Lakes Environmental Association
2017 Water Testing Report

Chapter 4—High Resolution Temperature Monitoring

Introduction to High-Resolution Temperature Monitoring

LEA began using in-lake data loggers to acquire high resolution temperature measurements in 2013. The loggers, which are also interchangeably referred to as HOBO sensors, temperature sensors, or thermistors, are used to provide a detailed record of temperature fluctuations within lakes and ponds in our service area. This information allows for a better understanding of the thermal structure, water quality, and extent and impact of climate change on the waterbody tested.

Each year, we attempt to capture the entire stratified period within the temperature record, from when stratification begins to form in the spring to when the lake mixes in the fall. Stratification refers to the separation of lake waters into distinct layers, and is a phenomenon that has important consequences for water quality and lake ecology. See Chapter 1, page 6 of the Water Testing Report for more information about stratification.

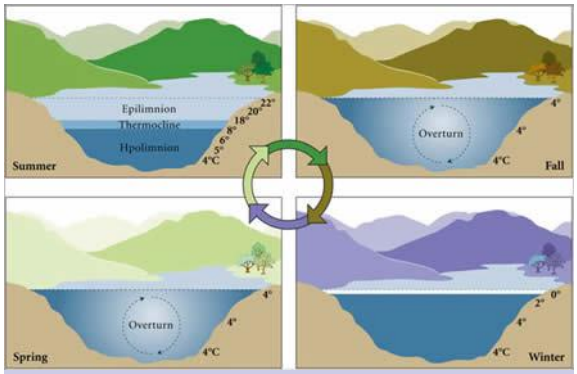
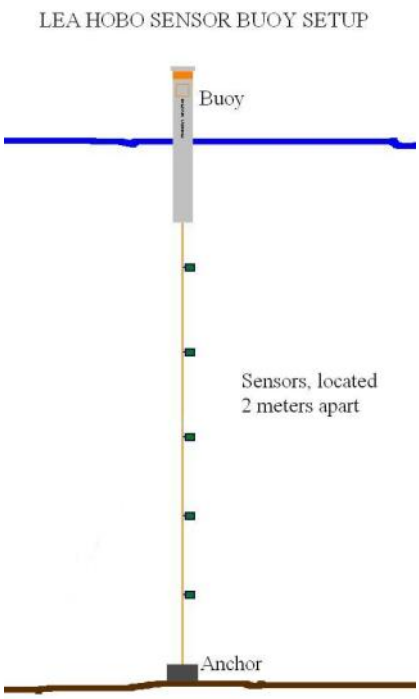


Diagram of Seasonal Stratification and Lake Mixing
Young, M. (2004). *Thermal Stratification in Lakes*. Baylor College of Medicine, Center For Educational Outreach.

Water temperature is critical to the biological function of lakes as well as the regulation of chemical processes. Lake temperature and stratification are greatly influenced by the weather. Air temperature, precipitation, and wind speed and direction can all affect water temperature and stratification patterns from year to year. Lake size, depth, and shape also greatly impact stratification timing and strength. The larger the difference in temperature between the top and bottom layers of the lake, the stronger the stratification is.



With funding and support from local lake associations, LEA has deployed temperature sensors at sixteen sites on twelve lakes and ponds. Sensors are attached to floating line held in place by a regulatory-style buoy and an anchor. The sensors are attached at 2 meter intervals, beginning 1 meter from the bottom and ending approximately 1 meter from the top. Each buoy apparatus is deployed at the deepest point of the basin it monitors. The setup results in the sensors being located at odd numbered depths throughout the water column (the shallowest sensor is approximately 1 meter deep, the next is 3 meters, etc.).

Temperature sensors are programmed to record temperature readings every 15 minutes. LEA has for many years used a handheld YSI meter to collect water temperature data. However,

this method is time consuming, resulting in only 8 temperature profiles per year. While temperature sensors require an initial time investment, once deployed, the sensors record over 15,000 profiles before they are removed in the fall. This wealth of data provides much greater detail and clarity than the traditional method ever could. Daily temperature fluctuations, brief mixing events caused by storms, the date and time of stratification set up and breakdown, and the timing of seasonal high temperatures are all valuable and informative events that traditional sampling can't accurately measure.

2017 Monitoring Season

Several weather events in 2017 impacted the thermal structure of the lakes and ponds in the area. The large snow pack coupled with cooler weather in the spring led to relatively late ice-out and high water levels in the spring. Temperature buoys were deployed in late April and early May. Stratification began to set up in mid-to-late May on most lakes, after being impeded by cold temperatures throughout spring and strong winds that caused mixing around May 15th.

Heavy storms at the end of June and beginning of July (including several tornadoes in the Bridgton area) affected stratification on most lakes and some temperature fluctuations at depth can be seen due to these events. Mixing caused by other storms, such as a thunderstorm on August 2nd, can also be seen in some of the graphs.

Many lakes saw temperatures peak on or around July 22nd. Compared to 2016, the timing of the peak was 6 days earlier and the maximum temperatures were slightly lower in most cases. Temperatures gradually cooled from then on, with a steeper decline toward the end of August. High winds on September 1st accelerated mixing in many lakes, although full mixing was delayed by unusually warm temperatures in the fall, particularly at the end of September. The timing of full mixing was later than usual on many basins. Storms between October 29th–31st brought very high winds, but despite this most lakes that were still partially stratified at that time did not fully mix.

High-Resolution Temperature Monitoring: How to Read the Graphs

Temperature monitoring summaries on the following pages include a graph for each lake, displaying all the data collected in the 2017 season. These graphs can be tricky to understand, so here are a few pointers:

A HOBO temperature sensor

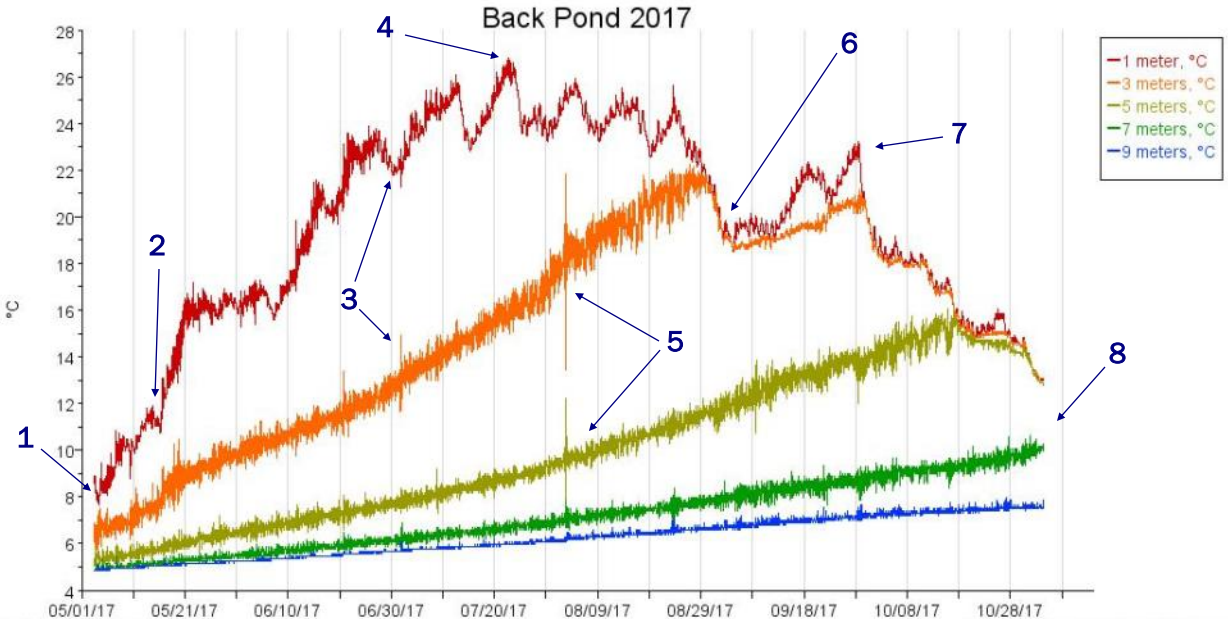
- Each colored line represents the temperature over time at a specific depth in the water. The topmost lines represent water near the top of the lake (red = 1 meter below the surface, etc.), with a difference of 2 meters (approx. 6 feet) in depth between each line.
- The graph shows temperature change over time – The horizontal axis (left to right) shows the date, while the vertical axis (up and down) shows the temperature (in degrees Celsius).
- Generally, the lines are close together on the left side of the graph (late April/early May), then widen out (June-August), then come back together on the right side of the graph (September-November). The top few lines may stay close to each other when the graph widens out, indicating these depths are within the epilimnion, or top stratified layer. Then, there is often a gap in the middle, indicating the rough position of the thermocline. Most of the time, the bottom lines stay relatively flat, indicating that they are within the hypolimnion, the deep, cold layer that makes up the lower portion of the lake.
- Large gaps between lines means there is a large temperature difference between one depth and another.
- The pattern in temperature displayed by the top line (the sensor nearest to the lake's surface) is strongly influenced by air temperature.
- During stratification, the epilimnion does not easily mix with the hypolimnion (hence, these lines do not touch each other). It is only when the temperature of the upper water cools down that the lake can fully mix. You can see this process happening on each graph: the temperatures near the surface get cooler and the deeper waters get warmer as the barrier between the two layers weakens and the waters begin to mix. The lines converge one by one until the temperature is the same at each depth. This is known as lake turnover or destratification.

Back Pond

The temperature record from Back Pond indicates relatively shallow stratification throughout the 2017 season. As seen in the graph below, the 1 meter (red line) sensor data is much more variable than the other depths, indicating that it is affected by air temperatures. The three meter (orange line) sensor data shows a steady temperature increase, but not as much short term variability in temperature. The one and three meter lines are far apart for much of the season, which means that there is a large temperature difference between these depths. At the height of the stratified period, the temperature at one meter deep hit 26.8 °C (80.2 °F) and the thermocline was located around 3 meters deep.

The following events can be seen in the graph below:

1) The pond had just begun to stratify when sensors were deployed May 3rd
2) Cooler spring temperatures meant surface water temperatures stayed cold until mid-May
3) Heavy rains and wind around July 1st can be seen causing temperature fluctuations
4) The peak in temperature occurred on July 22nd
5) Rain and thunderstorms August 2nd affected temperatures deep into the water column
6) High winds on September 1st caused mixing of the upper waters
7) Warm temperatures in the fall kept the pond stratified and raised surface water temperatures
8) Full mixing had not yet occurred when sensors were removed on November 3rd



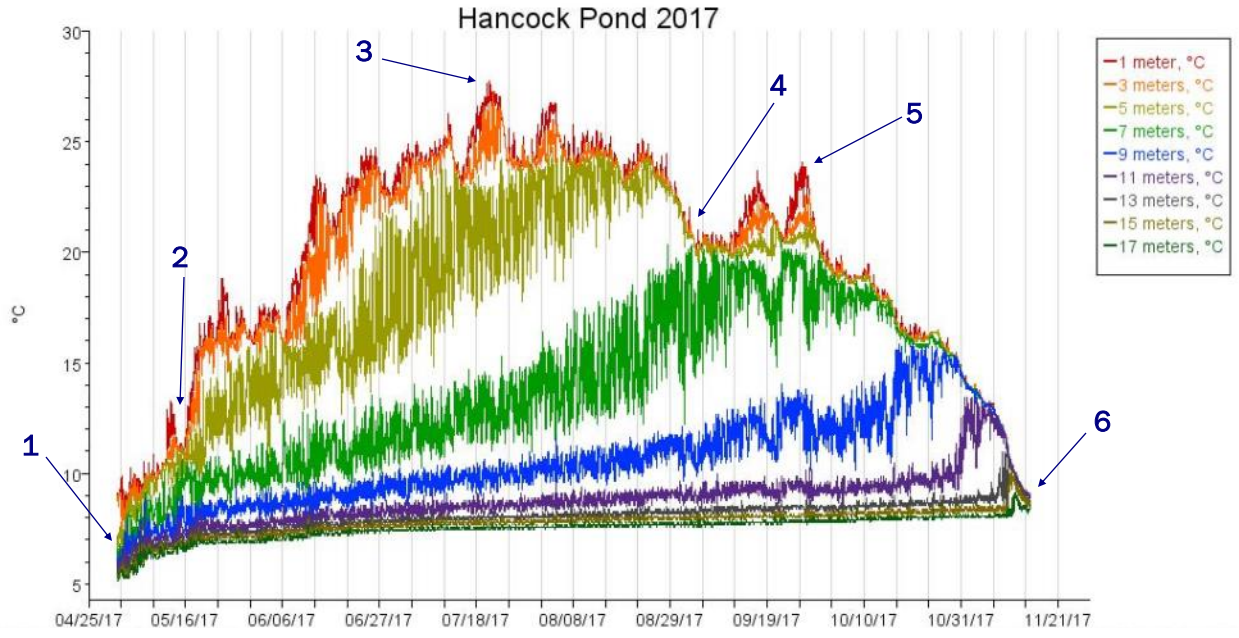
Peak Temperature	Full Mixing
7/22	After 11/3

Hancock Pond

The temperature record from Hancock Pond shows an almost complete record of temperatures throughout the entire stratified period. As seen in the graph below, the 1 and 3 meter data track very closely with each other. These depths are within the epiliminion, or top layer of the pond. The 5 meter line is more variable, but often is close to the 1 and 3 meter temperature. The variability of the 5 meter line suggests large swings in temperature that are characteristic of the thermocline. At the height of the stratified period, the temperature at one meter deep hit 27.8 °C (82.0 °F) and the thermocline was located at around 5 meters.

The following events can be seen in the graph below:

1) The pond had just begun to stratify when sensors were deployed May 1st
2) Cooler spring temperatures meant surface water temperatures stayed cold until mid-May
3) The peak in temperature occurred on July 21st
4) High winds on September 1st caused mixing, as shown by the simultaneous cooling of the top layer of water and warming of the waters around 7 meters deep (green line)
5) Warm temperatures in the fall kept the pond stratified and raised surface water temperatures
6) The lake had almost fully mixed when sensors were removed on November 15th



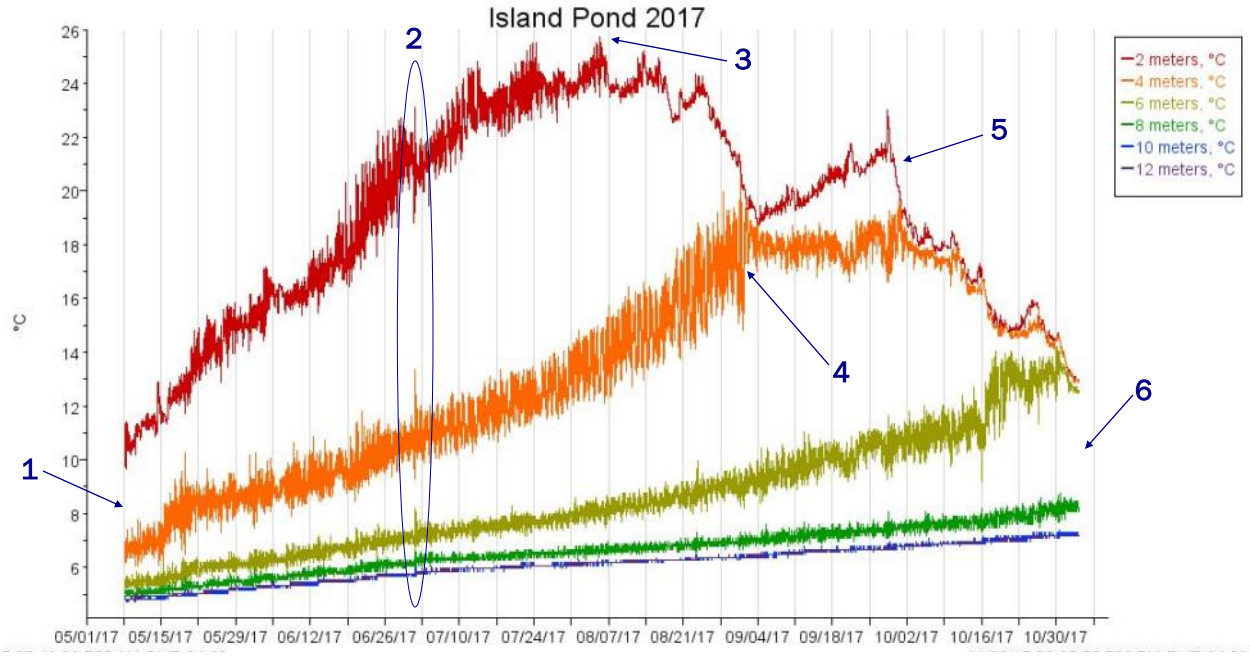
Peak Temperature	Full Mixing
7/21	After 11/15

Island Pond

The temperature record from Island Pond indicates relatively shallow stratification throughout 2017, with the thermocline being located somewhere between 3 and 4 meters deep for much of the season until mixing in September deepened it to around 5 meters. Island Pond is about 13 meters deep, and because sensors are placed starting 1 meter from the bottom, these sensors are at even-numbered depths, which is in contrast to the rest of the graphs in this report. The top-most sensor was located at around 2 meters deep, so the maximum temperature at this sensor was slightly lower than on other lakes at 25.7 °C (78.3 °F) and was reached several days later than on most other ponds measured in 2017. Surface temperature patterns are less distinct, especially in the first half of the graph, again because the sensor was further from the surface of the pond. Note that the 10 and 12 meter lines on the graph blend together because the sensors were at the same temperature throughout the season.

The following events can be seen in the graph below:

1) The pond had begun to stratify when sensors were deployed May 8th
2) Heavy rains and wind around July 1st can be seen affecting deep water temperatures
3) The peak in temperature occurred on August 5th
4) High winds on September 1st caused mixing
5) Warm temperatures in the fall kept the pond stratified and raised surface water temperatures
6) Full mixing had not yet occurred when sensors were removed on November 3rd



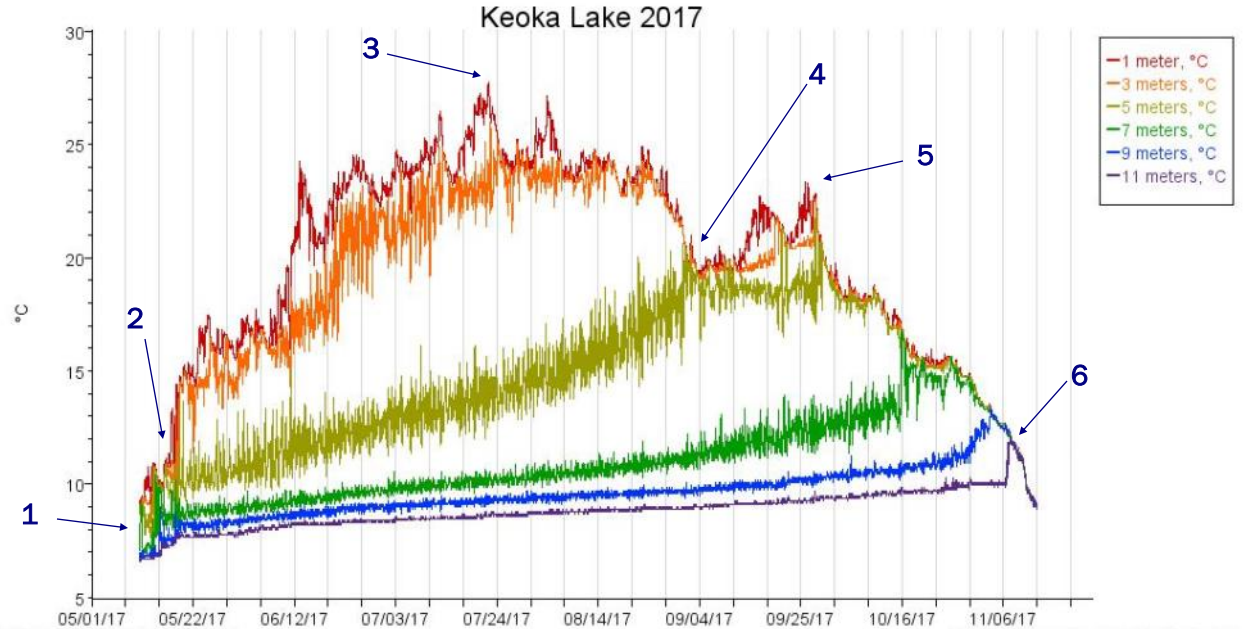
Peak Temperature	Full Mixing
8/5	After 11/3

Keoka Lake

The temperature record from Keoka Lake indicates relatively shallow stratification throughout the 2017 season. As seen in the graph below, the 1 and 3 meter data track closely with each other. This means that these two depths are within the top layer of the lake—the epilimnion. There is a large gap between the 3 and 5 meter lines for much of the season, indicating that the thermocline is somewhere between those depths over that time span. Falling air temperatures combined with high winds on September 1st caused mixing down to about 5 meters, lowering the thermocline depth to approximately 6 –7 meters for much of September. At the height of the stratified period, the temperature at one meter deep hit 27.8 °C (82.0 °F).

The following events can be seen in the graph below:

1) The pond had just begun to stratify when sensors were deployed May 11th
2) Cooler spring temperatures meant surface water temperatures stayed cold until mid-May
3) The peak in temperature occurred on July 22nd
4) High winds on September 1st caused mixing
5) Warm temperatures in the fall kept the lake stratified and raised surface water temperatures
6) Full mixing of the water column occurred on November 7th



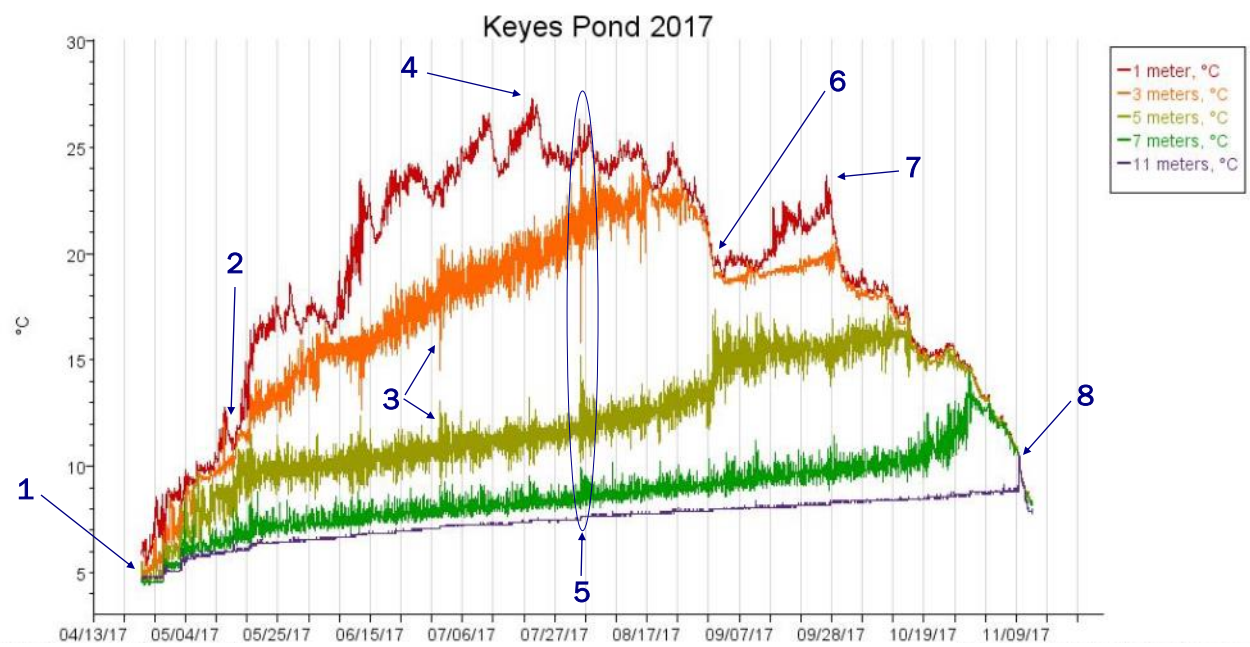
Peak Temperature	Full Mixing
7/22	11/7

Keyes Pond

The temperature record from Keyes Pond indicates relatively shallow stratification throughout the 2017 season. As seen in the graph below, the 1 meter (red line) sensor data is much more variable than the other depths, indicating that it is affected by air temperatures. The three meter (orange line) sensor data shows a steady temperature increase, but not as much short term variability as the 1 meter line until late in the season, when the thermocline deepened. The depth of the thermocline was located within the 3-5 meter zone for much of the season. At the height of the stratified period, the temperature at one meter deep reached 27.3°C (81.1 °F) and the thermocline was 3 meters deep. Note that 9 meter data is missing due to sensor malfunction.

The following events can be seen in the graph below:

1) The pond was well mixed when sensors were deployed April 24th
2) Cooler spring temperatures meant surface temperatures stayed cold until mid-May
3) Heavy rains and wind around July 1st can be seen affecting deep water temperatures
4) The peak in temperature occurred on July 22nd
5) Rain and thunderstorms August 2nd affected temperatures deep into the water column
6) High winds on September 1st caused mixing and warming in deeper waters
7) Warm temperatures in the fall kept the pond stratified and raised surface water temperatures
8) Full mixing occurred on November 10th



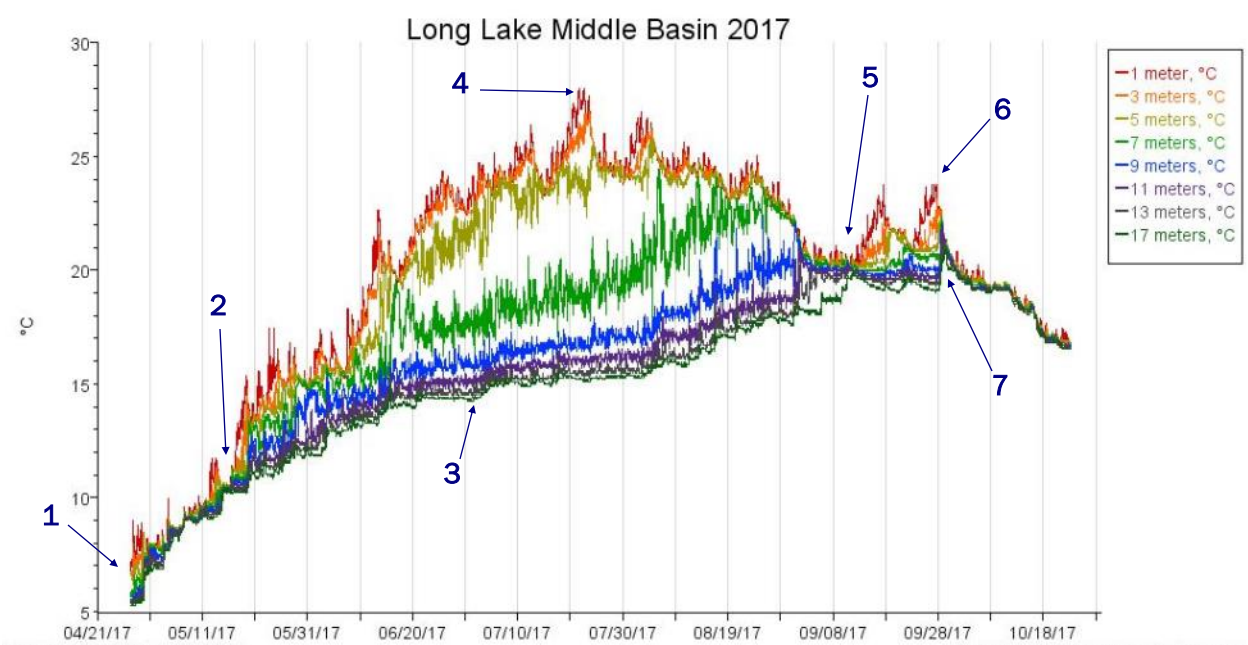
Peak Temperature	Full Mixing
7/22	11/10

Long Lake (Middle Basin)

Temperature patterns in Long Lake's middle basin are very different from those on other lakes in the area. Because of the large size of Long Lake, as well as its bathymetry, the waters are well mixed by winds and water currents. The waters at the bottom of the basin therefore warm much more than on other lakes and ponds. This weakens stratification by reducing the temperature gradient from the top of the lake to the bottom. The duration of stratification is much shorter, because the lake stratifies later and mixes earlier. At the height of the stratified period in 2017, the temperature at one meter deep reached 28.0 °C (82.4 °F) and the thermocline was around 6 meters deep. Note that 15 meter data is missing due to sensor malfunction.

The following events can be seen in the graph below:

1) The pond was well mixed when sensors were deployed April 27th
2) High winds in mid-May caused complete mixing, temperatures began to diverge shortly after
3) Temperatures increased over time at the bottom of the lake because of weak stratification
4) The peak in temperature occurred on July 21st and 22nd
5) High winds on September 1st almost caused full mixing
6) Warm temperatures in the fall kept the basin weakly stratified and raised surface temperatures
7) Full mixing occurred on September 29th



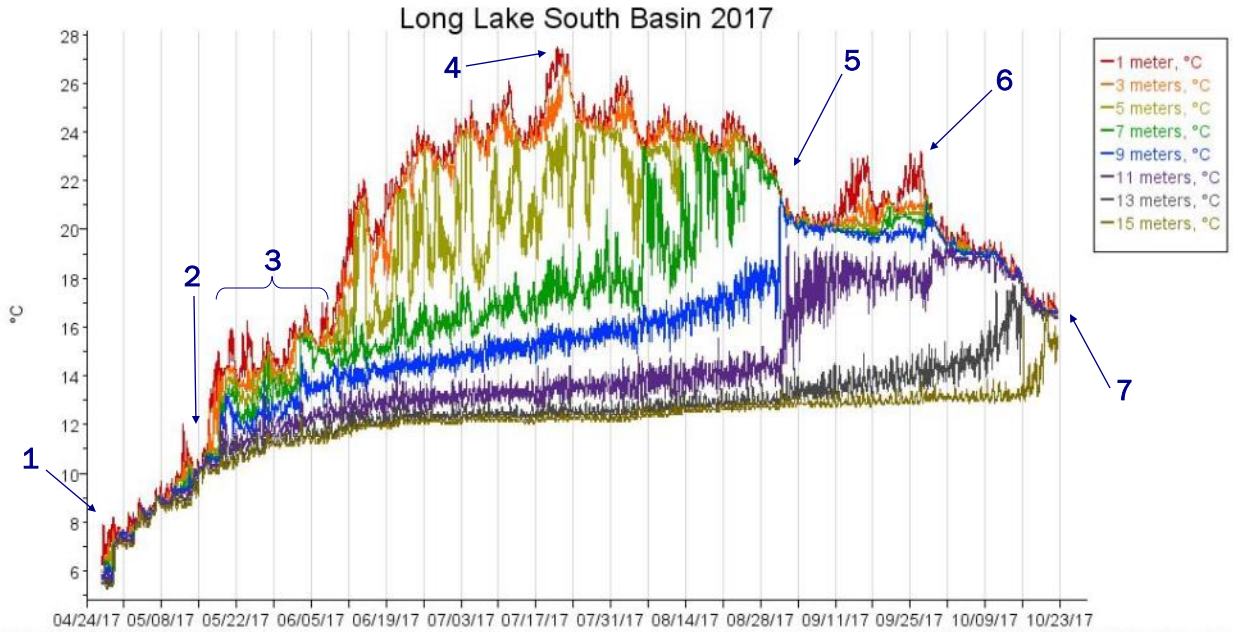
Peak Temperature	Full Mixing
7/21 and 7/22	9/29

Long Lake (South Basin)

The temperature patterns in Long Lake's south basin are unique due to the large size of the lake and the basin's morphometry. While more similar to a typical lake, the south basin also has some of the same characteristics as the middle basin. The basin stays mixed longer into the spring than the average lake, resulting in warmer bottom temperatures, weaker stratification, and a shorter duration of stratification. As seen in the graph below, the 1 and 3 meter data track very closely with each other. These depths are within the epiliminion, or top layer of the lake. The 5 and 7 meter lines are more variable and erratic, indicating the location of the thermocline. The deepening of the thermocline is evident around August 7th, when the magnitude of the temperature fluctuation of the 7 meter (green) line increases. At the height of the stratified period, the temperature at one meter deep hit 27.5 °C (81.5 °F) and the thermocline was around 6 meters deep.

The following events can be seen in the graph below:

1) The pond was well mixed when sensors were deployed April 27th
2) High winds in mid-May caused the entire basin to mix
3) Bottom temperatures warmed during a period of weak stratification that lasted until mid-June
4) The peak in temperature occurred on July 21st
5) High winds on September 1st caused deeper waters to warm and start to mix
6) Warm air temperatures in the fall raised surface water temperatures, delaying full mixing
7) The lake had almost fully mixed when sensors were removed on October 23rd



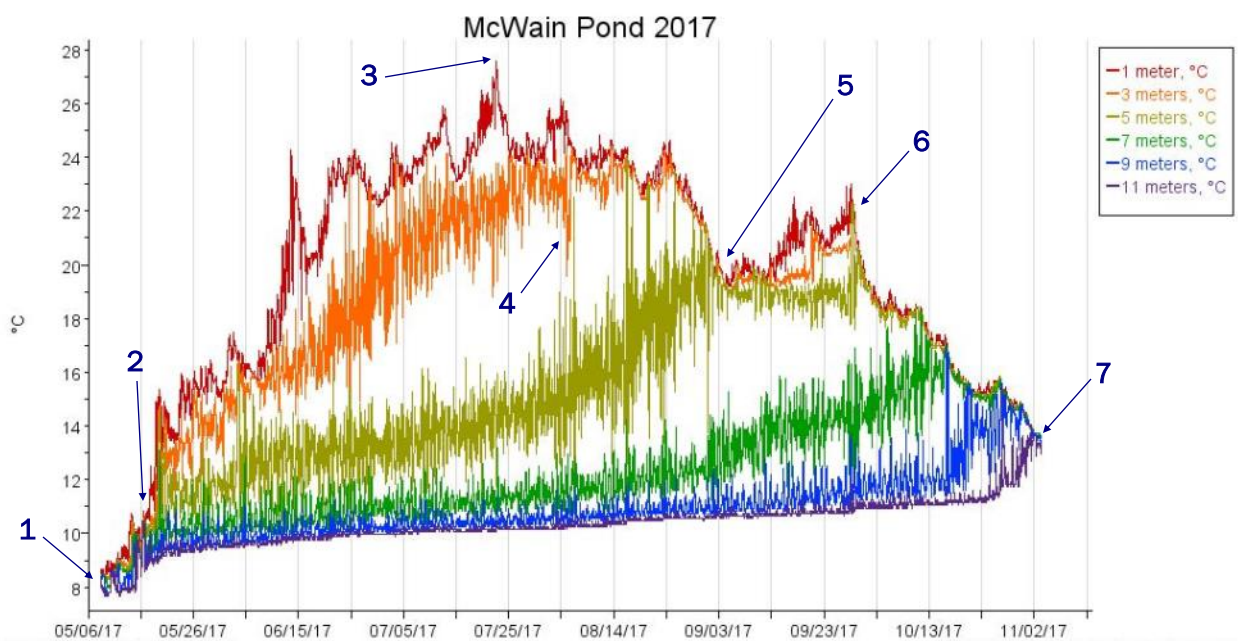
Peak Temperature	Full Mixing
7/21	After 10/23

McWain Pond

The temperature record from McWain Pond encompasses the entire stratified period. As seen in the graph below, the 1 meter (red line) sensor data shows distinct, sharp temperature fluctuations, indicating that it is strongly affected by air temperatures. The three meter (orange line) data shows a steady temperature increase across the first part of the graph, then it begins to follow the one meter line closely. The gap between the 3 and 5 meter lines indicates a large temperature disparity between one depth and the next. This indicates the approximate location of the thermocline. At the height of the stratified period, the temperature at one meter deep reached 27.4 °C (81.7 °F) and the thermocline was located at about 4 meters deep.

The following events can be seen in the graph below:

1) The pond was still well mixed when sensors were deployed May 8th
2) Cooler spring temperatures meant surface water temperatures stayed cold until mid-May
3) The peak in temperature occurred on July 22nd
4) Rain and thunderstorms August 2nd affected temperatures deep into the water column
5) High winds on September 1st caused mixing in of deeper water
6) Warm temperatures in the fall kept the pond stratified and raised surface water temperatures
7) Full mixing occurred on November 2nd



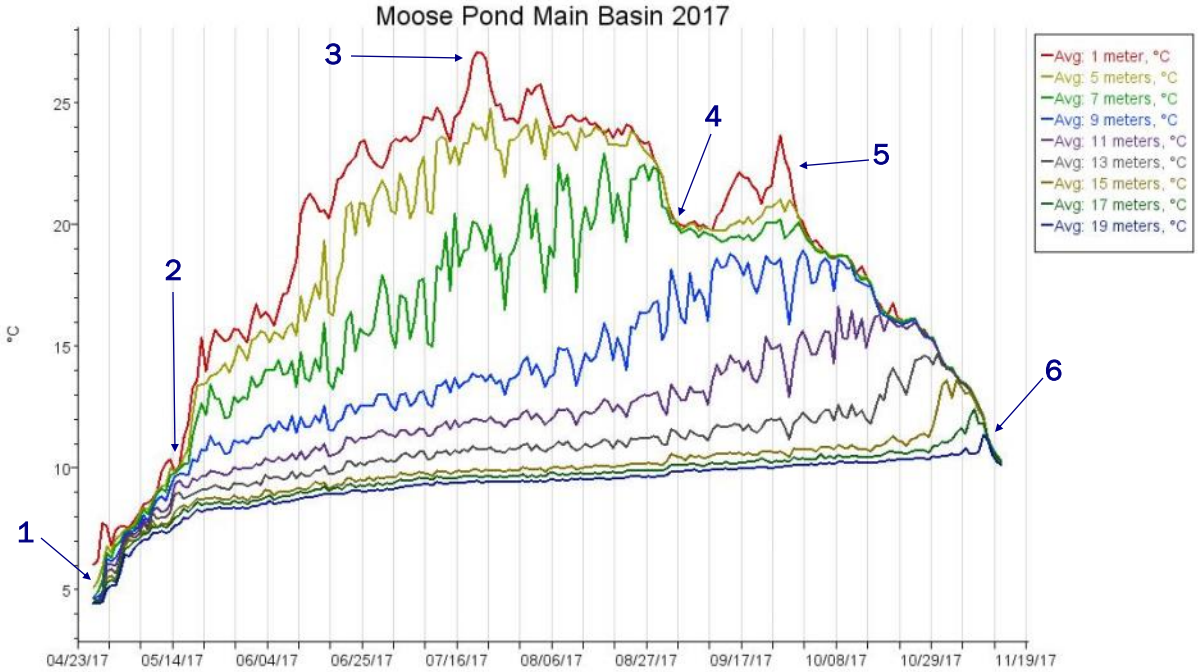
Peak Temperature	Full Mixing
7/22	11/2

Moose Pond (Main Basin)

The temperature sensor buoy on Moose Pond's main basin was not placed at the deepest point within the basin in 2017, which meant that the line on which the sensors were attached had a lot of slack. Because of this, the sensors moved around in the water much more than they would have been able to if the line was tight, and caused very large temperature swings that made the graph hard to read. For this reason, a graph of daily average values is presented below. The high temperature of 32.0 °C (89.6 °F) is much higher than on other ponds monitored in 2017 because the one-meter sensor was able to float close to the surface; however this spike in temperature cannot be seen in the average data graphed below. The thermocline was located between 6-7 meters for much of the season until mixing in early September deepened stratification. Note that data was unavailable for the 3 meter and 21 meter sensors.

The following events can be seen in the graph below:

1) The pond was still well mixed when sensors were deployed April 27th
2) Cooler spring temperatures meant the basin stayed well mixed until mid-May
3) The peak in temperature occurred on July 26th (full data) or July 21st (average data)
4) High winds on September 1st caused mixing and slight warming of deeper waters
5) Warm temperatures in the fall kept the basin stratified and raised surface water temperatures
6) Full mixing occurred on or around November 10th *The bottom-most sensor at 21 meters failed, so the turnover date listed is based on data from a sensor 3 meters from the bottom and is probably underestimated



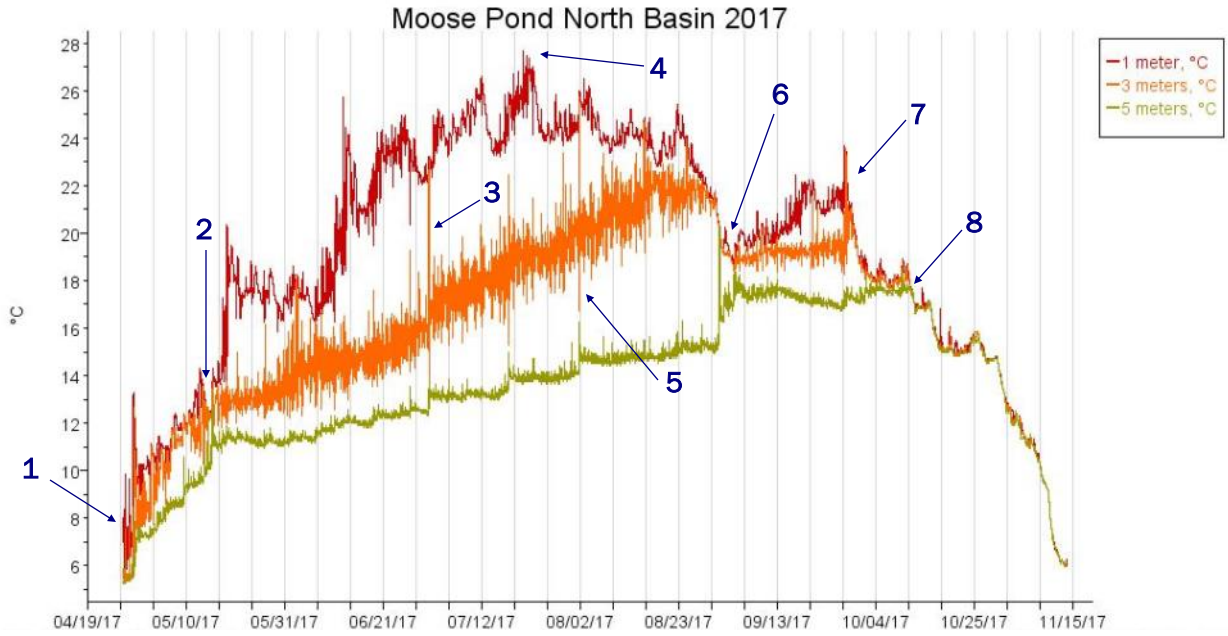
Peak Temperature	Full Mixing
7/21 or 7/26	11/10*

Moose Pond (North Basin)

Moose Pond's north basin is only about 6 meters deep. At this relatively shallow depth, the basin does not stratify strongly. The bottom temperature is influenced by air temperature as well as mixing, which causes it to warm incrementally throughout the summer. Storm events, such as around July 1st, August 2nd, and September 1st, impacted temperatures throughout the water column. However, the basin did remain stratified for several months in 2017. At the height of the stratified period, the temperature at one meter deep reached 27.7 °C (81.9 °F) and the thermocline was located at around 3 meters deep.

The following events can be seen in the graph below:

1) The pond had just begun to stratify when sensors were deployed April 27th
2) Cooler spring temperatures meant the basin stayed well mixed until mid-May
3) Heavy rains and wind around July 1st can be seen causing temperature fluctuations
4) The peak in temperature occurred on July 21st
5) Rain and thunderstorms August 2nd affected temperatures throughout the water column
6) High winds on September 1st caused almost complete mixing
7) Warm temperatures in the fall kept the basin weakly stratified and raised surface temperatures
8) Full mixing occurred on October 12th



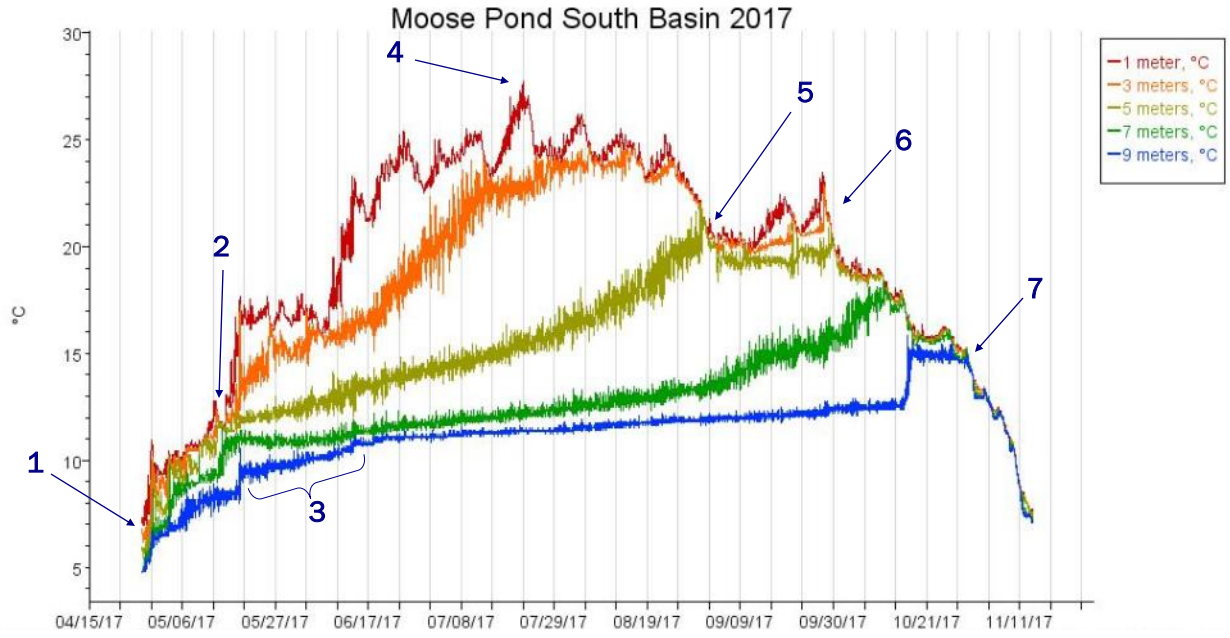
Peak Temperature	Full Mixing
7/21	10/12

Moose Pond (South Basin)

The temperature record from Moose Pond's south basin indicates relatively shallow stratification throughout the 2017 season. As seen in the graph below, the 1 meter (red line) sensor data show greater day-to-day variability than the other depths, indicating that it is affected by air temperatures. The three meter (orange line) data shows a steadier pattern but tracks well with the 1 meter data about halfway through the season. Over the course of the stratified period, the depth of the thermocline was anywhere from 3 to 7 meters in depth. At the height of stratification, the temperature at one meter deep reached 27.8 °C (82.0 °F) and the thermocline was located at approximately 5-6 meters.

The following events can be seen in the graph below:

1) The pond had just begun to stratify when sensors were deployed April 27th
2) Cooler spring temperatures meant surface water temperatures stayed cold until mid-May
3) Weak stratification allowed temperature to creep up at the bottom of the basin throughout May and early June
4) The peak in temperature occurred on July 22nd
5) High winds on September 1st caused mixing down to about 5 meters deep, weakening stratification and allowing for the gradual warming of deeper waters
6) Warm temperatures in the fall kept the basin stratified and raised surface water temperatures
7) Full mixing occurred on October 31st



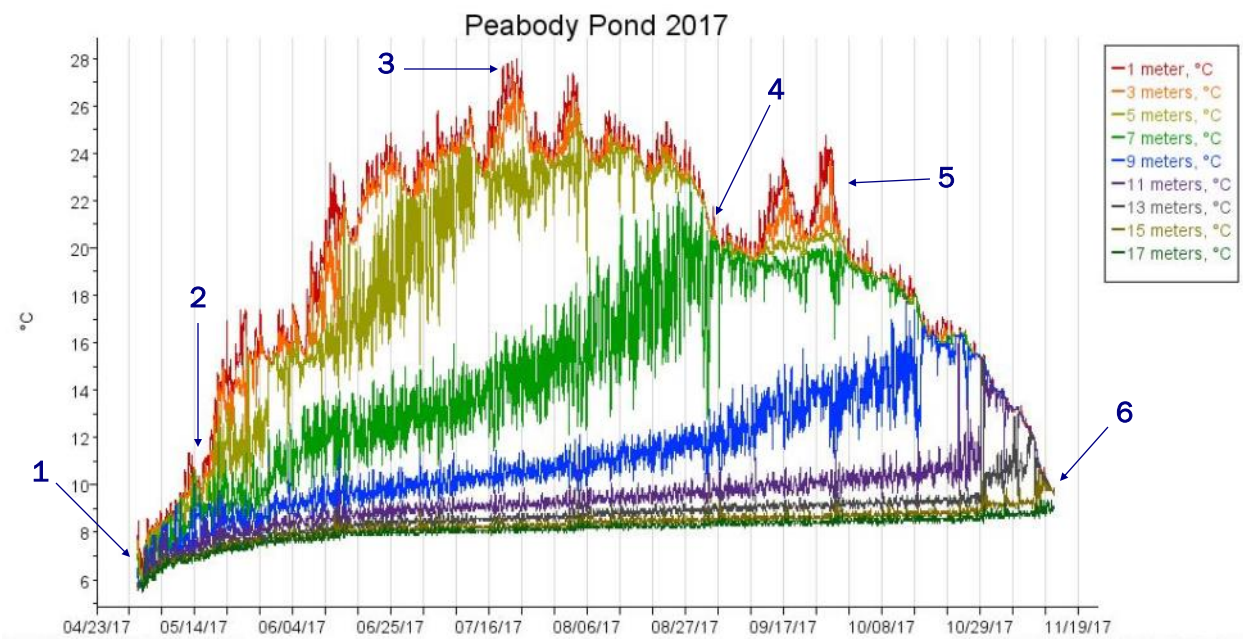
Peak Temperature	Full Mixing
7/22	10/31

Peabody Pond

The temperature record from Peabody Pond shows an almost complete record of stratification in 2017. As seen in the graph below, the 1 and 3 meter data track very closely with each other. This indicates the position of the top layer of water, known as the epiliminion. The 5 meter line is more variable, but often is close to the 1 and 3 meter temperature. The variability of the 5 and 7 meter lines show large swings in temperature that are characteristic of the thermocline. At the height of the stratified period, the temperature at one meter deep reached 28.0 °C (82.4 °F) and the thermocline was somewhere between 5 and 7 meters deep. Note that the Peabody Pond buoy was moved to a site on the northern part of the pond on May 30th.

The following events can be seen in the graph below:

1) The pond was still well mixed when sensors were deployed May 2nd
2) Cooler spring temperatures meant surface water temperatures stayed cold until mid-May
3) The peak in temperature occurred on July 22nd
4) High winds on September 1st caused temperature fluctuations deep into the water column
5) Warm air temperatures in the fall kept the pond stratified and raised surface temperatures
6) The lake had almost fully mixed when sensors were removed on November 14th



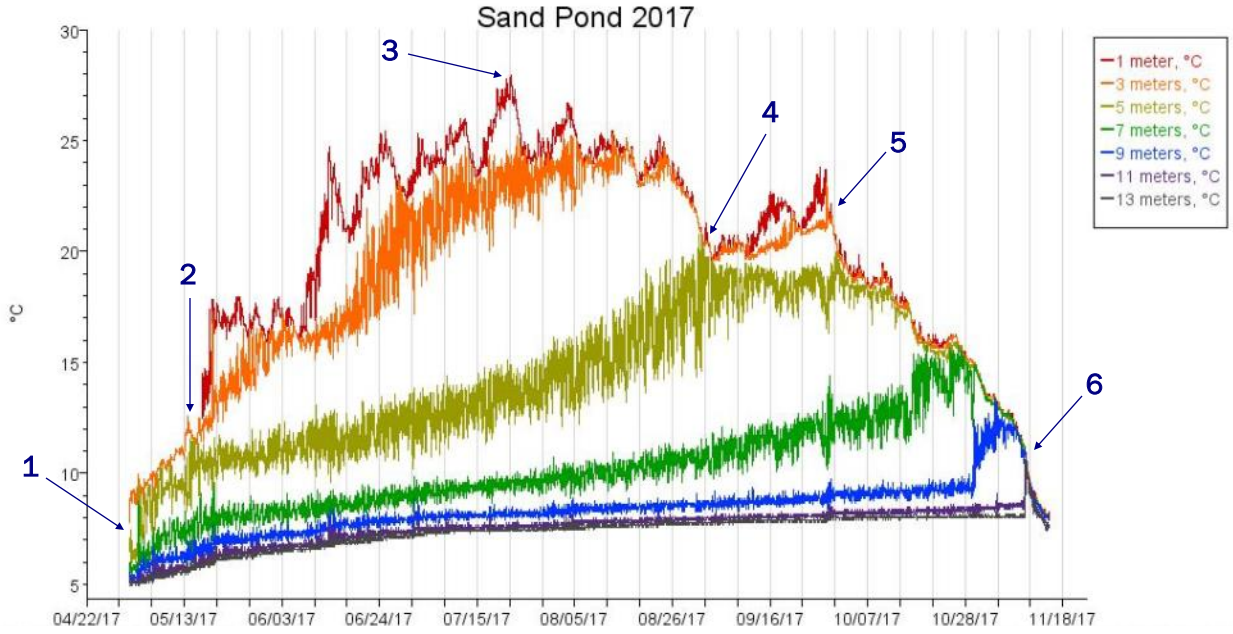
Peak Temperature	Full Mixing
7/22	After 11/14

Sand Pond

The temperature record from Sand Pond shows most of the stratified period. As seen in the graph below, the 1 meter (red line) sensor data shows distinct, sharp temperature fluctuations, indicating that it is affected by air temperatures. The three meter (orange line) data shows a steady temperature increase across the first part of the graph, then it begins to follow the one meter line closely. The gap between the 3 and 5 meter lines indicates a large temperature disparity between one depth and the next. Within this gap lies the thermocline, the boundary layer between the top and bottom layers of the pond. After high winds at the beginning of September, the thermocline deepened to about 6-7 meters. At the height of the stratified period in July, the temperature at one meter deep reached 28.0 °C (82.4 °F).

The following events can be seen in the graph below:

1) The pond had just begun to stratify when sensors were deployed May 1st
2) Cooler spring temperatures meant surface water temperatures stayed cold until mid-May
3) The peak in temperature occurred on July 22nd
4) High winds on September 1st caused mixing of waters down to 5 meters
5) Warm air temperatures in the fall kept the pond stratified and raised surface temperatures
6) Complete mixing occurred on November 10th



Peak Temperature	Full Mixing
7/22	11/10

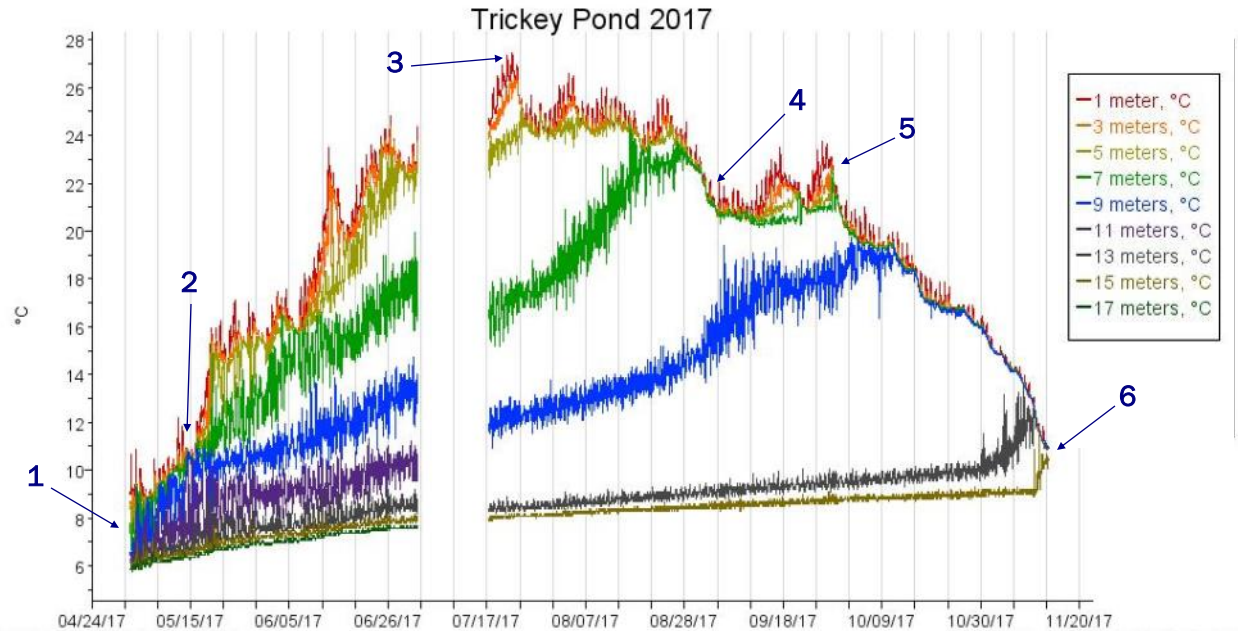
Trickey Pond

The temperature record from Trickey Pond indicates relatively deep stratification throughout the 2017 season. As seen in the graph below, the 1, 3 and 5 meter data track very closely with each other, which indicates that the epilimnion reaches down to at least 5 meters in the first half of the graph. The thermocline moved between 5 and 9 meters over the course of the stratified period. At the height of the stratified period in July, the temperature at one meter deep reached 27.5 °C (81.5 °F) and the thermocline was located at around 6 meters deep.

Note: The buoy became unmoored July 2nd, causing a gap in data until new sensors were deployed. The new sensor string, deployed on July 17th, was placed in a slightly different location north of the original buoy; this is why the 7 and 9 meter lines show a decrease in temperature. Also note that due to sensor malfunction, 11 and 17 meter data are missing from the second half of the graph.

The following events can be seen in the graph below:

1) The pond had just begun to stratify when sensors were deployed May 2nd
2) Cooler spring temperatures meant surface water temperatures stayed cold until mid-May
3) The peak in temperature occurred on July 22nd
4) High winds on September 1st caused mixing and warming of deeper waters
5) Warm air temperatures in the fall kept the pond stratified and raised surface temperatures
6) The lake had almost fully mixed when sensors were removed on November 13th



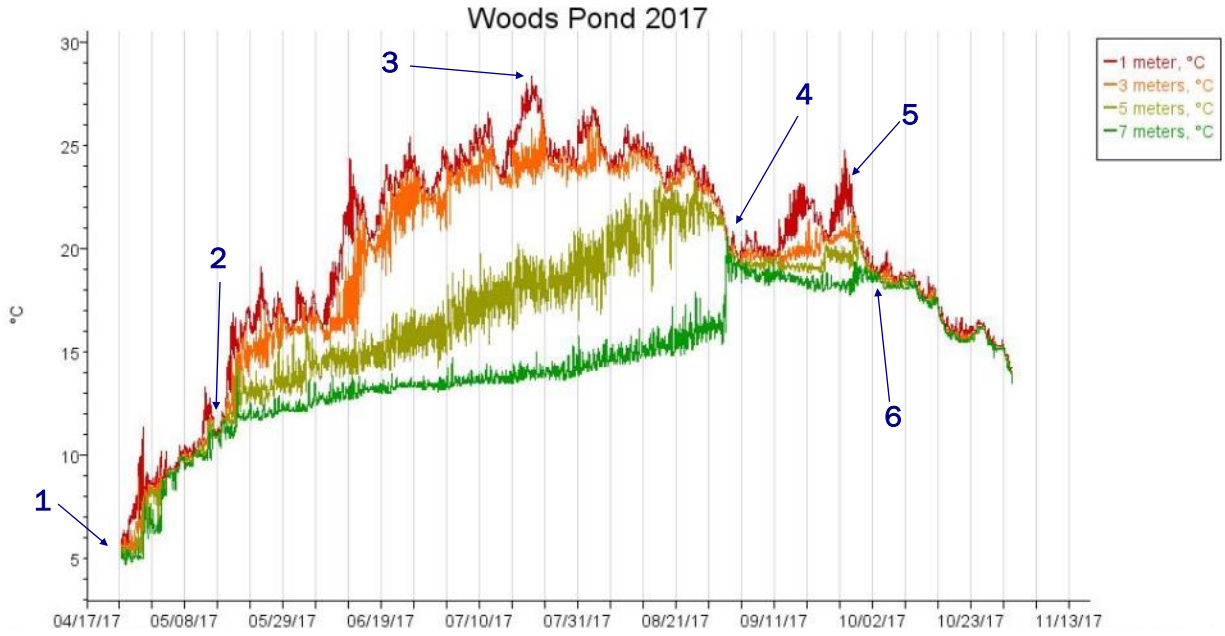
Peak Temperature	Full Mixing
7/22	After 11/13

Woods Pond

Woods Pond is about 8 meters deep. With its large surface area and relatively shallow depth, the basin does not stratify strongly. The bottom temperature is influenced by air temperature as well as mixing, making it subject to warming throughout the summer. However, the pond did remain stratified for several months in 2017. At the height of the stratified period, the temperature at one meter deep hit 28.4 °C (83.1 °F) and the thermocline was located at around 4 meters deep. This maximum temperature is slightly higher than in many of the other lakes measured because the water is highly colored, so it absorbs heat more effectively than clear water.

The following events can be seen in the graph below:

1) The pond was still well mixed when sensors were deployed April 24th
2) Cooler spring temperatures meant the pond stayed mixed until mid-May
3) The peak in temperature occurred on July 21st
4) High winds on September 1st caused the lake to destratify completely
5) Weak re-stratification occurred in September due to warm air temperatures
6) The pond mixed fully again on October 3rd



Peak Temperature	Full Mixing
7/21	9/1