Lakes Environmental Association
2019 Water Testing Report

Chapter 5—Spatial Water Quality Mapping

Spatial Water Quality Mapping Project

Introduction and Rationale

For decades, traditional lake monitoring programs have focused on water quality characteristics measured at a single location in a specific water body. Monitors travel to the deepest part of the lake, deploy an anchor, and collect all measurements and samples from that location. Here, the lake is assumed to be most uniform and representative of conditions in the system as a whole.

This methodology is relatively simple and cost-effective, but the assumption that one site represents the whole lake is not often tested. Patchiness is a common phenomenon in natural lake systems and stems in part from localized nutrient and sediment inputs, rain and wind events, and variation in bottom topography. Quantifying the scale and importance of patchiness is not easy to do and can be costly if replicating the traditional, single-site protocol at multiple locations around a lake.

An alternative is to use a multi-parameter sonde in a boat-mounted, flow-through configuration to collect water quality data all over the surface of a lake. The resulting high-resolution data can then be analyzed and mapped yielding an estimate of spatial variation or patchiness. This type of spatial comparative assessment has been done by a few other researchers in the country, but the methodology is still fairly new and has not yet been utilized in Maine. With it, one could test the assumption that single station sampling provides representative data for an entire lake and also monitor shallow, high-use areas for "hot spots" of water quality problems. With the generous support of Patagonia and eight different lake associations, LEA staff used their version of a flow-through system to survey and map water quality conditions across ten different lakes in the LEA service area during the summer of 2019. We gratefully acknowledge the use of a boat and help with boat launching from Jim Button and Bruce Whichard.

Methodology

The flow-through system consists of a water intake (PVC tube with elbow) clamped to a boat's transom and facing forward at about 0.5 m depth. As the boat moves along, a battery powered pump pulls water from the intake and pushes it through a flow-through cup mounted on the end of a YSI multi-parameter sonde secured in the boat. The data logger connected to the sonde collects measurements of temperature, conductivity, dissolved oxygen (DO), pH, turbidity, chlorophyll, phycocyanin (a pigment in cyanobacteria), and GPS coordinates, once every second. For this report, we focus only on temperature, DO, turbidity, chlorophyll, and pH.

We started each survey with a slow transit of the lake perimeter as close to the shore as could be done safely. We then covered the remaining lake surface with back-and-forth transects. Surveys took from an hour and half (Back Pond) to over six hours spread over two days (Moose and Hancock Ponds). At the end of each survey, we collected a vertical profile of the same parameters from surface to near bottom at the deep site.

Close up of sonde in flow-through configuration

Collected data was downloaded and cleaned of missing or flagged values, outliers, and duplicate locations. Raw data was smoothed using a 10 s

moving average to reduce noise and account for lag in the flow system. Data analysis consisted of variogram modeling, which determines the spatial correlation of the observations. A random sample of the data (the lesser of 3000 points or 30% of the total) and ordinary kriging were used to interpolate each parameter over a regular 10x10m grid (5x5m for Back and Middle). The resulting grid was used to create maps for each parameter.

The intake for the flow-through system had a tendency to generate bubbles in the system particularly when transitioning from slow to high speed. We suspect cavitation from the pipe edge or the boat bottom as the cause and moved the intake around plus limited boat speed to reduce the problem. Air bubbles can cause spurious high readings for the turbidity sensor especially.

The boat track line can be seen sometimes in the interpolated data. We believe that it is caused by the high density of data along the line and relatively wide gaps between tracks. A possible solution would be to increase the density of track lines or perhaps find an interpolation method which can account for that issue;

Results and Significance

Surveys using the flow-through system have allowed us to detect definite patchiness across the surface of the study lakes. Some of the variation seemed to correlate with differences in depth or lake shape. In other cases, parameters varied in a gradient from one shore to the other. While still other patterns of spatial variation appeared to be more random.

Regardless of the pattern, the observed horizontal variation in these lakes during summertime conditions was small relative to variation in the vertical dimension. In other words, the amount each parameter changed from surface to bottom was often many times greater than the amount of change over the entire lake surface. This vertical difference was due to the thermal stratification and associated chemical changes in deep water that typifies summer conditions for most of these lakes.

It appears from this data that a single site monitoring program should do a good job at characterizing lake conditions and trends. While the maps do make it appear as if there were hot spots, the range was mostly very small. This was a single point in time, however, and spatial variation may be different during different seasons, or after extreme weather events. We hope to address this and other questions with future field work.

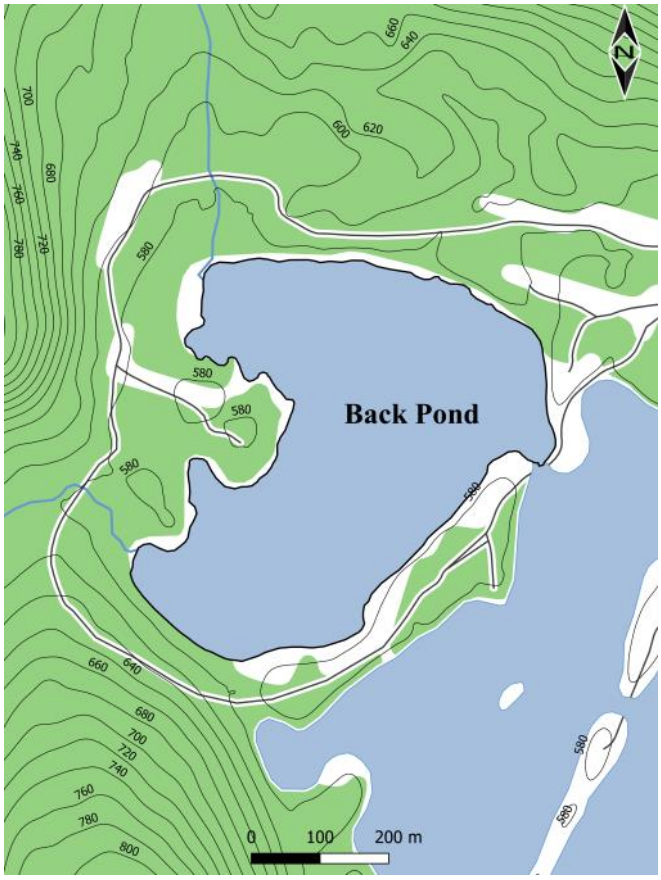
Lake Maps

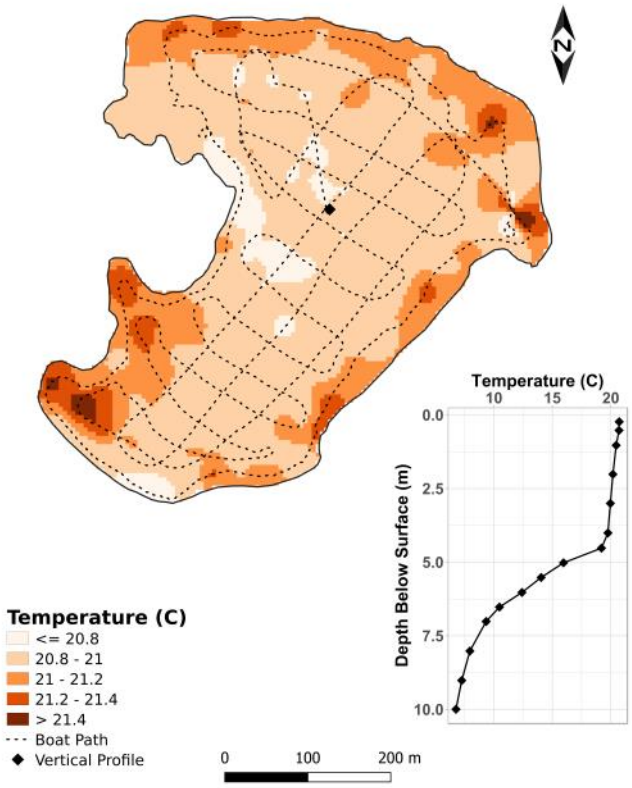
The following pages contain maps created from the interpolated flow-through data. Each map has an inset graph showing the vertical depth profile of the same parameter collected at the deep site (black diamond). The path of the boat during the survey is indicated by a dashed line on the temperature map; line color indicates specific day for two-day surveys. Range values determined from the variogram models was used to estimate patch size in meters for the different parameters.

Jake Moulton and flow-through system in action

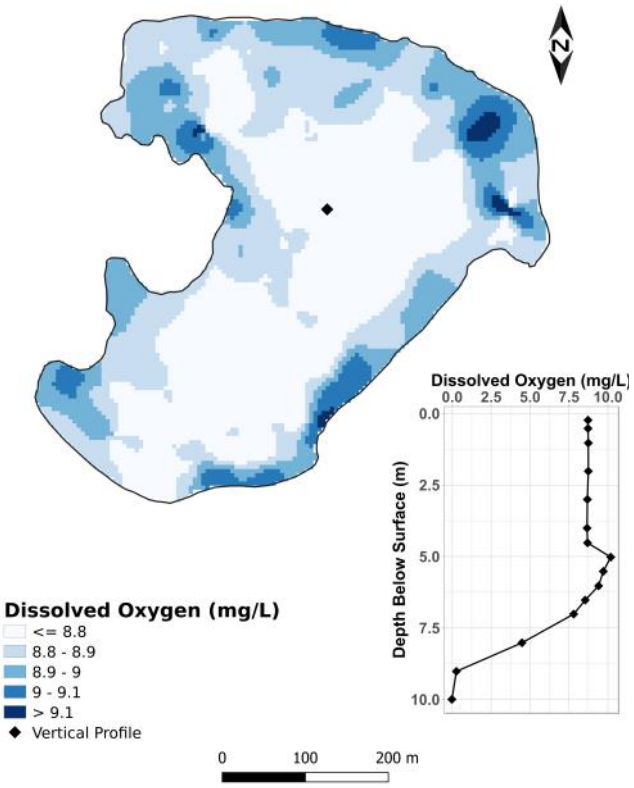
Back Pond - September 9, 2019

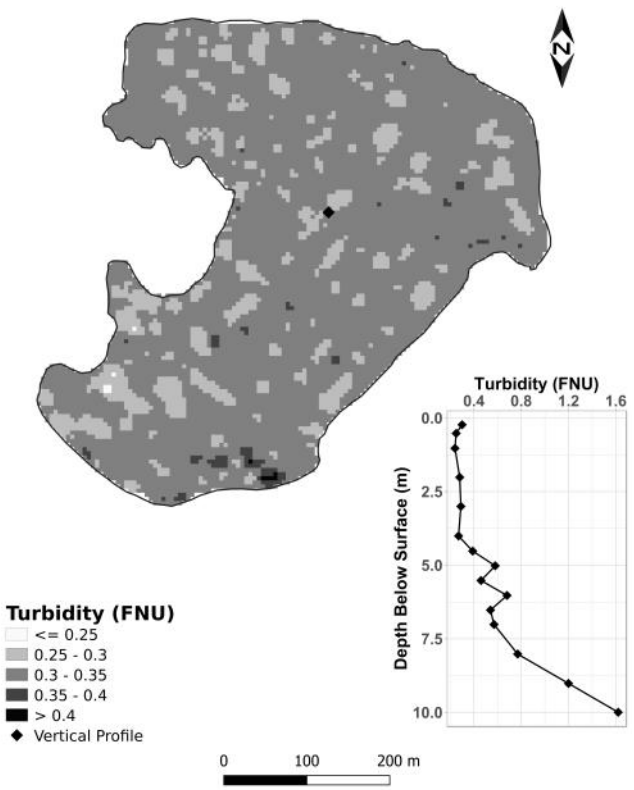
Back Pond was the smallest and last lake surveyed and the survey resulted in just over 5500 data points. Weather conditions were calm and mild and the survey took about one and half hours starting in the afternoon. Variation for all parameters was much greater with depth than across the surface. The more shallow lake perimeter was slightly elevated in temperature, probably due to more rapid heating of the smaller water volume in this area. Oxygen was also relatively elevated and above saturation (not shown) in the nearshore area and could be from aquatic plant photosynthesis. A similar correlation was not found for the hot spot of chlorophyll along the SW shore (note that it took ten times the surface chlorophyll to produce a noticeable increase in oxygen at 5 m depth). The slight increase in pH also could be explained by aquatic plant photosynthesis. Turbidity spatial pattern was mostly uniform. Patch size ranged from 10 to 56 m.

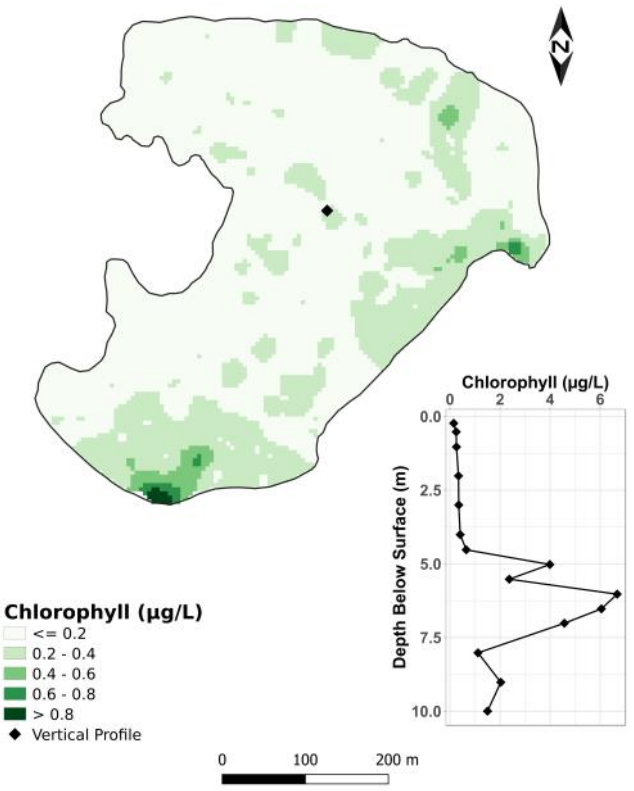


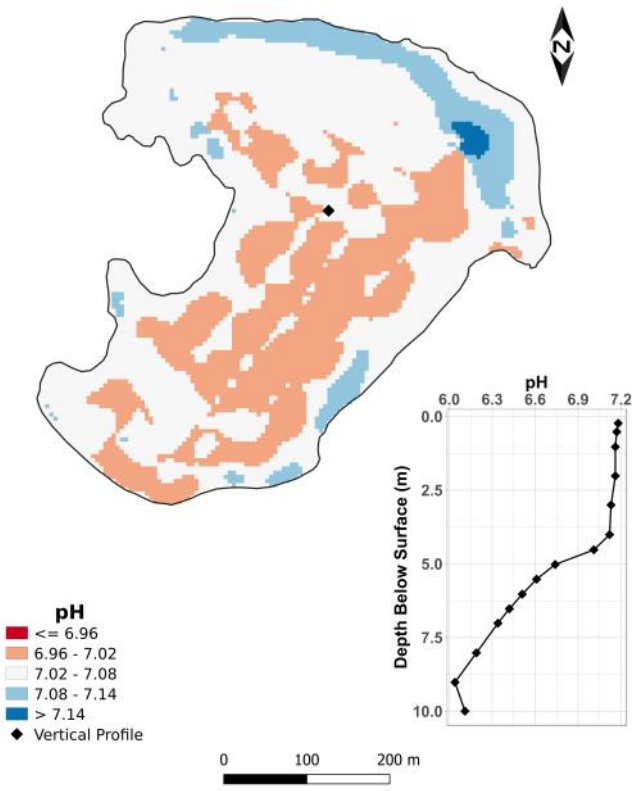


Back Pond - September 9, 2019



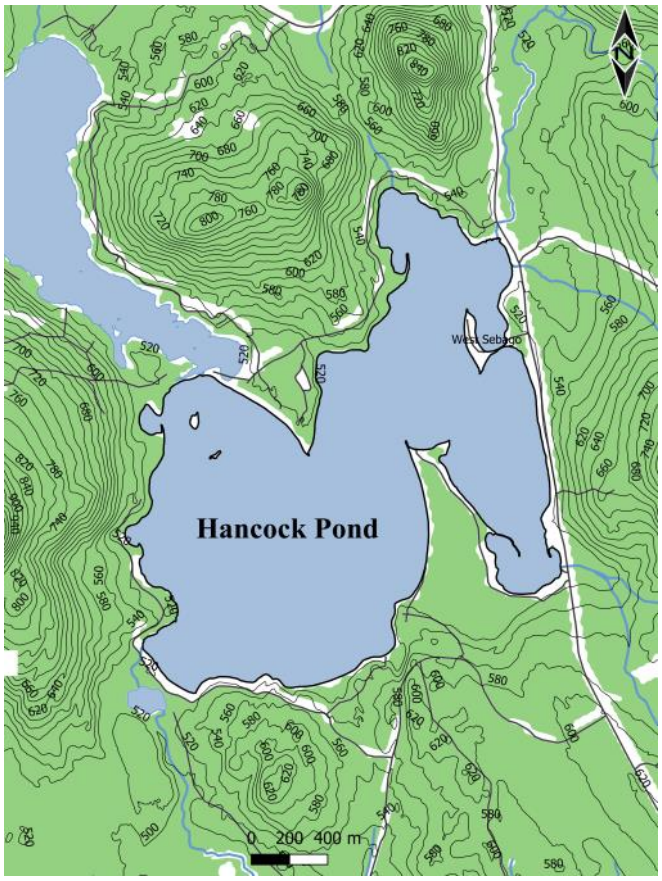


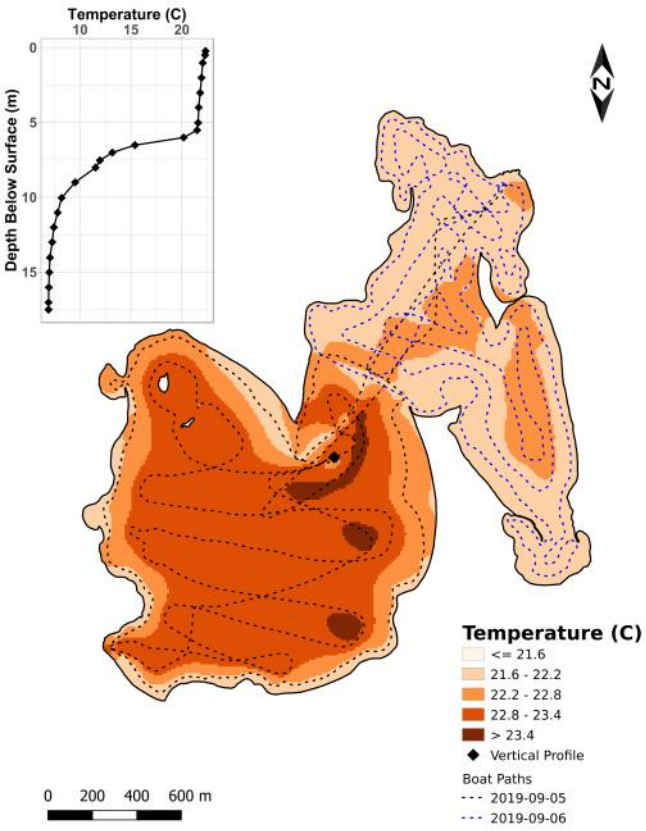




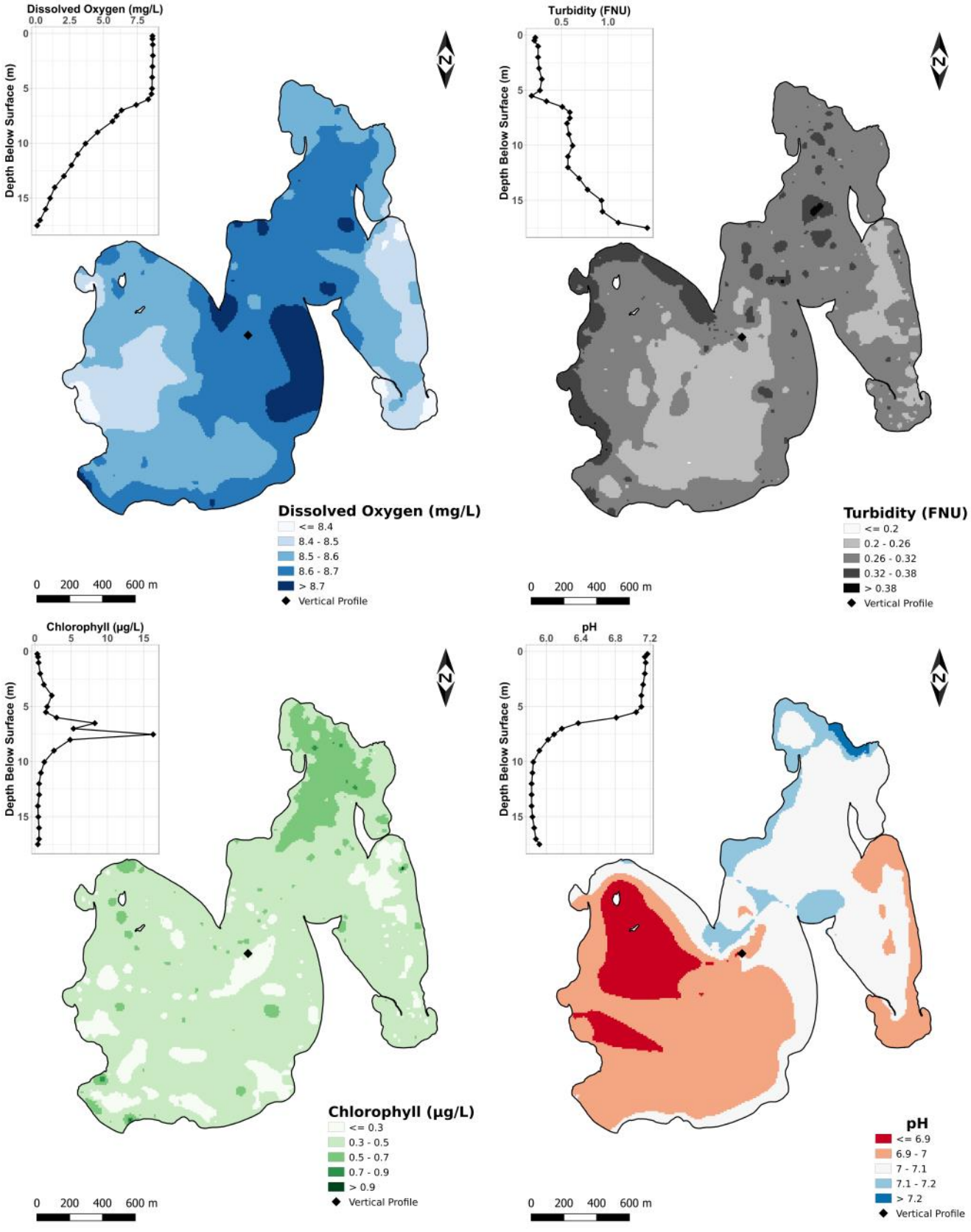
Hancock Pond - September 5-6, 2019

Hancock Pond was the second largest lake surveyed and the two-day survey resulted in just over 18000 data points. Weather was sunny and clear with light winds both days. Variation for all parameters was much greater with depth than across the surface. Water temperature was elevated in the open water area surveyed on the first day and not so much the second. The first day's open water area was surveyed later in the day following the perimeter survey and vertical profile collection, so it would have had more chance to heat up. Oxygen was elevated and above saturation (not shown) in the shallow areas on either side of the deep site, possibly a product of aquatic plant photosynthesis. Turbidity was slightly elevated in the shallow areas of the NW shore, which could be from sediment resuspension. Chlorophyll was slightly higher in the north basin, possibly influenced by the inlet streams in that area. pH showed small scale variation over large areas and remained essentially neutral (pH = 7). Patch size ranged from 70 to over 1100 m.



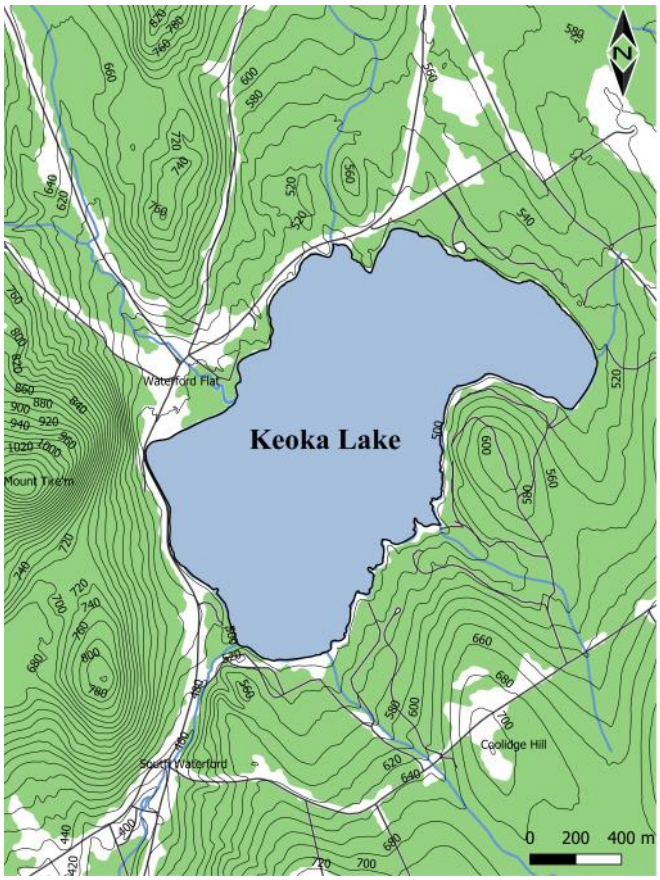


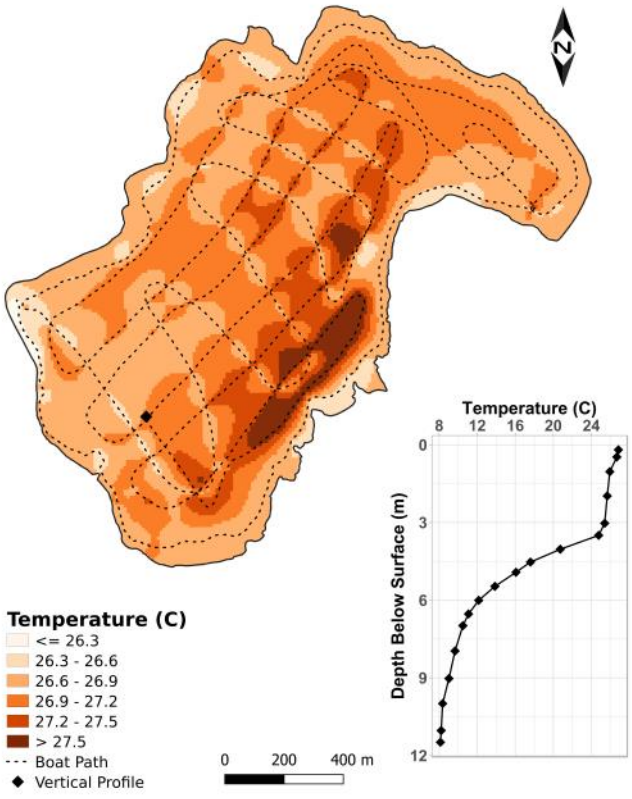
Hancock Pond - September 5-6, 2019



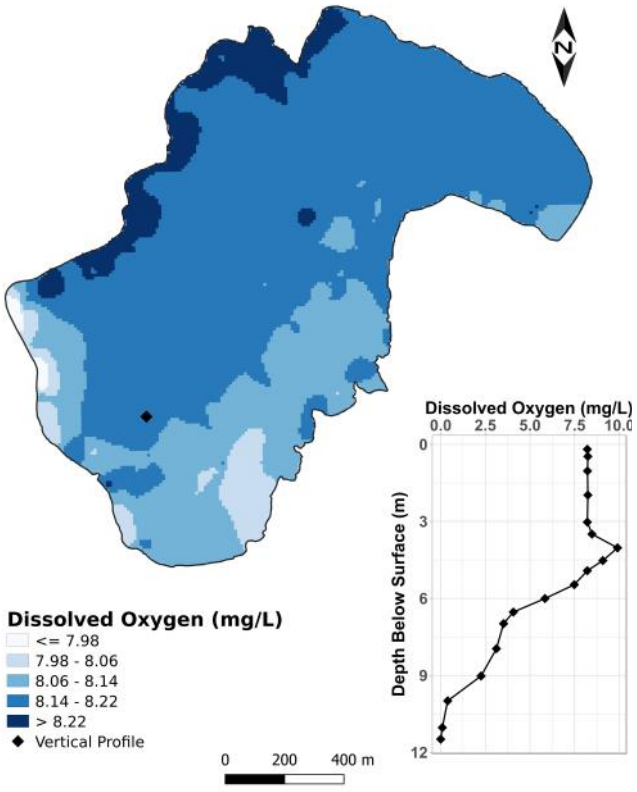
Keoka Lake - July 26, 2019

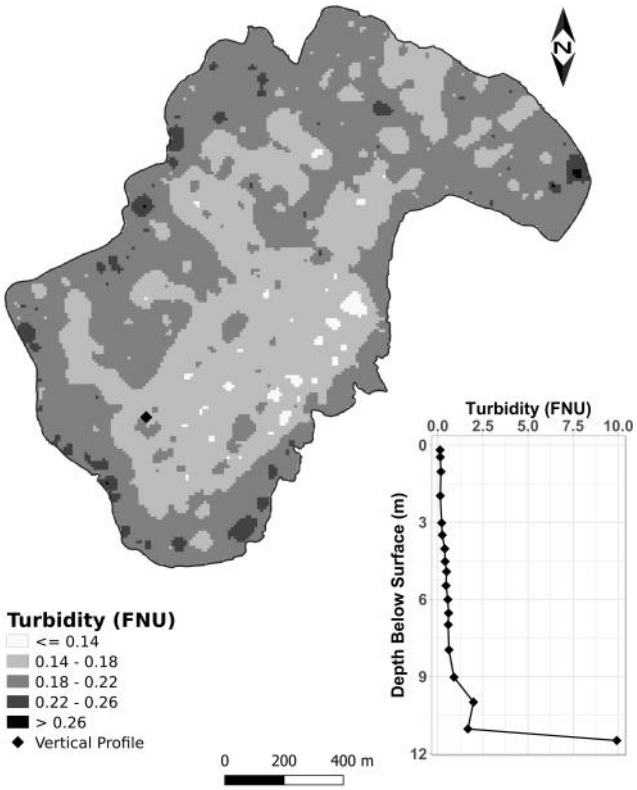
Keoka Lake was the first lake completed and the three hour, mid-morning to early afternoon survey resulted in just over 10900 data points. Weather was sunny, bright, and hot with light and variable winds. Variation for all parameters was much greater with depth than across the surface. Water temperature data showed a distinct pattern along the track line. Temperature was elevated off the southeastern shore, which was some of the last area surveyed and would have had more time to heat up. The observed decreasing gradient from north to south for dissolved oxygen could also be a function of later warming, since warmer water holds less oxygen. Oxygen saturation (not shown) was more uniform across the lake. Turbidity showed only little variation except for perhaps a slight elevation along the shore. Other than a few small patches perhaps influenced by inlet streams, chlorophyll was mostly uniform and low across the surface, especially compared to the high concentrations at the thermocline. pH was spatially uniform and close to neutral. Patch size ranged from 44 to over 1100 m.

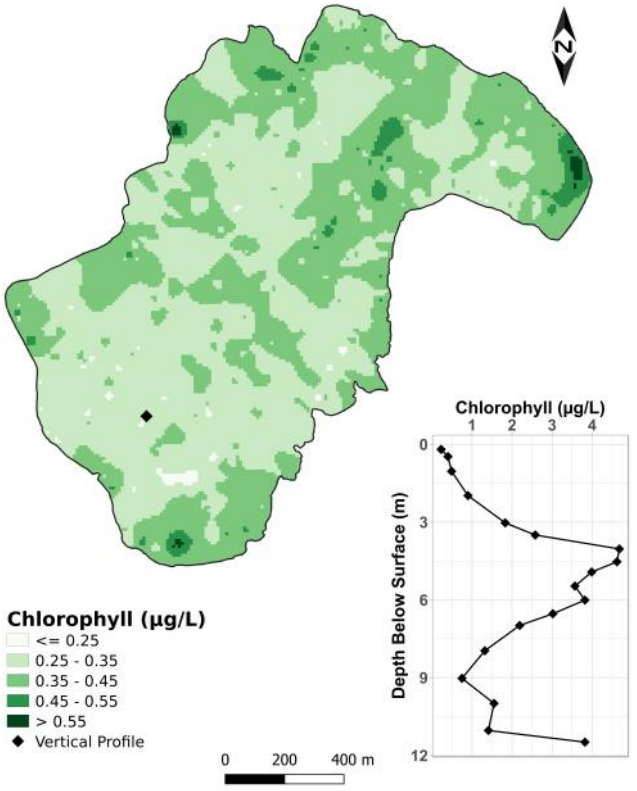


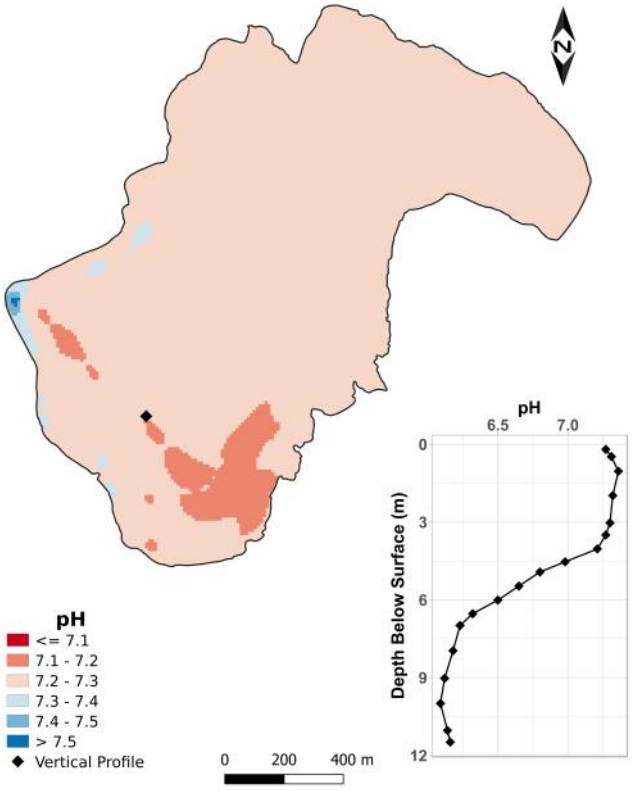


Keoka Lake - July 26, 2019



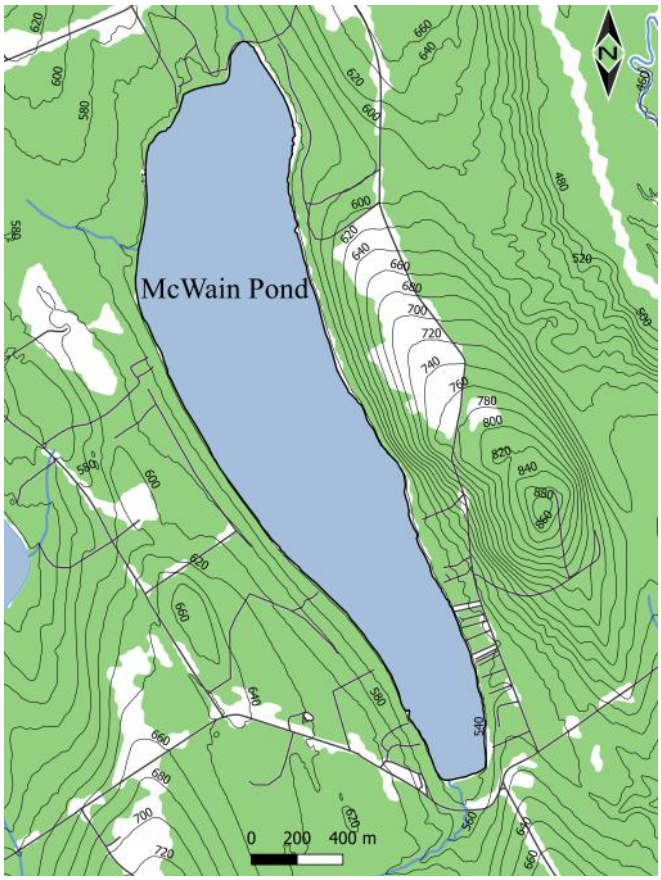


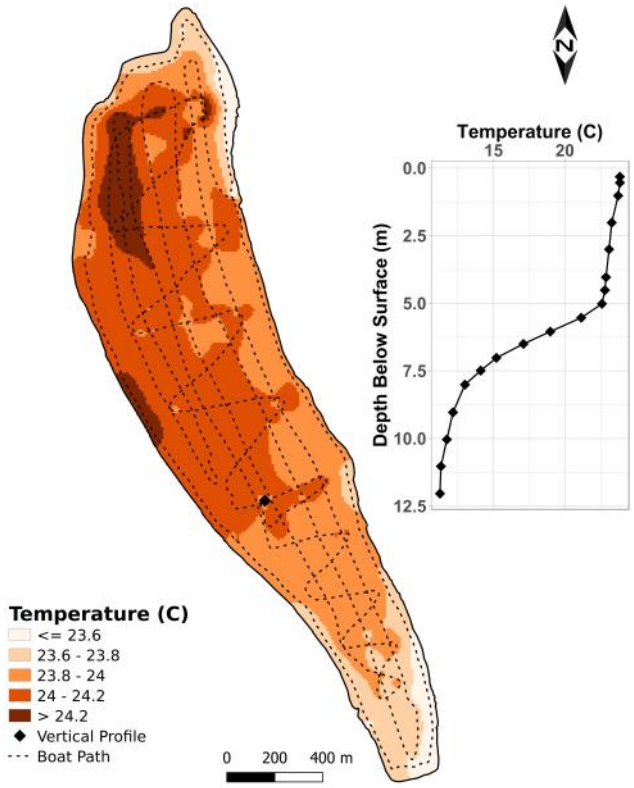




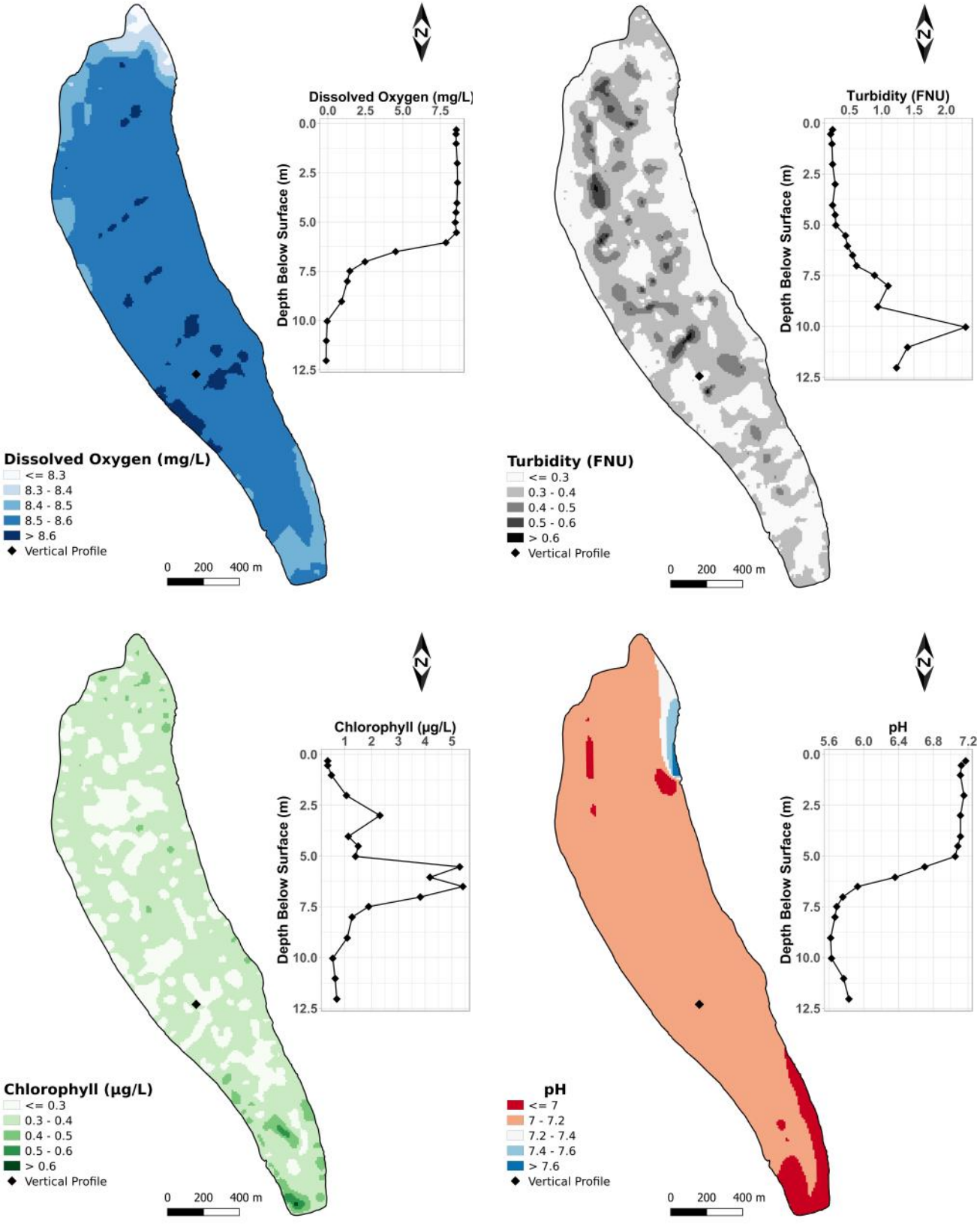
McWain Pond - August 28, 2019

The McWain Pond survey was completed in late August in just under three hours during mid-day and resulted in 10000 raw data points. Weather was partly sunny, mild, with light southerly wind picking up speed as the survey progressed. Variation for all parameters was much greater with depth than across the surface. Water temperature data showed a subtle, but distinct gradient with elevated values in the north and west areas. Topographic features could prevent the eastern shore from warming up as quickly, but we cannot rule out heating over the course of the survey. Oxygen and turbidity were more uniformly patchy. Some of the turbidity patches are an artifact of increased bubbles during faster runs across open water. Chlorophyll showed minor variation across the surface, especially compared to the significant sub-surface chlorophyll maximum. A small chlorophyll increase along the southern shore could be a function of the inlet stream. The inlet may also explain the slight decrease in pH (increasing acidity) seen in the same area. The remainder of the lake was mostly uniformly neutral pH. Patch size ranged from 42 to 252 m.



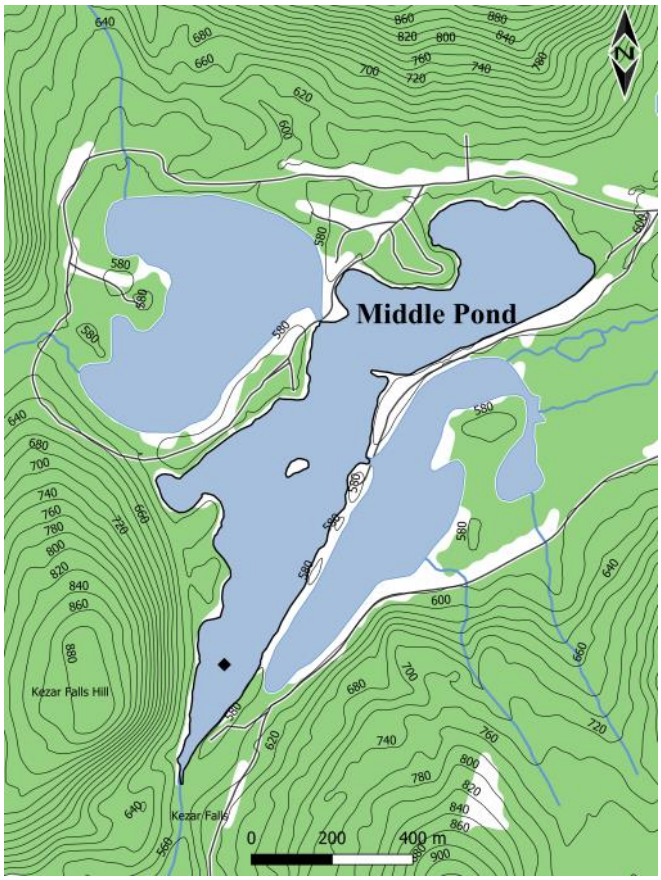


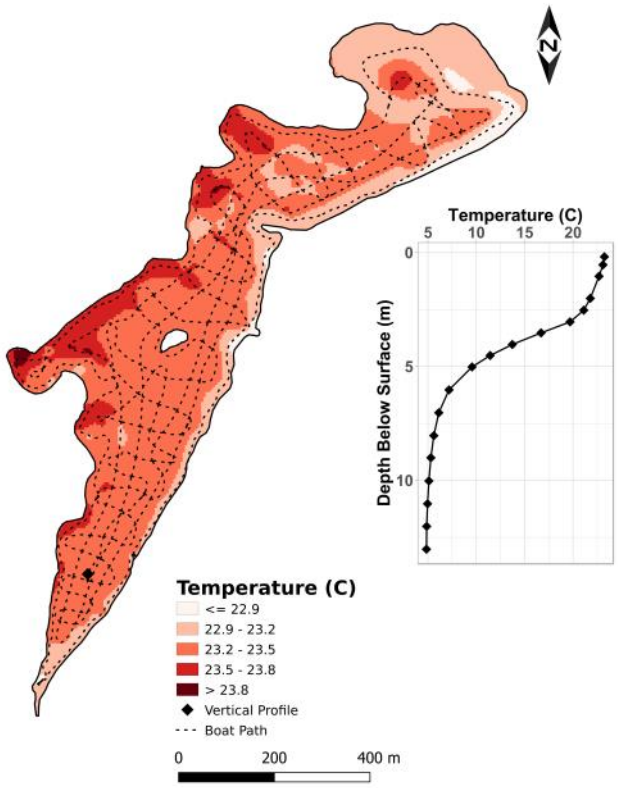
McWain Pond - August 28, 2019



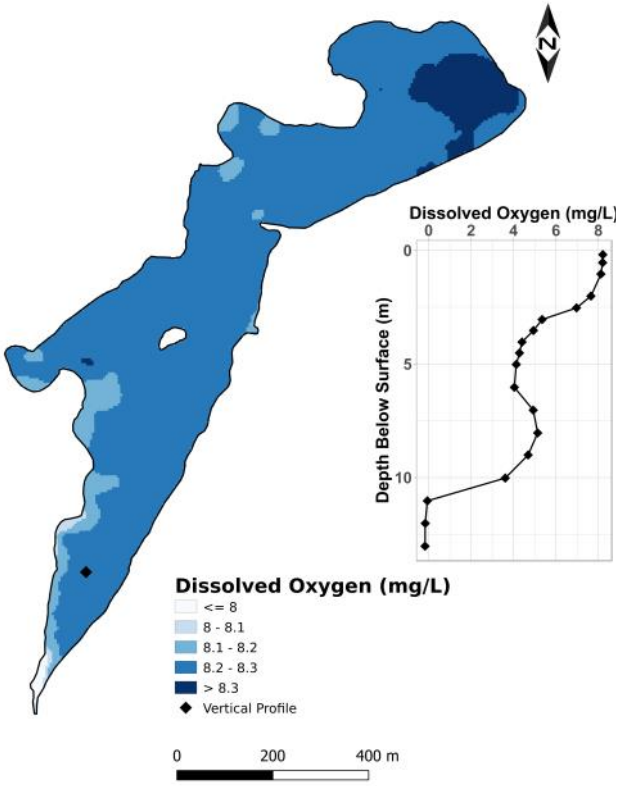
Middle Pond - August 30, 2019

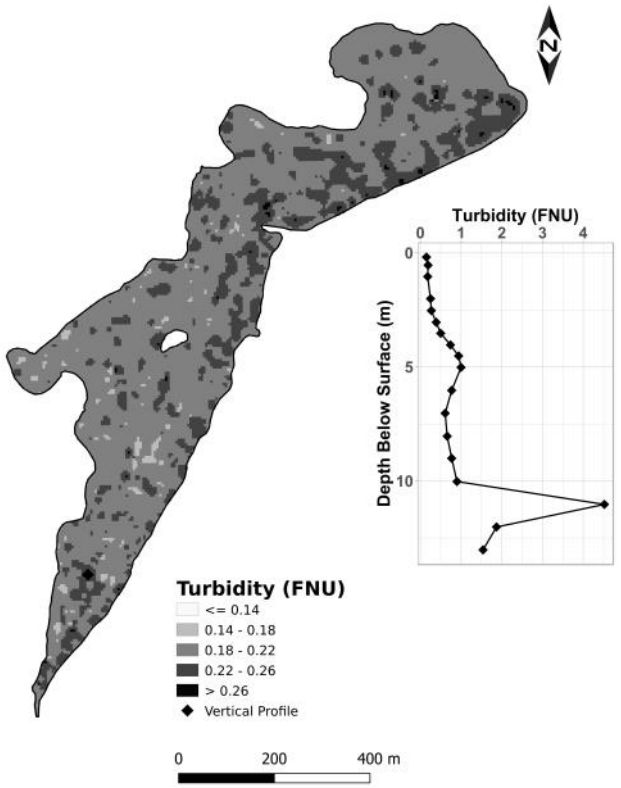
The Middle Pond survey took just over two and a half hours on a late August morning and resulted in almost 8000 raw data points. Weather was sunny, clear, and warm, with a moderate and gusty southwesterly breeze. Variation for all parameters was much greater with depth than across the surface. Water temperatures were very slightly elevated in the shallow, near-shore areas and coves on the west side, which could be a function of shading on the eastern shore. A patch of higher dissolved oxygen in the shallow, northeast basin was likely caused by the photosynthetic activity of the aquatic plants in this area. Turbidity and chlorophyll values were more uniformly patchy, except for some noticeable peaks of chlorophyll along the eastern shore and one western cove. pH data revealed areas of more acidic water along the middle axis of the lake, though the cause is not clear. Higher pH in the northeast basin could be from plant photosynthesis, but we cannot rule out a sluggish pH sensor that was still equilibrating with the water conditions. Patch size ranged from about 10 to almost 230 m.

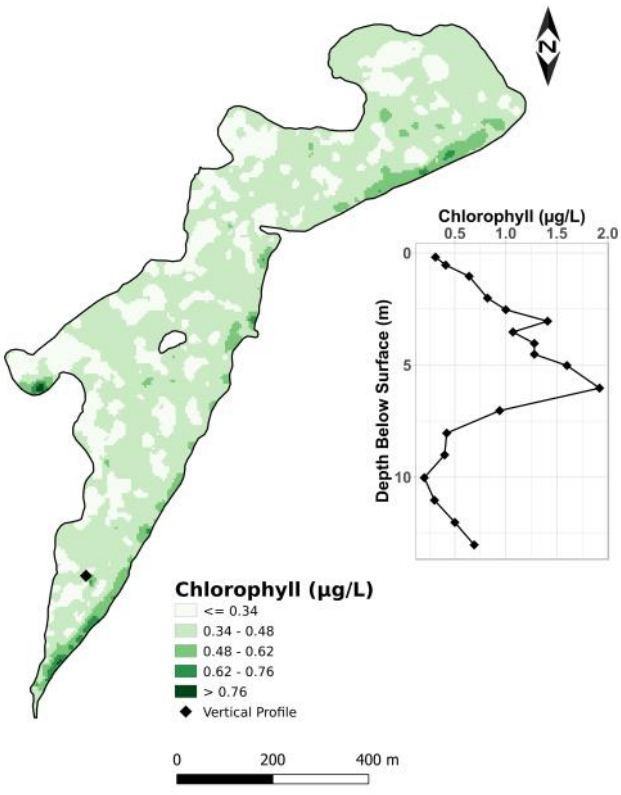


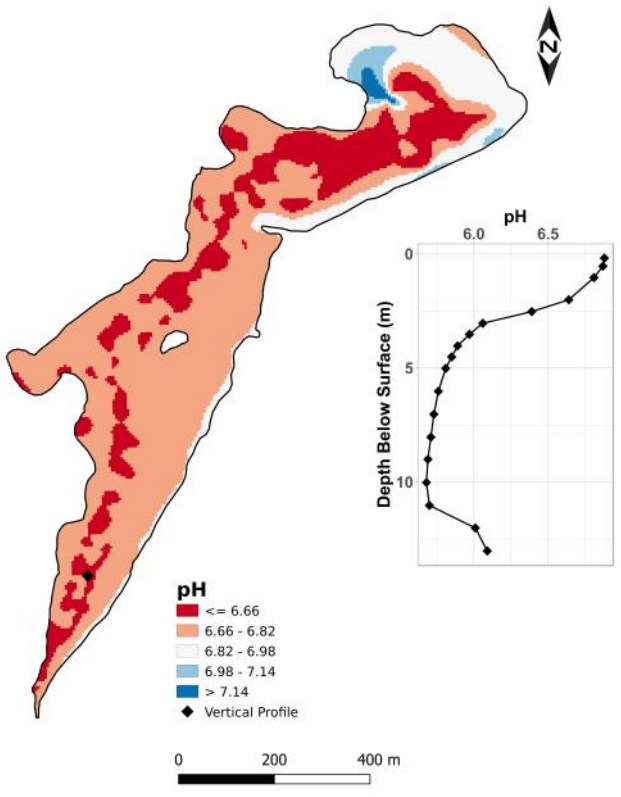


Middle Pond - August 30, 2019



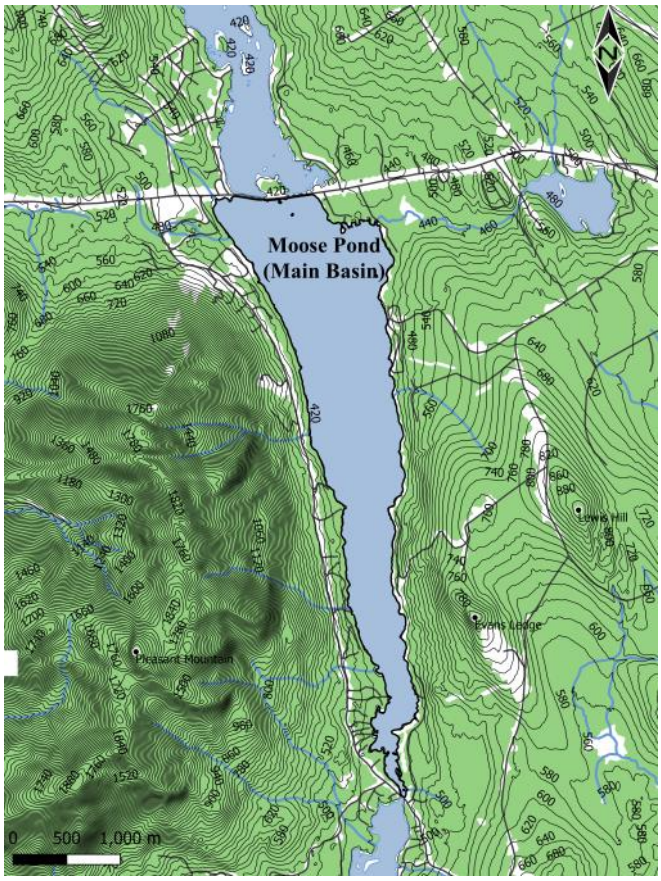


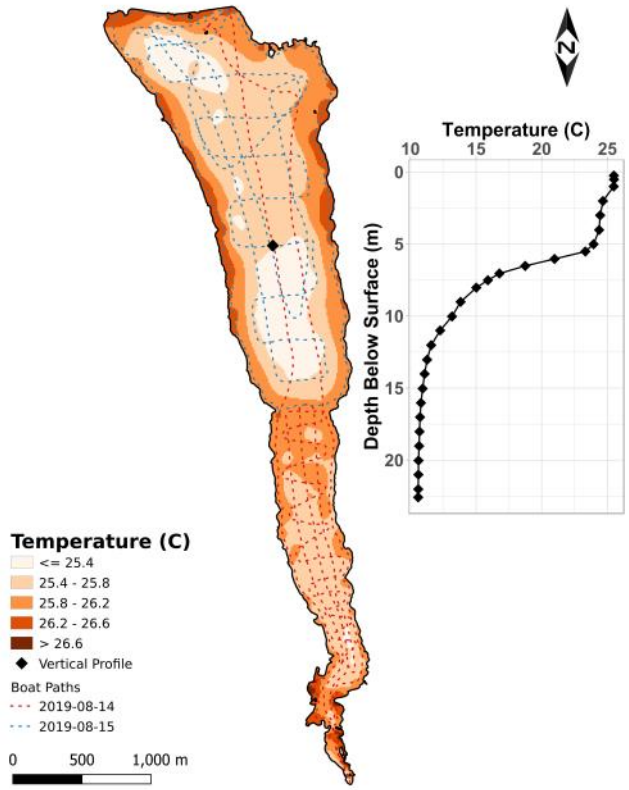




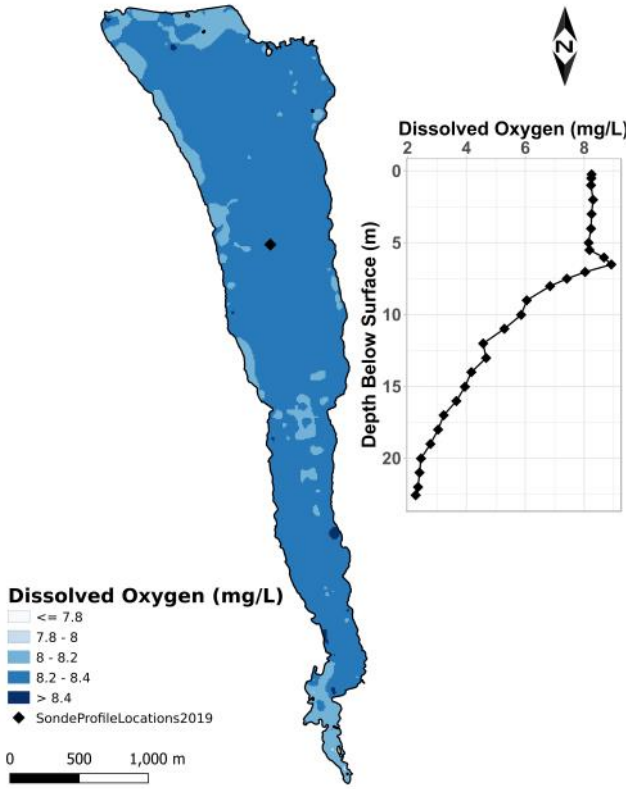
Moose Pond (Main Basin) - August 14-15, 2019

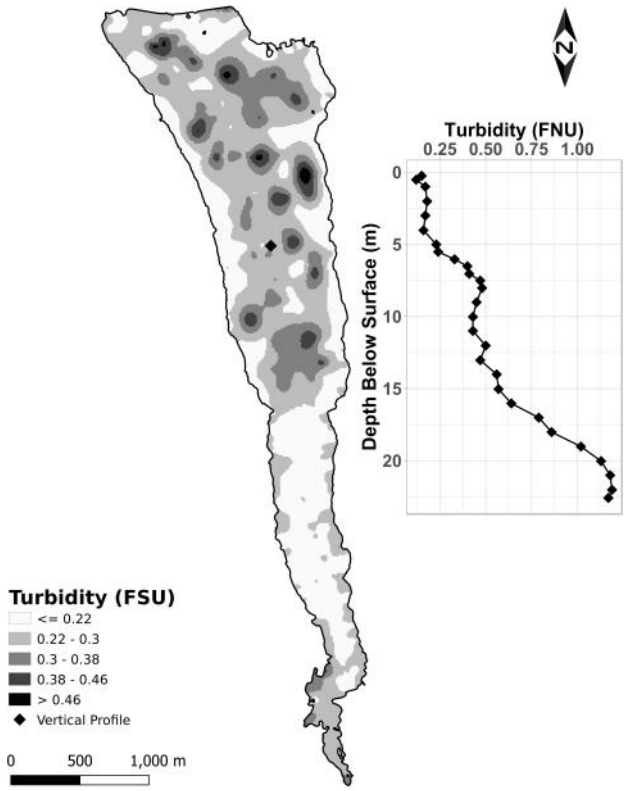
The Moose Pond survey took place only in the main basin and took six and a half hours over two afternoons in mid-August. This was the largest water body surveyed and about 19000 raw data points were collected. Weather was sunny and warm both days, with light south winds picking up on the second day. Variation for all parameters was much greater with depth than across the surface. Water temperatures were very slightly elevated along much of the northern near-shore areas, which was probably caused by shallow areas warming more quickly. The dissolved oxygen pattern was mostly uniform with minimal spatial variation. The turbidity pattern was more even in the southern sections, while many smaller patches showed up in the northern open water areas. This likely was a function of bubble formation at speed and with choppier conditions. Chlorophyll values were fairly uniform over large areas, except for elevated values in the southern narrows section. The spatial pattern for pH suggests a north to south gradient of increasing acidity, though the range is small especially when compared to the acidic bottom waters at the vertical profile site. The reason for the area of slightly lower pH in the narrows is unclear, but might be related to the decomposition of organic matter that collects from upper basin water. Patch size ranged from about 60 to over 300 m.

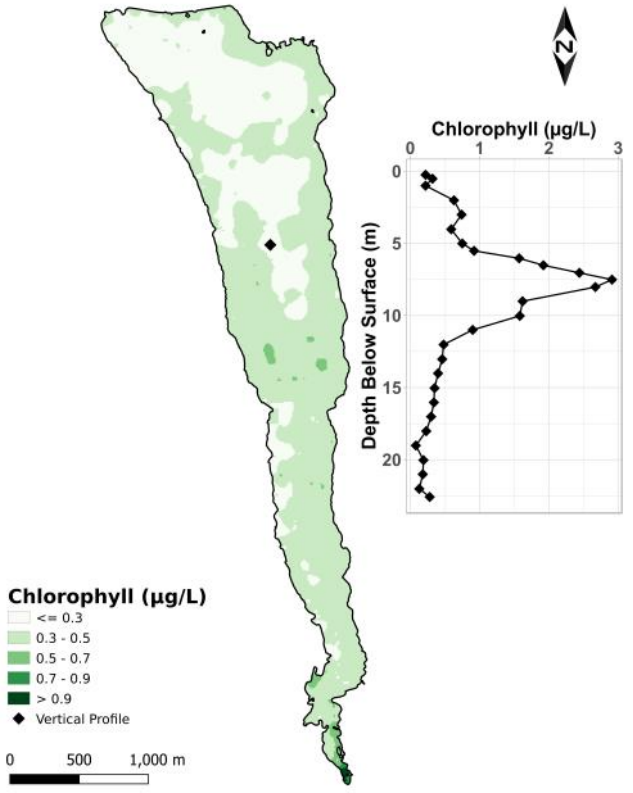


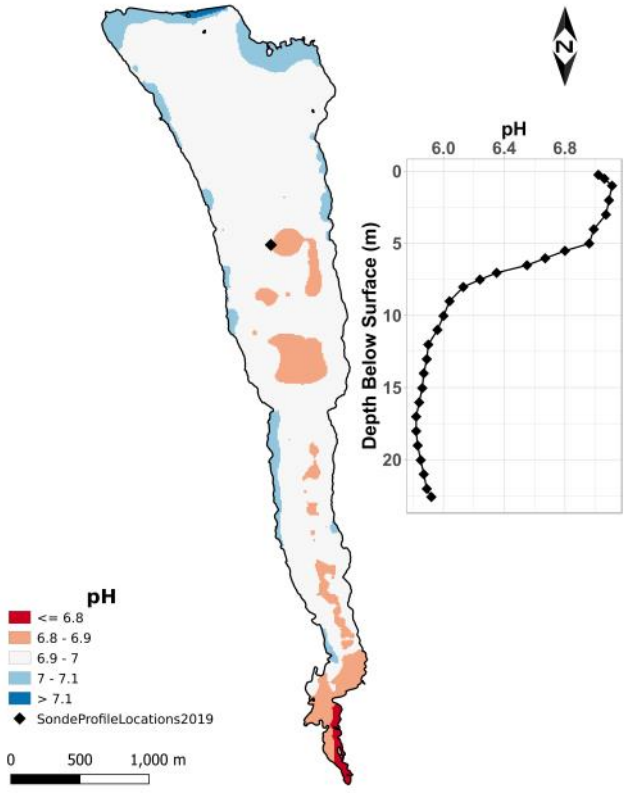


Moose Pond (Main Basin) - August 14-15, 2019



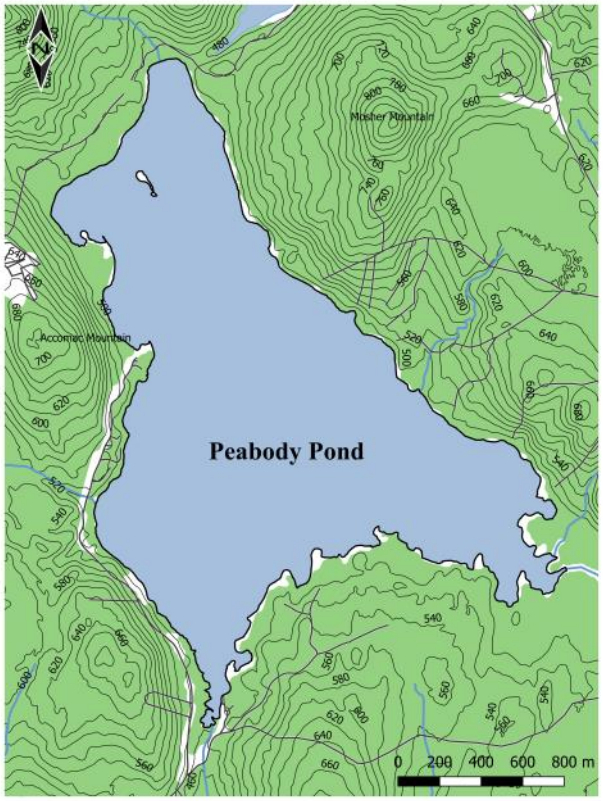


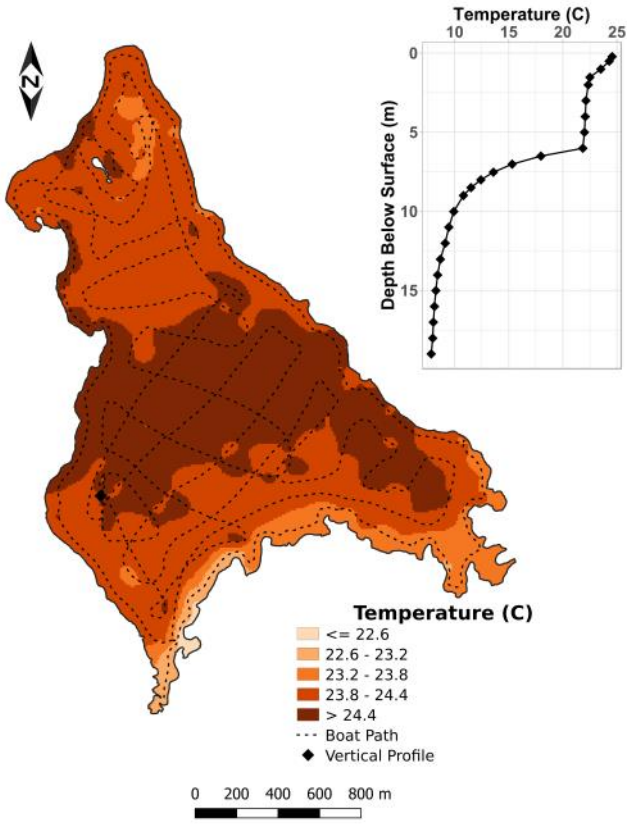




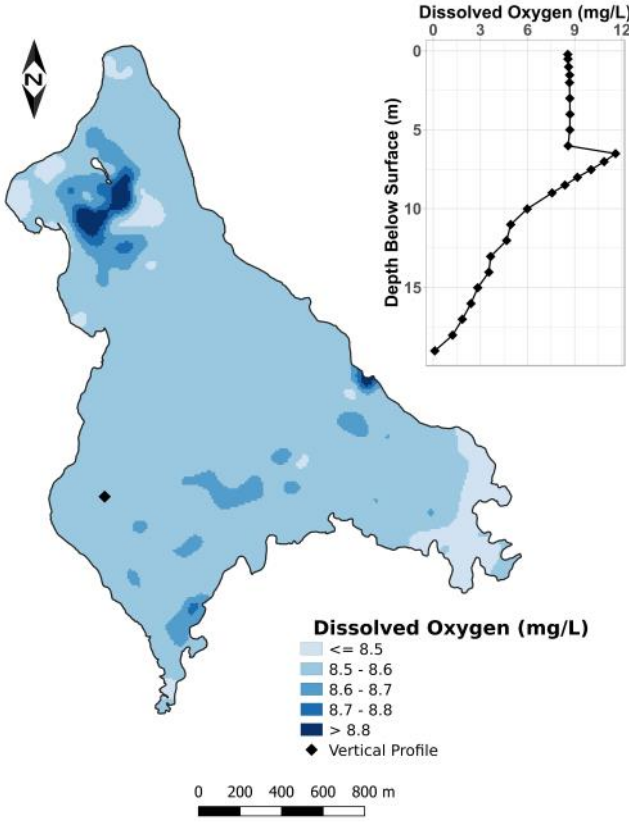
Peabody Pond - September 3, 2019

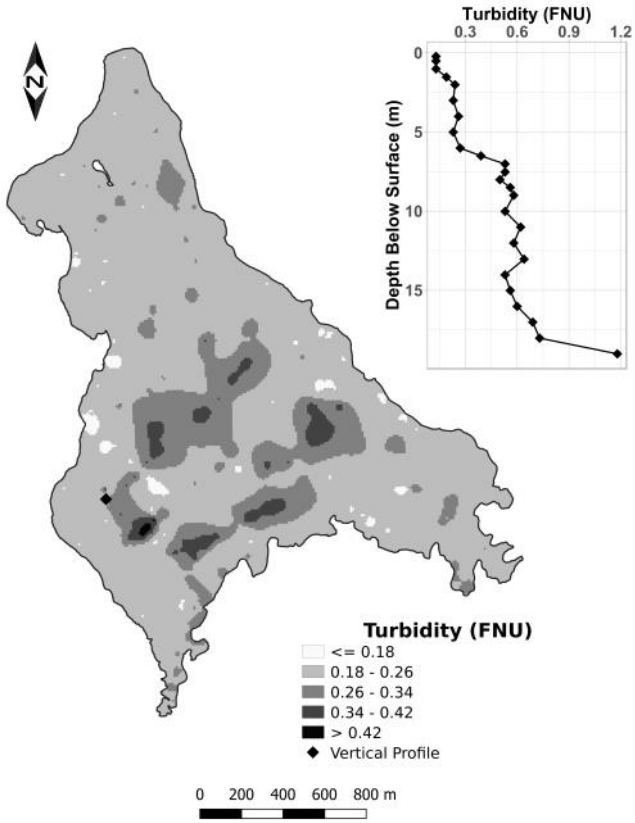
The Peabody Pond survey took almost four hours on an early September afternoon and yielded almost 13500 data points. Weather was a mix of sun and clouds with light and variable winds. Variation for all parameters was much greater with depth than across the surface. Water temperatures were a bit higher in the central part of the basin and slightly lower on the southern shore. This differential could be because of morning time shading of the shoreline areas, but there is also the possibility of warming that happened as the survey progressed. The dissolved oxygen pattern was mostly uniform except for a patch of elevated readings in the northern end and on the northeastern shore at the mouth of an inlet. Higher readings like those could be caused by aquatic plant photosynthesis happening there or nearby. The patches in the middle of the turbidity map may have some natural cause, but are more likely an artifact of bubble formation in the flow-through system at higher speeds. The chlorophyll pattern was a mix of higher concentration patches over mostly open-water areas. The northern patches could be due to growth enhanced by inputs from the inlet; it is not clear what is controlling the other patches. Even so, surface concentrations were ten times lower than the subsurface chlorophyll maximum recorded at the thermocline. The distribution of pH values showed mostly neutral conditions in the lake. The area of elevated pH down near the outlet could be from photosynthesis or since the survey started there, could be caused by a slow-acting pH sensor. Patch size ranged from about 60 to 1030 m.

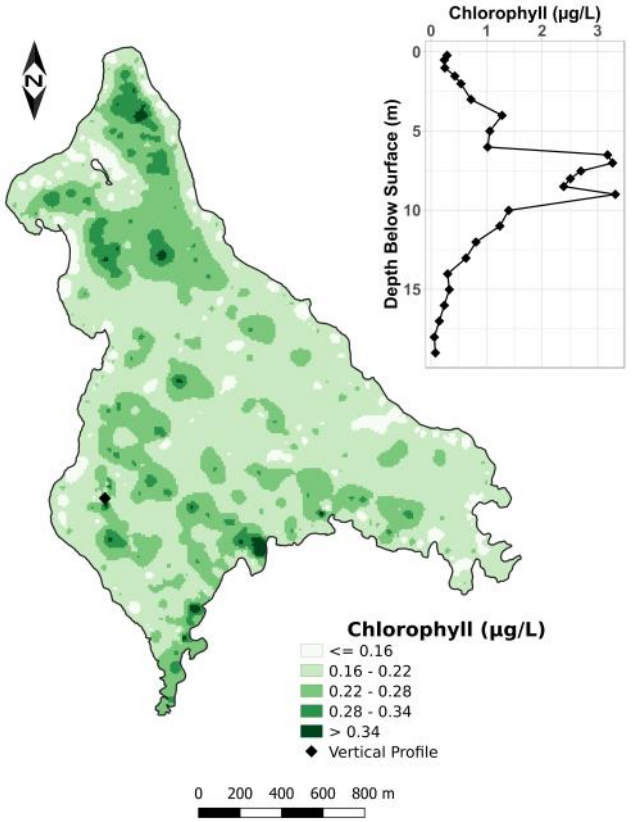


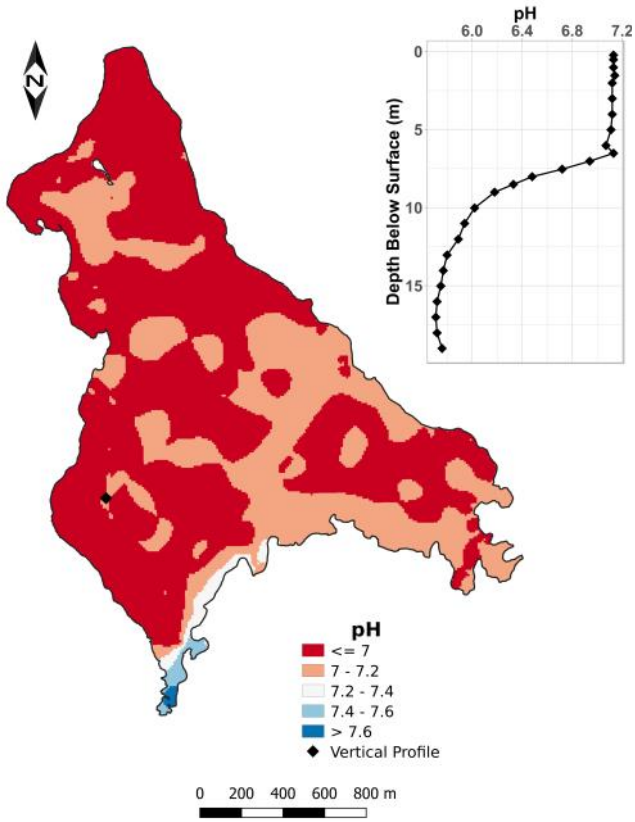


Peabody Pond - September 3, 2019



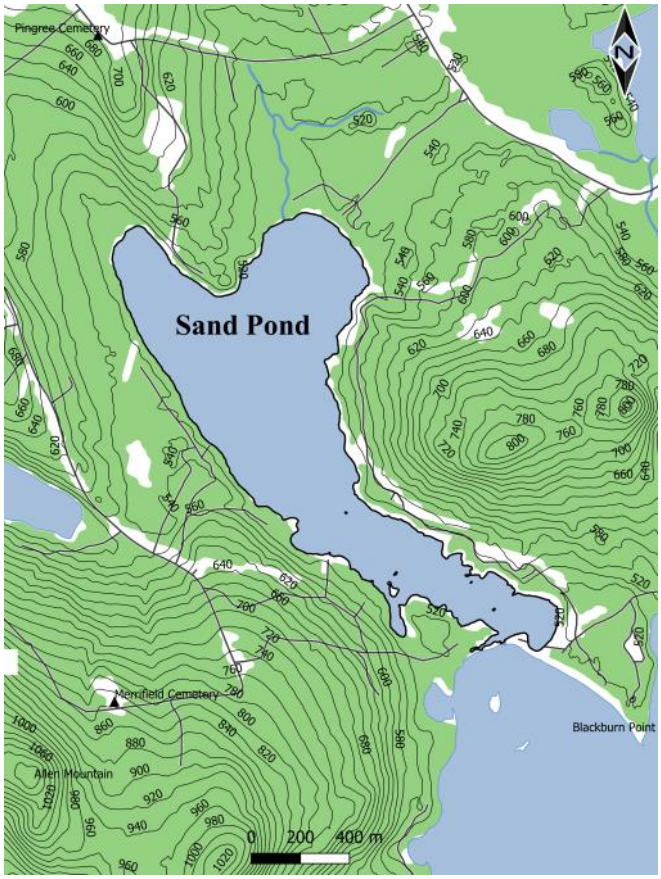


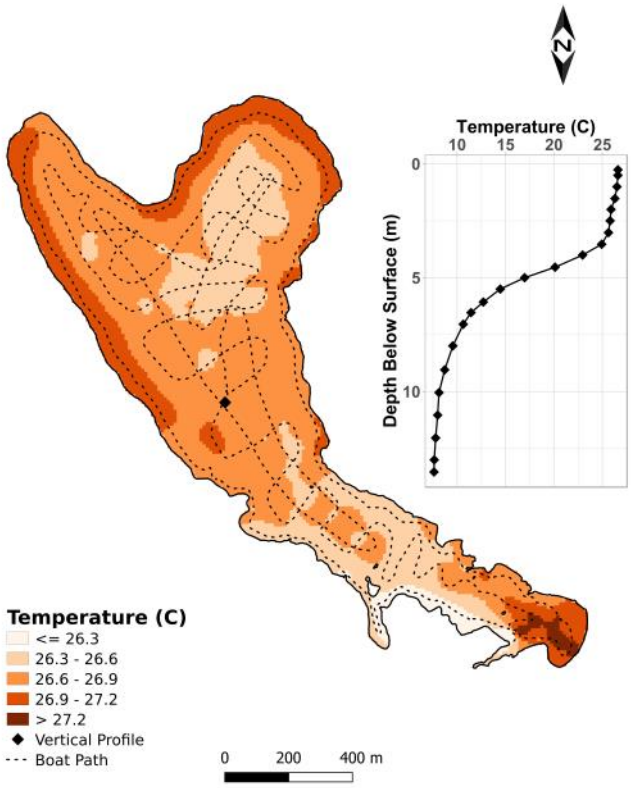




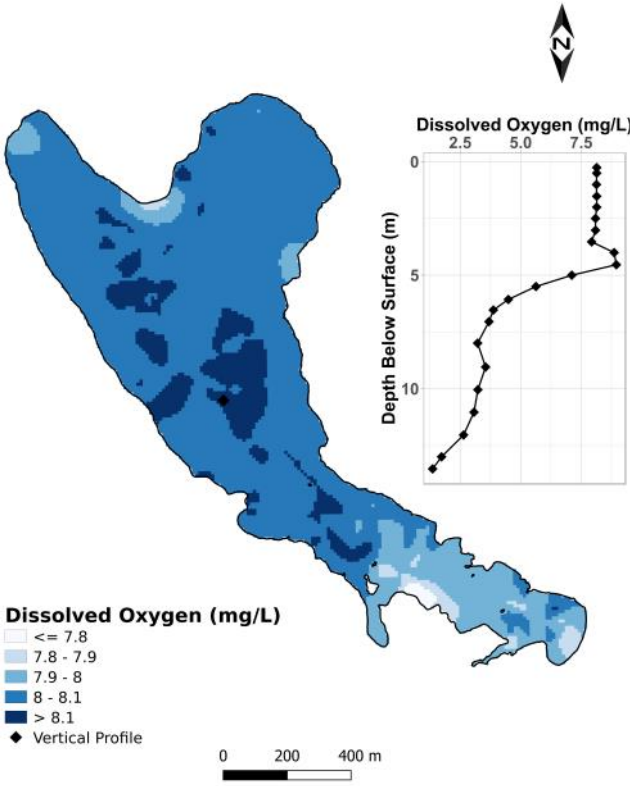
Sand Pond - August 6, 2019

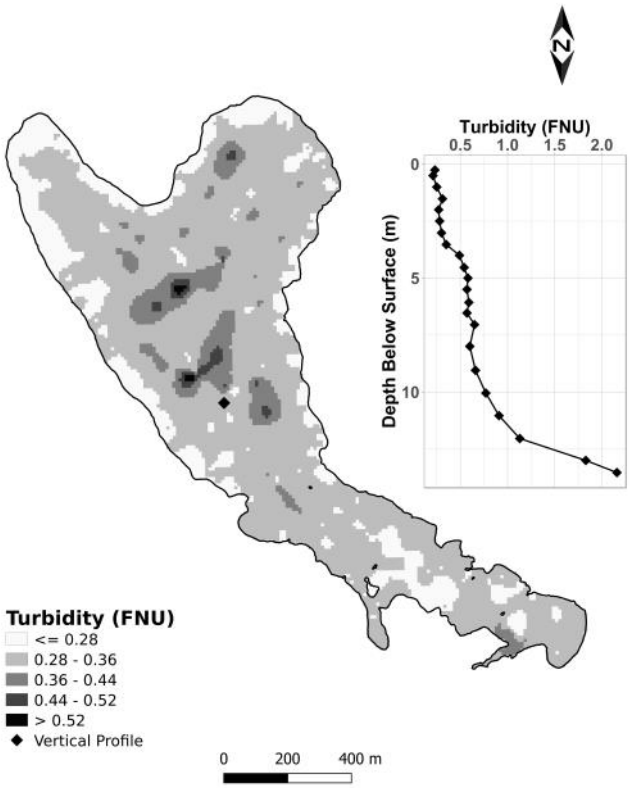
The Sand Pond survey took about two and a half hours during a morning in early August and yielded almost 8500 data points. Weather was clear, warm, and sunny with a light south breeze increasing in strength during the day. Variation for all parameters was much greater with depth than across the surface. Water temperatures were very slightly elevated along the northern shoreline and in the southernmost cove, probably due to the shallow depths and sunlight exposure. The dissolved oxygen pattern was mostly uniform except for patches of elevated readings in the open waters and lower concentrations in some shallow shoreline areas. The latter may be due to oxygen consumption in shallow sediments. The patches in the middle of the turbidity map may have some natural cause, but are more likely an artifact of bubble formation in the flow-through system at higher speeds. The chlorophyll pattern was a mix of higher concentration patches over mostly open-water areas and in two shallow cove areas. Still, surface concentrations were ten times lower than the subsurface chlorophyll maximum recorded at and below the thermocline. The distribution of pH values showed mostly neutral conditions in the lake. The area of elevated pH down near the outlet could be caused by plant photosynthesis or since the survey started there, could be caused by a slow-acting pH sensor. Patch size ranged from about 25 to 140 m.

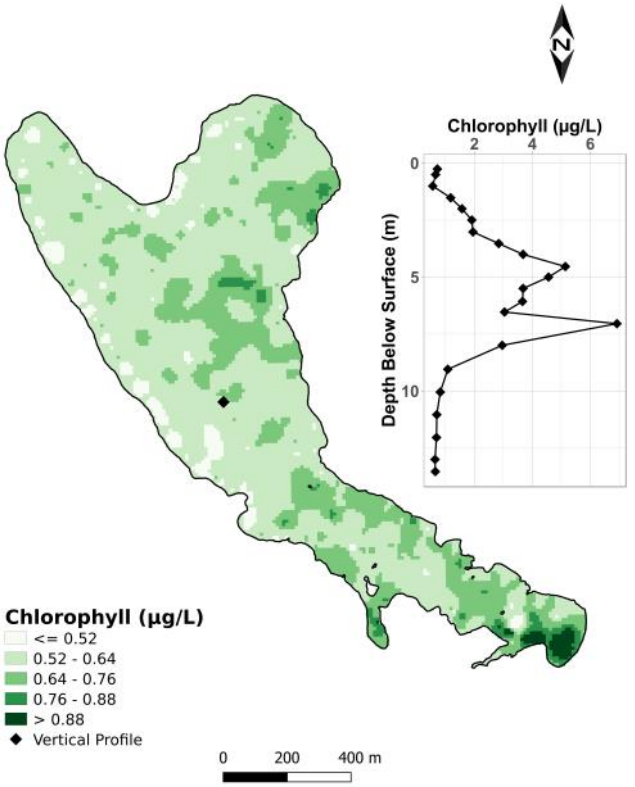


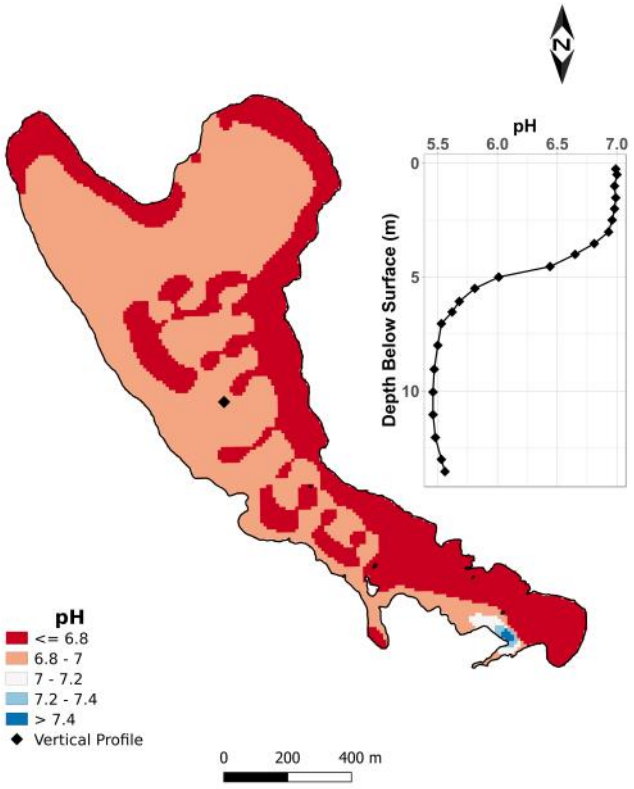


Sand Pond - August 6, 2019



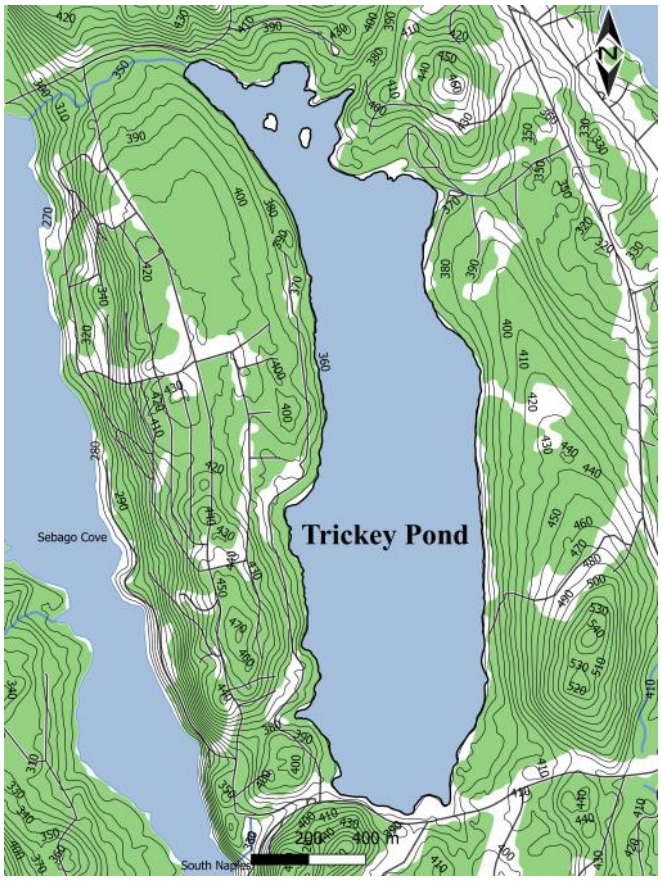


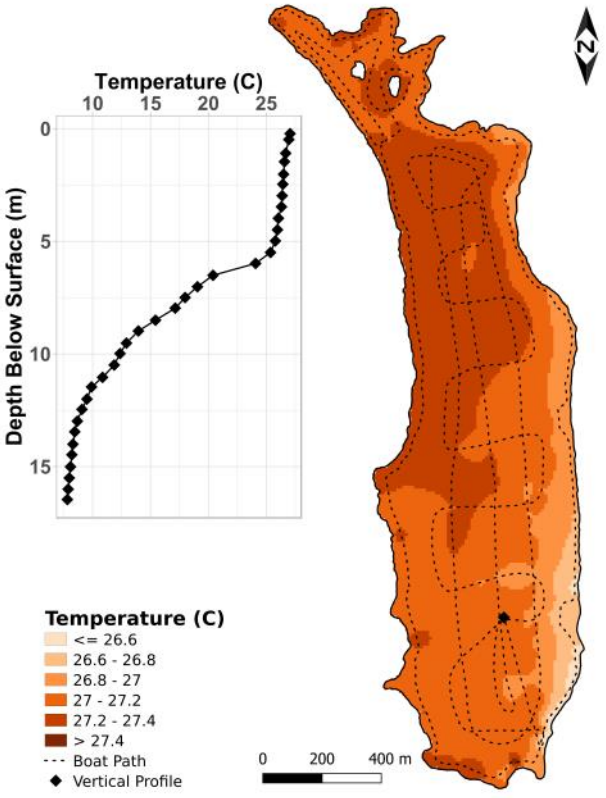




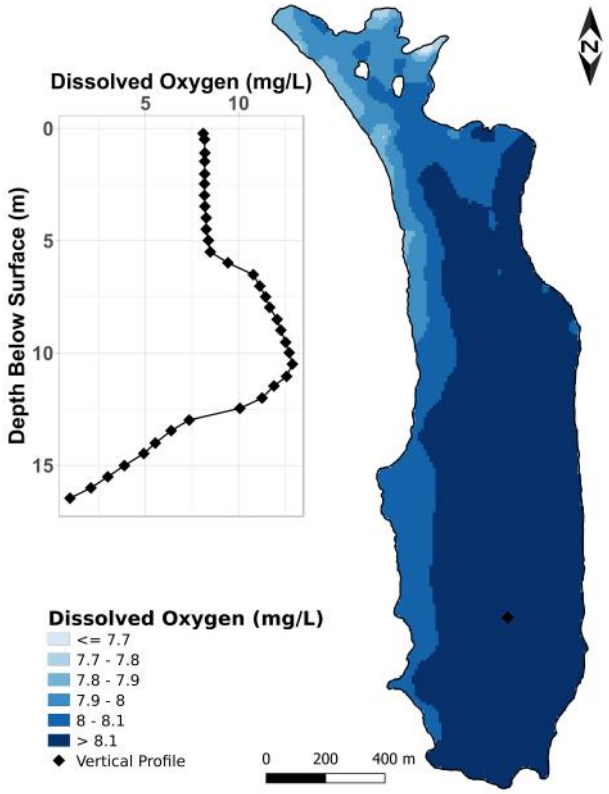
Trickey Pond - July 30, 2019

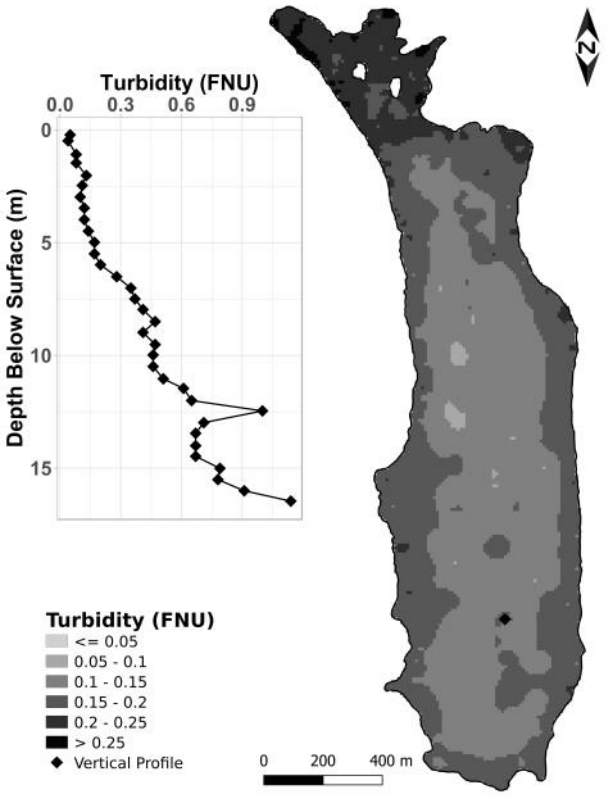
The Trickey Pond survey was completed in two and a half hours during a morning in late July and yielded almost 8800 data points. Weather was clear, warm, and sunny with a light southerly wind, increasing somewhat in strength during the survey. Variation for all parameters was much greater with depth than across the surface. Surface water temperatures varied by only about one degree, with cooler water along the southeastern shoreline. Since the survey started in the morning along this shaded side, delayed warming may have driven the observed pattern. Higher temperatures to the north could be caused by wind pushing warmer water masses around. Dissolved oxygen concentrations decreased in a gradient from southeast to northwest; sediment oxygen consumption in shallow waters could explain that pattern. The turbidity map revealed higher readings in the northern area, though overall the values were very low (very clear water) compared to deep water values. The eastern shore had patches of higher chlorophyll concentrations, though the cause is not clear. There are no inlets along the shore, but there is high topographic relief that could cause greater runoff from the land. Still, the massive subsurface chlorophyll maximum below the thermocline at 12.5 m dwarfs any of the surface chlorophyll patches. The lake mostly was at or above neutral pH, with a gradient of higher to lower values moving southeast to northwest, correlating nicely with the oxygen pattern. Patch size ranged from about 80 to over 3300 m.

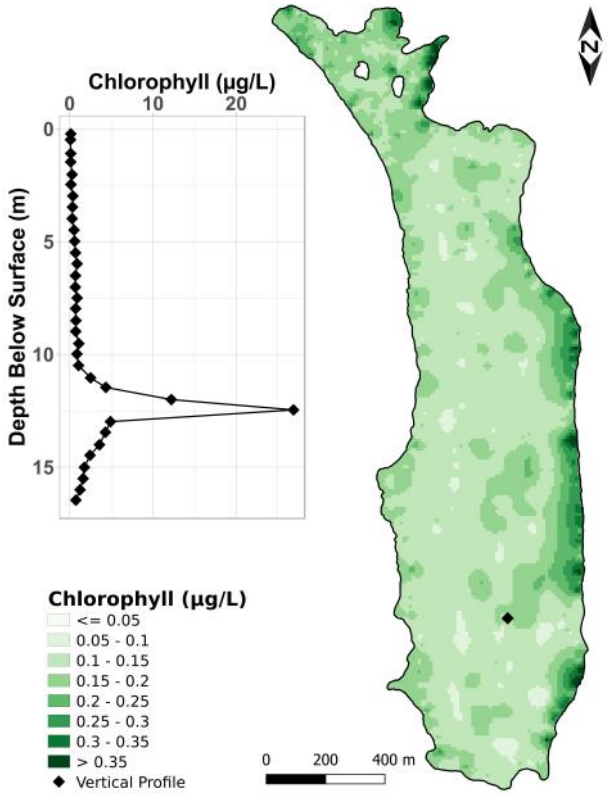


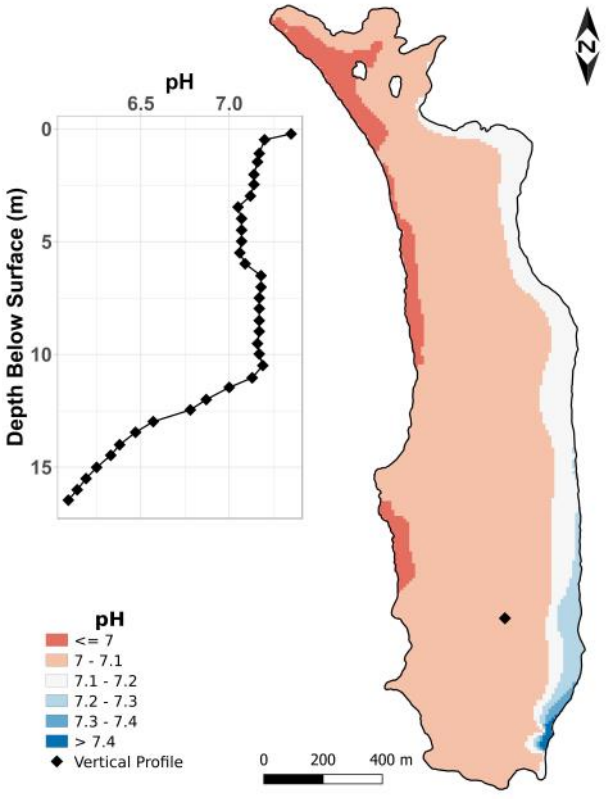


Trickey Pond - July 30, 2019



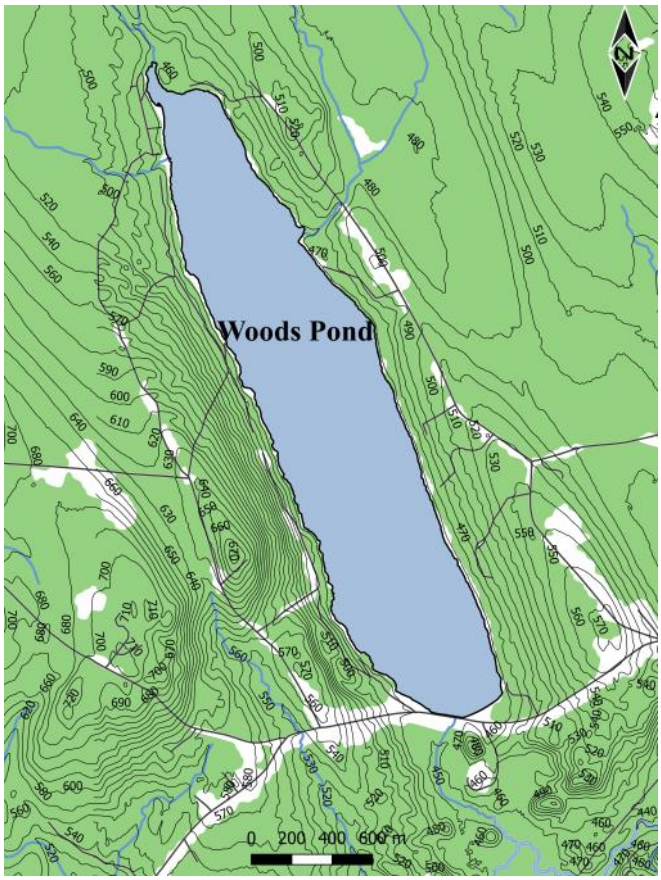


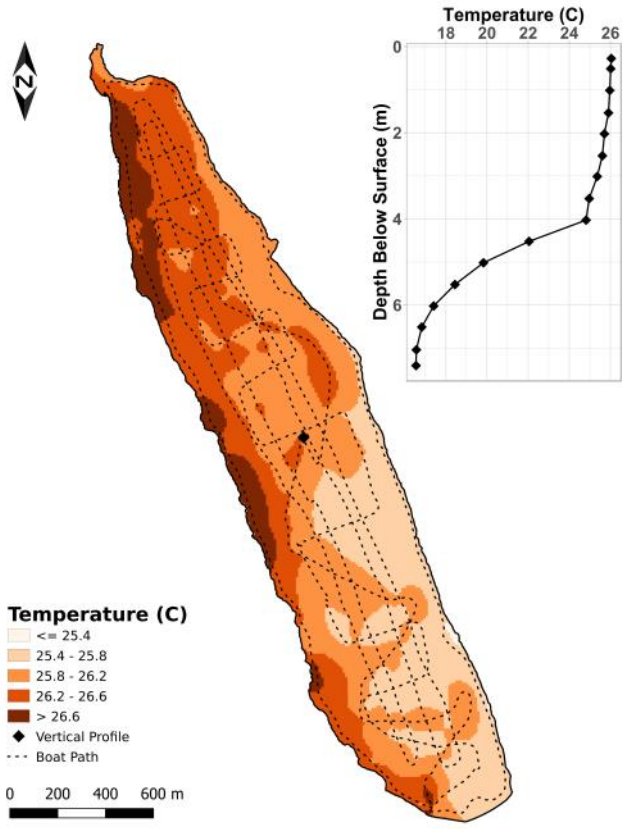




Woods Pond - August 9, 2019

The Woods Pond survey was completed in early August in just over three and a half hours during the middle of the day; almost 10400 data points were collected. Weather was sunny, clear, and warm, with a moderate north-northeast wind. Boat traffic was heavy and produced many waves that forced occasional speed and course corrections. Variation for all parameters was mostly greater with depth than across the surface. The variation in surface water temperatures was only about one degree, with cooler water along the southeastern shoreline (a possible artifact of starting the survey in the morning along this shaded side). The western shore could have warmed up more quickly to produce the observed pattern. A boat track pattern was visible in data also. Dissolved oxygen varied within a small range and some features could be explained by localized plant patches, or in the case of the northern inlet, a source of organic matter to cause oxygen declines. The turbidity map was very patchy and most likely caused by bubbles that developed in the flow-through system. Chlorophyll concentrations were a bit higher than the other surveyed lakes, but did not vary that much over the whole lake; subsurface chlorophyll was only slightly higher than the surface. The lake appeared to be mostly below neutral pH, with a north to south gradient of decreasing (more acidic) values. The cause of this is unknown, but the natural organic matter that colors the water tends to be acidic. Patch size ranged from about 70 to about 860 m.





Woods Pond - August 9, 2019