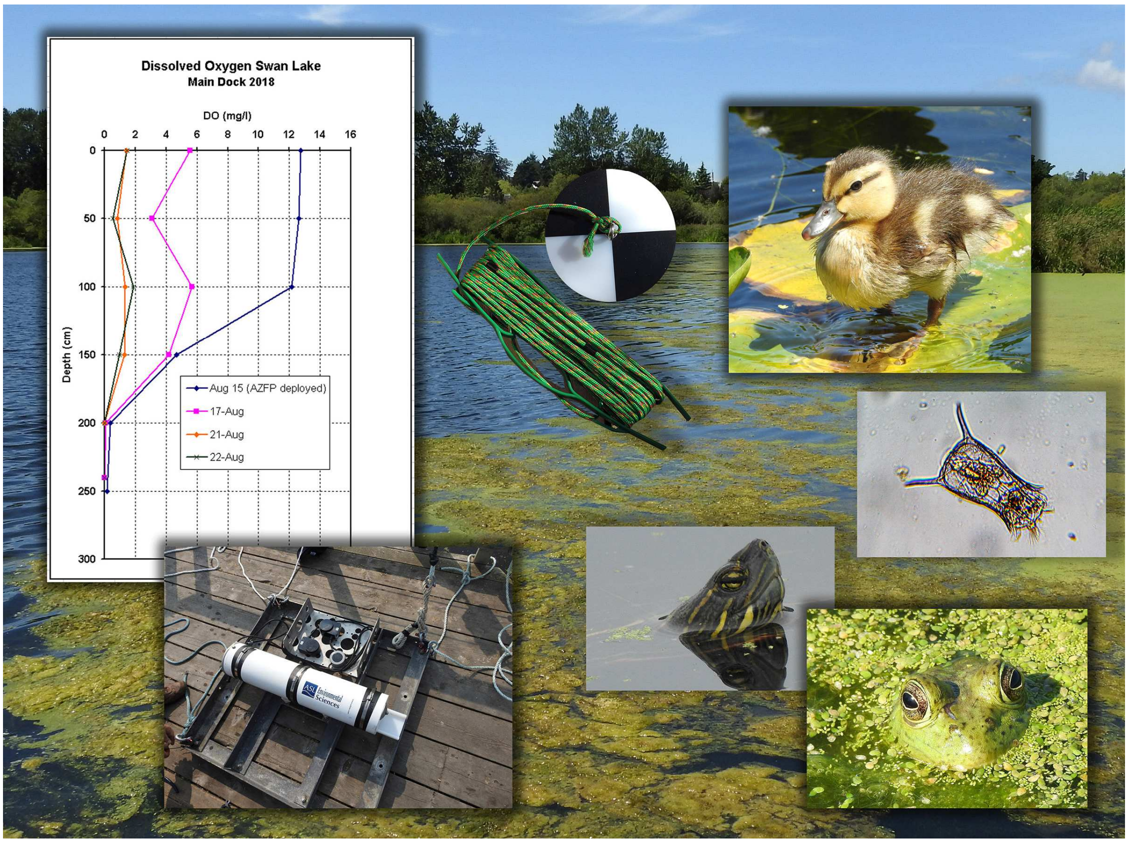
Swan Lake Water Quality Monitoring
April–October 2018



Submitted to
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Executive Summary

In this third consecutive year of water quality data collection for Swan Lake, water quality parameters are reported in the form of summary time series and monthly profile plots. Data collected from the April to October 2018 season are compared to previous years and some discussion is offered for patterns of seasonal variability and changes. Data from August and September show a prolonged hypoxic event not previously observed in the eight years of data collection that span 31 years (1977–2018). A novel approach is tested which utilizes an ASL Environmental Sciences' Acoustic Zooplankton Fish Profiler (AZFP) to measure acoustic backscatter within the water column of cyanobacteria, key organisms that influence dissolved oxygen concentrations at Swan Lake. Upon examination of this backscatter, diurnal patterns are observed in both vertical migration and target strength of the cyanobacteria *Aphanizomenon flos-aquae*. As hypoxia events appear to be an annual occurrence, a new aeration system was installed to mitigate the dissolved oxygen collapse of late summer and provide refuge areas for fish. It is hoped that these refuge areas will preserve and promote biodiversity.

Funding for this project was provided by the Royal Bank of Canada.

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1.0 Introduction

This is the third 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 biological systems that govern the seasonal changes at Swan Lake. In this year we saw a prolonged interval of wildfire smoke, tracked the effects of the phosphorous cycle and its importance to the biological communities, and added a test aeration system to provide refuge areas for fish in times of depleted dissolved oxygen hypoxia. Swan Lake introduced the Junior Naturalist Program which had a water quality component where students were given hands-on experience with water quality sampling techniques including water column profiling to measure dissolved oxygen concentrations, pH, temperature and oxygen reduction potential. Students collected data which were plotted for week to week comparisons. An experimental acoustic instrument was deployed which measured acoustic backscatter of algae, zooplankton and fish in the water column. The acoustic zooplankton fish profiler (AZFP) developed by ASL Environmental Sciences in Saanich was deployed for a month and data were recorded at one second intervals from three different frequency transducers. This instrument was provided free of charge along with a dissolved oxygen logger and a fluorometer.

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 last year's report 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 supplies large varieties of protected habitat in the midst of an increasingly developed landscape. Additional values of this feature are far-reaching as it gives rest to migratory birds, provides water filtration, 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 poor 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. 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 and, more recently, April until the beginning of October 2018.

In this report, data is presented which summarize measured water properties including dissolved oxygen, pH, temperature, nitrates and phosphates for the 2018 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 time series comparisons with the 2016 and 2017 sampling season.

2.0 Swan Lake Watershed

The general details about 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)

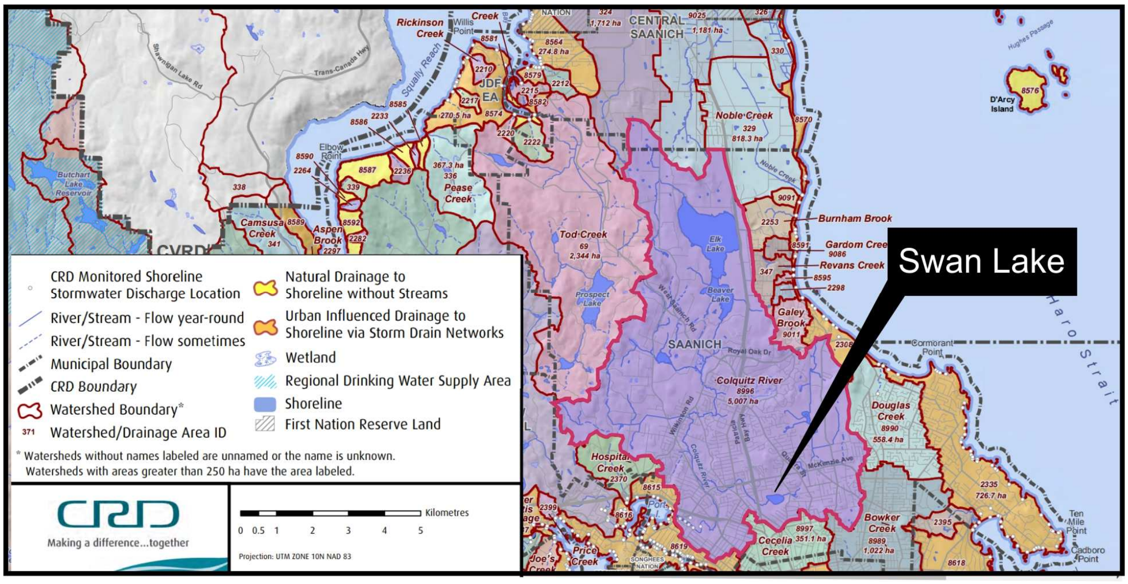

Figure 1. Swan Lake watershed boundary (Source CRD watershed maps).
(https://www.crd.bc.ca/docs/default-source/es-watersheds-pdf/regional-watershed-maps/watershedscrdoverview400dpired.pdf?sfvrsn=5d837aca_2)

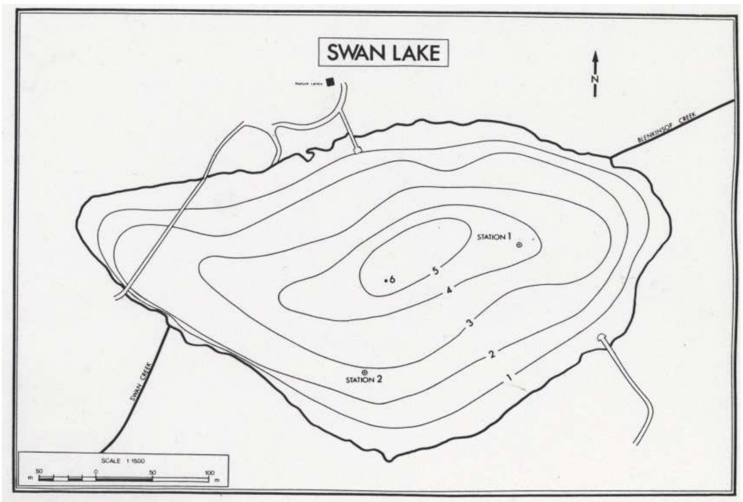

Figure 2. Swan Lake bathymetry (Townsend 2004).

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, several sites were selected and the positions of these sites are indicated in Figure 3. These sites were accessible by foot and offered a stable platform to work from. Each site will briefly be described and the selection rationale will be discussed.

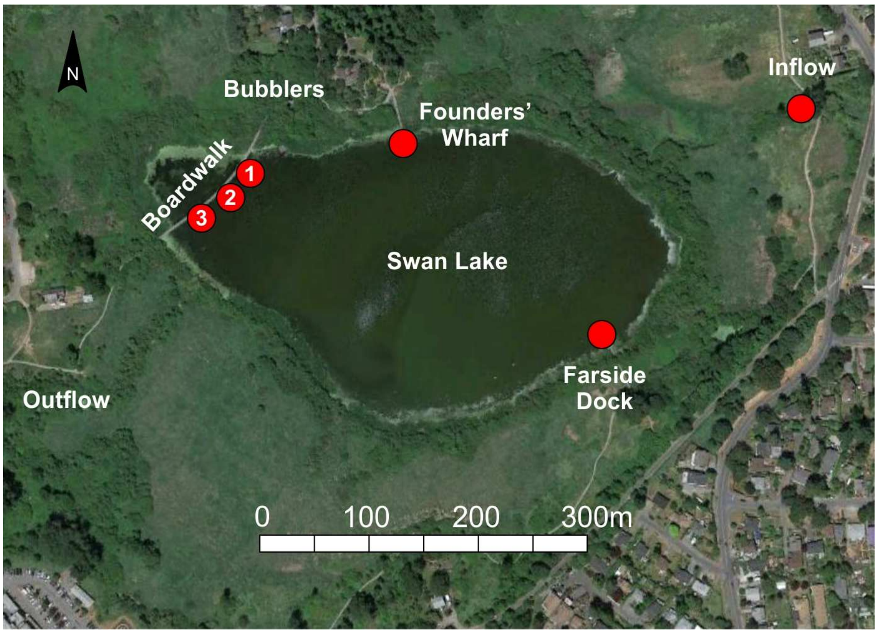

Figure 3. Water quality sample site.

Sampling was carried out around the lake in a counter-clockwise manner with the first site on the lake located at the first boardwalk bench (bench #1). This site was relatively shallow and was the first of three in a cross-sectional transect of the western segment of the lake. This site was close to the shoreline margin and often covered in duckweed or surface algae mats. Moving along the boardwalk, the next site was located at bench #2 in deeper water. This site was away from the north and south margins of the lake perimeter and was often clear of surface algae. Bench #3 was located relatively close to Swan Creek, the outflow of Swan Lake. At this site, significant accumulations of detritus were observed on the lake bottom from GoPro video and generally algae mats or thick duckweed covered the surface. By mid June, dismantling of the old wooden boardwalk had begun and access to the boardwalk sampling sites began to taper off with the last sample point taken at bench #3 on June 26. This made way for the new boardwalk installation which was completed and opened to the public on October 5, 2018.

The southeastern part of the lake was sampled from the south-side wharf (farside dock), a relatively shallow area with a large water lily population and often calm in comparison to other parts of the lake. From here water samples were taken and water properties measured at Blenkinsop Creek, a potential input of urban and agricultural runoff carrying nutrients to Swan Lake. The final sample site was located at the Founders' Wharf, a mid-point between the inflow and outflow creeks and one of the deepest sites sampled on the lake. Elapsed time to complete the sampling typically was about four and a half hours.

4.0 Methodology

Profiles were taken at each lake site at the surface, at 50 cm intervals and at the bottom. These profiles were taken with two YSI handheld meters and associated probes. The “ODO Profession” measured dissolved oxygen (DO) in percent saturation and mg/l of oxygen as well as water temperature. The YSI “ProfessionPlus” was used to measure pH at the same intervals. In addition, a secchi disk was used to measure turbidity and a GoPro 4 Silver was used to acquire underwater video for visual inspection. Daily barometric and 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. 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.

Video recordings were made by lowering a two-metre 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, bottom plant life, bottom hardness and the presence of detritus.

Water samples were typically taken at the bench #2, the inflow creek and the Founders’ Wharf as well as a few spot samples taken from the boardwalk and the farside dock. These samples were analyzed for nutrients using the YSI “9500 photometer.” Both nitrate and phosphorous were tested by following strict procedures using reagents and timed mixing intervals. These values were recorded for temporal comparisons.

5.0 Data Summary

Temperature

Climate data was collected from the weather station located on the roof of the nature house. This weather station was part of a school based weather station network (http://www.victoriaweather.ca/station.php?id=134). Daily minimum, maximum and average temperatures are plotted in Figure 4.

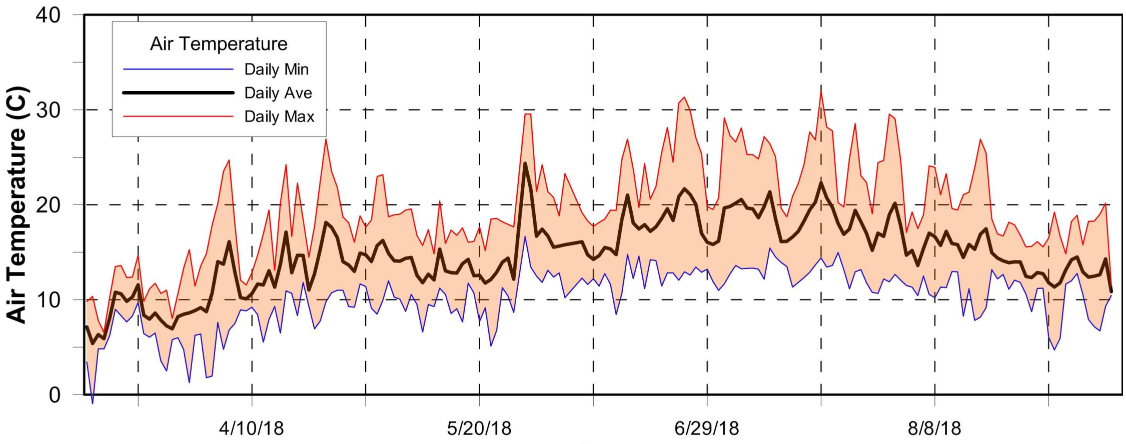

Figure 4. Air temperature at Swan Lake.

Air temperatures were compared to water temperature profiles taken throughout the sampling season at the Founders' Wharf. Note the water temperatures even at depth were for the most part warmer than the average daily temperatures (Figure 5).

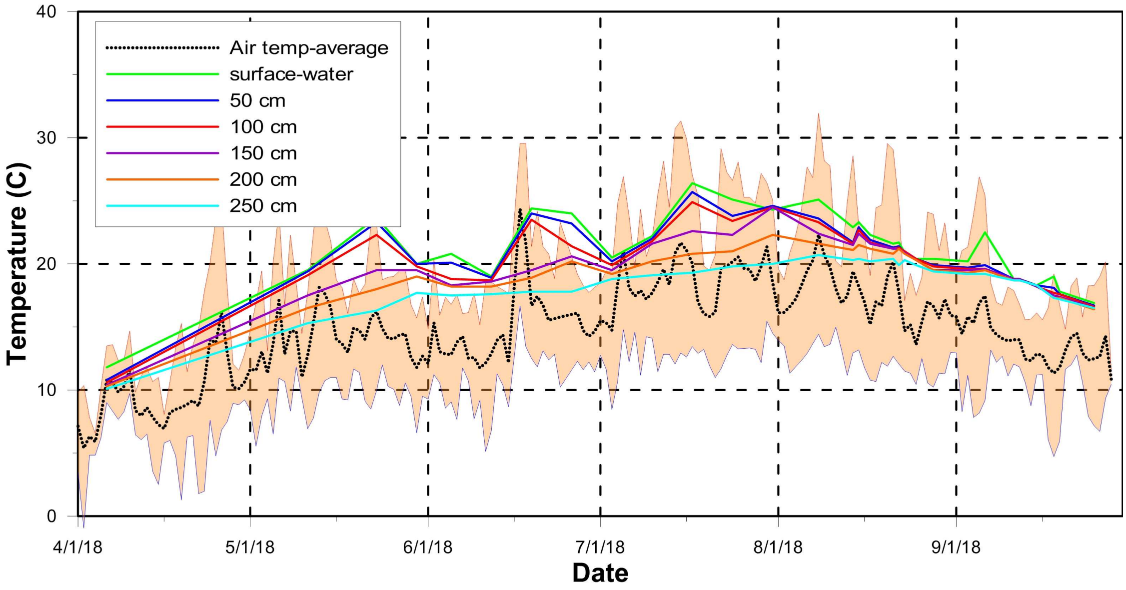

Figure 5. Water temperature at depth compared to air temperature.

Solar Energy

As cyanobacteria and aquatic plants are dependent on solar input, the solar insolation—which is a measure of solar energy (Figure 6)—was plotted for the entire monitoring program.

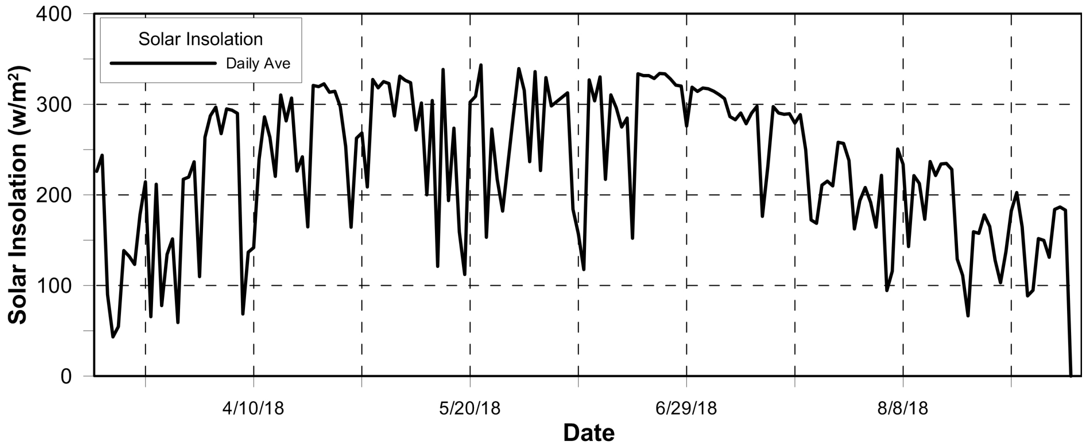

Figure 6. Solar insolation at Swan Lake.

Winds

Winds at Swan Lake play an important role in the distribution of floating algae and mechanical mixing. They contribute to heat fluxes and introduce oxygen to the upper water column through wave action. Wind speed is plotted in Figure 7 and binned wind speed and direction is plotted in Figure 8. Note that the winds predominantly come from the Southwest.

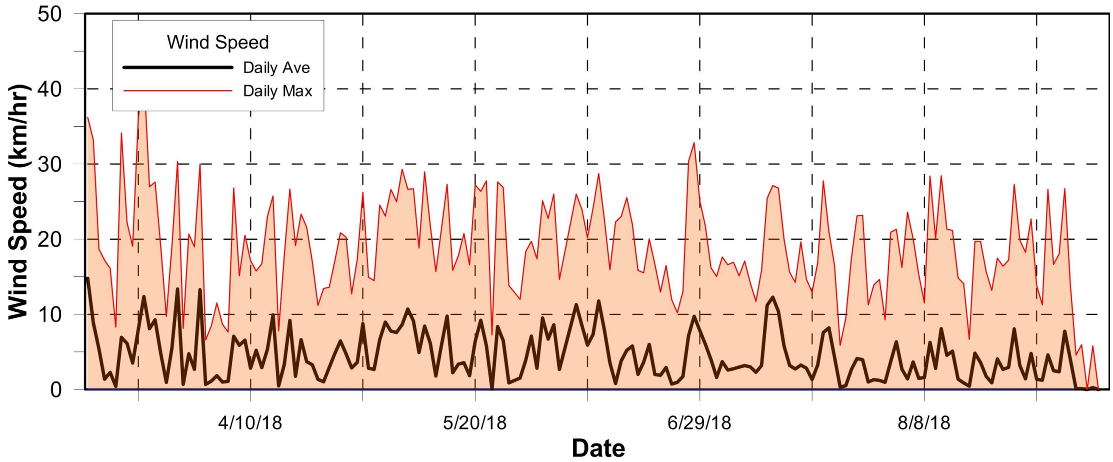

Figure 7. Wind speed.

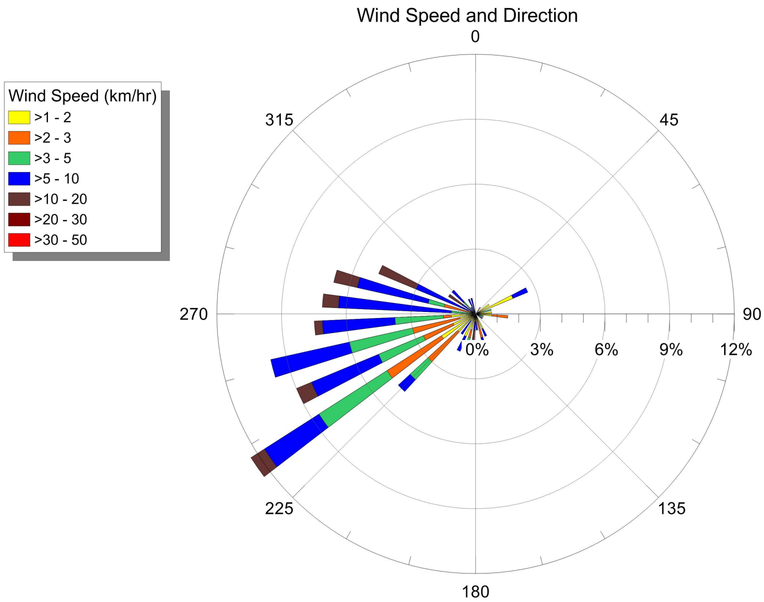

Figure 8. Wind rose showing wind direction.

Barometric Pressure

Barometric pressure is used in the calculation of dissolved oxygen percent saturation. The YSI dissolved oxygen probe has an internal barometric pressure sensor and values obtained from the YSI unit were occasionally compared to the atmospheric barometric pressure measured at the Swan Lake weather station (Figure 9). These comparisons were in all cases equal.

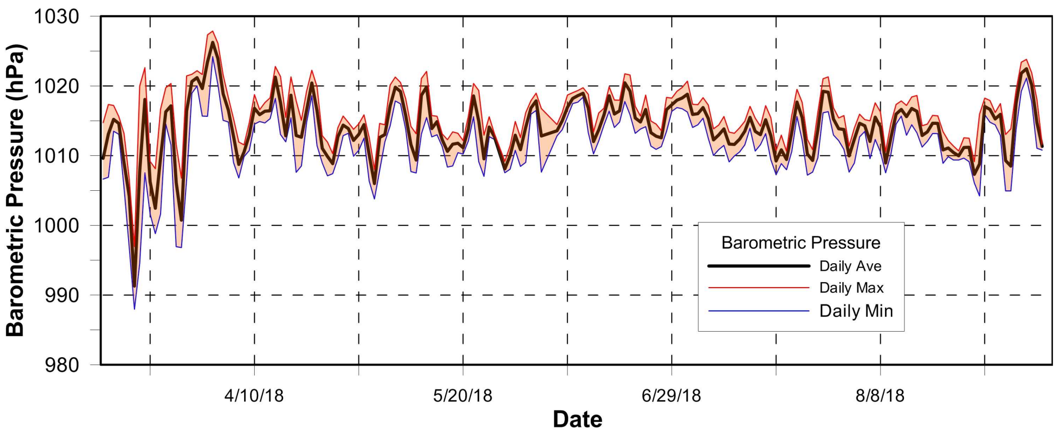

Figure 9. Barometric pressure.

Wildfire Smoke

Both in 2017 and in this year's monitoring, smoke became a significant climatic modifier impeding the amount of sunlight penetration into the lake. Starting in the first week of August, smoke appeared with varying intensity and lasted for about a month. Figure 10 shows examples of the smoke extent over Vancouver Island during this time.

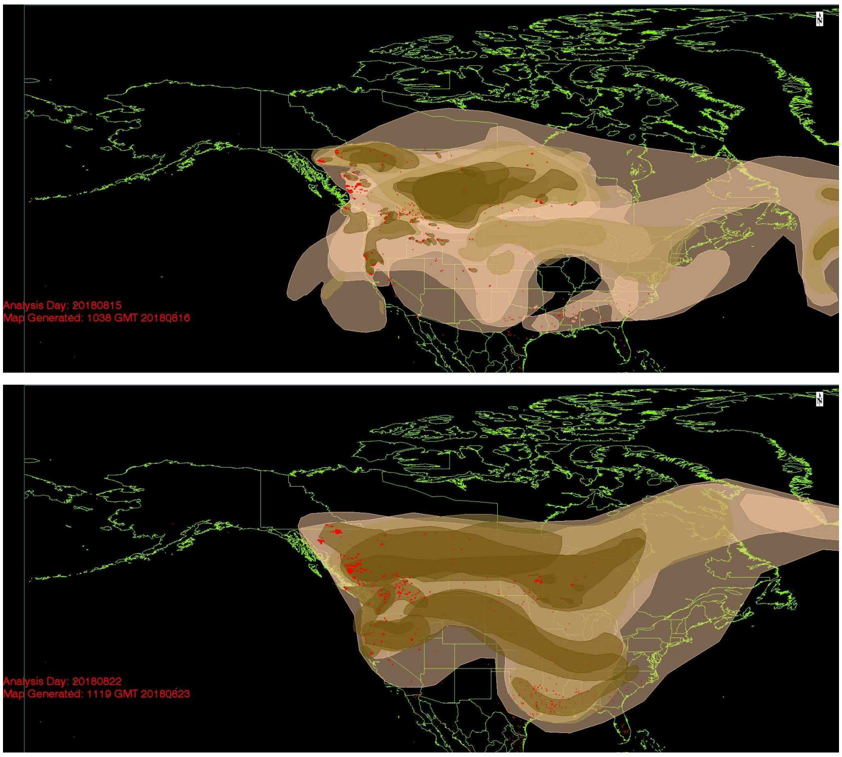

Figure 10. Extent of wildfire smoke showing examples of extremes.

Air quality data from the Victoria Topaz monitoring station were examined to quantify the intensity of smoke particulates. Particulate matter ≤ 2.5 microns (PM 2.5) showed that the dense smoke of August 2018 had the highest recorded values in Victoria since the installation of the BC Ministry of Environment air quality monitoring stations in the early 1990s. Figure 11 shows the air quality index as well as the PM 2.5 for August 2018. Table 1 outlines the impact of the air quality health index (AQHI).

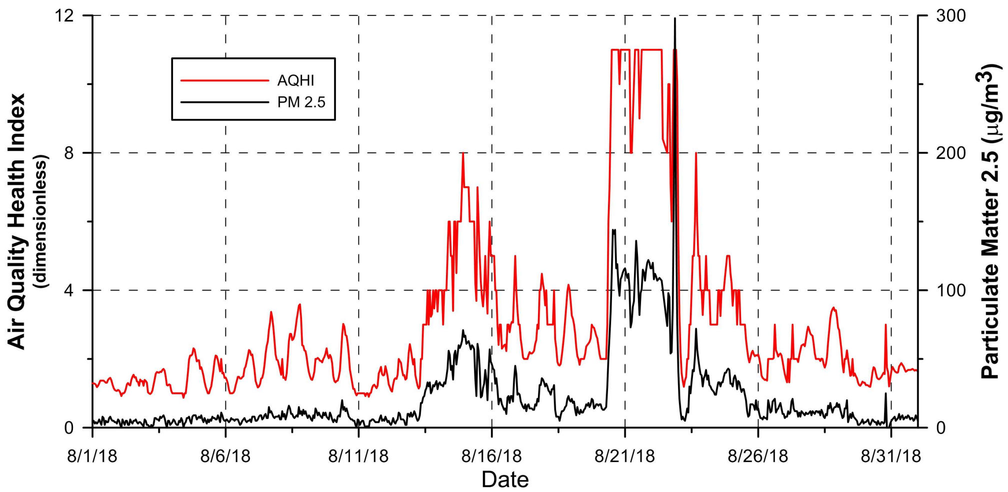

Figure 11. Air quality and smoke particulate concentrations.

Table 1. Air quality index with explanation.

Air Quality Health Index Categories and Health Messages

The AQHI uses a scale to show the health risk associated with the air pollution we breathe.

The following table provides the health messages for 'at risk' individuals and the general public for each of the AQHI Health Risk Categories.

Health Risk	AQHI Index	Health Messages	
		At Risk Population[1]	General Population
Low	1 - 3	**Enjoy** your usual outdoor activities.	**Ideal** air quality for outdoor activities.
Moderate (MOD)	4 - 6	**Consider reducing** or rescheduling strenuous activities outdoors if you are experiencing symptoms.	**No need to modify** your usual outdoor activities unless you experience symptoms such as coughing and throat irritation.
High	7 - 10	**Reduce** or reschedule strenuous activities outdoors. Children and the elderly should also take it easy.	**Consider reducing** or rescheduling strenuous activities outdoors if you experience symptoms such as coughing and throat irritation.
Very High	Above 10	**Avoid** strenuous activities outdoors. Children and the elderly should also avoid outdoor physical exertion.	**Reduce** or reschedule strenuous activities outdoors, especially if you experience symptoms such as coughing and throat irritation.

[1] People with heart or breathing problems are at greater risk. Follow your doctor's usual advice about exercising and managing your condition.

Source: Environment Canada

* If the AQHI index has increased to 7 (high health risk), it is usually because of high concentrations of smoke particles (PM2.5) in this community.

In 2017, it was noted that the lake's dissolved oxygen collapse that led to an extensive fish kill was preceded by thick smoke in early August and again in early September. Figure 12 shows the AQHI and PM 2.5 for both 2017 and 2018. Note that this year's PM 2.5 and AQHI values far exceeded last year's data with the highest ever recorded PM 2.5 of 298 mg/m^3 on August 22 at 21:00.

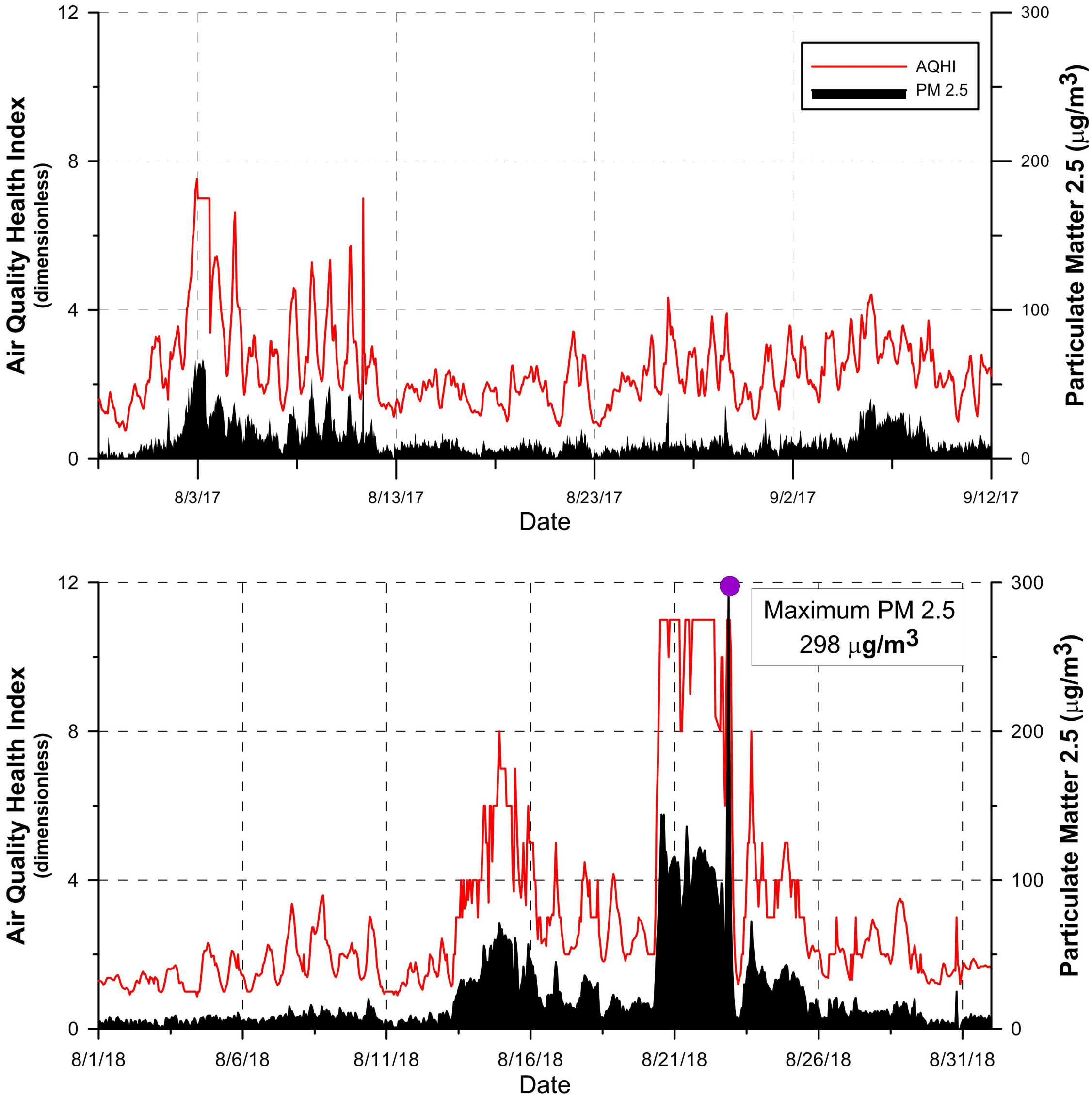

Figure 12. Air quality and PM 2.5 concentrations for 2017 (top) and 2018 (bottom).

Turbidity

The turbidity of the water was measured throughout the study period 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 invisible 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 13 shows the secchi disk depths recorded for this sample season.

It was noted throughout the summer months that there was an abundance of suspended filament-like algae (*Aphanizomenon flos-aquae*) distributed vertically within the water column. In mid-July, populations of this organism as well as surface algae, including duckweed, impeded light penetration significantly as can be seen by the secchi depth plot (Figure 13 (top)). Secchi depths from 2018, 2017 and 2016 were all plotted on Figure 13 (bottom).

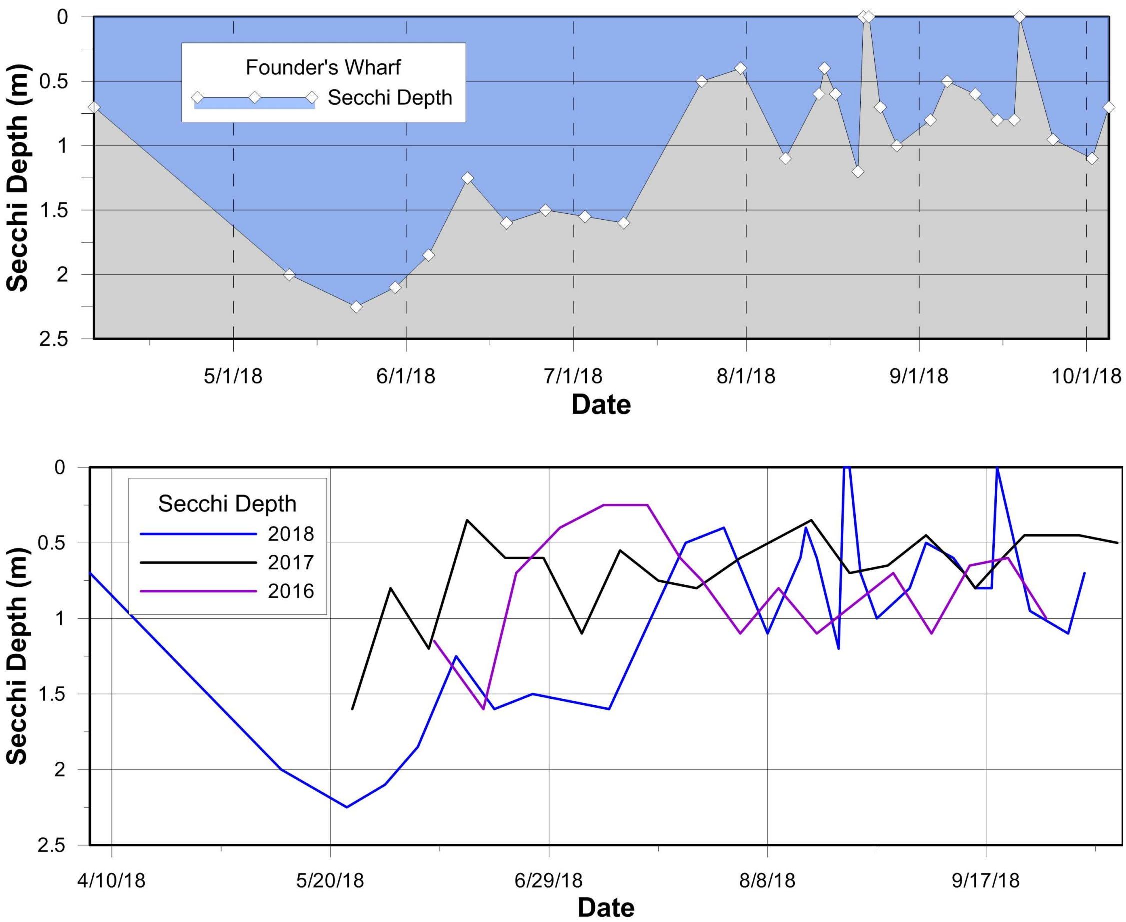

Figure 13. Secchi depth for 2018 (top) and comparison with previous years (bottom).

Water Colour

Surface water colour has long been used as a method to characterize water quality indicators such as chlorophyll, the green pigment found in cyanobateria, and coloured dissolved organic material (Novoa et al., 2014). Oceanographers and limnologists have used a standardized colour swatch called the Forel-Ule scale (Figure 14) in conjunction with a secchi disk to describe water colour. To determine the Forel-Ule value, the secchi disk was lowered into the water column until it was no longer visible. This depth was recorded as the secchi extinction depth. The disk was then raised until it became visible again and this depth was recorded as the eruption depth. The secchi depth is the average of these two values. The secchi disk was then brought up to half the secchi depth and the Forel-Ule scale was compared to the colour of the submerged secchi disk.

Both a physical print-out of the scale and an Android app called Citclops were used to determine the appropriate Forel-Ule value. The values of the scale represent a range of water types as described in the following paragraph by Wernand and Van Der Woerd 2010:

“These colours cover a large range of water types that are found in nature; oligotrophic waters appear indigo-blue and cover the Forel-Ule (FU) scale numbers 1 to 4, mainly due to the scattering and absorption of pure water. The colour of natural waters changes when more substances are present in the water, like algae, suspended (inorganic and organic) material and dissolved organic material. The colour range of mesotrophic water is approximately bluish green to greenish blue (FU5 to FU9), of eutrophic water greenish blue to yellowish green (FU10 to FU14) and hypereutrophic waters from yellowish green to greenish brown (FU15 to FU18). The last scale numbers (FU19 to FU21) brownish green to brown cover the colour of humic acid dominated waters.”

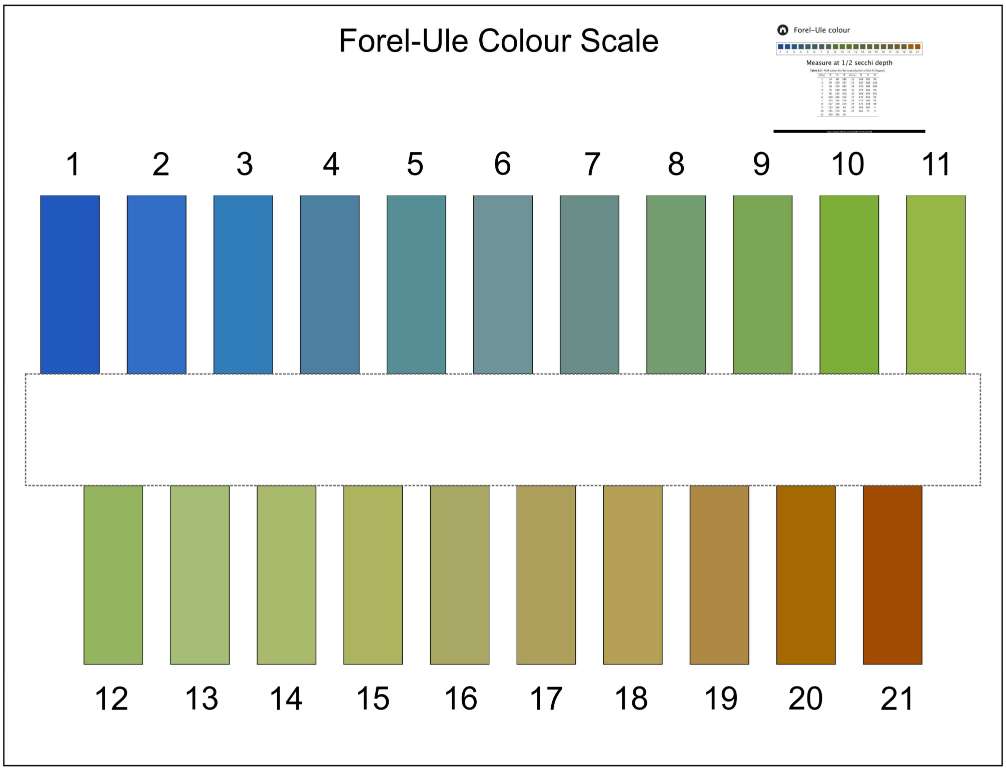

Figure 14. Forel Ule colour scale table.

The recording of the Forel-Ule values began at the beginning of June and the values are displayed in Figure 15. There were some field dates where no values were recorded due to 100% duckweed coverage.

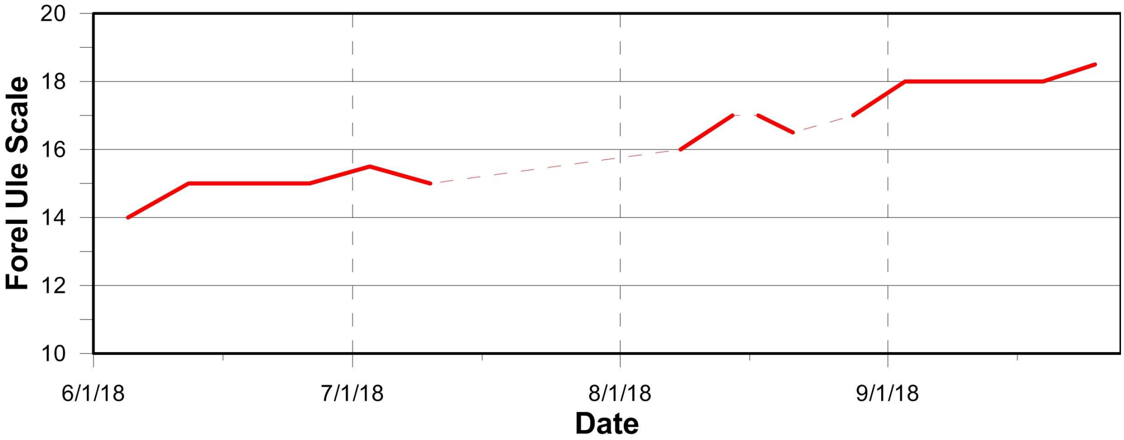

Figure 15. Seasonal Forel Ule colour values.

Dissolved Oxygen

Probably the single most important measurable parameter of the lake is the amount of dissolved oxygen (DO). This element promotes and sustains biological activities. Oxygen enters into the aquatic environment via two main pathways. Some atmospheric oxygen diffuses into the water at the air/water interface. This process can be accelerated through mechanical mixing such as wind and wave action, surface rain impacts or through turbulent flow such as water moving through creeks and rivers. The second pathway, which contributes to most of the dissolved oxygen at Swan Lake, is through plants and cyanobacteria. Dissolved oxygen levels are in a constant state of flux and vary daily based on production in the daylight and consumption during the night due to biological respiration. This creates a diurnal cycle of high levels during the day and relatively low levels at night. Oxygen levels respond to available nutrients and vary seasonally based on climatic influences and hydrological inputs (Ministry of Environment, Lands and Parks 1997).

During the summer months, the long days of bright sunlight, warm water temperatures and supply of nutrients present ideal conditions for macrophytes, algae and bacteria growth. This has both positive and negative impacts. The positive impact is the prolific production of oxygen through the process of photosynthesis. In this process, CO_2 combines with water nutrients and sunlight to produce glucose that feeds the plants. As a by-product of this reaction, oxygen is liberated and made available. The negative impacts of surface algal overgrowth are the blocking of sunlight to biota in the water column and to bottom plants as well as the potential die-off of biota should nutrients be consumed or if sunlight is obscured for a series of consecutive cloudy days. The bacteria employed in the decomposition of these large numbers of algae results in a significant depletion of oxygen, especially in the deeper portions of the water column. Should the oxygen level become anoxic throughout the water column, fish kills can occur and did occur September 2017 as well, to a lesser visible extent, September 2018.

The YSI ODO probe was used to measure profiles at each of the sample sites. All sites typically had oxygen gradients where values at the surface were typically high and values at the bottom were, for the most part, anoxic. During summer algae blooms, oxygen levels at the surface were often super-saturated. Figure 16 displays monthly DO profiles starting in April, where oxygen concentrations were high even at depth and ending in September where values were at or below 2 mg/l, the limit at which hypoxia is defined.

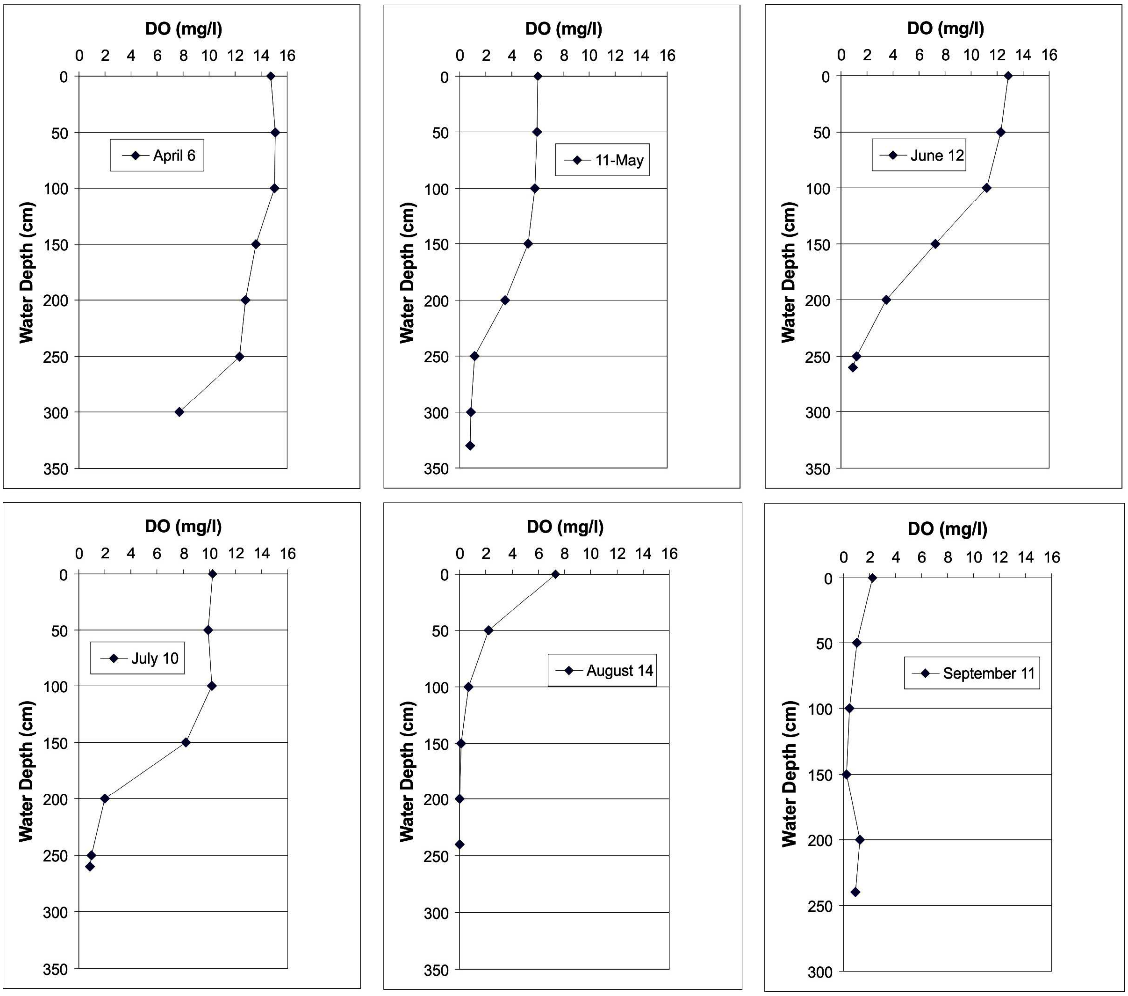

Figure 16. Monthly DO profiles.

Dissolved oxygen data were assembled to produce time series curves for each depth at the Founders' Wharf site. These curves are presented in Figure 17.

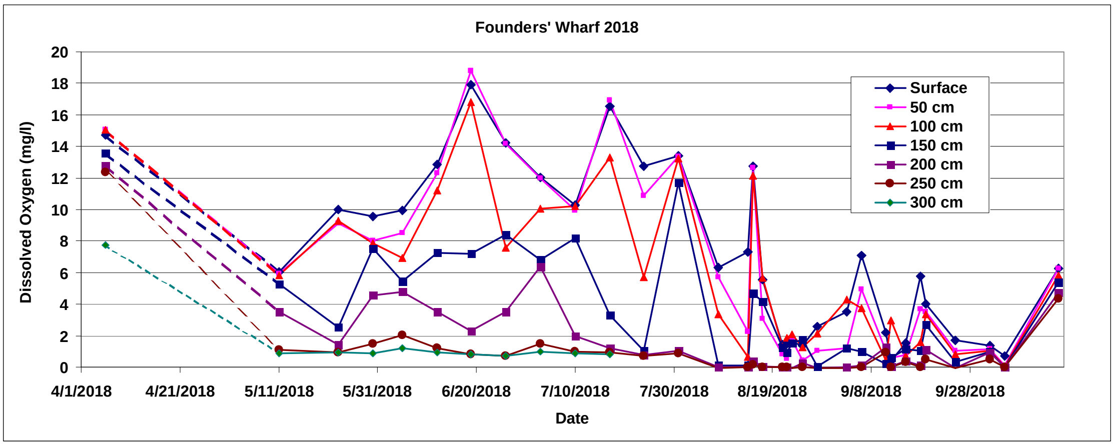

Figure 17. DO concentrations at depth for Founders' Wharf.

Similarly, DO profiles and time series curves were plotted for the farside dock data and are depicted in Figures 18 and 19.

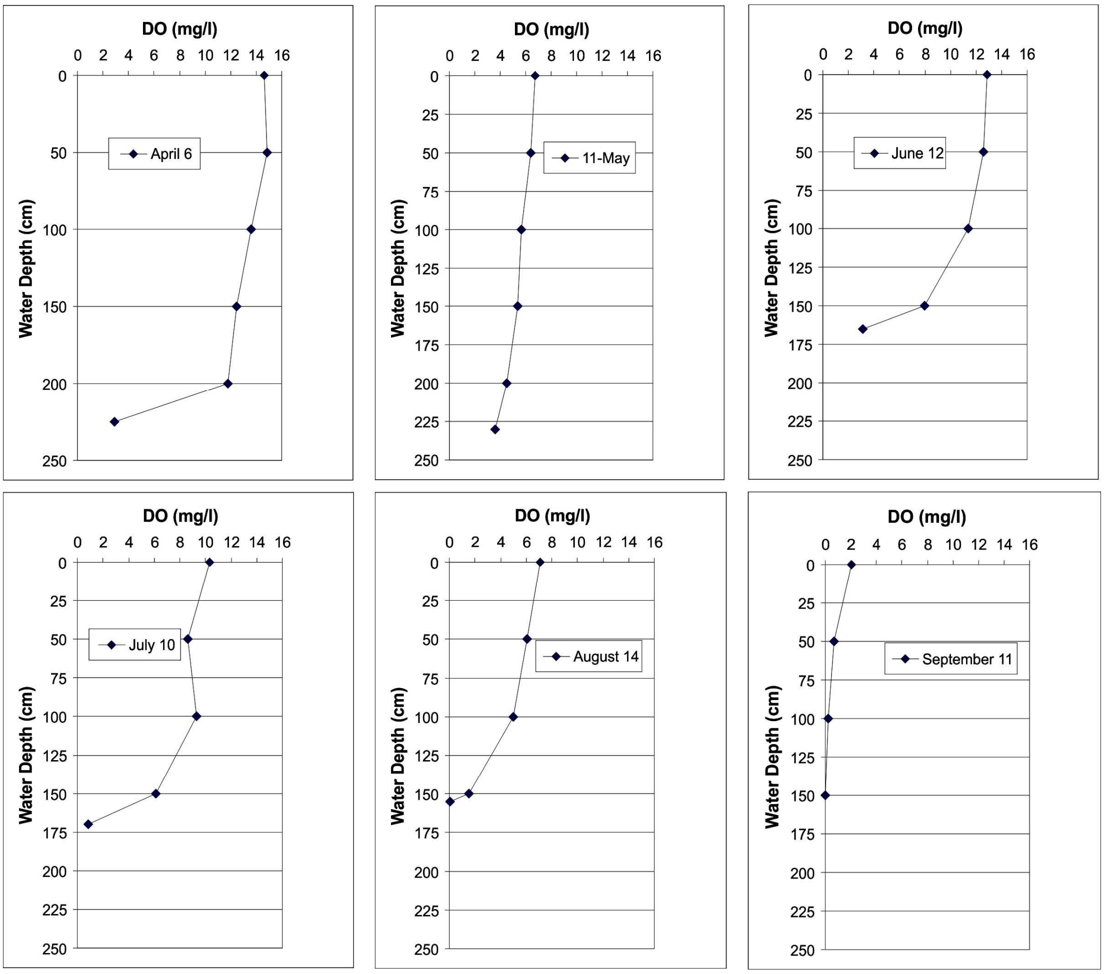

Figure 18. DO concentrations at depth for farside dock.

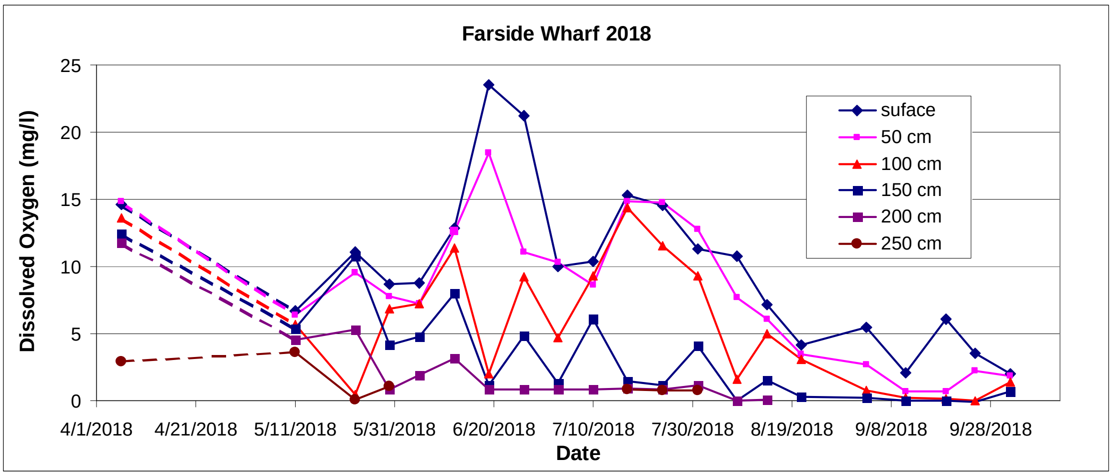

Figure 19. DO concentrations at depth for farside dock.

In both the dissolved oxygen time series plots, oxygen levels dropped in mid-August. In the case at Founders' Wharf, this drop was dramatic and sustained with what appeared to be a short punctuation of recovery followed by another quick drop. This hypoxic event coincided with the dense smoke associated with the numerous wildfires. As will be seen in the Nutrients section of this record, this drop also coincided with a depletion of phosphorous, a nutrient essential for plant/cyanobacteria photosynthesis .

As this sample season added another dissolved oxygen curve to a now growing number of data sets, a comparison curve was plotted that overlaid six years of data that spanned a 31 year period (Figure 20). Clearly of the time series plots, 2018 stands out as the year with the longest sustained hypoxic event and the latest dissolved oxygen recovery date.

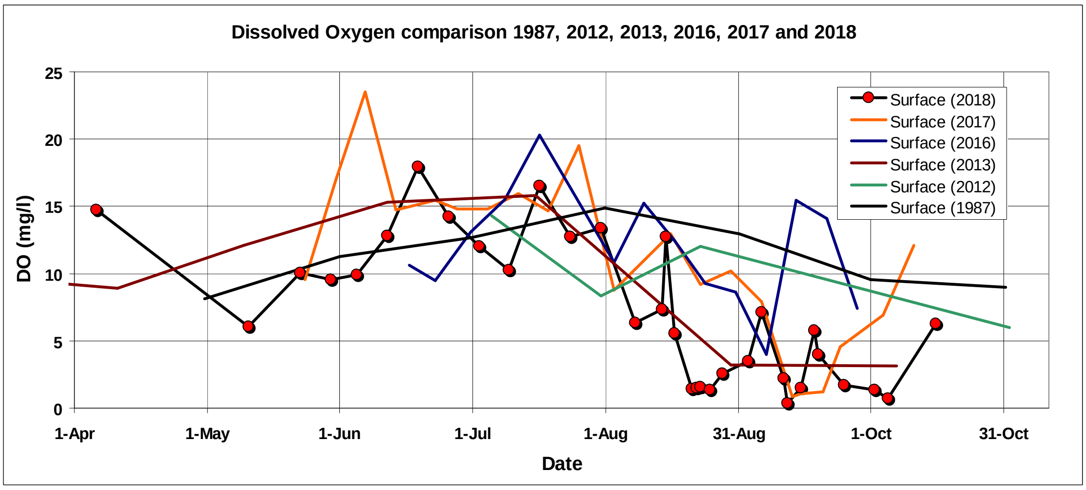

Figure 20. DO curves for six years of data collection.

pH

The pH values were recorded throughout the sampling period with the exception of the interval of July 11–August 8. The pH probe had developed an intermittent problem and its recommended lifespan had expired. A new probe was ordered and this gap in the data was because of the time required to order and ship the replacement parts.

As with the dissolved oxygen data, profiles and time series of pH were plotted for both the Founders' Wharf and the farside dock (Figures 21 and 22).

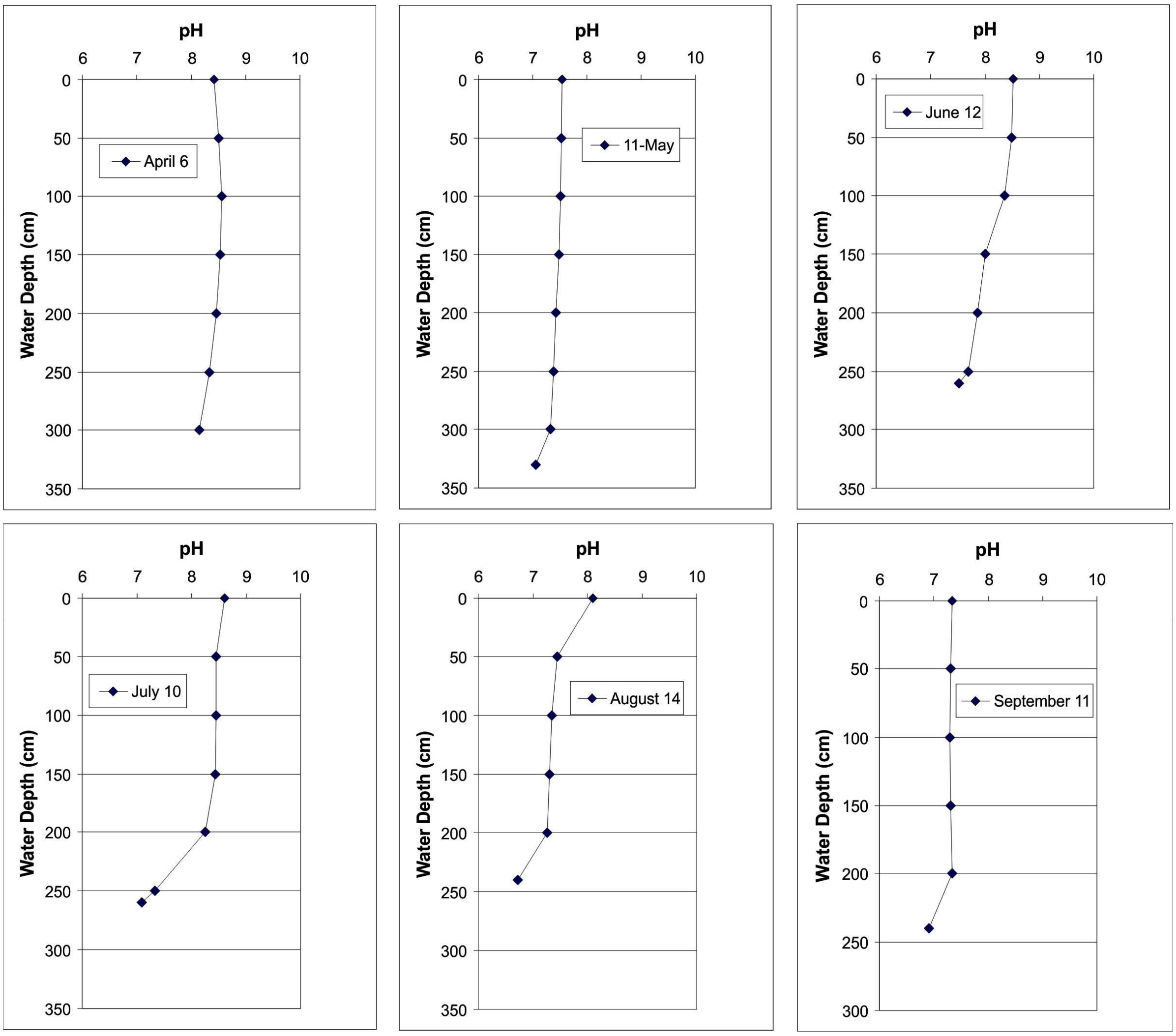

Figure 21. Monthly pH profiles for Founders' Wharf.

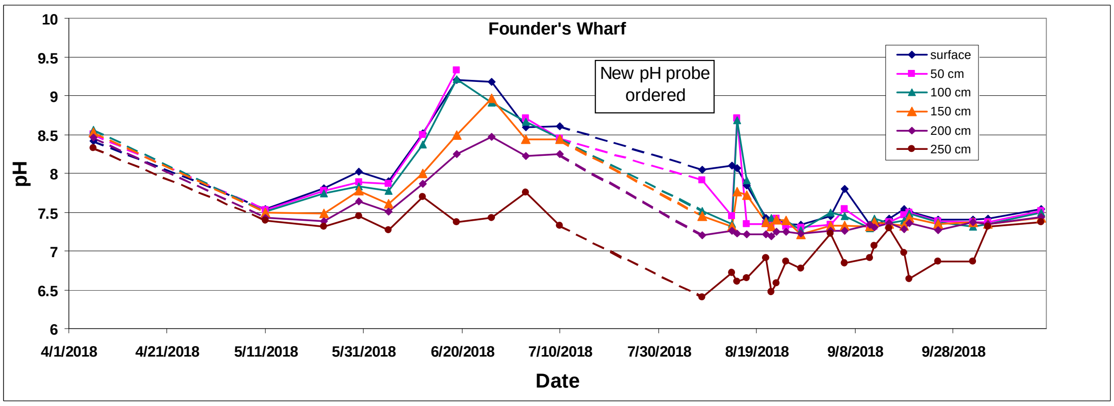

Figure 22. Time series plot of pH for Founders' Wharf.

Similar plots were generated for the pH of the farside dock (Figures 23 and 24).

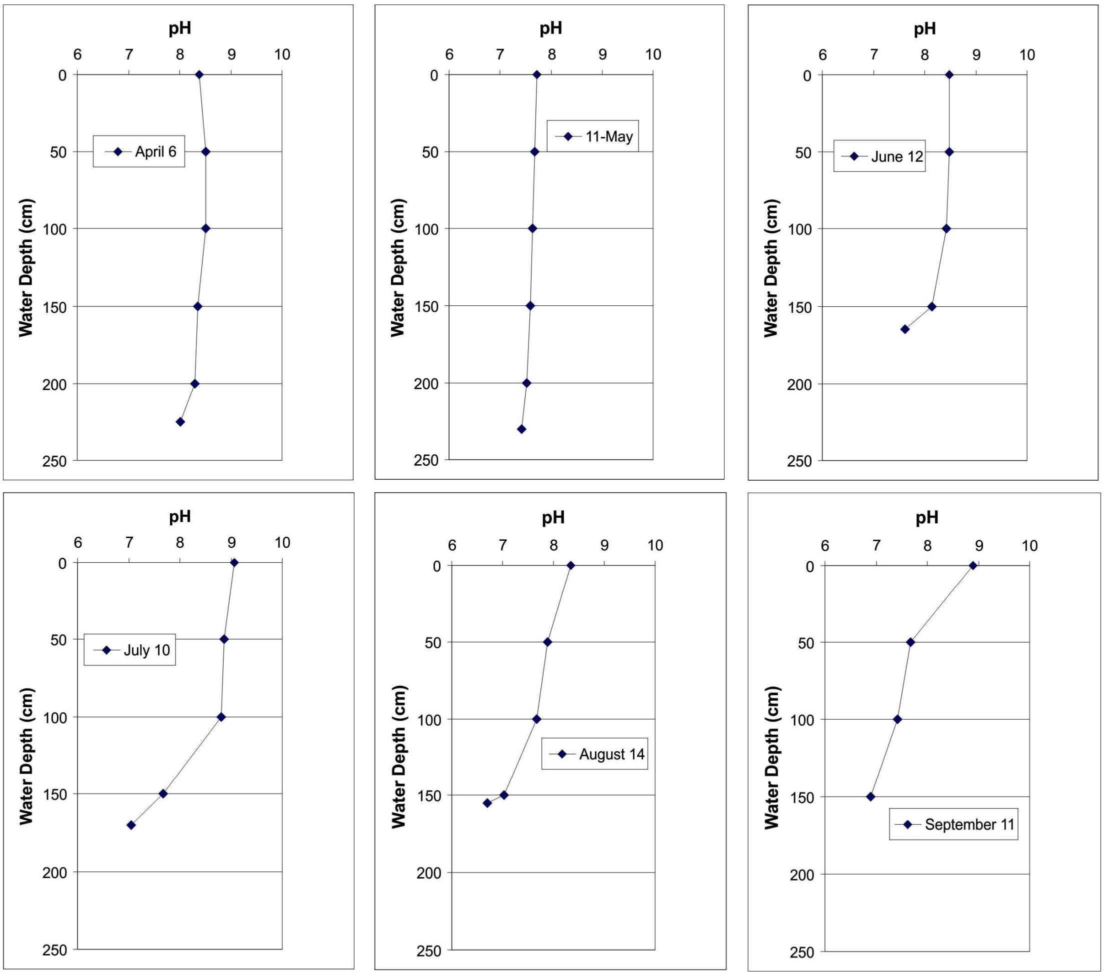

Figure 23. Monthly pH profiles for the farside dock.

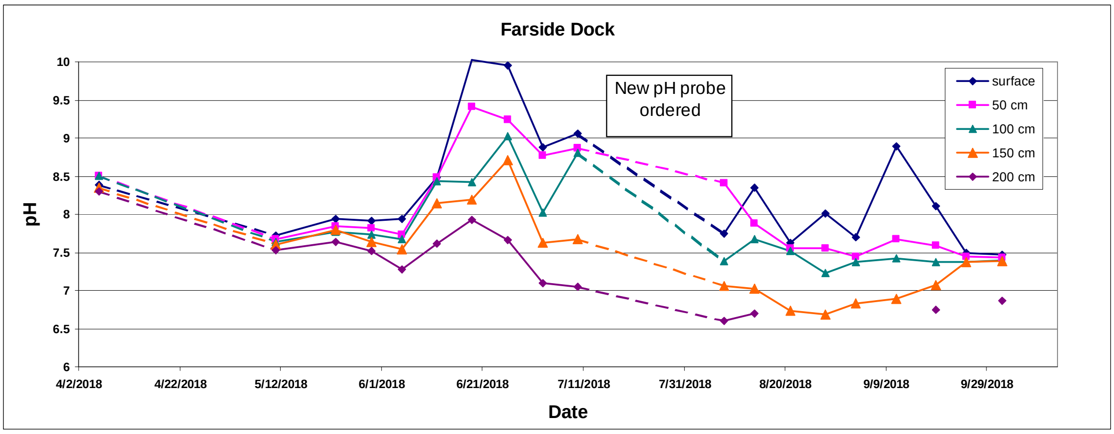

Figure 24. Time series plot of pH for the farside dock.

Note the relatively high pH values throughout the spring and summer months with profile gradients having similar slopes as the dissolved oxygen profiles. Typically, pH values are higher at the surface and decline with depth.

The photosynthetic processes at work in the lake are largely what influences pH. 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 sinking biota, liberating H+. This hydrogen ion combines with H_2O and dissolved CO_2 to create carbonic acid as describe in equation 3:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \quad . \qquad (3)$$

Nutrients

Water samples were taken at several sample sites around the lake. The inflow creek site was considered of great importance as it has the potential to be a vector for external nutrient loading. Water samples were taken in a shady area just downstream from the walking trail wooden bridge at Blenkinsop Creek. Other water sample sites included the Founders' Wharf, the farside dock and the boardwalk bench #2. The Founders' Wharf data and the inflow creek were the only two sites where sampling was done throughout this year's monitoring program. Bench #2 was interrupted by the boardwalk replacement and the farside dock was added once the bench #2 site was unavailable. Figures 25 and 26 present both nitrate and phosphate concentrations for the Founders' Wharf and inflow creek. Water samples were taken approximately 10 cm below the surface and nutrient analysis was done by using a prescribed set of procedures using a YSI 9500 photometer and reagents.

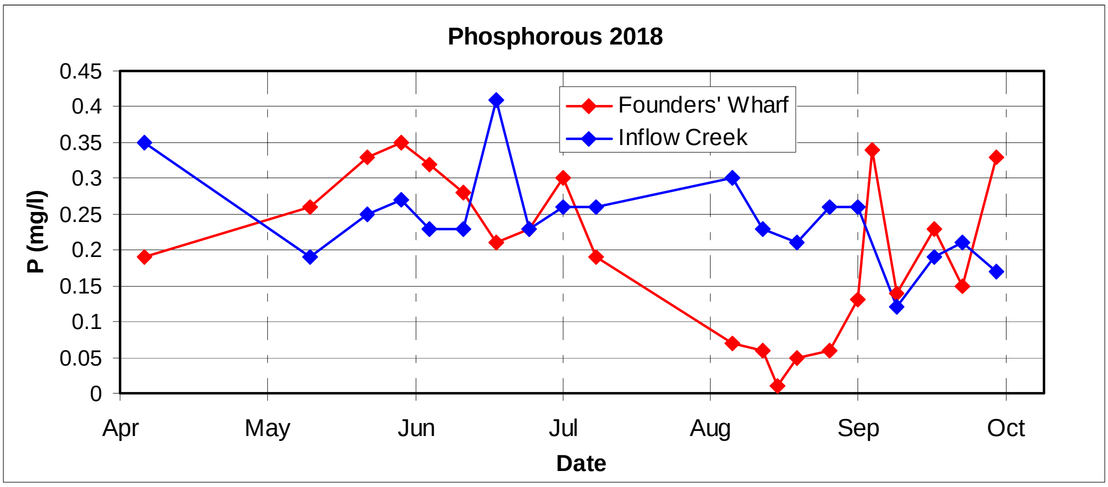

Figure 25. Phosphorous time series plots for Founders' wharf and inflow creek.

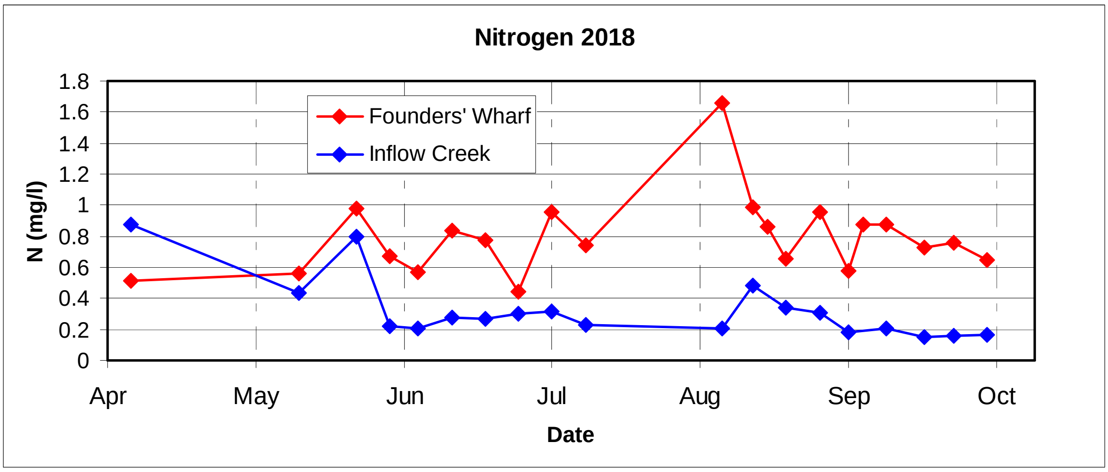

Figure 26. Nitrogen time series plots for Founders' wharf and inflow creek.

Note that the inflow creek did not experience the phosphorous drop in August that was apparent at the Founders' Wharf site. As the phosphorous cycle has its origins in rocks and sediments as well as fertilizers, the water flowing through the creek is more apt to transport agricultural nutrients and soluble phosphorous via sediment or rock contact. Lake phosphorous, however, is subject to plant and cyanobacteria uptake through the process requirements of photosynthesis. Also worth noting is that the inflow creek nitrogen levels were generally less than half the Founders' Wharf nitrogen levels. This may be due to the process that some lake algae can fix atmospheric nitrogen.

Annual comparisons were made for both phosphorous and nitrogen for the last three years of data collection (Figure 27).

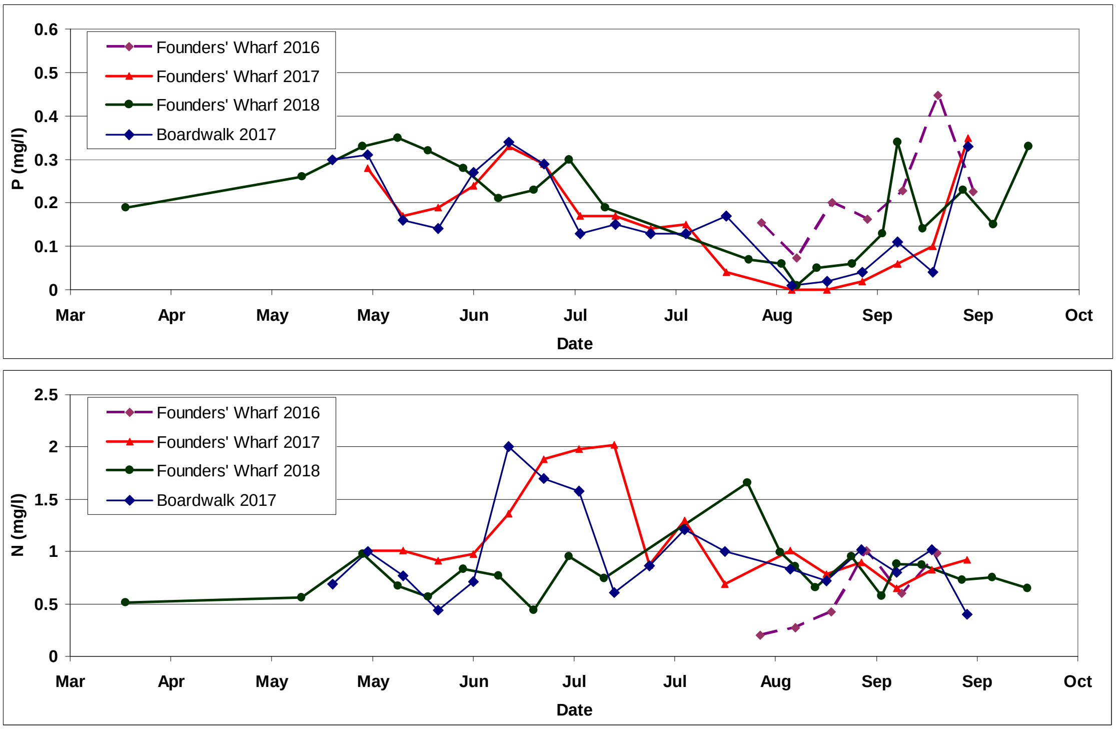

Figure 27. Phosphorous and nitrogen time series comparisons with previous years.

In each of the three years of the phosphorous data, the hot sunny weather produced vast populations of algae which consumed the limited amount of phosphorous available within the lake system. In all cases, phosphorous values dropped to their lowest seasonal values at the end of the first week of August. These low values were short-lived as phosphorous levels rebounded back to values typical of May or June. This rebound shows the return of available phosphorous, initially consumed by cyanobacteria and then liberated through the process of decomposing organisms that return the phosphorous to the water column as they die off.

Lake Hypoxia

It was noted that dissolved oxygen levels collapsed in August which coincided with the lowest seasonal values of phosphorous. This decline led to a lake-wide hypoxic event. Hypoxia is defined as aquatic dissolved oxygen levels at or below 2 mg/l. As the hypoxic event began, the following note was sent out to Swan Lake staff to give background on some of the dynamics involved.

"Over the summer months, you may have noticed an abundance of what looks like small blades of grass floating at the surface as well as suspended in the water column. These cyanobacteria, called *Aphanizomenon flos-aquae*, through the process of photosynthesis, produce huge amounts of oxygen. They replicate quickly during the warm summer period feeding on the high nitrogen and phosphorous levels found in Swan Lake. With the ideal conditions of calm bright sunny days, and rich available nutrients, these cyanobacteria, along with other species such as *Lyngbya* can create dense blooms. These blooms can block out sunlight to important oxygen producing plants lower in the water column. A typical profile of oxygen during the summer shows very high oxygen levels at the surface and almost completely no oxygen at the bottom of the lake. These blooms consume nutrients at a great rate, but this is only sustainable for a limited time. As nutrient levels drop off, particularly phosphorous, the suspended cyanobacteria begin to die off. As they die, they drop to the bottom of the lake where decomposing bacteria are standing by. These decomposers consume oxygen. In the late summer, as we've seen this year and years in the past, duckweed, the small floating green disc-like plants usually limited to the margins of the lake begin to increase in numbers. Although nutrients may be dropping off in the water at this time, duckweed has the ability to absorb nitrogen from the atmosphere directly (Zuberer, 1981). In calm conditions, duckweed can exponentially multiply to create a thick layer that covers the entire lake. This layer can completely shut down any photosynthesis in the water column. Low phosphorous and no sunlight can lead to a mass die-off of any of the organisms that generate oxygen. The once thriving *Aphanizomenon flos-aquae* now rain down to the bottom fueling the further removal of oxygen through decomposition. If the timing of the cyanobacteria blooms, the nutrient drops, calm warm conditions and the development of an extensive duckweed layer all occur in just the right order and duration, a perfect storm is created resulting in a complete collapse of oxygen throughout the water column and results in fish kills. This year (2018) Swan Lake experienced a brief fish kill in and around August 23 where a small number of sticklebacks were observed dead at the surface. The lake is now in recovery mode and oxygen levels have now begun to rebound back into safe limits." (correspondence, Rob Bowen, Sept 15, 2018)

Figure 28 shows the monthly comparison of DO profiles at the Founders' Wharf. Note the hypoxic profiles of August 21 and 22.

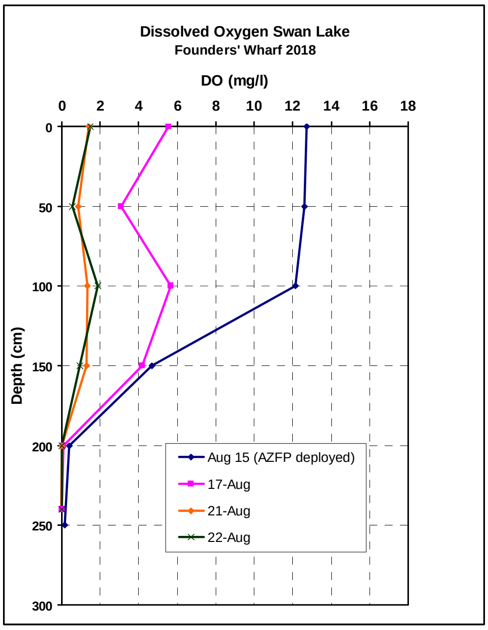

Figure 28. Monthly DO profiles depicting oxygen collapse in August 2018.

The dissolved oxygen data for the Founders' Wharf were gridded in order to create a contour plot which delineates the oxygen-rich waters from those that are anoxic (Figure 29). This plot displays the onset of the oxygen level collapse and shows a time series of water column data throughout the sampling period. The colour scale indicates dissolved oxygen in mg/l. Note that the black fill represents values less than or equal to 2 mg/l, a value intolerable to all fish in the lake. This contour is bounded by a white contour line. The second white contour line indicates a dissolved oxygen level of 5 mg/l. This line indicates the base of a threshold for safe limits.

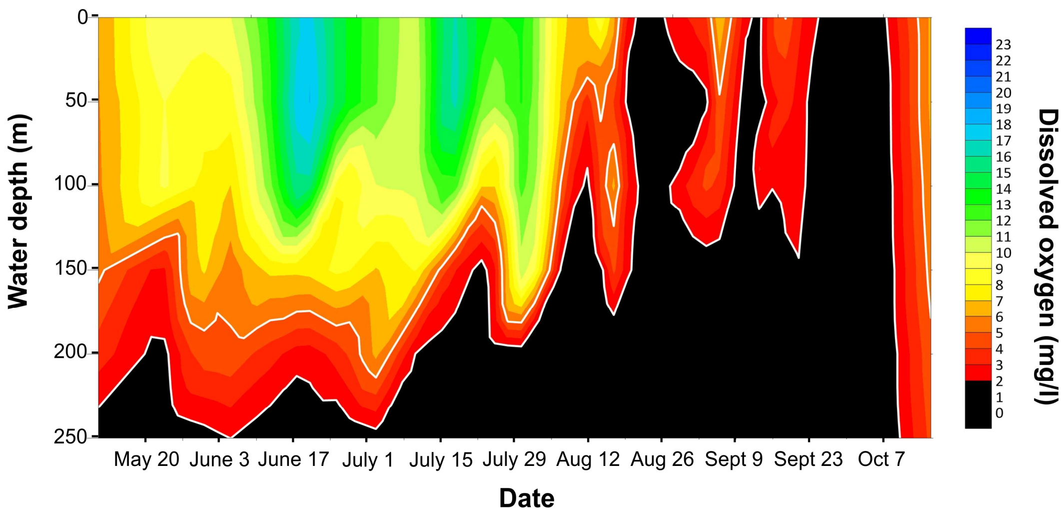

Figure 29. DO time series for water column at Founders' Wharf sample site.

6.0 New Interpretative Program

Given the variability and importance of water quality to the biodiversity and abundance of species, Swan Lake introduced a new program called the Junior Naturalist Program (Figure 30) which includes a lake study component.

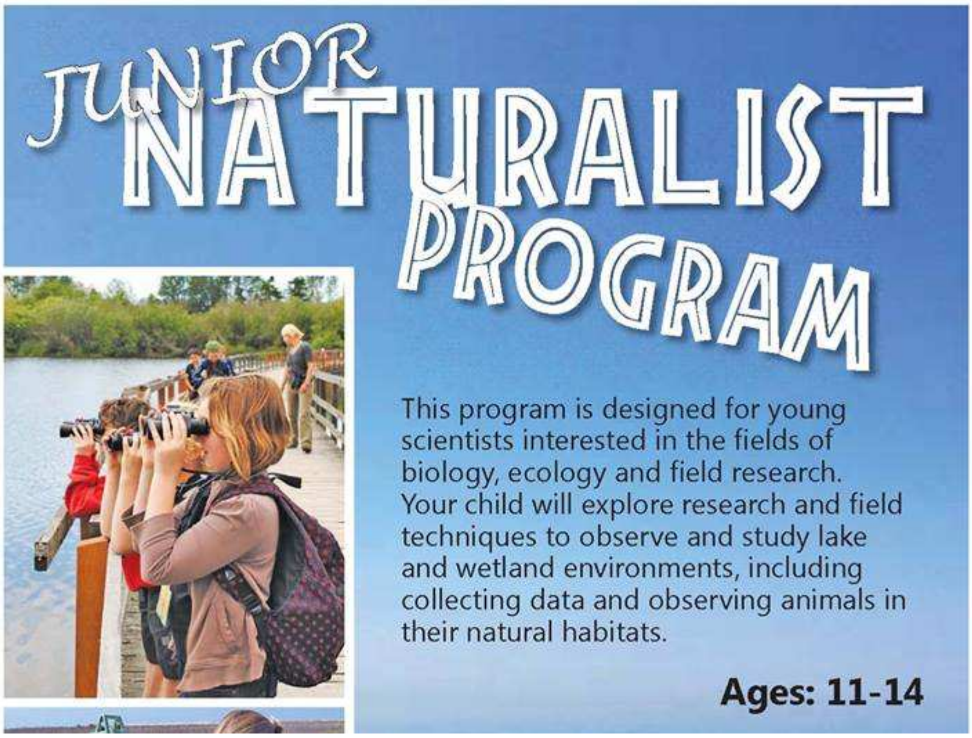

Figure 30. DO time series for water column at Founders' Wharf sample site.

In this program developed by Swan Lake naturalist Asta Mail, students were introduced to some of the field techniques used in carrying out water quality monitoring. This was presented in a hands-on format where there was a brief description of the instrumentation and the general principles of how measurements are made. Students were supplied with data sheets and conducted dissolved oxygen and pH profiles. These data were later plotted to look at gradients and variability.

To demonstrate how effective the cyanobacteria *Aphanizomenon flos-aquae* (AFA) are at producing dissolved oxygen, the following bucket experiment was set up as a study for the students (Figure 31).

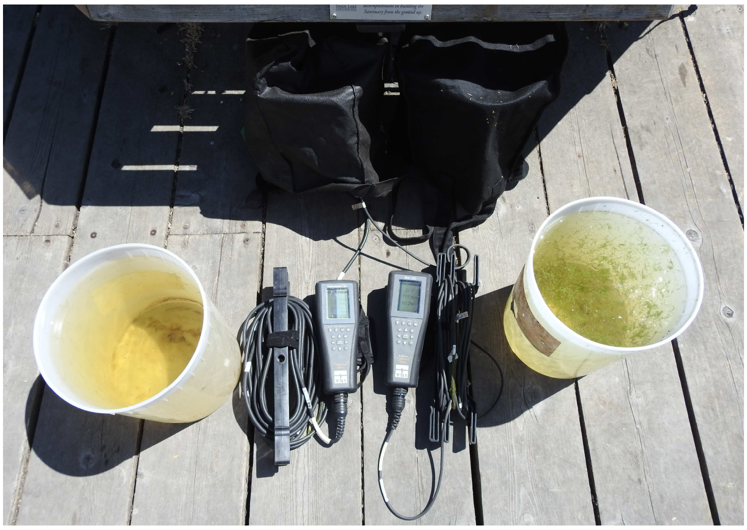

Figure 31. Cyanobacteria bucket test.

Bucket Test

2 buckets with AFA
2 buckets with AFA filtered out (filtered by plankton net to remove all filaments)
One with and one without AFA placed in the sun for one hour
One with and one without AFA covered with felt bag and placed in the shade for one hour.

Initial values in situ at 10:30 am were as follows:
DO % 117.9 DO mg/l 10.27, pH 8.61, temp 22.2, ORP 166.9.

Table 2. Bucket test results.

Parameter	Bucket with AFA in sun	Bucket with AFA in darkness
Temp	23.7	21.8
DO%	140.8	114.1
DO mg/l	11.95	10.03
pH	8.96	9.01
ORP	78.1	131.9
Time	11:33	11:38
	Bucket no AFA in sun	Bucket no AFA in darkness
Temp	23.8	21.9
DO%	122.1	116.8
DO mg/l	10.31	10.24
pH	8.93	8.95
ORP	111.9	152.8
Time	11:36	11:45

The data clearly shows a significant increase in oxygen production in the bucket with AFA exposed to the sun (10.27 mg/l to 11.95 mg/l) in contrast to the bucket with AFA shaded from the sun (10.27 mg/l to 10.03 mg/l) where respiration marked a decline in oxygen.

These and other such experiments and monitoring procedures create learning opportunities and it is hoped that a similar program will continue into the future.

7.0 Acoustic Zooplankton Fish Profiler

The Acoustic Zooplankton Fish Profiler (AZFP) is an autonomous scientific echosounder that has been used successfully in ocean environments to detect the presence and abundance of zooplankton, fish, suspended solids and bubbles. The AZFP uses multiple frequencies to measure acoustic backscatter in high spatial and temporal resolutions. This is the first application of the AZFP in a shallow freshwater eutrophic system. The instrument was configured with three transducers with the following frequencies: 200, 769 and 1250 kHz. As the cyanobacteria *Aphanizomenon flos-aquae* is present in great abundance and because it is a relatively large filament bacteria with lengths that typically exceed 1-cm, it was thought that this organism would present a detectable acoustic target. It is well known that this species plays a key role in producing dissolved oxygen within lake systems (Woods et al., 2006; Hoilman et al., 2009)). It was observed in the 2017 monitoring season that the late summer die-off of this species coincided with a collapse in oxygen level to a state of lake-wide hypoxia.

Deployment

The AZFP transducers and battery assembly were mounted to a bottom frame along with a taut line subsurface float that had attached to it an Alec optical dissolved oxygen logger and logging flourometer. These two loggers were suspended in the water column at a depth of 0.75 m. A sketch of the mooring is depicted in Figure 32. The instrument was deployment August 15, 2018 and was in the water at 11:35 am (Figures 33–36).

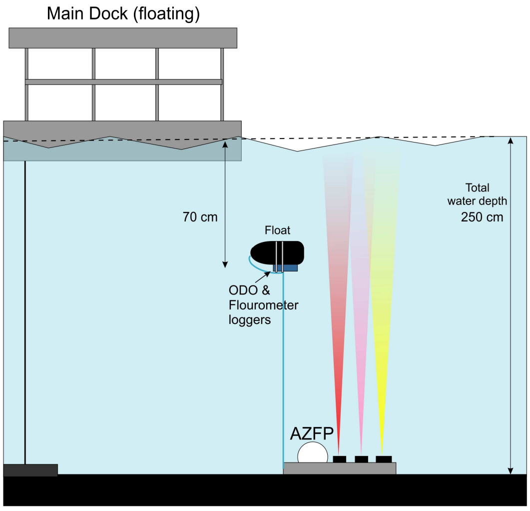

Figure 32. AZFP mooring diagram.

Figure 33. Rob Bowen and Jay Rastogi with AZFP mooring.

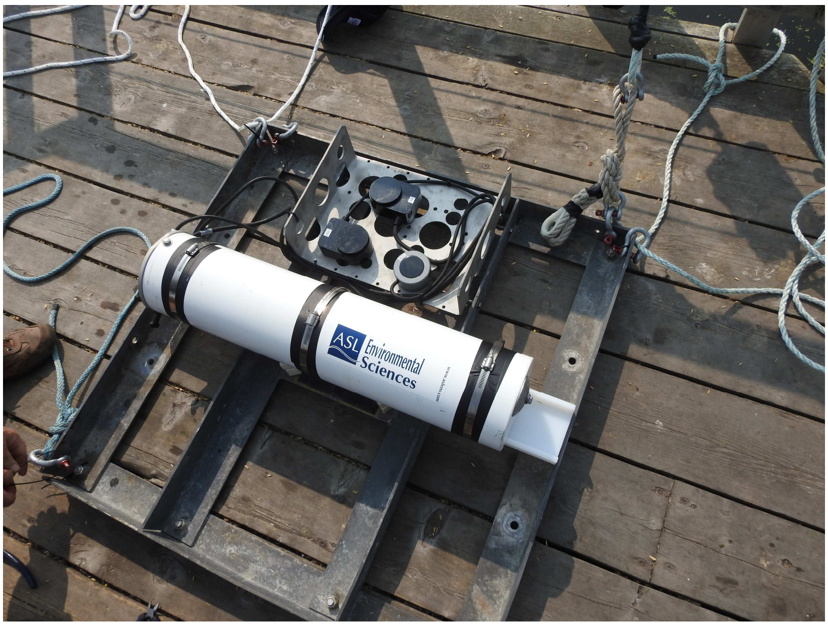

Figure 34. AZFP bottom frame showing pressure case and transducer array.

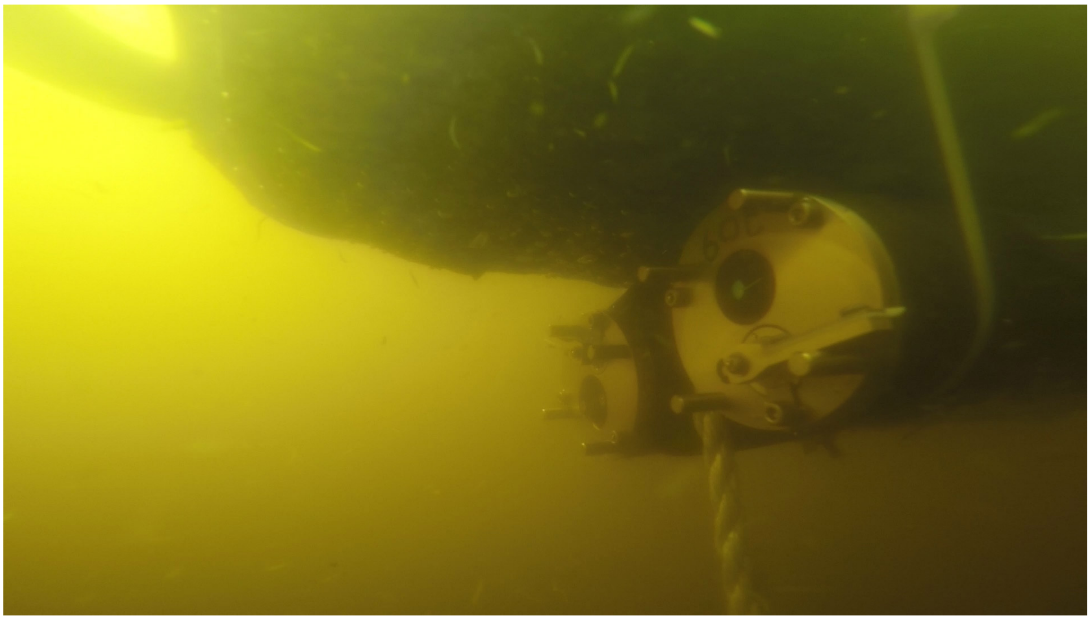

Figure 35. Underwater view of DO and Flourometer loggers.

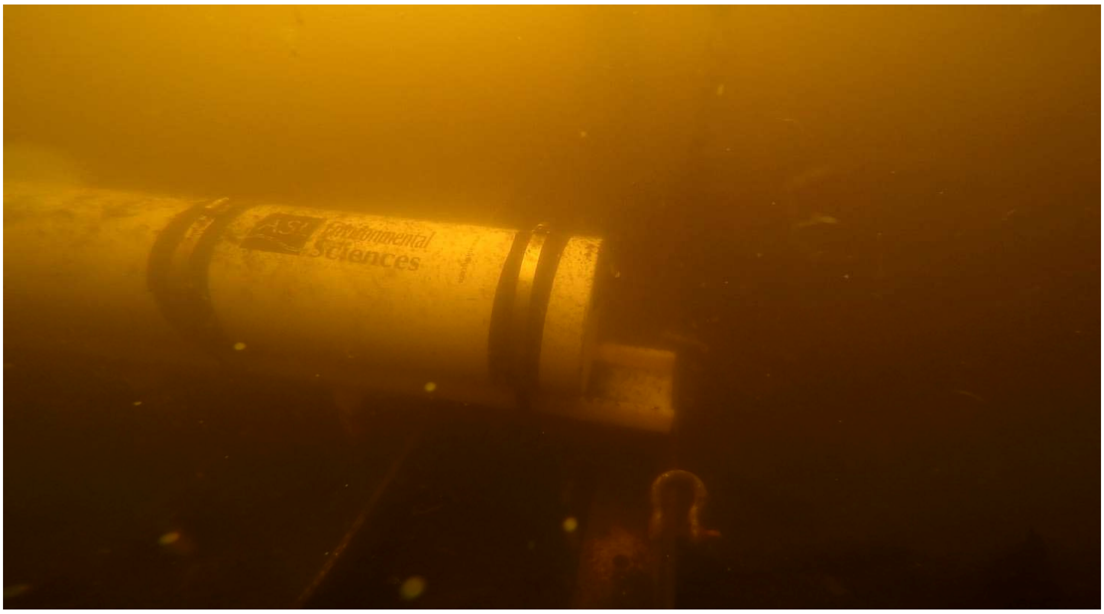

Figure 36. Underwater view of AZFP mooring showing upward orientation.

Recovery

The instrument was recovered on September 12 at 9:10 am (Figure 37). The deployment period was August 15–September 12, 2018. The total time in water was 30 days.

Figure 37. Rob Bowen with Matt Stone of ASL Environmental Sciences.

Mooring Data

All data was successfully downloaded for analysis. These included:

- Fluorometer logger (sample rate every 10 minutes)
- Alec ODO data logger (sample rate every 10 minutes)
- 200 kHz transducer (sampling rate one Hz)
- 769 kHz transducer (sampling rate one Hz)
- 1250 kHz transducer (sampling rate one Hz)

Chloryphyll-a

Chlorophyll-a data was plotted and is presented in Figure 38. From the DO profiles of Figure 16, oxygen levels dropped to hypoxic sometime around the 21th of August. This was a time where phosphorous levels were dropping to annual lows and it was noted from GoPro video that AFA abundance diminished until it was no longer present in the water column by August 25th. The chlorophyll-a levels also show this same decline over the Aug 15–21 period. As AFA contains large amounts of chlorophyll-a, this decline is likely associated with the AFA die-off.

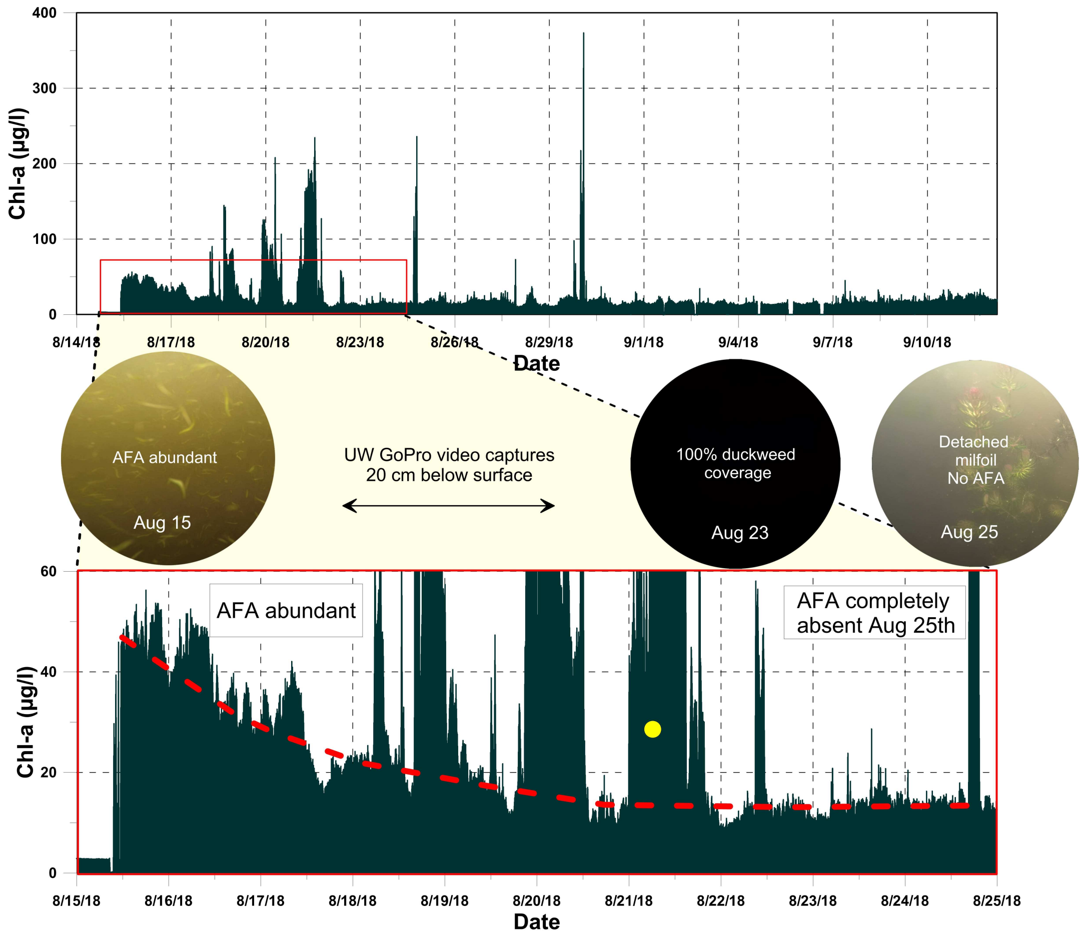

Figure 38. Chlorophyll-a time series plots showing the decline of Chl-a levels. Top plot shows the complete deployment period. Bottom plot shows an inset of these data.

There were occurrences of large spikes in the Chlorophyll-a data. These spikes are attributed to a collection of detached milfoil plants that freely drifted within the lake. As the AZFP had a subsurface float that held the DO and fluorometer loggers, these plants would snag on the mooring line and collect above and in front of the AZFP transducers and data loggers. On August 21st, GoPro video showed just such a collection of milfoil attached to the subsurface float directly in contact with the loggers (Figure 39).

A yellow dot was placed on the lower panel of Figure 38 showing that this collection of milfoil resulted in a large spike in chlorophyll-a that lasted almost a day before drifting off. It was noted that these plants were dotted with numerous aquatic snails and were both living and in various states of decay.

Figure 39. Collection of detached milfoil snagged on loggers.

Dissolve Oxygen Logger

The DO logger provided insights into the diurnal cycle of oxygen production and respiration at Swan Lake. Figure 40 shows the DO logger data along with the field data collected from the YSI hand held unit where both values were obtained from the same depth in the water column. Note both DO and temperature from the two acquired data sets overlay very well. The YSI data was consistently collected in the morning which tended to be near daily low points for both DO and temperature when placed into the diurnal context of the logger data. It is surprising to note the extremes between peaks and troughs, especially at the beginning of the record where high–low values range from 16–2 mg/l. The diminishing amplitude of the DO concentrations may be related to the die-off of the AFA, extinguishing DO input from photosynthesis and DO removal due to respiration. As noted earlier, AFA was no longer visible in the water column by August 25.

Just after this die-off, there appears to be a rebound in oxygen levels for about a week. During this period, an influx of phosphorous is released (see Figure 25) likely due to recycling through the decomposing organisms. Recovery of the lake system after hypoxia often is initiated by fast-growing organisms that played minor roles in oxygen production while AFA dominated. These organisms tend to be small, fast growing and short lived (Stachowitsch, 1991; Diaz and Rosenberg, 1995).

Note also that temperature is strongly correlated with oxygen levels. The diurnal cycle of DO is in phase with the diurnal cycle of the water temperature. Temperature exerts a strong modulation as a decrease in temperature reduces the metabolic processes within the photosynthetic organisms (Steckbauer et al., 2011).

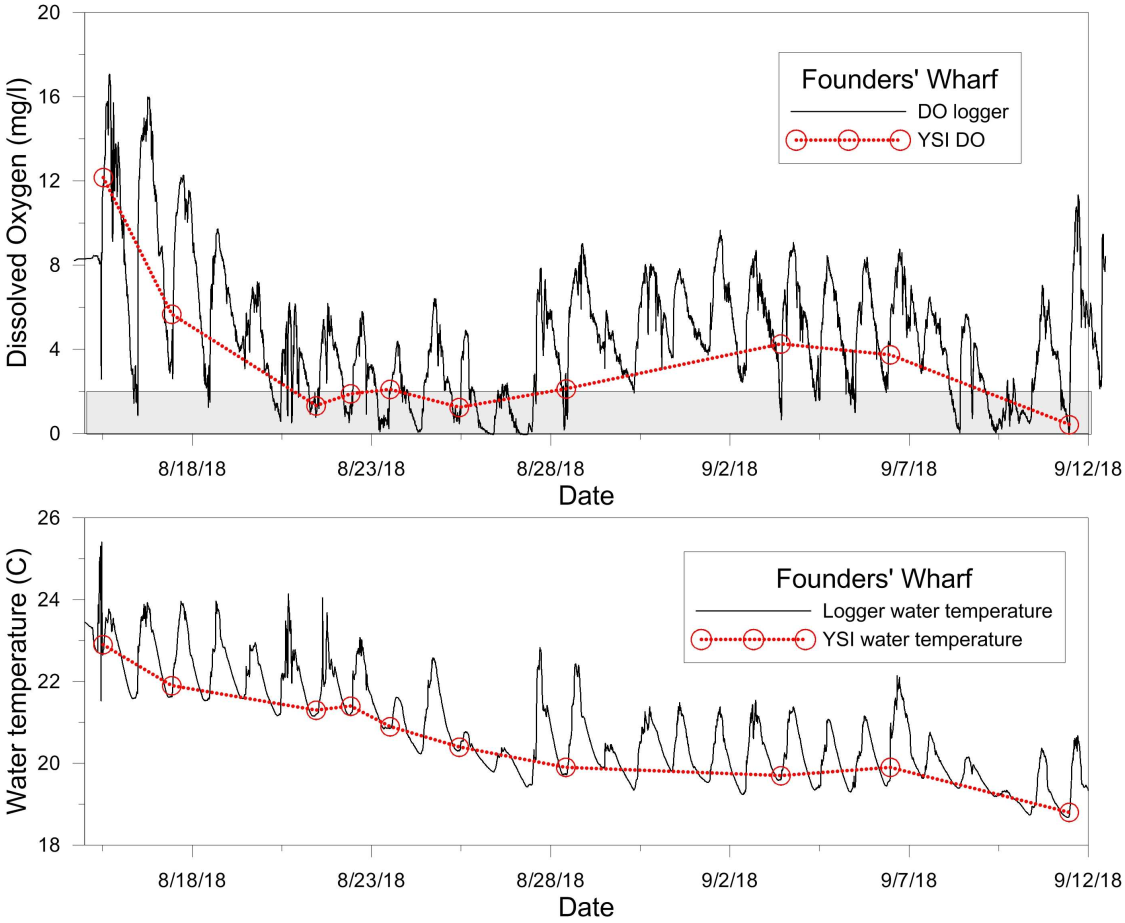

Figure 40. DO and temperature diurnal cycles with YSI data overlay.

Also of note is that the lowest oxygen values tend to be at sunrise after a full night of respiration. This agrees with the findings of Anderson et al., 2017. By examining the DO diurnal cycle, single point sampling can be misleading and is dependent upon the time of day at which the sample is taken. Figure 41 compares oxygen concentrations based on time of day. Two 24-hour cycles are displayed to show this diurnal pattern.

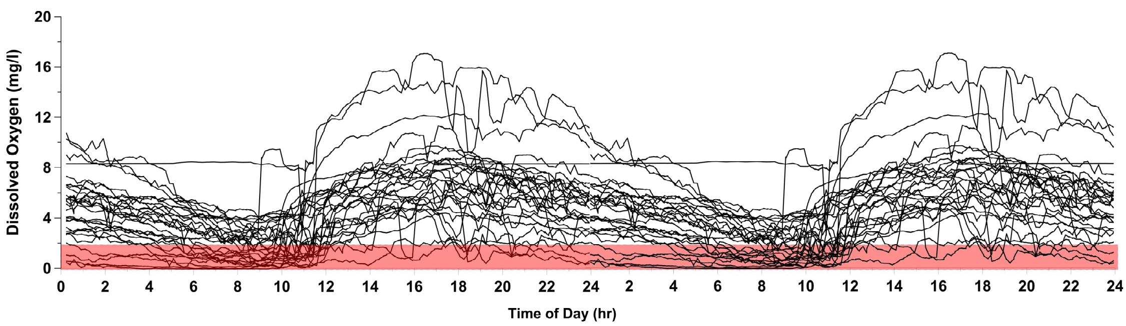

Figure 41. DO concentration by time of day (Aug 15–Sept12).

High resolution temporal sampling of chlorophyll-a and DO provide an excellent set of data useful for interpretation of the AZFP acoustic backscatter data. As the AZFP data sampled every second in three frequencies, massive amounts of data were acquired. Only a preliminary treatment is presented in this report.

AZFP Acoustic Backscatter

The AZFP emits ultrasonic pulses of different frequencies to insonify zooplankton, fish and, in this application, cyanobacteria filaments within the water column. A quick look at the backscatter data shows Swan Lake to be a dynamic environment with several interesting acoustic features. A few of these features are described.

During the monitoring program, it was routine to drop a GoPro camera down through the water column to observe light penetration, cyanobacteria abundance and look for the presence of fish. In Figure 42, the AZFP detected one of these GoPro deployments. On August 17 at 10:30 am, the GoPro camera was detected by all three frequencies. The backscatter from this camera are displayed in the three panels below. As the transducers were mounted in different positions horizontally, the transducer views of the camera are slightly different as are the target strengths. As target strength is a function of the frequency of the transducer and the acoustic absorption of the object (Urick, 1975), it is expected that there would be slight differences.

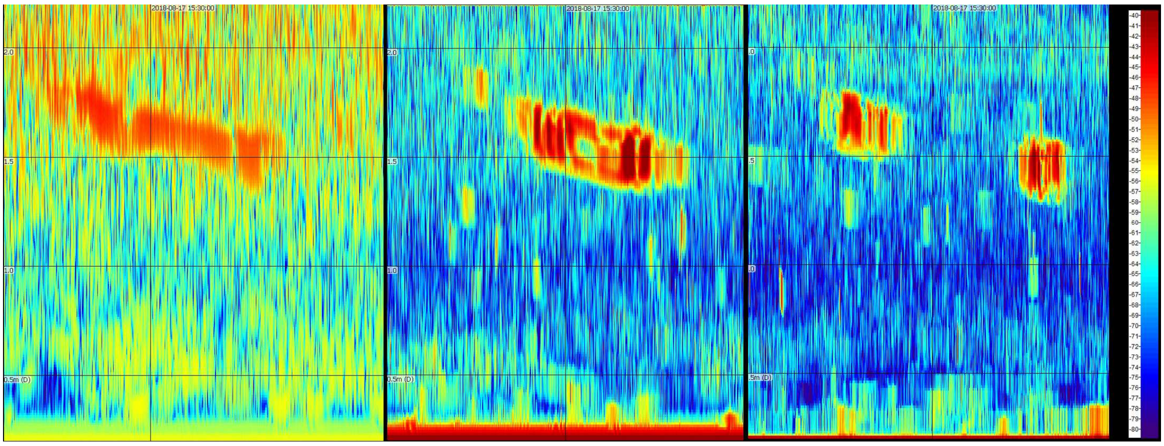

Figure 42. GoPro camera as seen by the three frequency transducers (left to right: 200, 769 and 1250 kHz).

Figure 43 depicts a strong signal of duckweed mixing down into the water column due to winds and waves which created a surface disturbance (August 18 at 7:00 pm). On this date, the winds had gusts up to 30 km/hr creating surface waves. As much of the duckweed is pushed to the lake margins by winds from the predominantly southwest direction, duckweed was transported away from the margins and mixed with the waves presenting bright reflectors at the water surface.

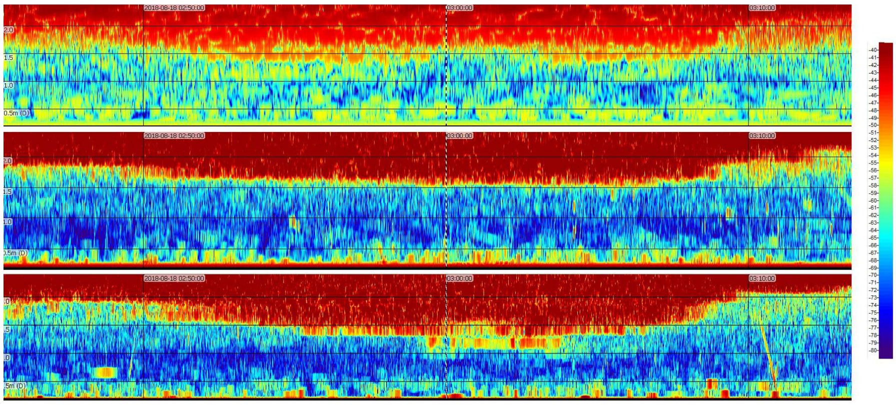

Figure 43. Duckweed mixed into upper water column by wind and waves.

The large collection of milfoil that was snagged to the subsurface float and observed by the GoPro on August 21 (Figure 37) was clearly visible in the backscatter data. Figure 44 shows this milfoil mass as a bright target especially in the higher frequencies. Looking back at the chlorophyll-a plot (Figure 36), there are wide bands of elevated chlorophyll-a on the 19th, 20th and the 21st. Based on the verified GoPro footage of the 21st, the strong backscatter and the high chlorophyll-a band on the 21st, it is likely that the strong backscatter targets of the 19th and the 20th are also detached milfoil that travel through the acoustic beams.

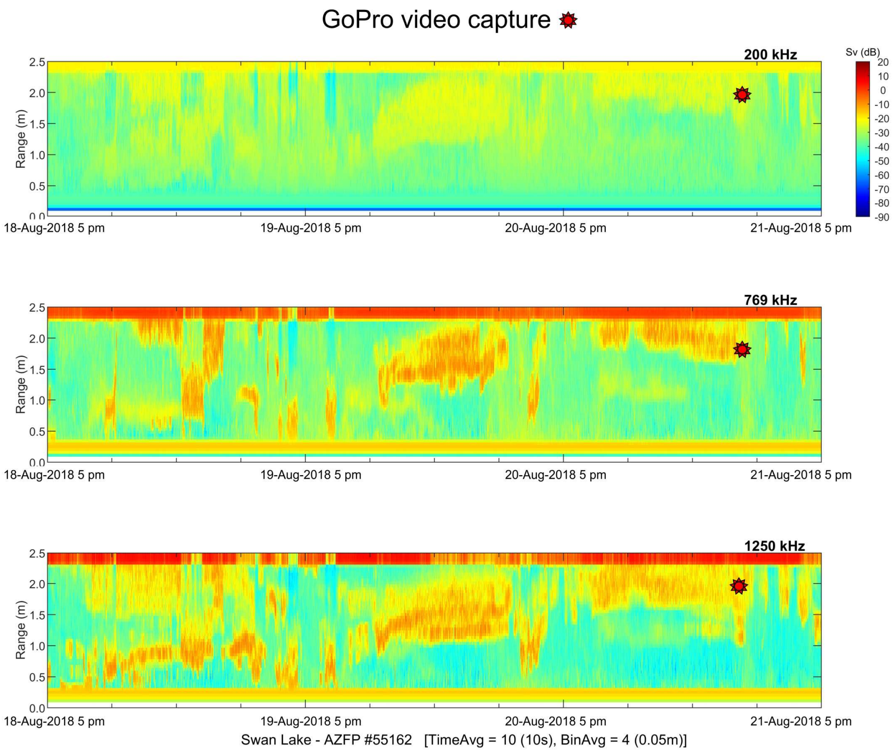

Figure 44. Milfoil present in the backscatter of all three frequencies.

AFA and Backscatter

To interpret the backscatter data specifically in terms of the AFA presence, it is important to understand some of the attributes of this species. AFA is a cyanobacteria that can regulate its vertical position within the water column. This is achieved by regulating elongated vacuoles within this filamentous organism. Vacuoles are either inflated with gases for lift or ballasted with carbohydrate production to add mass to sink in the water column (Woods and Gartner, 2010). The greatest influence on these controls are the availability of light and nutrients. In periods of light, where the growth capacity of the cells is exceeded, these organisms reduce the production of gases to their vacuoles and ballast with carbohydrates to reduce light exposure. The net result is a downward movement during the daylight hours. During the night, if nutrients are present, AFA consume the carbohydrate ballast and or inflate their vacuoles to achieve upward movement in the water column (Woods and Gartner, 2010; Porat et al. 2001).

Backscatter intensities were also found to vary during a 24-hour period. Woods and Gartner (2010), found that backscatter intensities of AFA increased during the night when AFA vacuoles were most inflated. In calm conditions, AFA therefore move vertically and change intensity during a 24-hour period.

On August 14th and 15th, a GoPro camera was lowered into the water column which revealed a large, well distributed population of AFA. No detached milfoil, fish or other visible organisms were present on either of these days so backscatter during this time is likely dominated by the AFA presence. On the evening of August 15th and on the early morning of August 16th there were no winds, creating very still conditions on the lake. Backscatter was plotted for this 12-hour calm interval in order to observe possible AFA vertical migration free from the influence of wind driven surface mixing. These data are plotted in Figure 45. Note that at approximately 21:10 on August 15, there appears to be a rise in the AFA targets into an organized band in the 50 cm to 150 cm depth below surface. This band slowly moved upwards to the surface increasing in target strength until about midnight when the vertical distribution of AFA widened into three distinct bands. These three bands lost their definition around 2:30 am. Target strengths declined throughout the rest of the night until about 5:40 am where very few targets were visible in the dB range displayed on this plot.

Horizontal slices were extracted from the backscatter data. This was done to compare the DO logger data at its depth (~70 cm below surface) to the target strength slice at the same depth. Figure 46 shows this comparison along with coincident solar input, chlorophyll-a and water temperature. Maximum oxygen levels in this three-day sample occurred sometime around 6–7 pm in the evenings with the lowest levels sometime between 11 am and noon. The steepest slope in the oxygen profiles were immediately after these lowest levels. Target strengths were low during daylight hours but higher during the night.

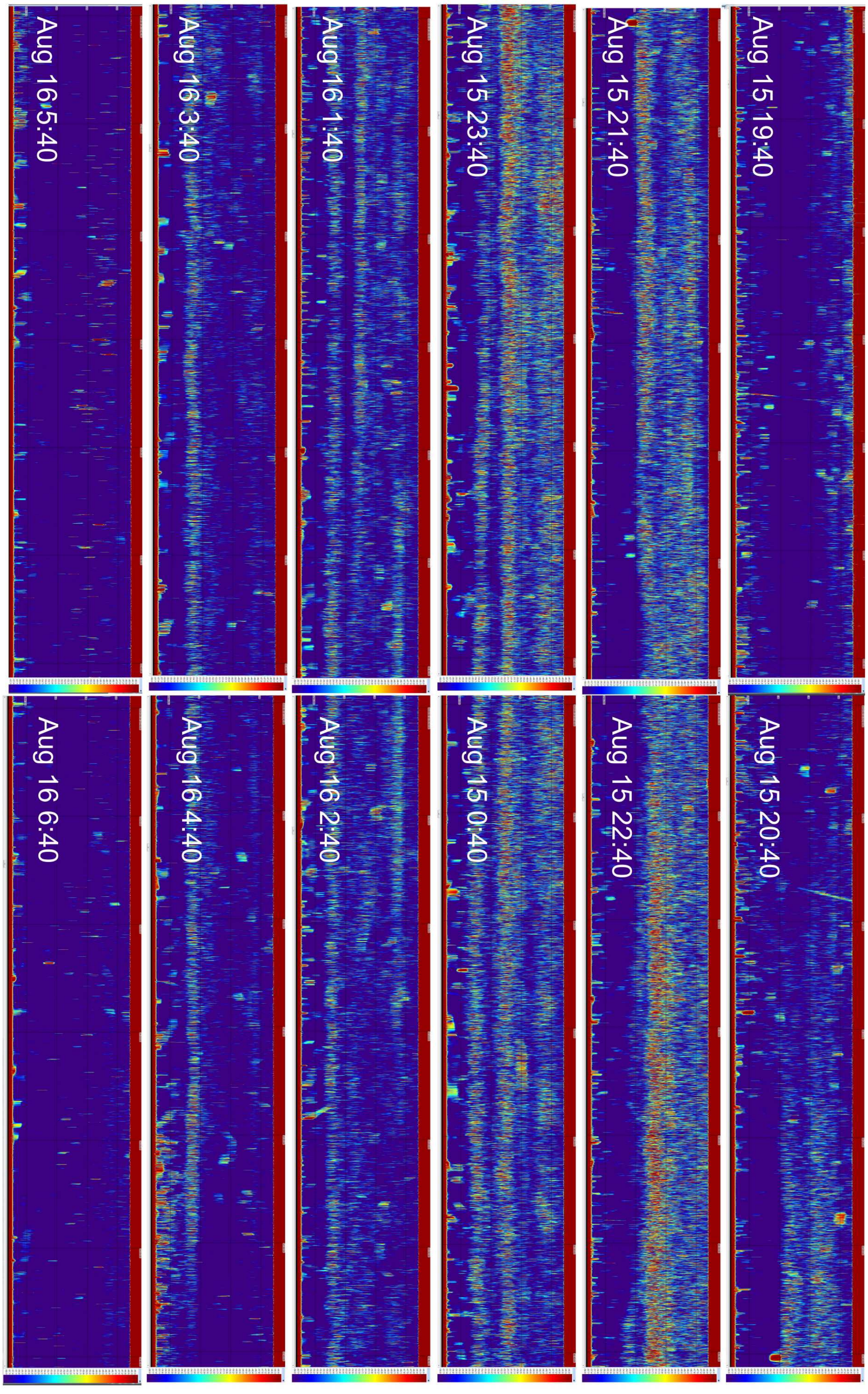

Figure 45. A 12-hour backscatter plot using the 769 kHz transducer (Aug 15–16).

Peak target strengths were near midnight on the 15th, 10 pm on the 16th, and 9 pm on the 17th. The chlorophyll-a curve shows a decline over this sample period suggesting a decline in AFA populations. Also of note is the strong correlation of the water temperature with the oxygen levels. As was discussed earlier, as water temperature decreases, metabolic processes diminish such as those required in the photosynthesis process.

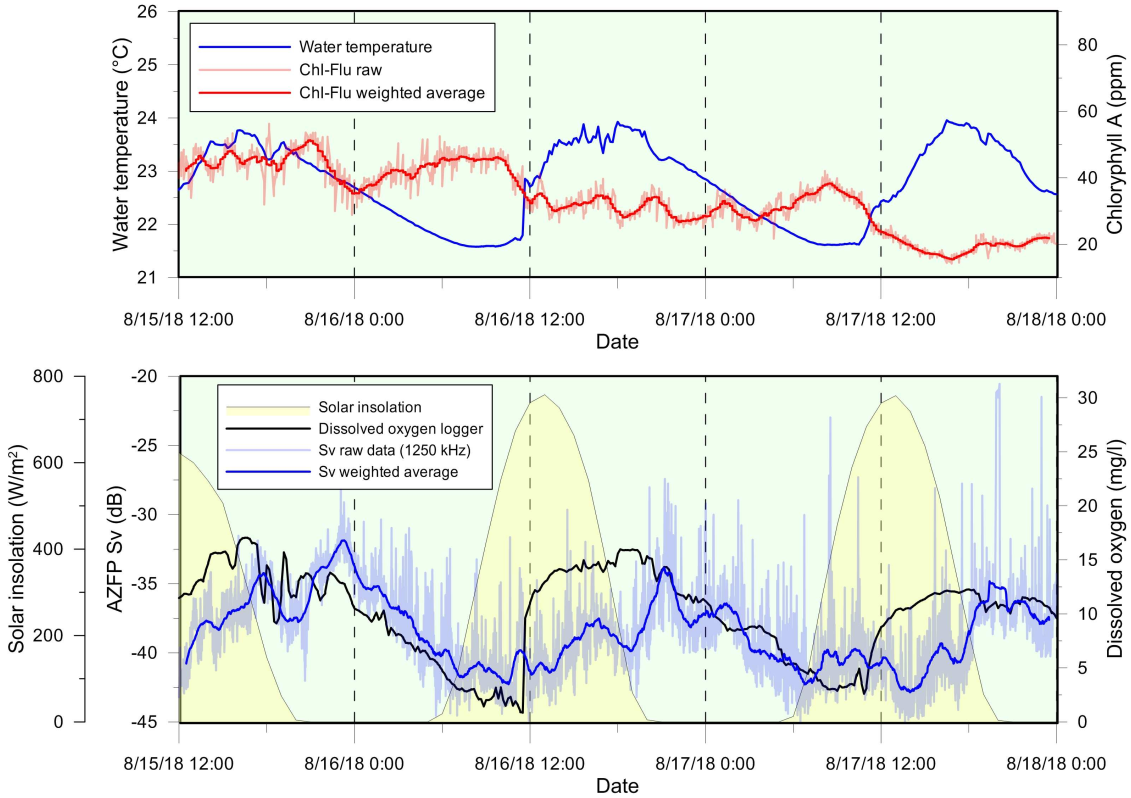

Figure 46. DO, target strength, chlorophyll-a, solar input and water temperature comparison (Aug 15–18).

All the horizontal backscatter slices were integrated vertically to investigate the full water column target strength behavior. This was useful to determine if the AFA target strength had a diurnal cycle throughout the water column and not just at the DO logger depth as observed in Figure 46. Figure 47 shows this integration of the three transducers where the sum of the integrated values were divided by the number of horizontal slices. This gave an average target strength for the water column at any given time. There appears to be a cycling pattern to the target strength with lower values during the day and peak levels during the night. In all three days of data, there appears to be more than just a single diurnal sinusoid. Note the target strength rise during the day and just at the point where daily oxygen levels peak there's a relatively steep drop in the target strength. This decline is short-lived as the target strength again starts to increase to a night-time peak followed by a target strength drop until dawn.

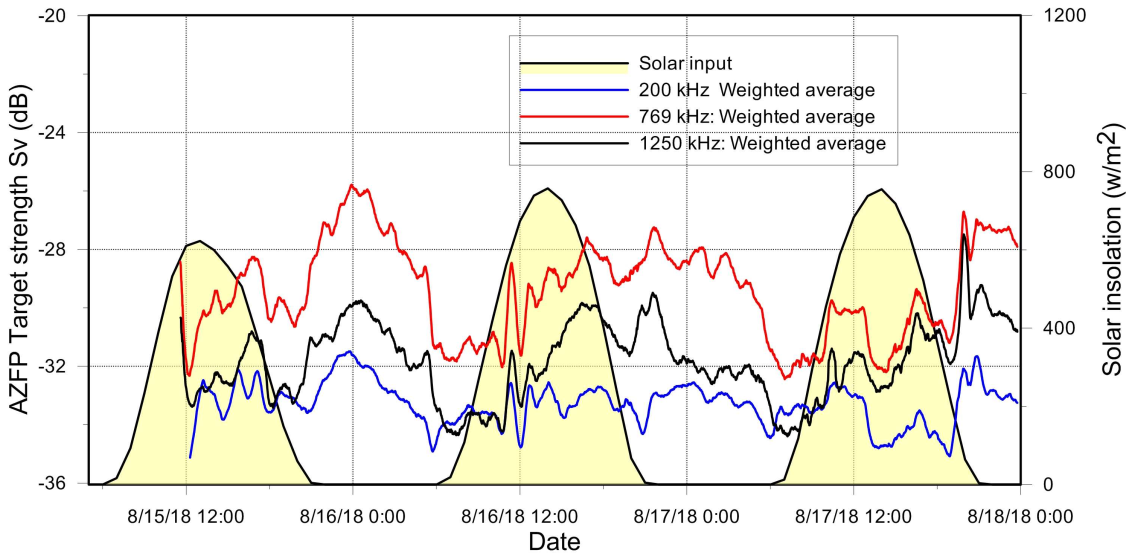

Figure 47. Horizontal backscatter slices vertically integrated to observe target strength.

8.0 Aquatech Fine Bubble Aeration Installation

Discussions about adding aerations at Swan Lake have been ongoing over the years. As hypoxic conditions appear to be an annual event, it has become increasingly important to develop strategies to offset this late summer trend. This past year Allan Tweten of Aquatech Environmental Systems Ltd. was contacted, and a small aeration system was designed to test at Swan Lake. A budget was agreed upon and the installation of two 50 foot aeration lines were placed and activated on September 18 at about 1:00 pm. The following photos show the aeration lines and their installation (Figure 48–51).

Figure 48. New aeration lines on boardwalk deck.

Figure 49. Air line manifold.

Figure 50. Air line deployment.

Figure 51. One of two aeration lines showing the gentle convective bubble streams.

The Aquatech 02B2 linear aeration system (Figure 52) utilizes a double row of fine bubbles that gently rise through the water column to promote mixing and the reduction of thermal and dissolved oxygen stratification. This means that fish and other organisms can thrive throughout the water column. The slow rise rate of these small bubbles (less than one foot per second) also cools the water column and increases contact time with oxygen allowing more oxygen to be transferred to the water.

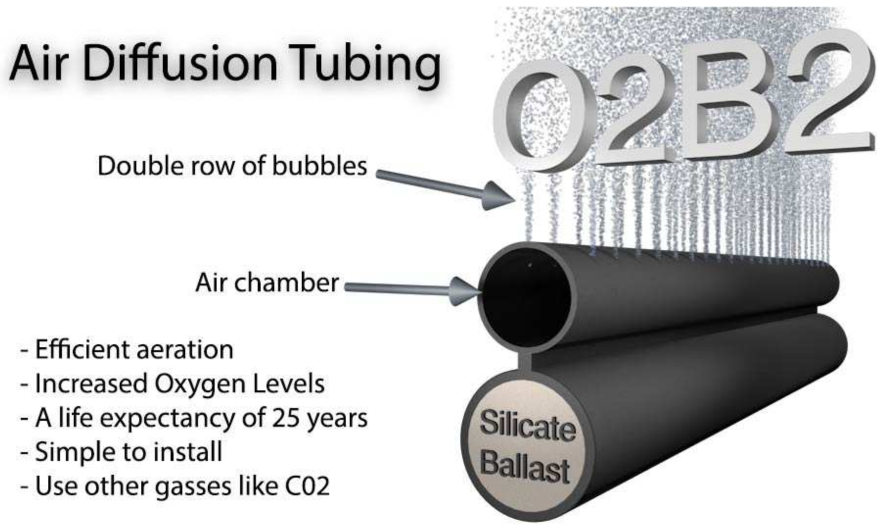

Figure 52. Aquatech O2B2 aeration tubing (source: Aquatech website).

For more information about the Aquatech O2B2 system please view the following links:

http://aquatechenvironmental.com/
https://www.youtube.com/watch?time_continue=2&v=5ShvGufOoag

8.0 FlowCam

A FlowCam was used to analyze a water sample taken on June 14. Potential collaboration with UVic who have a FlowCam in their lab that they are not presently using are being pursued for next year's study. Figure 53 shows the results of a single sample taken from Swan Lake.

Figure 53. FlowCam images of organisms at Swan Lake.

9.0 Conclusions

Of the eight years of data collected over the past 31 years, this year had the most extreme and prolonged hypoxic event. Climatic influences continue to play a role in water quality at Swan Lake as summer drought and extreme wildfire smoke strain the natural resilience of the lake. It is apparent that there is a decline in biodiversity as the hypoxic event only resulted in a small number of dead fish. Despite oxygen levels dropping below tolerance levels, there were no dead catfish or sunfish as were observed in September of 2017 during a shorter hypoxic event.

Duckweed blooms are becoming quite common including many intervals in August, September and at the beginning of October where the entire lake is covered with a thick blanket of duckweed that impedes sunlight penetration. Seasonal patterns now observed over several years show the highest DO concentrations and pH in the months of June and July followed by a decline to hypoxic conditions by mid to late August. This decline coincides with a diminishing concentration of phosphorous. Dissolved oxygen logger data clearly show a diurnal cycling of oxygen production through photosynthesis during daylight hours followed by a decline of DO through plant respiration.

The AZFP proved useful as it tracked the vertical migration of the AFA in the water column. Backscatter data showed the AFA increased its target strength during the night. As O_2 levels began to decline, AFA target strength increased. Vacuoles fill with gases as carbohydrates are consumed during the night.

As hypoxic conditions appear to be an annual event, it is hoped that the aeration lines will provide refuge areas for fish and other mobile organisms during late summer hypoxic onset.

10.0 Recommendations

To improve the understanding of the biological systems at work at Swan Lake, a number of recommendations are included below.

Obtain a fishfinder/sonar to detect fish presence and abundance. In addition to fish detection, carry out a bathymetric survey to map lake bottom and classify aquatic plant life.

Add the ability to measure CO_2. CO_2 is an essential element for photosynthesis as well as a controlling compound for the production of carbonic acid and bicarbonate, both of which influence the pH.

Monitor the influence of the aeration system and contrast it with water properties outside of the influence of the bubbles.

Add a solar light detector at depth to measure light penetration.

Establish a relationship with the UVic lab for access to the FlowCam (phyto/zooplankton imager).

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