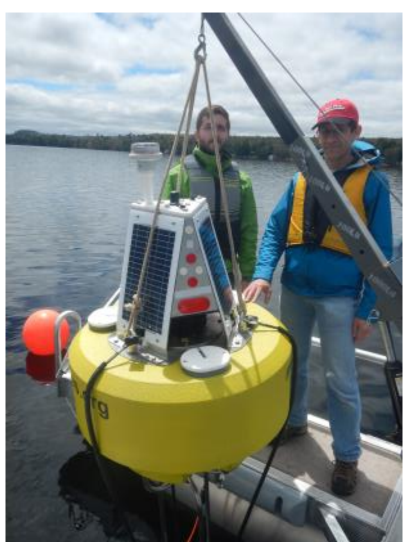
Lakes Environmental Association
2018 Water Testing Report

Chapter 2—High Resolution Automated Monitoring Buoys



LEA's Automated Testing Buoys

Each year, LEA deploys two fully automated monitoring buoys – one on Highland Lake and one on Long Lake. These buoys collect water quality information at 15-minute intervals throughout the spring, summer, and fall. This data is transmitted to us in real time, so we can see conditions change on the lake as they happen. The goals of LEA's testing buoy program are to better understand the condition of our lakes, to raise awareness of water quality issues locally, and to contribute to worldwide research and knowledge on lakes.

The Highland Lake Buoy

The Highland Lake buoy was first deployed in 2014 and contains temperature and oxygen sensors at 2-meter intervals from the surface of the lake to near the bottom. It also contains two solar radiation sensors and a chlorophyll sensor, as well as a small weather station for measuring precipitation, barometric pressure, relative humidity, wind speed and direction, and air temperature. The Long Lake buoy was first deployed in August, 2016. Like the Highland Lake buoy, it contains oxygen and temperature sensors at 2 meter intervals. It also has chlorophyll sensors located at three depths. Both buoys contain three 10-watt solar panels and a rechargeable battery as their power supply.

The advantages of these buoys are that they automate and enhance the water quality monitoring process. Using traditional (manual) water testing techniques, we are only able to collect data once every two weeks from each lake, usually around the same time of day. In contrast, the buoy automatically collects readings from each sensor at 15-minute intervals, resulting in 96 readings for each parameter every day. We are also able to leave the buoy in the water over a longer period of time than the traditional monitoring season. The wealth of additional data provided gives us a much more detailed picture of what is happening in the lake at any given time.

The information collected by the buoys allows us to better understand lake dynamics throughout the growing season. The combined and simultaneous measurements of water temperature, dissolved oxygen, algae, and weather conditions lets us see the effects of wind and precipitation events in real time, thus allowing us to better interpret how these factors affect lake conditions.

Another aspect of the buoy program is our ability to collaborate with researchers on a larger scale by sharing ideas and methods and contributing to research. Buoys similar to LEA's can be seen in lakes throughout New England and the world. An international organization called GLEON (Global Lake Ecological Observatory Network) helps to connect researchers that collect and use lake data, particularly from automated monitoring buoys, for a variety of projects. GLEON's mission is "to understand, predict, and communicate the impact of natural and anthropogenic influences on lake and reservoir ecosystems."

LEA could not have purchased either buoy without a great deal of support from several sources. The Highland buoy was funded by a grant from an anonymous foundation and contributions from landowners around Highland Lake. The Long Lake buoy was funded by a very generous donation from a resident of Long Lake, foundation funding, and contributions from lakefront landowners. LEA worked closely with Colby College professor Dr. Whitney King and Fondriest Environmental to design and set up the buoys.

Deployment

The 2018 buoy deployments started with the Long Lake buoy on May 24th, followed by the Highland Lake buoy, which was installed on June 7th (three weeks later than in 2017). The Highland buoy needed replacement temperature and oxygen sensors, and the installation and configuration of that equipment contributed to the delay. Both buoys were in place recording data until early November, when they were removed from the lakes (November 9th for Highland, November 12th for Long). The sensors were cleaned and calibrated on site several times throughout the deployment period. The Highland buoy's modem had to be replaced early in the season, but there was no loss of data. Together, both buoys collected over 31,000 complete sets of sensor readings during their time on the water.

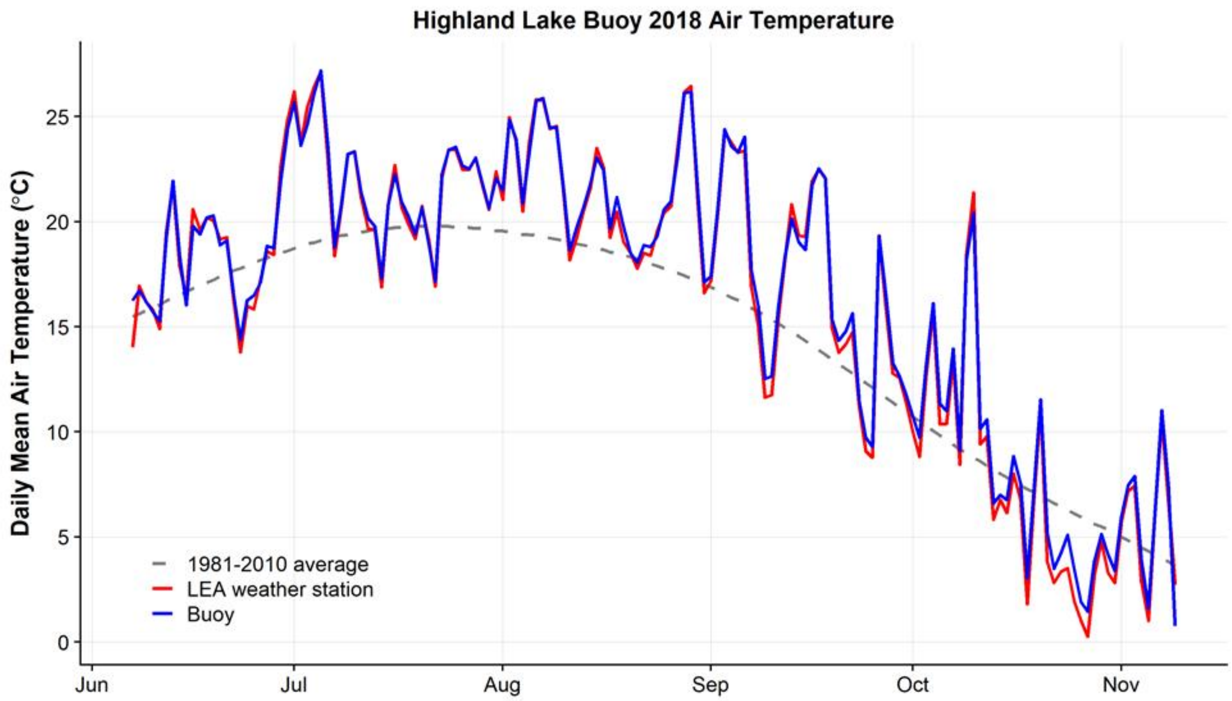
The Long Lake Buoy

2018 Results

The report begins with a summary of weather conditions that contributed to the temperature, oxygen, and chlorophyll patterns seen on each lake in 2018. Individual reports generated from each buoy's data begin after the weather summary.

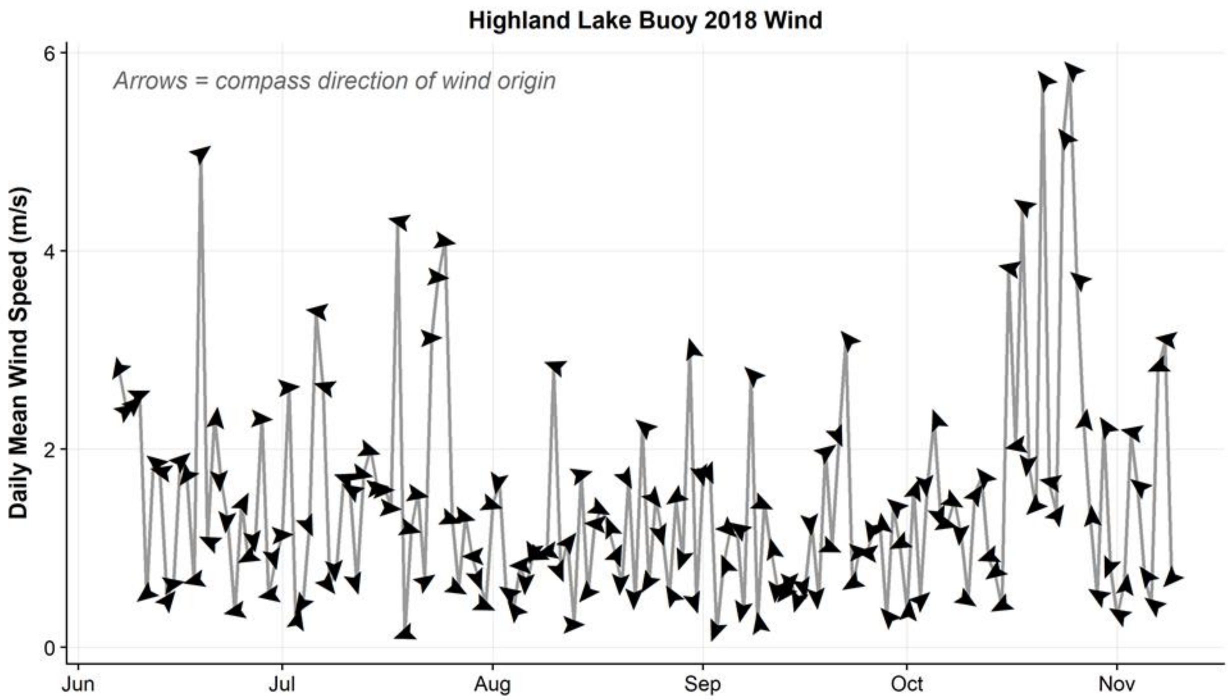
Both lakes showed remarkably similar temperature patterns, despite differences in overall size and shape between the two lakes; both lakes mixed within two days of each other. Anoxia (absence of dissolved oxygen) affected both lakes in 2018, but as in previous years, Highland Lake developed anoxia sooner than Long Lake (mid-July as opposed to the beginning of September). Chlorophyll fluorescence in Highland Lake was relatively low throughout the deployment, with somewhat higher readings during the late spring and fall. Long Lake chlorophyll fluorescence was higher in general, with maximum values often seen at the deeper sensors.

Meteorological Conditions over the 2018 Season



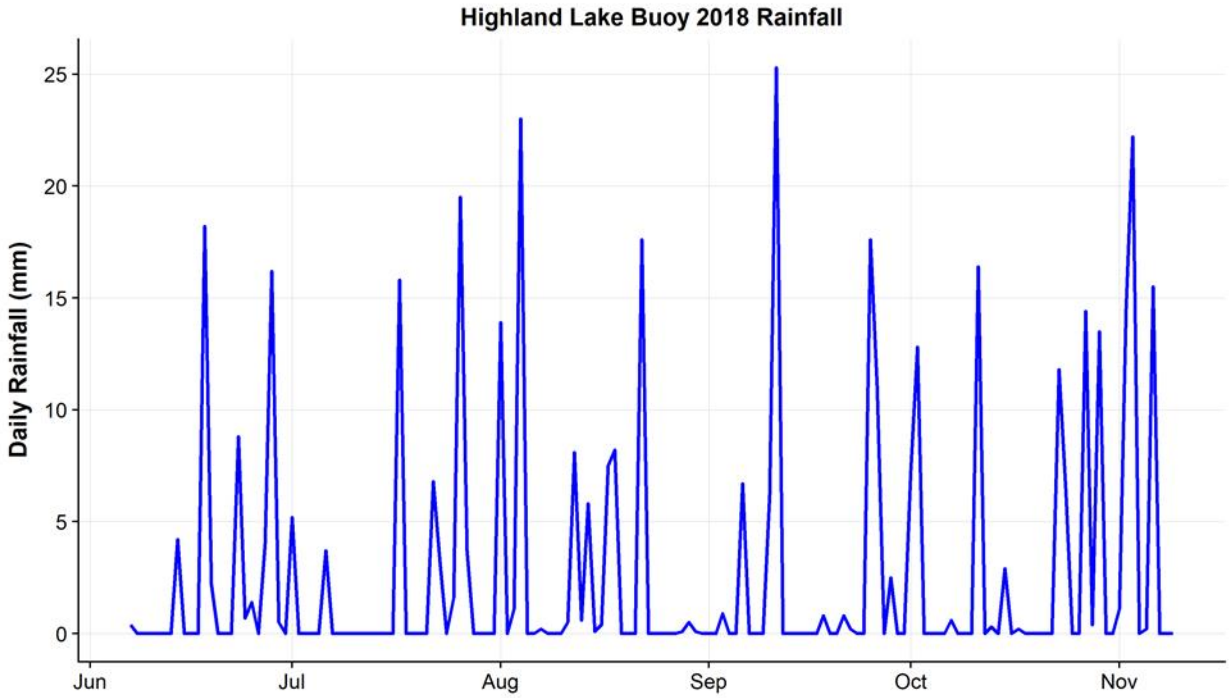
Local weather conditions (air temperature, wind, rain) play a major role in controlling lake water quality. The meteorological sensors on the Highland Lake buoy collect weather and water data simultaneously, and in this section we summarize the weather results. Because the two lakes are geographically close together, the Highland Lake weather data are applicable to Long Lake as well. Air temperature is important for understanding the heating and cooling of lake water. The above air temperature data (blue line) followed a typical seasonal pattern, but was higher than average temperatures for this area (1981-2010, gray dashed line) for much of the record, especially during the summer months. Air temperature readings on the buoy ranged from -1.3 to 32.9 °C (29.7 to 91.2 °F). Our nearby weather station (red line) near the east shore of Highland Lake recorded almost identical readings, differing only in the extreme values (maximum temperature recorded was 34.0 °C or 93.2 °F), which shows how lake water can have a moderating influence on the overlying air temperature.

Meteorological Conditions over the 2018 Season, Continued



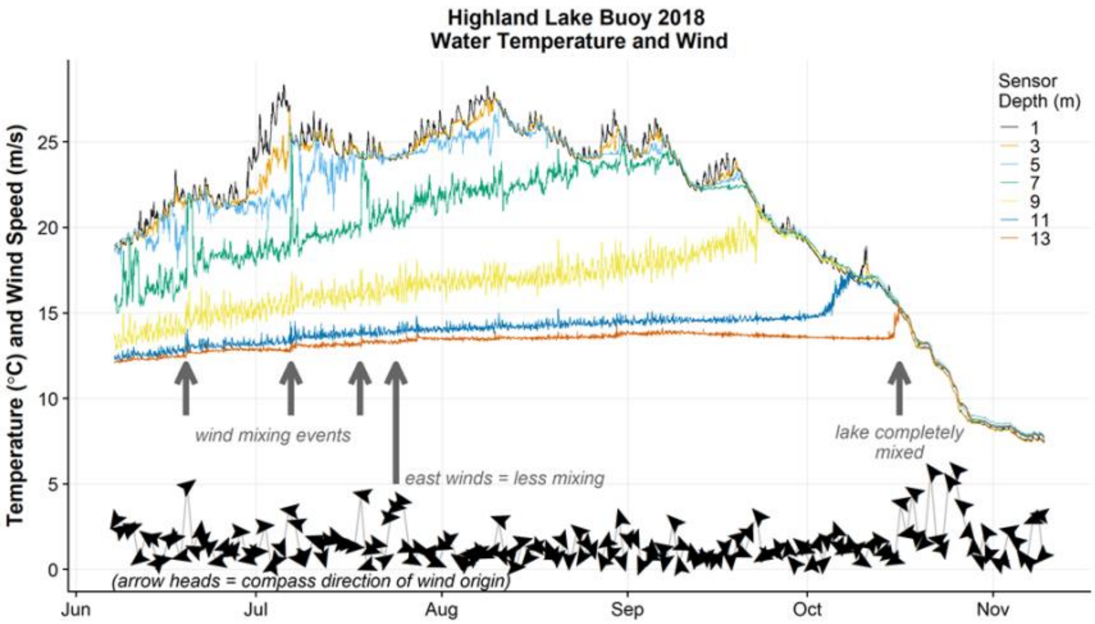
Wind also has a significant impact on conditions within a lake. Together with temperature, wind can control the physical structure of a lake, like the change from being stratified to being fully mixed. Wind speed and direction measurements recorded by the buoy were quite variable at the 15-minute and hourly scale, so broader scale patterns were examined using daily mean values. In the figure above, the height of the arrow head denotes the mean wind speed and the direction the arrow head points is the compass direction (north = straight up) from which the wind is blowing, like a weather vane. Daily mean wind speed ranged from 0.12 to 5.8 m/s (0.24 to 13 mph). The buoy recorded a maximum wind speed of 16.7 m/s (37 mph) on October 16th. Wind direction varied over the course of the season, though for many of the days with stronger winds (> 2 m/s), the winds came from more northerly directions. A notable exception to that was in late July when winds blew from the east for three days.

Meteorological Conditions over the 2018 Season, Continued



Rain supplies water to a lake, but sediment and nutrients can be delivered along with it, depending on rain amount and intensity. Total rain recorded by the buoy during the deployment was about 416 mm (16.4 in), quite a bit less than the 30-year normal rainfall of 612 mm (24.1 in) for May through October. This was drier than the same period in 2017, though more precipitation fell in all of 2018 than 2017. Rainfall events occurred fairly regularly throughout the period, and no single day total exceeded about 25 mm, or one inch, of rain. The most time without rain was 10 days in July. High intensity storm events have the most impact on water quality because of the erosion and pollution potential. In mid-June, the buoy recorded a maximum reading for rain intensity of 39.3 mm per hour (1.55 in/hr), though most of the time when rain fell, it was at about 2 mm/hr.

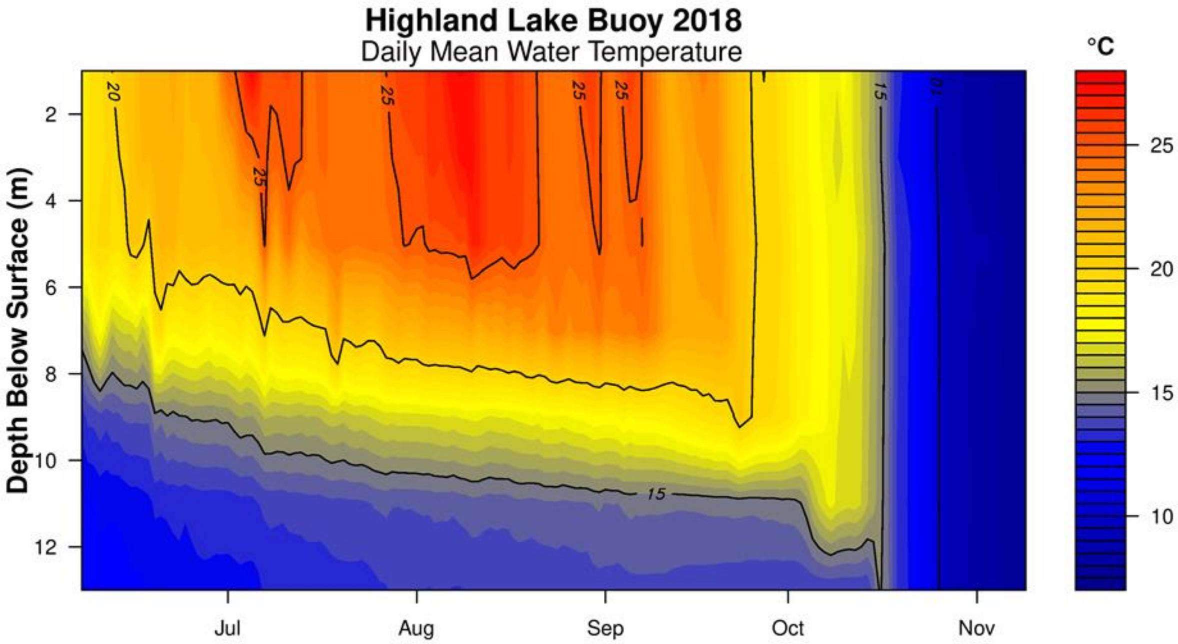
Highland Lake



Data from the individual temperature sensors, along with daily winds, are shown in the above figure. Each colored line represents water temperature at a specific depth below the surface at a 15-minute interval. The maximum recorded temperature on Highland Lake was 28.4 °C (83.0 °F) on July 5th, and the minimum temperature was 7.4 °C (45.3 °F) right before the buoy was removed for the season. Daily heating and cooling of the surface water can be seen by the saw-tooth pattern of the 1 m sensor data. Temperature variation was more irregular and sometimes greater in the middle of the water column due to the "sloshing" of internal waves (or seiches). Stratification (indicated by wide spaces between lines) had already occurred at the beginning of the deployment and partial mixing (lines getting closer together) happened throughout the season, especially at times of high winds. Good examples of this can be seen on June 19th, July 7th, and July 18th, when the temperature readings as deep as 7 m increased to surface values following strong winds. Interestingly, the strong easterly winds later in July did not have a similar effect on mid-water temperatures because the wind imparts less energy across the shorter east to west lake dimension compared to the longer north to south dimension (also called fetch). Surface waters started cooling in August and September, which reduced the resistance to mixing in the water column. Complete mixing occurred on October 16th following significant wind events that continued through the latter half of October. This turnover date was much earlier than in 2017, but closer to the previous years' mixing dates (see table below). By comparison, Long Lake mixed completely just two days later than Highland Lake.

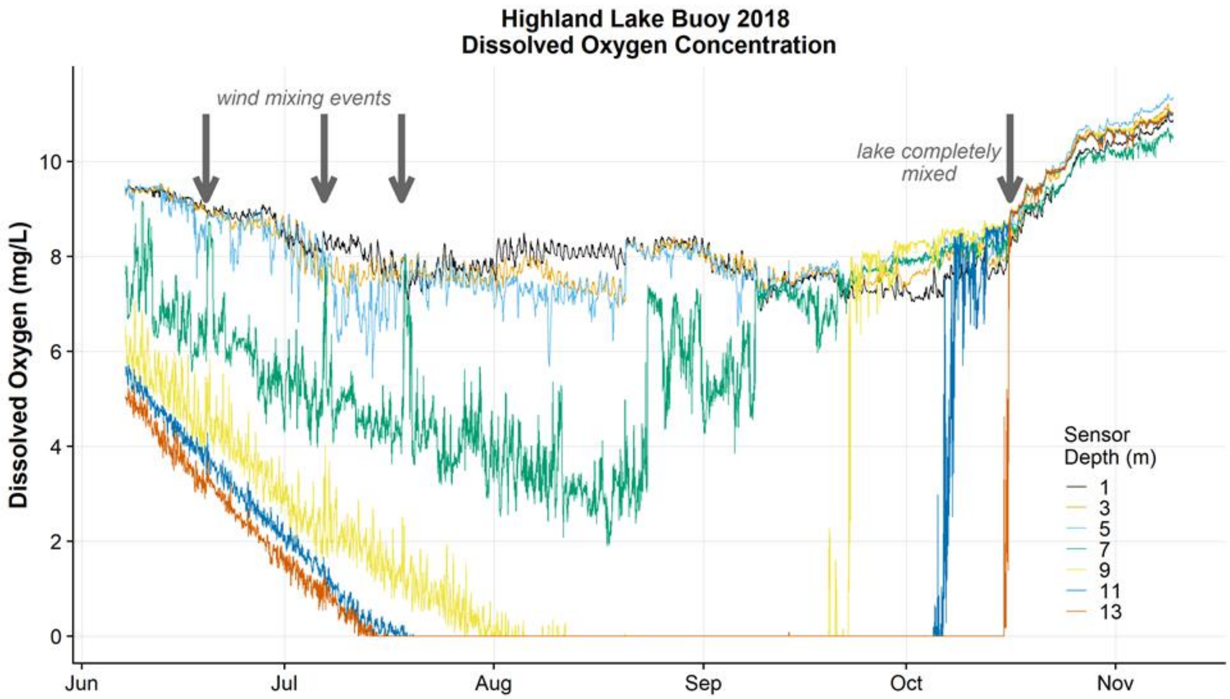
Date of Fall Turnover (Complete Mixing) by Year						
LAKE	2013	2014	2015	2016	2017	2018
Highland Lake	after 10/11	10/12	10/11	10/10	11/4?	10/16

Highland Lake



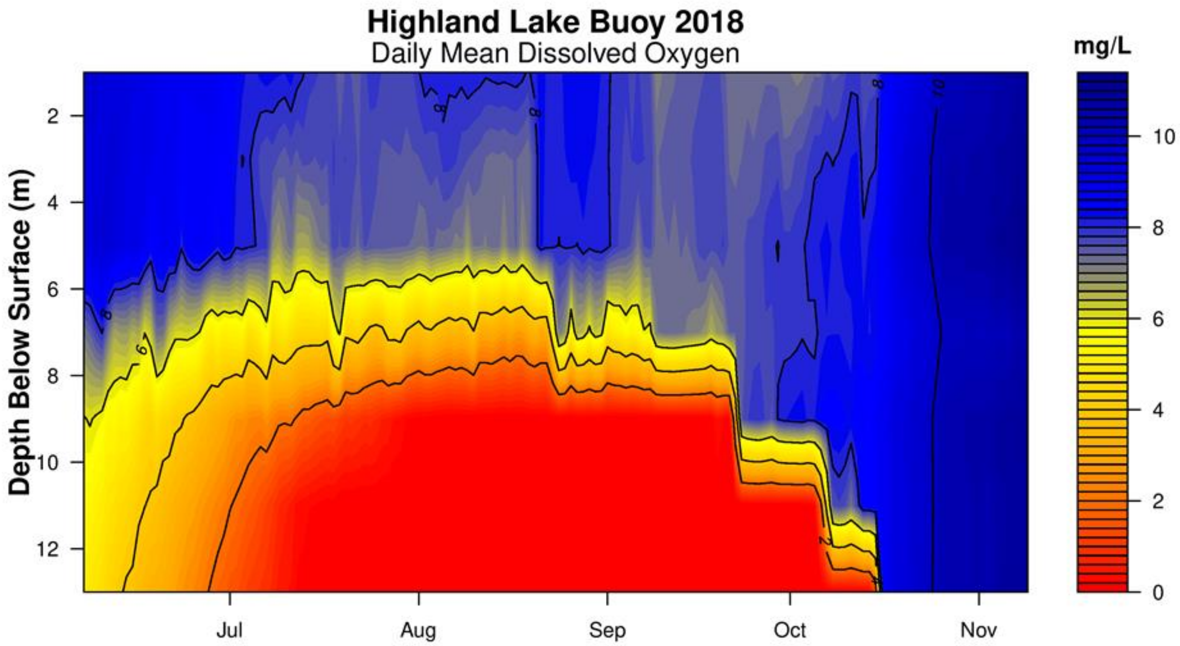
Another, perhaps easier way to visualize the temperature data is with contour plots (or heat maps). In the above figure, which uses daily mean values, temperature across depth and time is represented by colored contours, where the red to yellow to blue color range corresponds to a high to medium to low temperature range. Temperature stratification shows up as areas of the plot where colors change from lake surface to bottom and contour lines are roughly horizontal (from June through early October). Where the contours come closest together is often referred to as the thermocline. Vertical contour lines indicate mixed conditions, and areas of a single color from top to bottom (such as November) indicate completely mixed conditions. The effect of wind, like the June and July events previously discussed, can be seen as dips in the contour lines. Warm, stratified conditions stand out as darker red areas in July through early September. The downward sloping contours show that the upper layer (epilimnion) deepened throughout the summer. The graph also illustrates how, despite stratification, the lower layer water (hypolimnion) gradually warmed over time until the lake mixed in the fall. Temperature distribution information is critical for knowing where suitable fish habitat is and for knowing when phosphorus-laden bottom waters might be mixed to the surface.

Highland Lake



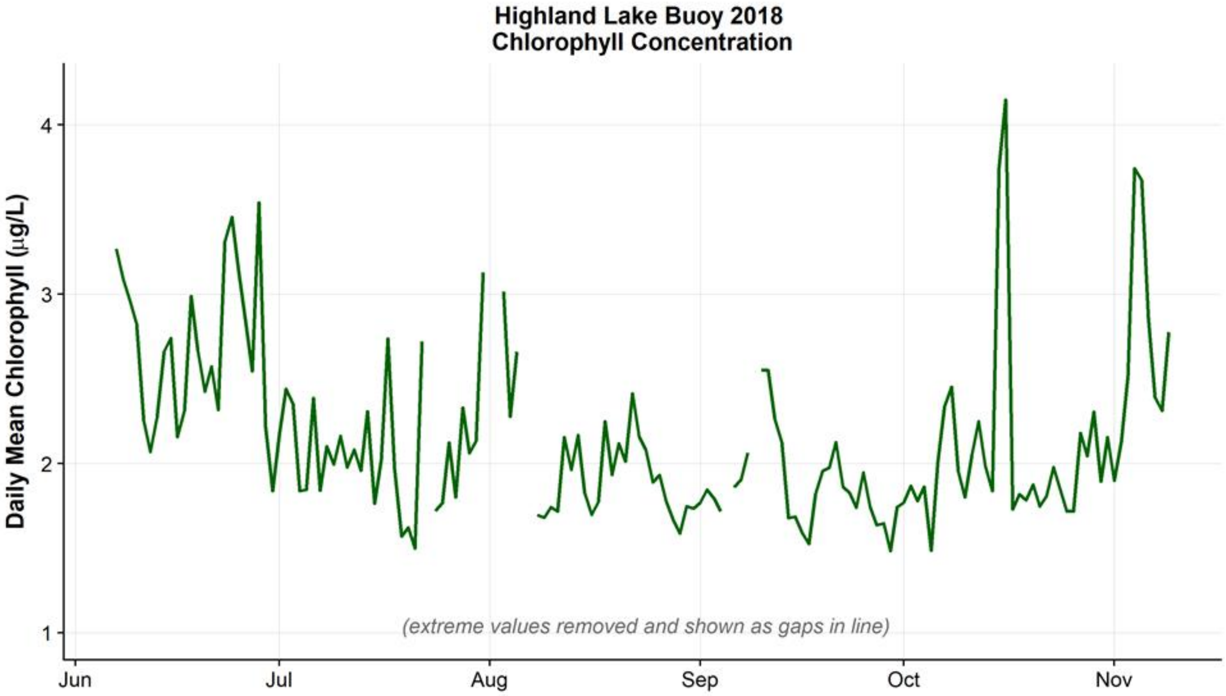
The same types of plots used for temperature can be used to examine dissolved oxygen (DO) data from the buoy. The figure above shows a pattern of generally decreasing DO from the start of the record through early fall. Some of that is simply due to warming water, since cold water can contain more DO than warm water, all else being equal. Oxygen in the deeper waters, however, decreased more rapidly. This is due to biological consumption (animals and bacteria using oxygen) and the lack of aeration (wind mixing) because of stratified conditions; by mid-July, deep DO readings reached zero (anoxia). The effect of wind mixing on oxygen is also visible in the figure at mid-water depths (e.g., rapid increases in 7 m DO in mid-June and early and mid-July). The daily warming-cooling cycle, the daily cycle of photosynthesis and respiration, and the back and forth rocking of internal waves are responsible for the smaller variations in DO concentration. By mid-October, the water column was completely saturated with oxygen after temperatures dropped and winds fully mixed the lake.

Highland Lake



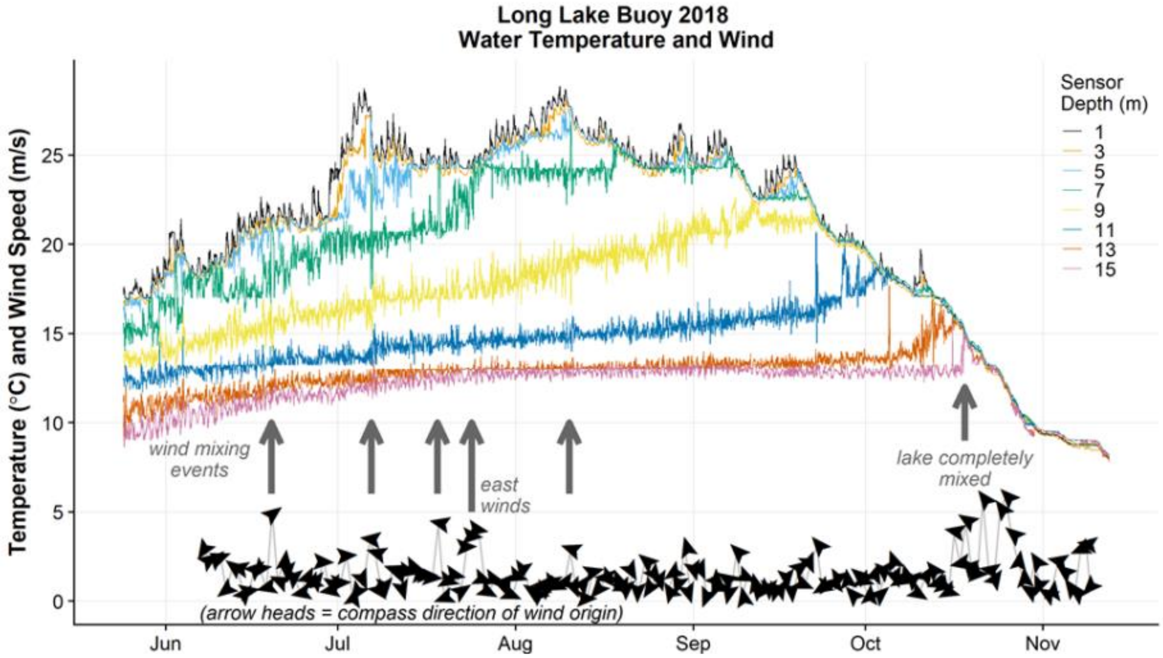
Another way to illustrate the buoy dissolved oxygen (DO) data is with depth-date contour plots, though in the above figure we have reversed the color scheme used for temperature so that red and blue signify low and high DO, respectively. The contour plot highlights nicely the pattern of lower DO concentrations in summertime deep waters and provides a quick visual gauge of where and when hypoxic (< 2 mg/L) conditions occur. As was seen in the previous line plot, Highland Lake bottom water became anoxic (DO = 0) starting in mid-July and remained so until mid-October, when the water column mixed completely. Prior to that, more minor wind mixing events can be seen in the downward dips in the DO contours. Besides wind and water temperature, the major control of lake water DO concentrations is biological activity (i.e., respiration and photosynthesis). Oxygen is a byproduct of photosynthesis, so actively growing algae can increase DO concentrations. On the other hand, lake water DO is reduced when microbes, fish, and plants respire or “breathe”. When the lake is stratified, oxygen in the bottom layers cannot be replenished easily, leading to first hypoxia, then anoxia. Fish tend to avoid and are stressed when moving through areas that have DO concentrations below about 4 mg/L, while anoxic bottom waters allow phosphorus stored in sediments to be released for use by algae; these phenomena highlight the importance of collecting DO data.

Highland Lake



The Highland buoy contains one sensor mounted 1.5 m from the lake surface that measures chlorophyll concentrations using fluorescence. The amount of this pigment (found in all plants and algae) can be used as a proxy for algae biomass and as a measure for the productivity of a lake. However, it is important to note that field fluorescence is a relative measure, and is not as accurate as lab-based chlorophyll measurements. Daily mean chlorophyll, shown above, fluctuated between 1.5 and almost 4 µg/L, with generally higher readings in spring and fall. There were the occasional extreme peaks in late July, early August, and early September, though these were removed from the plot for clarity. In most cases these peaks were the result of only one or a few extreme readings in the raw data, which suggests a sensor error or biofouling problem. Submerged equipment often gets coated with an algal film and it is possible some of that influenced the readings. The peaks could reflect algal growth, though had there been a real bloom at those times, the fluorescence data probably would have remained elevated for longer. Also, there were no obvious wind-driven mixing events at those particular times to have brought up enriching nutrients or viable algae cells from deeper waters. On the other hand, the chlorophyll peaks in October and November were associated with strong northwesterly winds and elevated rainfall around that time.

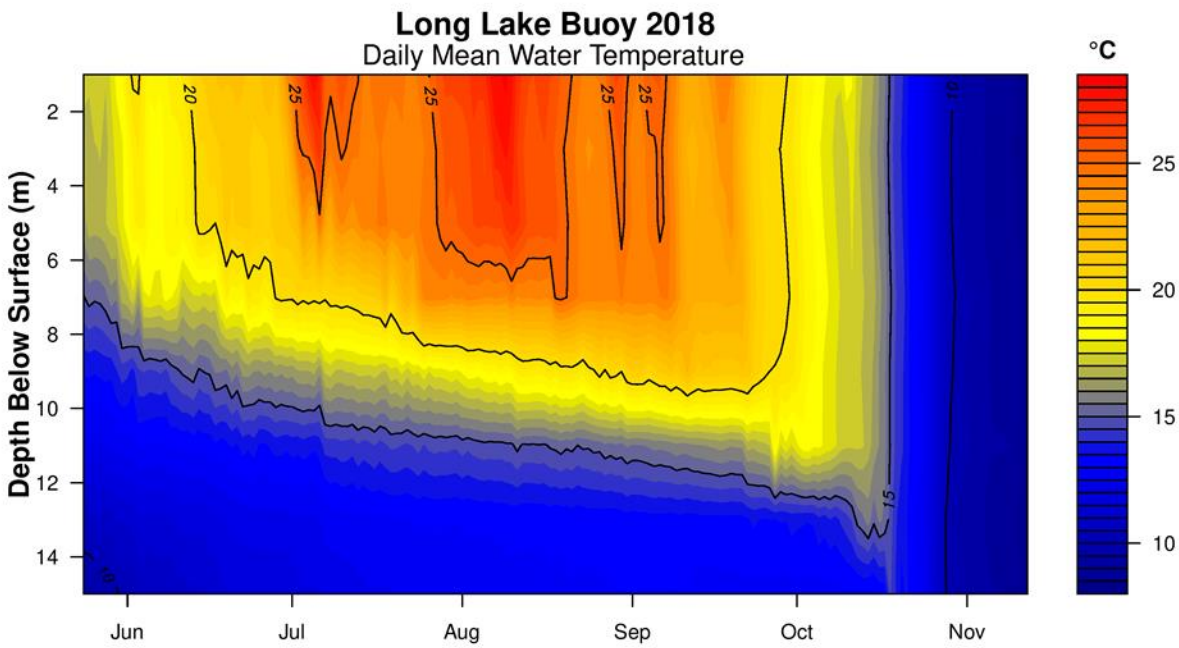
Long Lake (North Basin)



Data from the individual temperature sensors, along with daily winds, are shown in the above figure. Each colored line represents water temperature at a specific depth below the surface at a 15-minute interval. The maximum recorded temperature on Long Lake was 28.9 °C (84.0 °F) on August 8th, and the minimum temperature was 7.8 °C (46.0 °F) right before the buoy was removed for the season. Daily heating and cooling of the surface water can be seen by the saw-tooth pattern of the 1 m sensor data. Temperature variation was more irregular and sometimes greater in the middle of the water column due to the "sloshing" of internal waves (or seiches). Stratification (indicated by wide spaces between lines) had already occurred at the beginning of the deployment and partial mixing (lines getting closer together) happened throughout the season, especially at times of high winds. Good examples of this can be seen for June 19th, July 7th and 18th, and August 10th, when the temperature readings as deep as 7 m rapidly and briefly increased to surface values following strong winds. Three days of strong easterly winds later in July did not have as strong of a mixing effect, though temperature at 7 m did eventually warm to surface values. This is likely because the wind imparts less energy across the shorter east to west lake dimension compared to the longer north to south dimension (also called fetch). Surface waters started cooling in August and September, which reduced the resistance to mixing in the water column. Complete mixing occurred on October 18th following significant wind events that continued through the latter half of October. This turnover date was much earlier than in 2017, and even a bit earlier than other known mixing dates (see table below). By comparison, Highland Lake mixed completely just two days prior to Long Lake.

Date of Fall Turnover (Complete Mixing) by Year						
LAKE	2013	2014	2015	2016	2017	2018
Long Lake North	10/25	10/23	No Data	No Data	11/4	10/18

Long Lake (North Basin)



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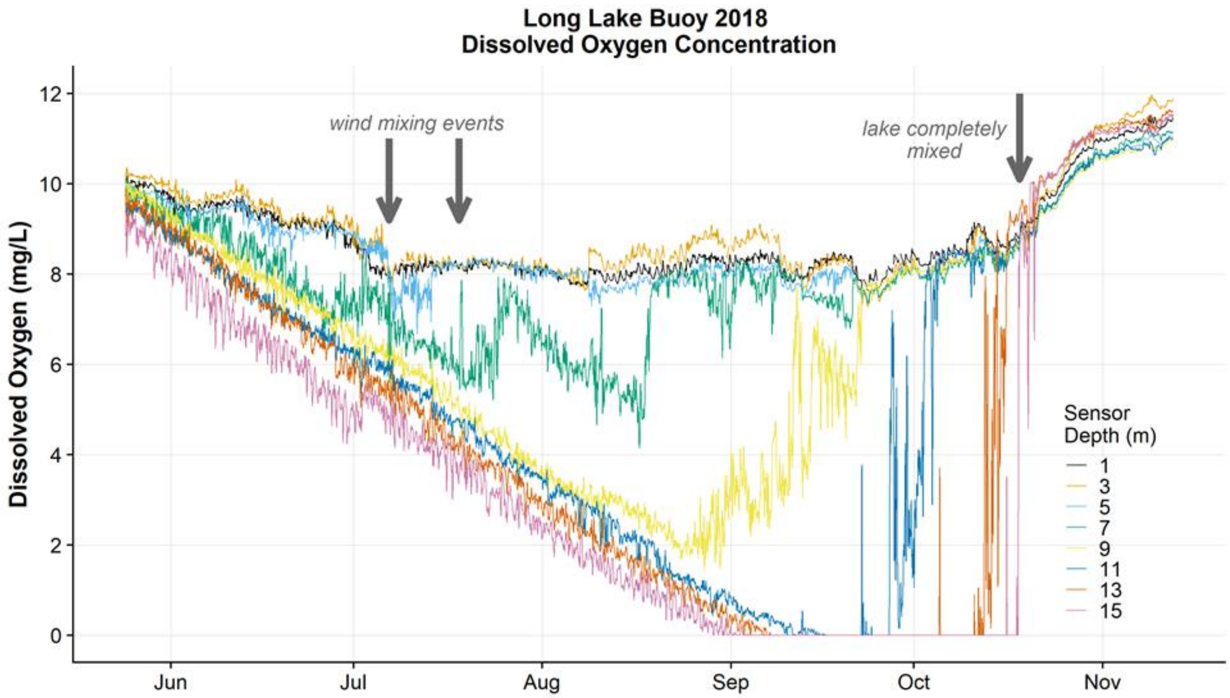

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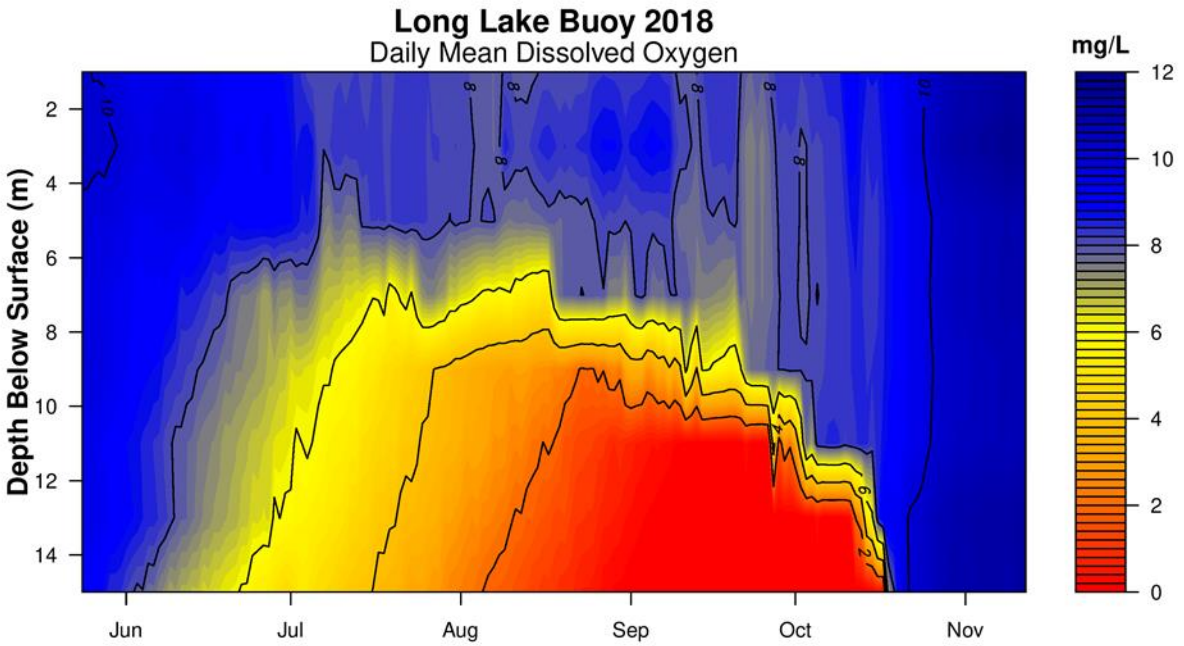

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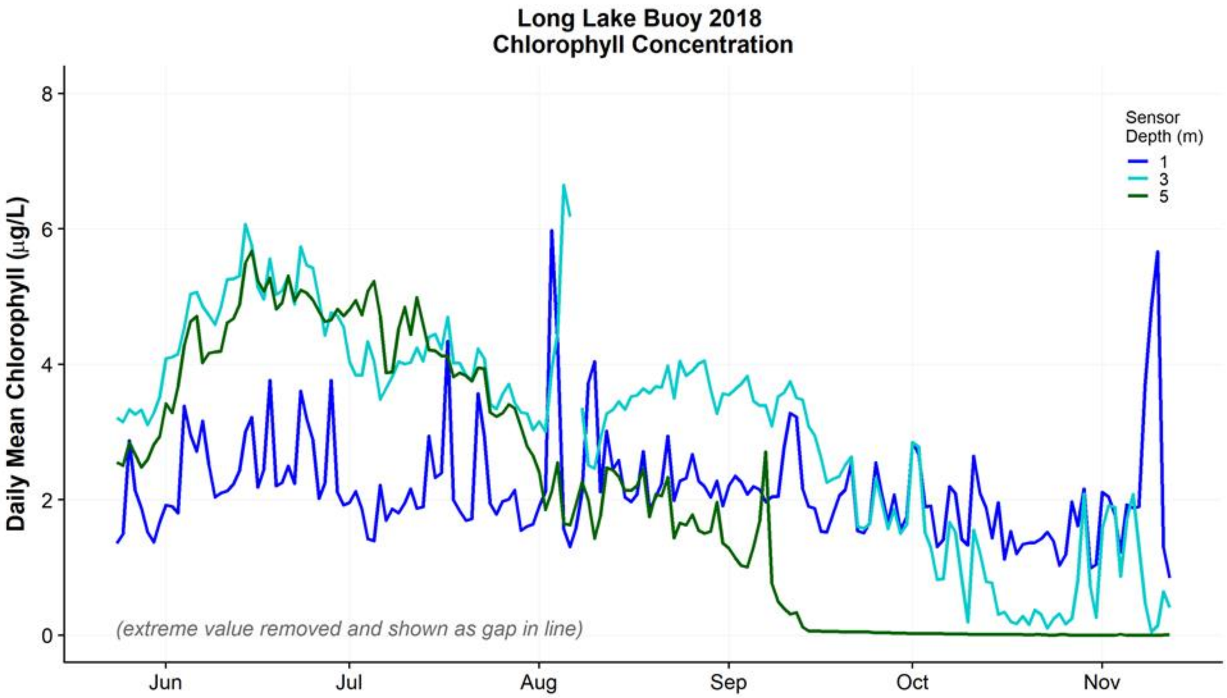
Long Lake (North Basin)



The Long Lake buoy contains sensors at three different depths (1, 3, and 5 m) below the lake surface that measure chlorophyll concentrations using fluorescence. The amount of this pigment (found in all plants and algae) can be used as a proxy for algae biomass and as a measure for the productivity of a lake. It is important to note, however, that field fluorescence is a relative measure and is not as accurate as lab-based chlorophyll measurements. For Long Lake, daily mean chlorophyll at 1 m fluctuated around 2 µg/L throughout the deployment except for peaks in early August and November. The sensors at 3 and 5 m recorded higher chlorophyll than the 1 m sensor during June, July, and some of August and September. This indicates an unequal distribution of algae throughout the water column, which could be caused by algae moving to or growing better at depths with lower light levels. We are not sure what happened to the 5 m sensor in September and it will need testing for next season. Also, there was one extreme peak at 3 m in August that was removed from the record. This extreme mean value was caused by a few, extra-high readings in the raw data, which suggests a sensor error or biofouling problem. Submerged equipment often gets coated with an algal film and it is possible some of that influenced the readings. The peaks could reflect algal growth, though had there been a real bloom at those times, the fluorescence data probably would have remained elevated for longer. Also, there were no obvious wind mixing events at that particular time to have brought up enriching nutrients or viable algae cells from deeper waters. On the other hand, the November chlorophyll peak was associated with elevated rainfall around that time.