 49. Typical DO pattern at Swan Lake.

Figure 50 shows contour plots of the DO concentrations at the Founders' Wharf for the last eight years. These contour models give a quick visual means of observing patterns and anomalies in DO concentrations within the water column. In the 2017 dataset, a prolonged hypoxic event led to the fish kill of that year. It can be seen that each year a significant amount of the lower water column is anoxic. Also of note are the surface algal blooms denoted by elevated DO concentrations depicted as green and blue shadings.

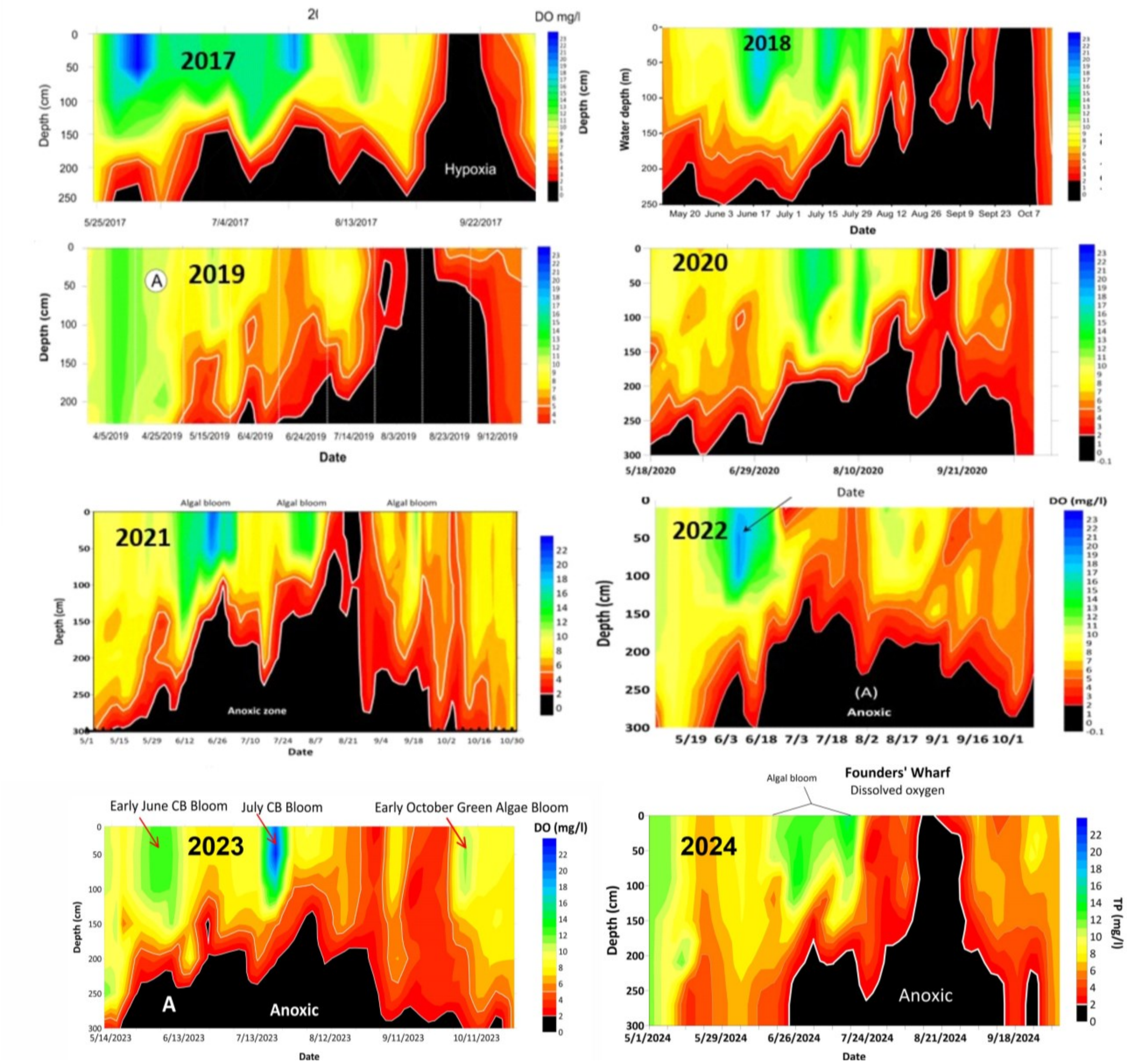

Figure 50. Contour models of DO concentrations at the Founders' Wharf spanning 2017–2024 data.

6.2 pH

The pH levels for the last nine years are compared in Figure 51. Dynamics in pH are, at times, huge with massive gradients between surface and bottom water. On June 26th a maximum surface to bottom gradient of 2.41 pH units was observed in three meters of water at the Founders' Wharf site. In the comparison plot below, the limits of the pH range from surface waters for the nine years is approximately 3.2 pH units spanning a pH of approximately 6.8 to 10. In contrast but not shown here, bottom waters tend to acidity ranging as low as a pH of 6.6 this year at the Founders' Wharf site.

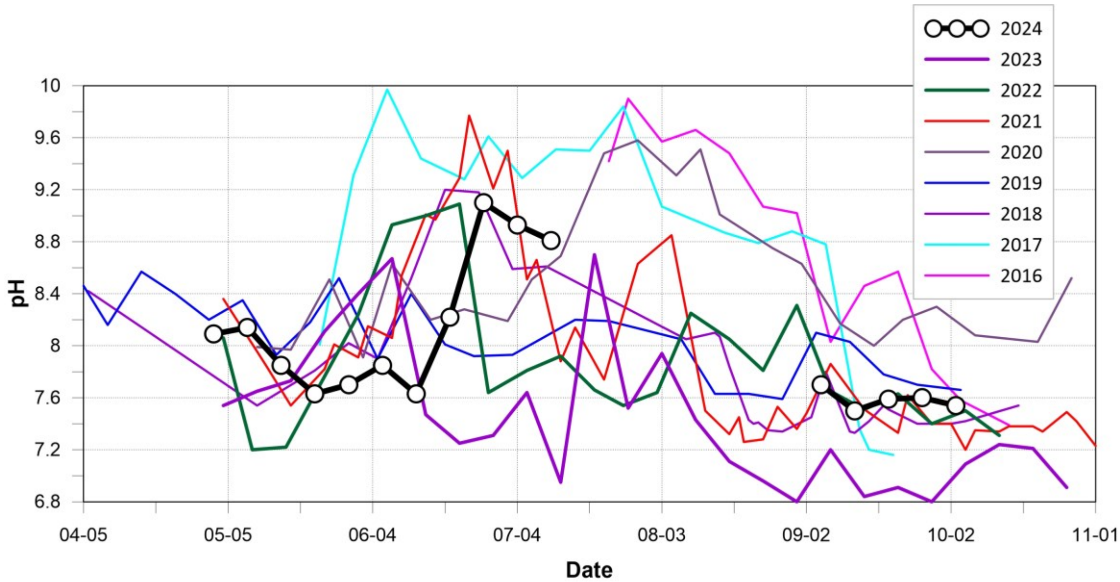

Figure 51. Interannual comparison of pH time series at Founders' Wharf.

6.3 Secchi Depth

The Secchi depth data for the last nine years are plotted in Figure 52. Water clarity this year improved by 0.7 m between the early May and July blooms. The best measured condition at Swan Lake occurs in the early part of the sampling period with a year-to-year variability of about one meter. This data spread tapers to about 0.5 m in the 0.5 to 1 m range in September and October with a trend towards improved clarity at the end of the sampling period.

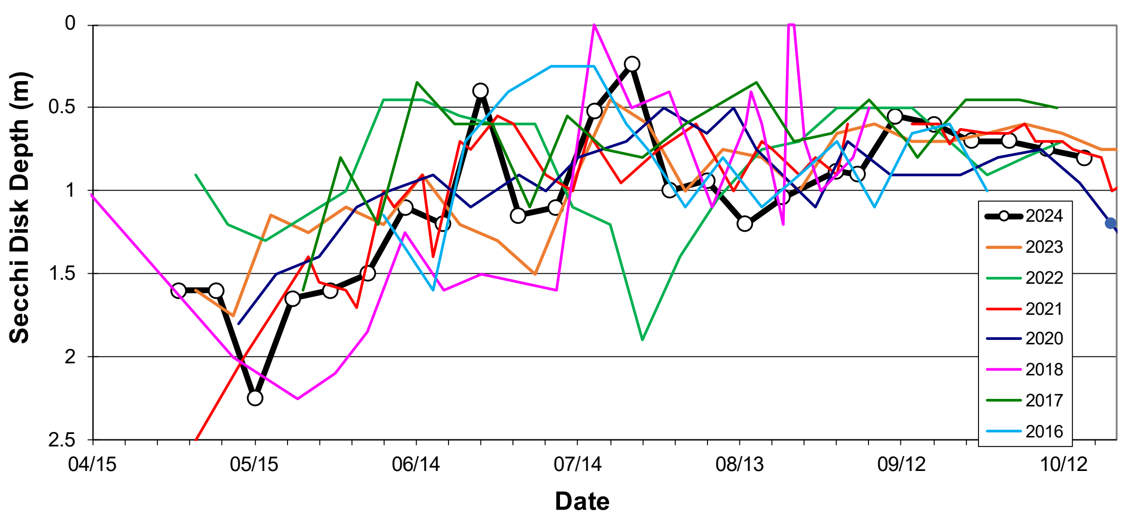

Figure 52. Interannual comparison of Secchi depth time series at Founders' Wharf.

6.4 Nutrients

Nutrients were plotted for the last nine years to compare annual variations of these parameters. For total phosphorus (Figure 53), the highest seasonal peak of surface waters was found at the boardwalk on May 8th with a value of 0.36 mg/l. The peak value for the Founders' Wharf site was 0.29 mg/l on May 22nd. At the benthic layer, the TP values were highly concentrated with peak values of 2.28 mg/l at the Founders' Wharf on May 26th and 1.56 mg/l at the boardwalk site on July 3rd.

Generally, in the months of July and early August, the phosphorus values drop to seasonal lows. This is typically followed by a relatively rapid recovery in mid-September.

The cycling of phosphorus appears to be a repeatable pattern at Swan Lake with relatively high levels in the spring followed by a drop in August and then a return to spring values in the late summer/early fall. Historical phosphorus values have been placed on this plot as well, indicating phosphorus concentrations of the 1970s and 1980s (Harnadek, 1987). It's important to note that these are surface water concentrations and do not necessarily reflect the deeper water legacy concentrations that influence TP internal loading in the lake. Unfortunately, none of the historical data were available during the late June to mid-September period, a period where phosphorus concentrations dip due to active algal blooms.

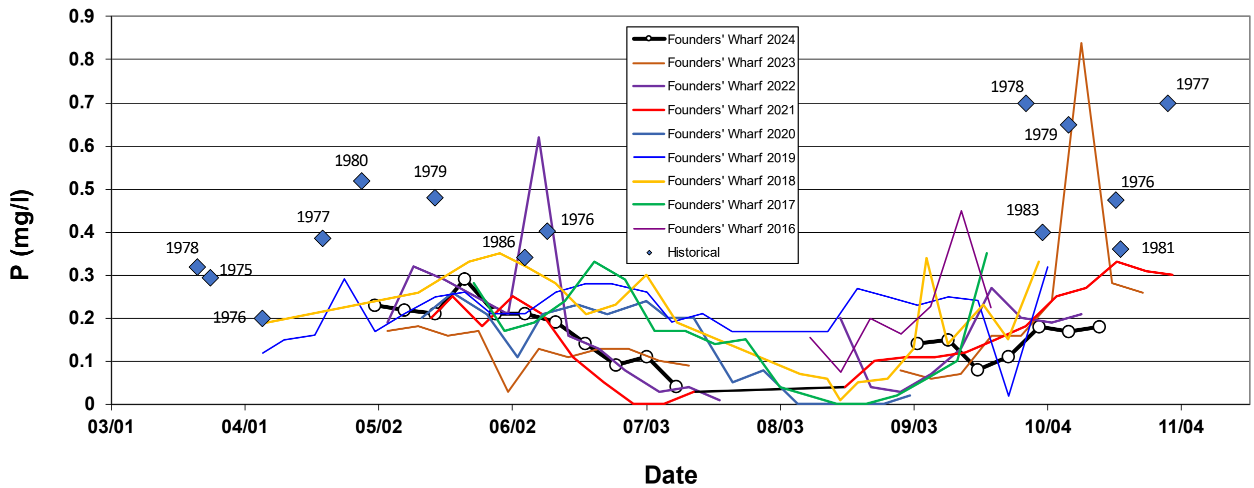

Figure 53. Interannual comparison of Founders' Wharf phosphorus concentrations.

Figure 54 displays contour maps of the last five years of phosphorus over the sample seasons spanning 2020 to 2024.

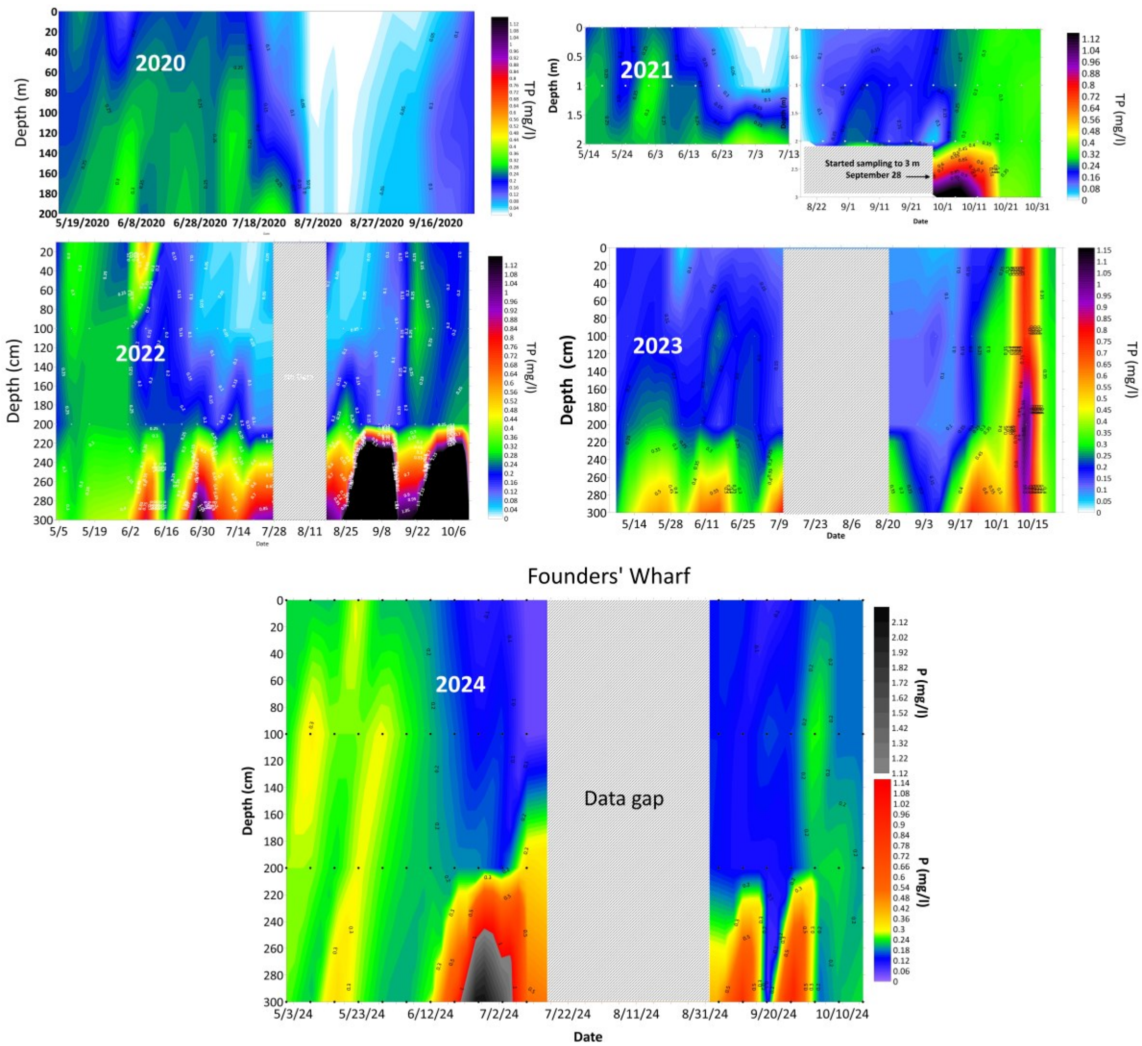

Figure 54. Comparison of phosphorus contour maps of the years 2020 to 2024.

Figure 55 shows the Blenkinsop Creek phosphorus values over the sample seasons. This creek continues to contribute to the high phosphorus load going into the lake well above the defined threshold of eutrophic in terms of trophic state classification. Fortunately, the discharge of this creek tapers to very low flow conditions in the summer months reducing its TP impact on external TP loading.

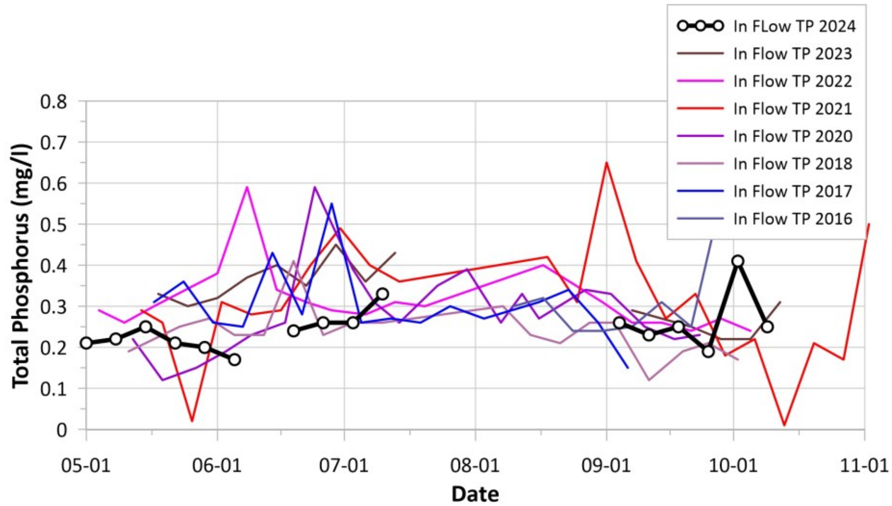

Figure 55. Interannual comparison of inflow creek phosphorus concentrations.

To put Swan Lake in the context of other lakes of the area, Figure 56 shows the total phosphorus concentrations at Elk Lake over a 35 year period. Note the axis is in micrograms per liter. The values displayed here at their highest point are about six to seven times less than those measured at Swan Lake.

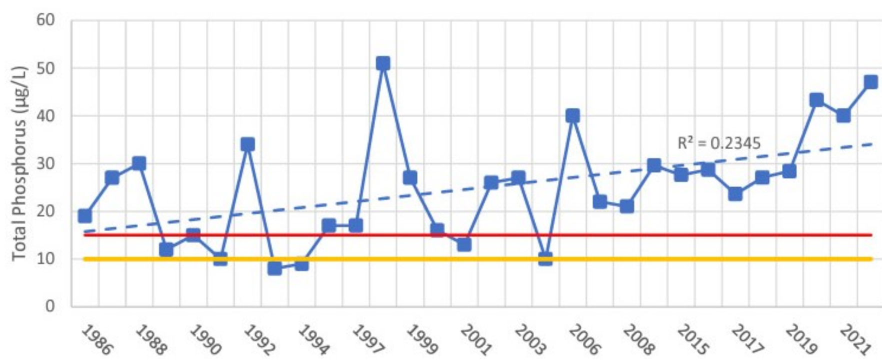

Figure 56. Total phosphorus concentrations measured at Elk Lake (Nielsen, 2023).

Nitrogen concentrations were plotted for the last nine years (Figure 57). Of note this year were the extremely high nitrogen concentrations that were recorded in May and June. These values dropped by a factor of eight by September followed by a brief increase in concentration to the end of the sampling period.

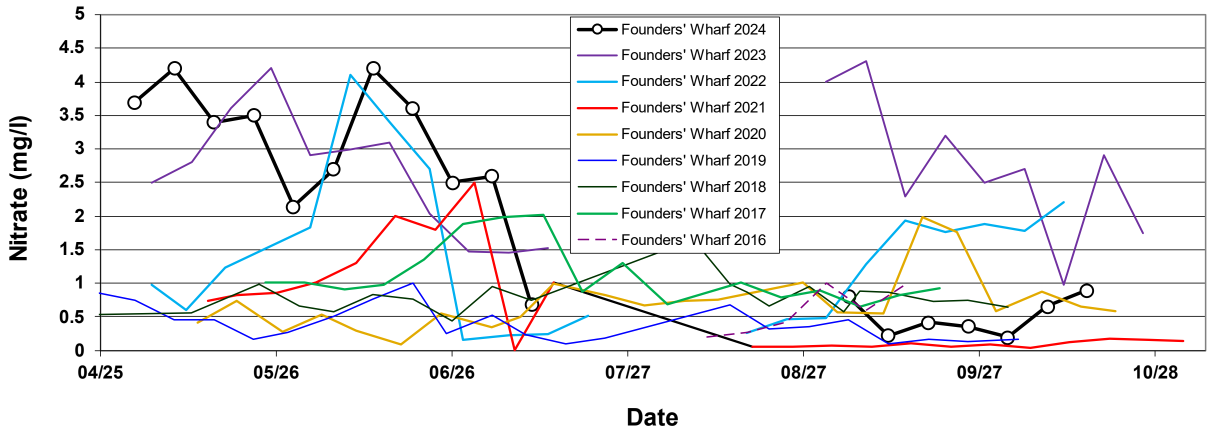

Figure 57. Interannual comparison of nitrogen.

6.5 Water Temperatures

Figure 58 displays both the surface and bottom water temperatures for the last nine years at the Founders' Wharf site. The 2021 heat dome saw lake temperatures rise to nearly 30°C and still stands out as an anomaly. Note the relatively cool spring of this year's data. The scatter between curves in the spring is relatively high when compared to the near uniform collapse of the curves in the fall. Note the a-symmetrical shape of the curves where water temperatures rise over a longer period of time than the cooling period of the fall where mixing due to fall storms accelerates the release of heat from the lake.

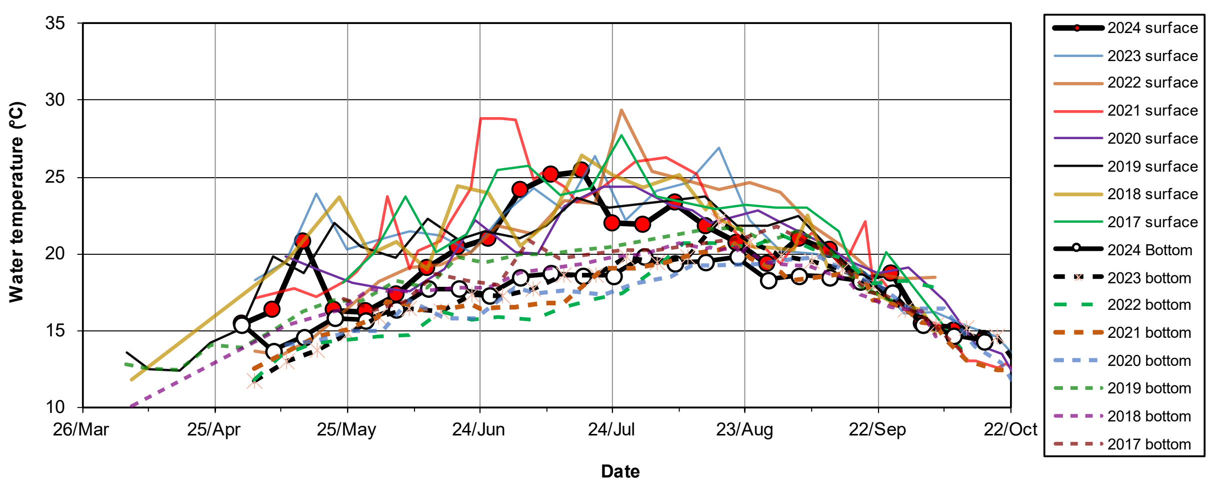

Figure 58. Surface and bottom temperatures for 2017–2023 (Founders' Wharf).

7.0 Lab Samples

Figure 59. Water sample taken from west bay September 11 to test for cyanotoxins.

On September 11, the west bay was completely covered by thick algal mats (Figure 59). There were areas that had surface scums potentially containing toxins. A water sample was taken from this area and brought to MB Laboratories in Sidney. The lab analysis of this sample is summarized in table 3.

Table 3 Laboratory analysis of water sample taken September 11.

Rob Bowen

13Sep24 2:09p
Source: Lake
Type of Sample: water
No of Samples: 1

Arrival Temp: 23.0C
PD B1188 1309K

W182864

Sample: Agal Bloom 11Sep24 2:00p

Compound		Sample	units	So	Blank	% Recovery REF STD
Microcystin-LR	MC-LR	ND	ug/L	0.002	ND	112
Microcystin-YR	MC-YR	ND	ug/L	0.002	ND	84
Microcystin-RR	MC-RR	ND	ug/L	0.002	ND	100
Microcystin-LA	MC-LA	ND	ug/L	0.003	ND	94
Microcystin-LF	MC-LF	ND	ug/L	0.002	ND	101
Microcystin-LW	MC-LW	ND	ug/L	0.006	ND	88
Microcystin-HtyR	MC-HtyR**	ND	ug/L	0.003	ND	84
Microcystin-Total	T.MC *	ND	ug/L			
Anatoxin A	ANA-A	ND	ug/L	0.002	ND	98
Nodularin	NOD	0.057	ug/L	0.010	ND	102
Cylindrospermopsin	CYLINR	ND	ug/L	0.010	ND	91
Domoic Acid	DA	ND	ug/L	0.010	ND	113

* sum of microcystins in scan
**desmethylated microcystin HtyR Reference MC-YR
STD = analytical reference standard

MC = Microcystin
ND = none detected

Method Ref: MBL-S05-LC/MS/MS Algae Toxins rev 5-23Jun23; EPA Method 544. EPA/600/R-14/474
Sevasti-Kiriaki A et al., Feb 2017 J. Haz Materials 323(A) 56-66; PICES 2021 Session 57 27Oct21

Drinking Water Limit: 1.5ug/L Can DW Guidelines 2024
1.6ug/L Microcystin (children-Adults) & 3 ug/L Cylindrospermopsin US EPA Jul24
Recreation Limit: 8.0ug/L Microcystin & 15 ug/L Cylindrospermopsin US EPA Jul24

R. Bilodeau
Analytical Chemist

H. Hartmann
Sr.Analytical Chemist

MB LABORATORIES LTD
PO Box 2103, Sidney BC V8L 3S6 T:250 656-1334 E: info@mblabs.com W: mblabs.com

Rob Bowen

13Sep24 2:05p
Lake
water
1

W182864

Arrival temp.: 23.0C
PD B1188 1309K

ALGAE

Sample: Swan Lake Algal Bloom 11Sep24 2:00p

RISK ASSESSMENT:

Test Result	Sample Value Cells/100cc	Risk Criteria	Yes	No	Risk Level
Total Algae+Protozoa Count	514000	are there >100000 cells/100c	1	0	1
Cyanophyte or HAB Dominate	no	total>10,000/100cc OR count > 50% total cells	2	1	1
Bio Diversity	16	# genera ≥ 5	-1	1	-1
					TOTAL: 1
Risk: 4 = high; 2 = moderate; 0-1 = low		RISK LEVEL:	LOW		

W. Riggs
Sr. Microbiologist/Phycologist

The lab found no microcystins, a species of concern in the region, in their analysis. This cyanotoxin had been observed in previous years through routine microscope imaging. There was only one potential toxic species detected in this year's sample. A small concentration of Nodularin was detected at very low levels, well below the acceptable drinking water threshold of 1.5 micrograms/l (Guidelines for Canadian Recreational Water Quality Cyanobacteria and Their Toxins, 2022). MB Labs has been developing an Algal Bloom risk assessment index. Based on their markers and the sample provided, Swan Lake presents as low risk of toxic blooms. There is always the potential, however, with the abundance of cyanobacteria in the system for localized flare-ups.

Water samples taken throughout the study period were examined under the microscope revealing the key algal species responsible for photosynthesis as well as the zooplankton species that play key roles in the food web at Swan Lake. Although this work is not reported here, the following link refers to a collection of organisms found in Swan Lake over the last five years.

8.0 Summary and Conclusions

This is the ninth consecutive year of a consistent sampling program measuring some of the major water quality indicators. Each year, the lake has distinct patterns that are triggered by temperature, sunlight, nutrients and biological processes. With variations in weather patterns, lake responses differ from year to year with the succession of the biological constituents constantly adjusting and competing to optimize their unique position in the ecosystem. These changing weather patterns make it difficult to extract trends in the data as the physical, biological and chemical attributes all respond in concert to these variations. For instance, a few years ago in 2021 we saw the extreme heat dome and several atmospheric rivers. Last year we saw long periods of drought. In previous years thick smoke has had a detrimental effect on DO during the late summer when the lake is at its lowest point of resilience. Despite these significant variations, Figure 49 describes what appears to be common features to the seasonal patterns of DO concentrations.

In summary, Figure 60 shows many key parameters considered in this report lined up on the same axis.

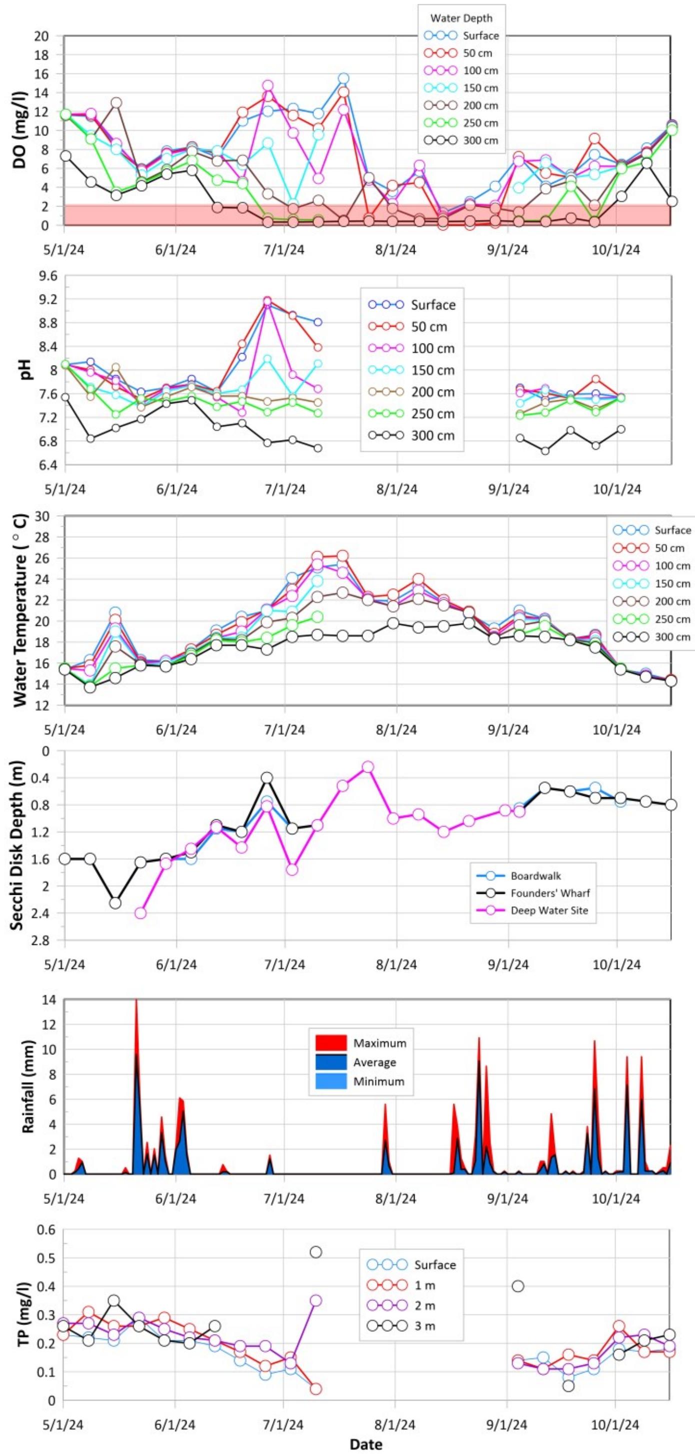

Figure 60. Summary of some of the main characteristics of the 2024 sample season.

Each year water quality measurements are continuing to contribute to a greater understanding of the processes at work at Swan Lake. The benefits of a consistent monitoring program are numerous.

- Monitoring provides a method to document physical, chemical and biological characteristics of the lake.
- Monitoring provides data for a science-based approach to possible interventions.
- Lake studies give insights into complex interrelationships such as DO and nutrients.
- Monitoring provides useful educational opportunities through interpretive programs or citizen science involvement.
- Monitoring gives a powerful explanatory tool to explain lake events such as algal blooms and fish kills.

During the sampling site visits, numerous visitors asked a wide range of questions pertaining to the lake. This provided opportunities to describe lake processes and the instruments that are used to collect data. There were many very satisfying exchanges with people of all ages. This was also a time where people spoke of their knowledge of birds, dragonflies and the local history of the lake and surrounding area. On numerous occasions people commented that they were glad that this work is being done and valued Swan Lake as a special place to protect.

During this past year, level 1 data collection was carried out for 12 consecutive weeks complying with the BCLSS guidelines measuring Secchi disk depth, DO and temperature profiles. Sampling was carried out at the deepest part of the lake down to a depth of 6 m.

As this report is essentially a data summary, the collection of data can be used to further examine the following issues:

- the solar variations and photosynthetic DO production,
- nutrient cycling and lake restoring forces,
- the effect of rain on the system,
- the impact of wind and its direction, and
- the influence of water temperature.

9.0 Recommendations

The following recommendations are listed to improve the sampling program.

(1) Consider extracting phosphorus during periods where the benthic layer concentrates phosphorus. This method of hypolimnetic withdrawal syphons phosphorus from the benthic layer (Silvonen et. al., 2022) during times where seasonally high phosphorus levels concentrate in a narrow vertical band near the bottom of the lake.

(2) Consider ways to quantify cyanobacteria populations to better define thresholds of bloom states.

(3) Conduct a topographic survey of the wetland area so that the estimates of flood volumes can be better constrained.

(4) Continue to develop a catalogue of surface algae, macrophytes and water column zooplankton and phytoplankton.
(5) Sample bottom sediments and image, using a microscope, the bottom decomposers.
(6) Add to the photometry testing the element iron as this is a key element that interacts with phosphorus in the benthic zone.
(7) Create educational posters or an interactive multimedia on lake processes to be displayed in the Nature House. With the now extensive collection of water quality data, microscope images and insights about the various processes at work, there is opportunity to create interesting static or dynamic education content.
(8) Place a lake water level staff to enable visual checks of water level changes.
(9) Monitor surface algae extent using a time-lapse trail camera mounted to a pole overlooking the lake. This would provide another metric and be expressed as daily percentage coverage.
(10) Re-configure the LG Sonic so that the transducer is in deeper water out of the influence of macrophyte interference
(11) In next year's data collection, create a webpage portal that posts the weekly data so that viewers can see near real time plots of the current conditions of the lake.
(12) Recommend scheduling profiling collection during the summer months to avoid data gaps.
(13) Recommend that all sensitive water quality monitoring equipment be kept indoors to prevent condensation damage to electronics.

10.0 Acknowledgements

The 2024 Swan Lake Water quality monitoring program was funded by Swan Lake and Christmas Hill Nature Sanctuary under the direction of Dr. Cara Gibson.

The author would like to acknowledge Deanie Harding, Kristen Banasch, Ben Milligan and Dylan Simpson of Swan Lake who completed the Level 1 water quality study. Some of this data was used in this report to span the data gap of July 17–August 31.

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For interannual comparisons, data were used that were acquired during the previous eight years of lake study including Bowen, 2016, 2017, 2018, 2019, 2020, 2021, 2022 and 2023 contract reports submitted to Swan Lake Christmas Hill Nature Sanctuary.