Lakes Environmental Association
2019 Water Testing Report

Chapter 3—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 and weather patterns on the waterbody tested.

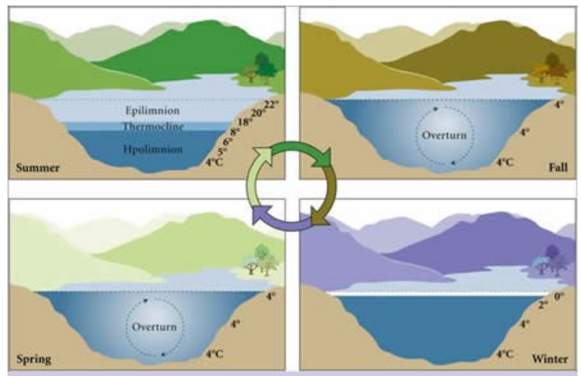
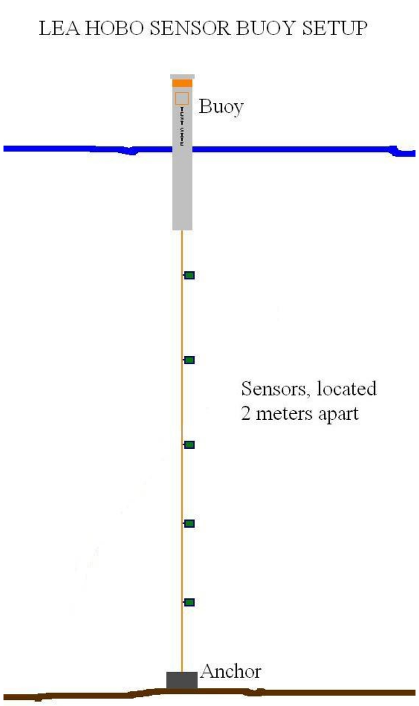


Diagram of Seasonal Stratification and Lake Mixing
Young, M. (2004). *Thermal Stratification in Lakes*. Baylor College of Medicine, Center For Educational Outreach.

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 natural phenomenon that has important consequences for water quality and lake ecology. See Chapter 1, page 7 of the Water Testing Report for more information about stratification.

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 thirteen lakes and ponds. Sensors are attached to a 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.

2019 Monitoring Season

Spring ice-out, which occurred on most lakes in late April, was later than in many recent years, but was close to the historical average. A large winter snow pack caused lake water levels to be high as spring temperatures contributed to melting. Temperature sensors were deployed between May 1st – 14th, and by that time, all of the lakes had begun to stratify.

A HOBO temperature sensor

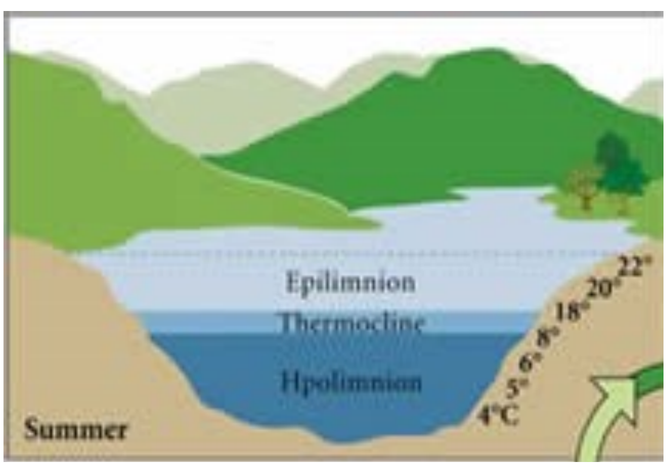
The highest recorded temperatures across all lakes were between July 21 and August 8th. This is consistent with the usual timing of the peak in temperature, which is typically in late July. Temperatures gradually cooled throughout late summer and fall. The timing of mixing depended greatly on lake depth, size, and shape.

Lack of significant summer rainfall, coupled with high temperatures, led to very low lake levels throughout much of the summer season. Water levels did not recover until fall. This is noteworthy because fluctuations in water levels affect the relative depth of the temperature sensors.

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 2019 season. These graphs can be tricky to understand, so here are a few pointers:

- 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 from the bottom, 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 because temperature is fairly uniform throughout the water column (late April/early May), then widen out (June-August), then come back together on the right side of the graph when temperature is again uniform (September-November). The top few lines may stay close to each other when the graph widens out, indicating these depths are within the epilimnion (see below). 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.
- Large gaps between lines means there is a large temperature difference between depths.
- 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.



Stratification Terms

Epilimnion: The warm, top layer that forms when a lake stratifies. It is heavily influenced by air temperature and is well mixed by wind.

Thermocline: A zone of rapid temperature and density change that separates the epilimnion from the hypolimnion.

Hypolimnion: The cold, bottom layer that forms when a lake stratifies. This layer is cut off from the surface layer and cannot mix with it until stratification breaks down.

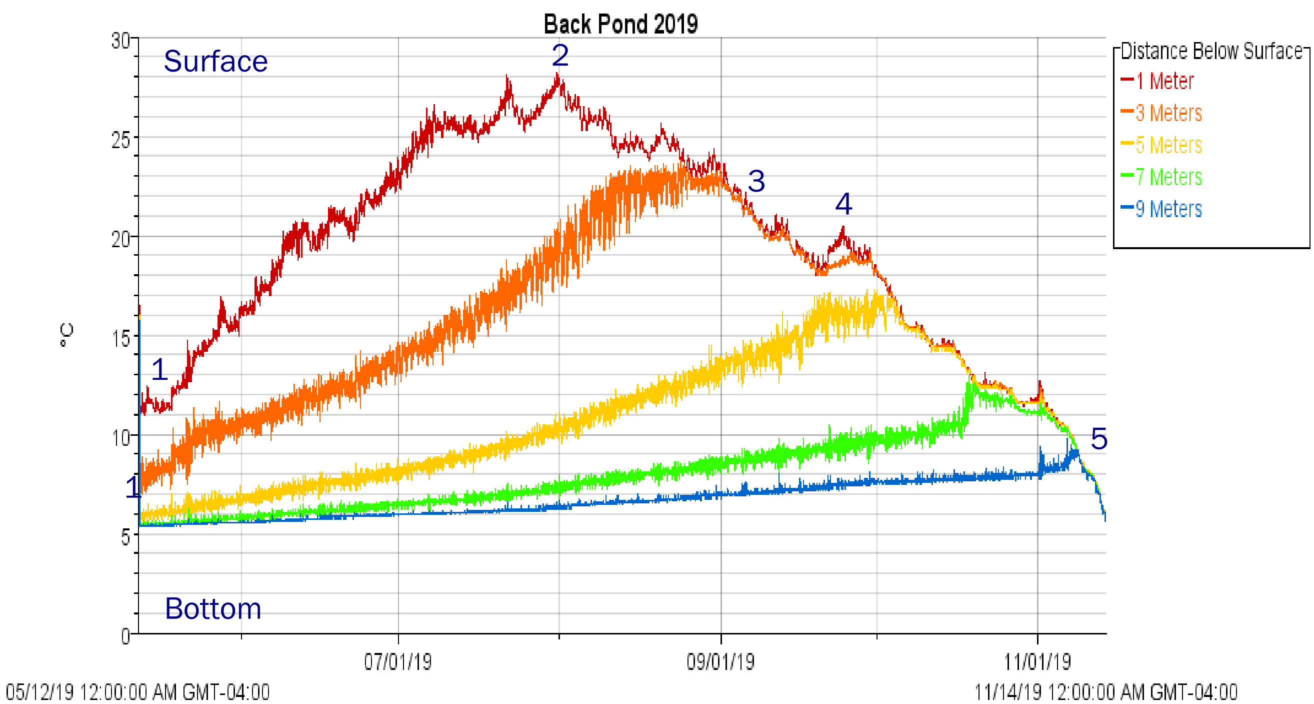
Back Pond

Summary

The water column of Back Pond distinctly and strongly divided into layers based on temperature (stratified). The temperature between 1 - 3 meters increased dramatically following air temperature increases, but there was very little change in temperature over the season in the deepest waters. Large temperature differentials like this result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. The pond had just stratified when sensors were deployed on May 12.
2. The peak in temperature of 26.9 C (80.4 F) occurred on July 31.
3. Cooling air temperatures allowed water between 1 and 3 meters to mix in early September but stratification persisted below 3 meters.
4. After a warm spell in late September, waters between 1 and 3 meters briefly re-stratified.
5. Full mixing occurred on November 9.



Peak Temperature	Full Mixing
7/31	11/09

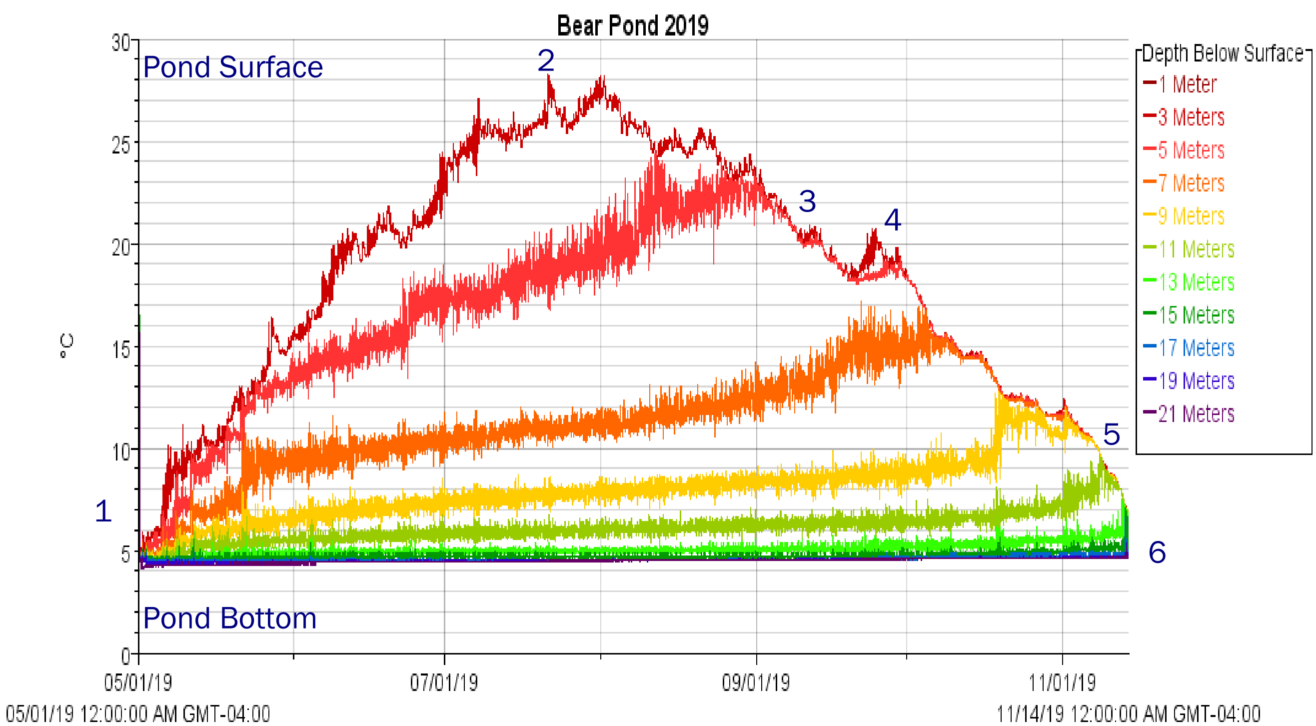
Bear Pond

Summary

The water column of Bear Pond distinctly and strongly divided into layers based on temperature (stratified). The temperature in the upper waters (1—7 meters) increased dramatically following air temperature increases, but there was little change in temperature over the season in the deepest waters (11—21 meters). Large temperature differentials like this result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae. Note that the surface sensor (1 meter) malfunctioned during the season and was excluded from analysis.

The following events can be seen in the graph below:

1. There was only a 2 degree temperature difference between the top and bottom of the pond when the sensors were deployed on May 1.
2. Surface water temperature peaked on July 21 at 28.3 C (82.9 F).
3. Cooling air temperatures allowed water between 3 and 5 meters to mix in early September but stratification persisted below 3 meters.
4. After a warm spell in late September, waters between 3 and 5 meters briefly re-stratified.
5. Bear Pond was almost fully mixed when the sensors were removed on November 14.
6. There was virtually no change in the water temperature between 17—21 meters throughout the season.



Peak Temperature	Full Mixing
7/21	After 11/14/2019

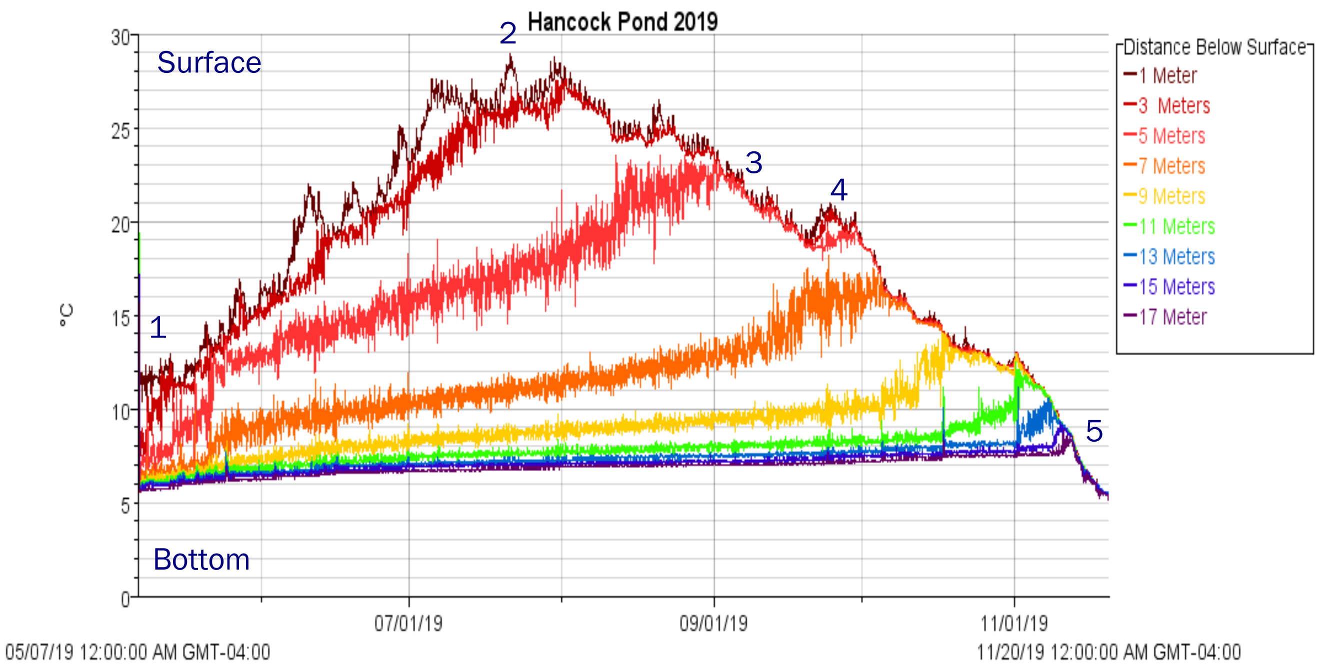
Hancock Pond

Summary

The water column of Hancock Pond distinctly and strongly divided into layers based on temperature (stratified). The temperature in the upper waters (1—7 meters) increased dramatically following air temperature increases, but there was very little change in temperature over the season in the deepest waters (13—17 meters). Large temperature differentials like this result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. The pond had just begun to stratify when sensors were deployed May 7.
2. The peak in temperature (29.0 C/ 84.2 F) occurred on July 21.
3. As surface waters cooled, water temperature between 1—5 meters equilibrated and mixed.
4. After a warm spell in late September, waters between 1—5 meters briefly re-stratified.
5. The pond fully mixed on November 13th.



Peak Temperature	Full Mixing
7/21	11/13

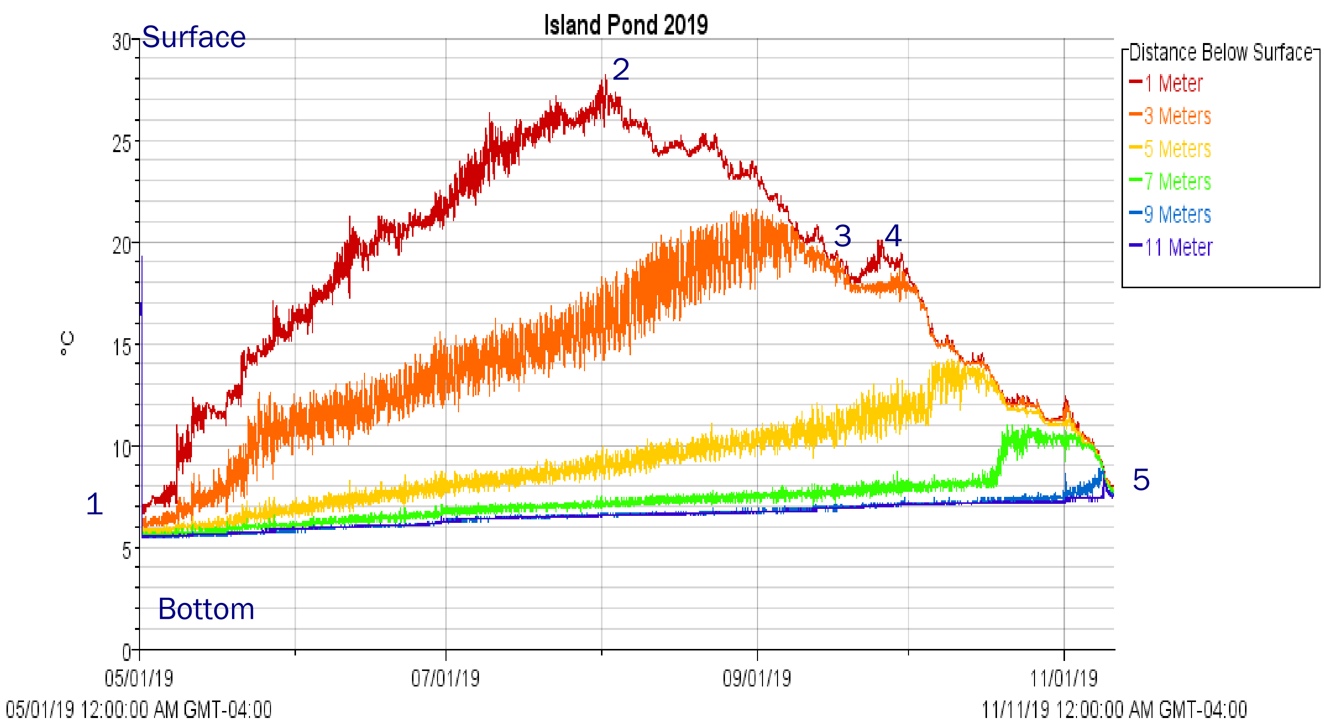
Island Pond

Summary

The water column of Island Pond distinctly and strongly divided into layers based on temperature (stratified). The temperature in the upper waters (1—3 meters) increased dramatically following air temperature increases, but there was very little change in temperature over the season in the deepest waters (9—11 meters). Large temperature differentials like this result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. There was less than a 2 degree temperature difference between the top and bottom of the pond when sensors were deployed on May 1.
2. The peak in temperature (27.6 C/ 81.7 F) occurred on August 1.
3. As surface waters cooled, water temperature between 1—3 meters equilibrated and began to mix.
4. After a warm spell in late September, waters between 1—3 meters briefly re-stratified.
5. Full mixing had just occurred before the sensors were removed on November 11th.



Peak Temperature	Full Mixing
8/01	before 11/11/19

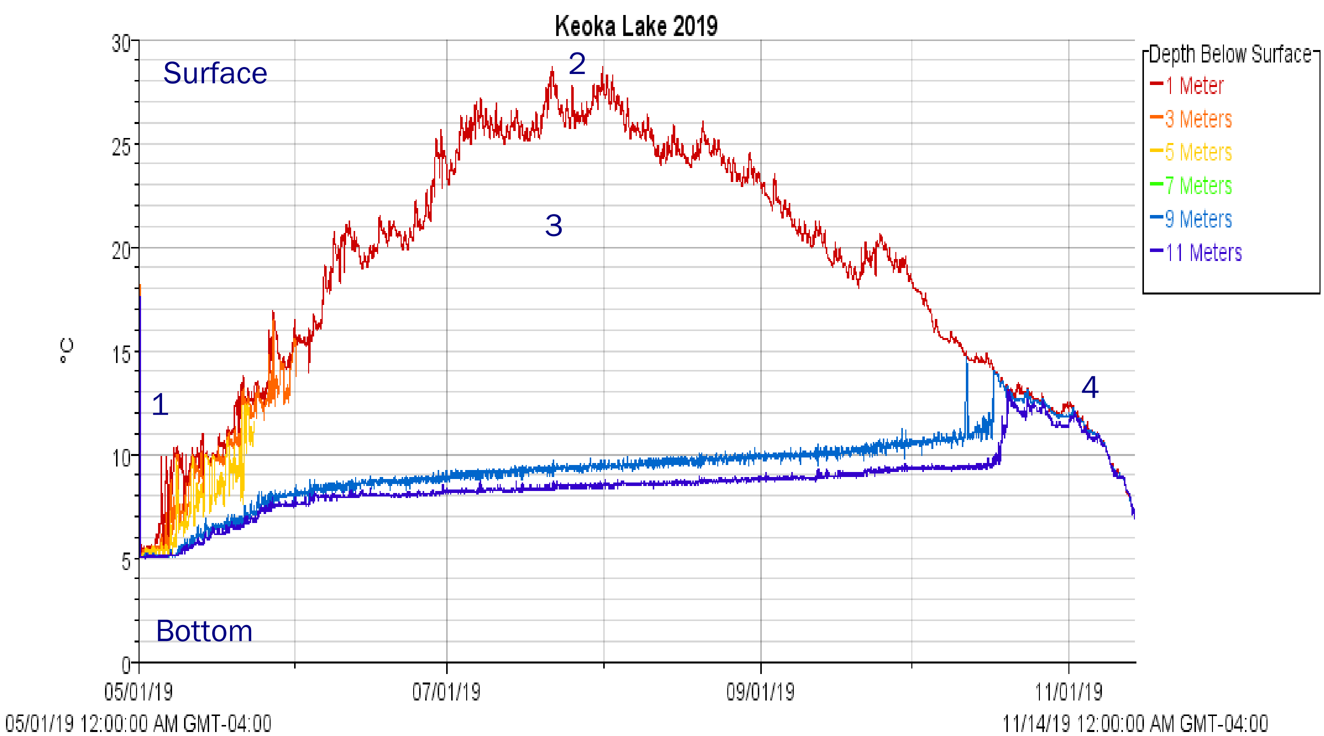
Keoka Lake

Summary

Although there is a large gap in the 2019 dataset, the remaining data from Keoka's season-long temperature profile looks similar to the 2018 profile. Based on available data, we can conclude the water column of Keoka Lake distinctly and strongly divided into layers based on temperature (stratified) in the warmer months. The temperature in the upper waters increased dramatically following air temperature increases but there was very little change in temperature over the season in the deepest waters (9—11 meters). Large temperature differentials like this result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. Stratification began on May 5.
2. Peak temperature (28.7 C/ 83.7 F) was seen on July 31.
3. Due to equipment malfunction, data from the 3 meter, 5 meter, and 7 meter sensors are missing.
4. The lake fully mixed on November 6.



Peak Temperature	Full Mixing
7/31	11/06

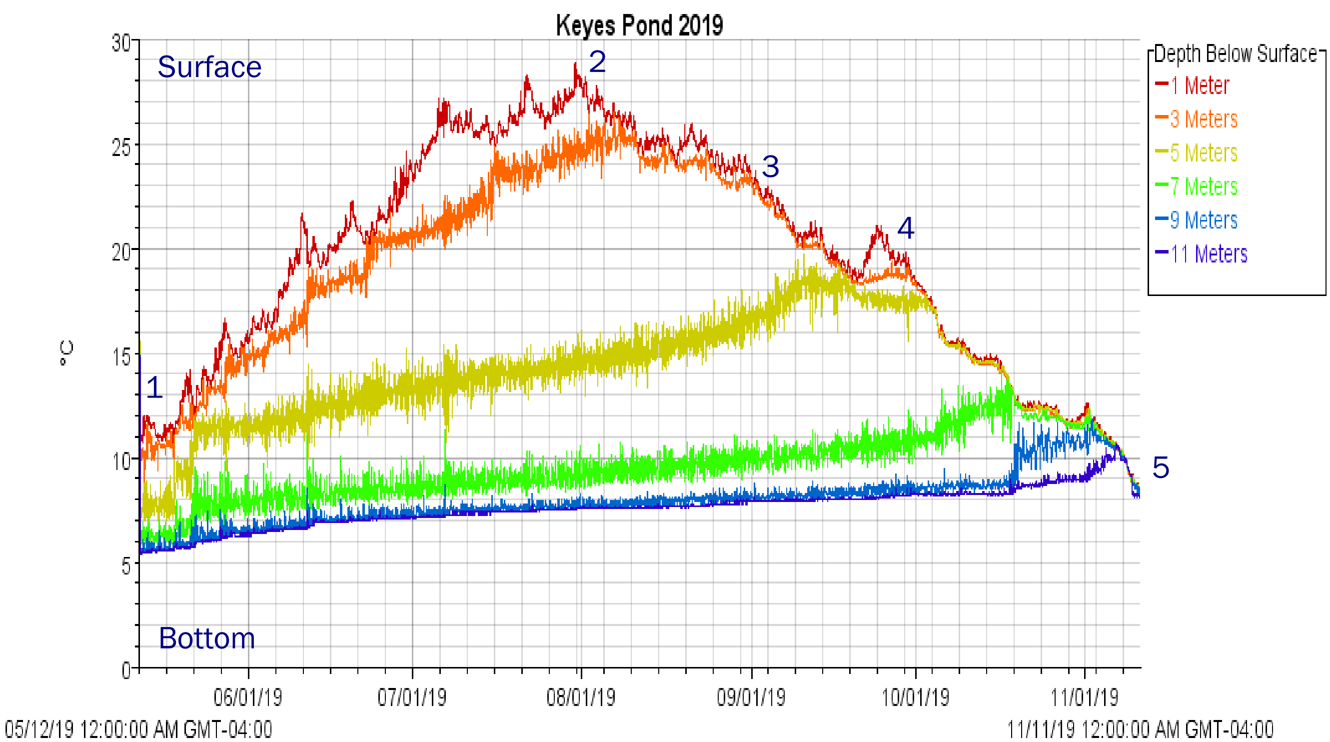
Keyes Pond

Summary

The water column of Keyes Pond distinctly and strongly divided into layers based on temperature (stratified). The temperature in the upper waters (1—3 meters) increased dramatically following air temperature increases, but there was little change in temperature over the season in the deepest waters (9—11 meters). Large temperature differentials like this result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. The pond was already mildly stratified when sensors were deployed on May 12.
2. Peak temperature (28.9 C/ 84.0 F) was reached on July 30.
3. As surface waters cooled, water temperature between 1—3 meters equilibrated and began to mix.
4. After a warm spell in late September, waters between 1—3 meters briefly re-stratified.
5. Full mixing occurred on November 7.



Peak Temperature	Full Mixing
7/30	11/07

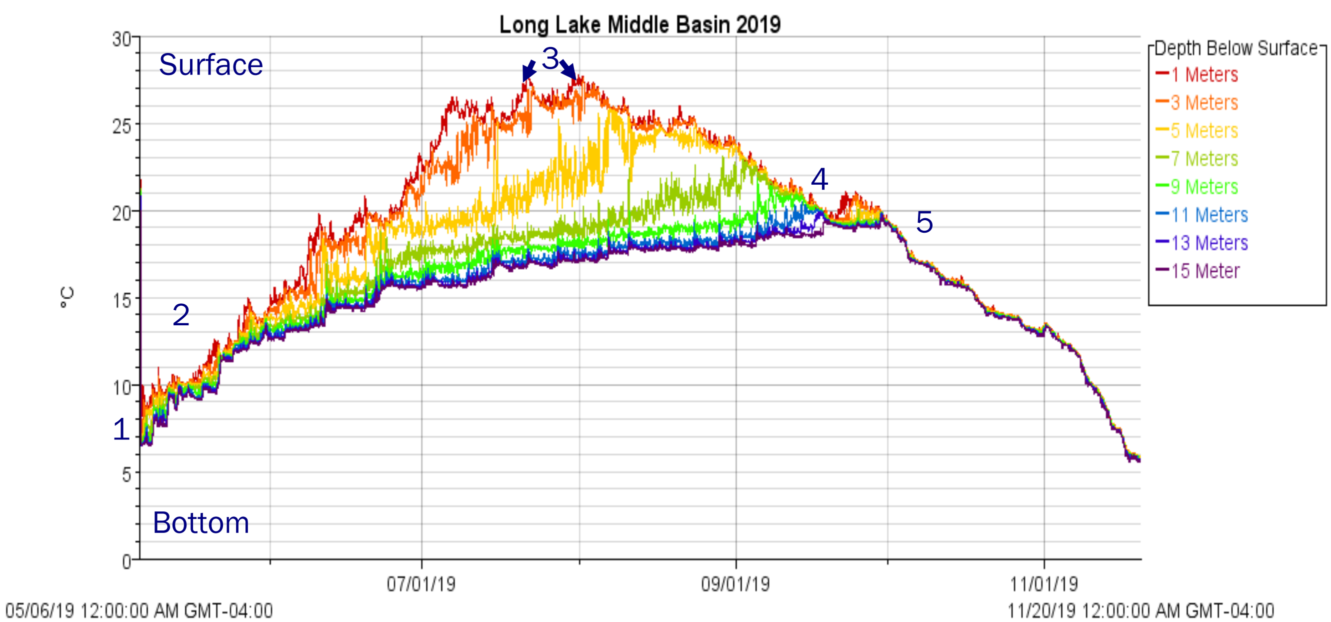
Long Lake (Middle Basin)

Summary

The temperature of deep waters (11—15 meters) in the middle basin of Long Lake continually increased all season long. This type of consistent temperature increase results in a relatively weak stratification (division of waters into layers based on temperature), meaning that the temperature difference between surface waters (1-3 meters) and deep waters (11-15 meters) isn't as large as other lakes with similar depths. Long Lake's weak stratification is likely the result of the lake's long length, which runs parallel to the most dominant northwest wind direction. This large length of open water (fetch size) allows for the build-up of large surface and internal waves. Due to large waves, strong and sustained winds in the summer could break down the lake's stratification and allow for nutrient-rich bottom waters to mix with upper waters during algae growing season.

The following events can be seen in the graph below:

1. There was less than a 4 degree temperature difference between the top and bottom of the lake when sensors were deployed on May 6.
2. Temperature increased uniformly throughout the water column until mid-June when temperature differences between layers began to widen.
3. Surface water temperature (27.9 C/ 82.2 F) peaked on July 21 and July 30.
4. Full mixing first occurred in mid-September, after which the basin mildly re-stratified.
5. The lake mixed fully again on October 1 and remained mixed.



Peak Temperature	Full Mixing
7/21 & 7/30	9/22

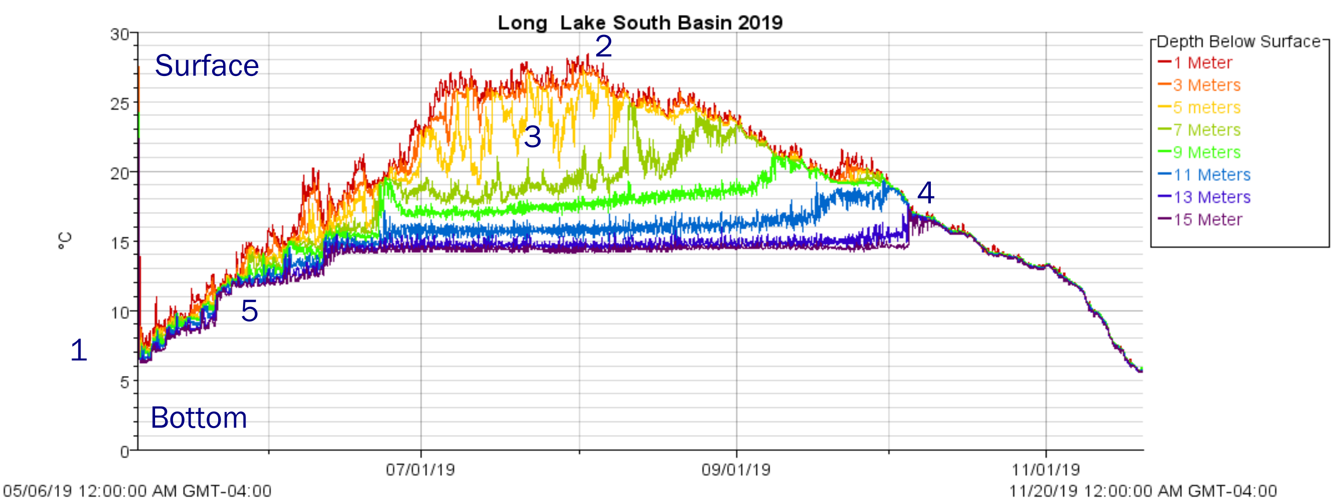
Long Lake (South Basin)

Summary

The temperature of deep waters (13—15 meters) in the south basin of Long Lake increased dramatically until mid June, when temperature stabilized through September. The deep water temperature increase seen in the south basin is not as pronounced as the deep water temperature increase seen in the middle basin. This indicates that the temperature difference between surface waters (1-3 meters) and deep waters (11-15 meters) in the south basin is a little larger than the temperature difference between the same depths in the middle basin. While the south basin is slightly more stratified than the middle basin, it is not strongly stratified. Long Lake's weaker stratification is likely the result of the lake's long length, which runs parallel to the most dominant northwest wind direction. This large length of open water (fetch size) allows for the build up of large surface and internal waves. Due to large waves, strong and sustained winds in the summer could break down the lake's stratification and allow for nutrient-rich bottom waters to mix with upper waters during algae growing season.

The following events can be seen in the graph below:

1. There was less than a 4 degree temperature difference between the top and bottom of the lake when sensors were deployed on May 6.
2. Surface water temperature (28.5 C/ 83.3 F) peaked on August 2.
3. Wide temperature ranges seen in the 5 meter depth (yellow line) could be the result of large internal waves mixing in water from warmer depths.
4. The lake mixed fully again on October 10 and remained mixed.
5. Deep water temperatures increased rapidly through mid June and leveled off for the duration of the summer months.



Peak Temperature	Full Mixing
8/02	10/10

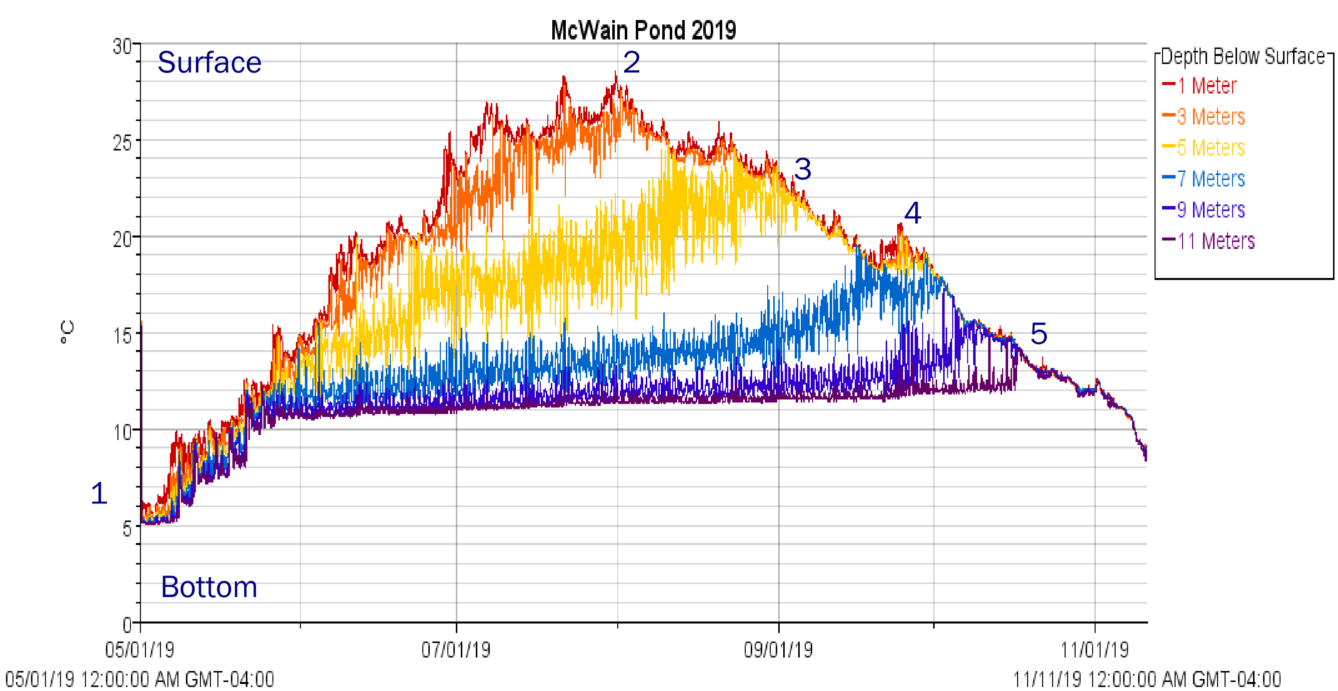
McWain Pond

Summary

The water column of McWain Pond divided into layers based on temperature (stratified), but the rapid increase in bottom temperatures early in the season resulted in moderate amounts of stratification. The temperature in the upper waters (1—3meters) increased dramatically following air temperature increases and after deep water temperatures stabilized, there was little change in temperature over the season in the deepest waters (11 meters). Large temperature differentials like those seen between surface waters (1 meter) and deep waters (11 meters) result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. There was less than 2 C difference between surface and deep waters when sensors were deployed on May 1.
2. Peak temperature (28.6 C/ 83.5 F) was reached on July 31.
3. As surface waters cooled, water temperature between 1—3 meters equilibrated and began to mix.
4. After a warm spell in late September, waters between 1—3 meters briefly re-stratified.
5. Full mixing occurred on October 17.



Peak Temperature	Full Mixing
7/31	10/17

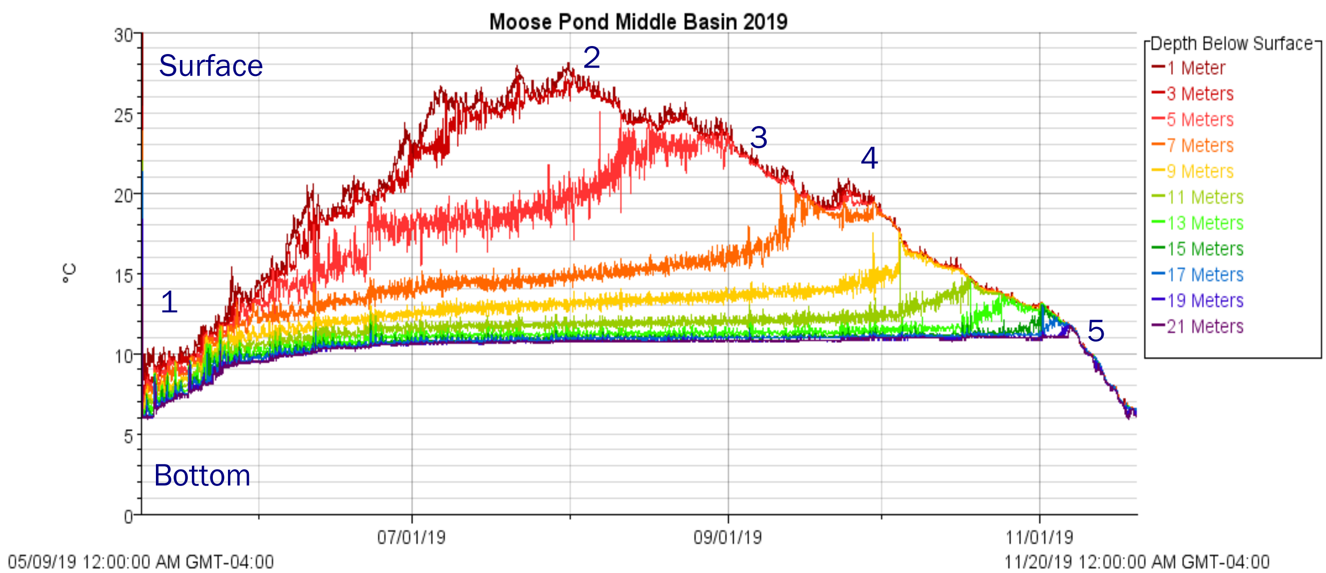
Moose Pond (Middle Basin)

Summary

The water column of the middle basin in Moose Pond distinctly and strongly divided into layers based on temperature (stratified). The temperature in the upper waters (1—3 meters) increased dramatically following air temperature increases, but there was very little change in temperature over the season in the deepest waters (13—21 meters). Large temperature differentials like this result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. Temperature increased uniformly throughout the water column from the time sensors were deployed on May 9 until mid June when temperature differences between layers began to widen.
2. Peak temperature (28.0 C/ 82.4 F) was reached on July 30.
3. As surface waters cooled, water temperature between 1—3 meters equilibrated and mixed.
4. After a warm spell in late September, waters between 1—3 meters briefly re-stratified.
5. Full mixing *occurred on November 7.*



Peak Temperature	Full Mixing
7/30	11/7

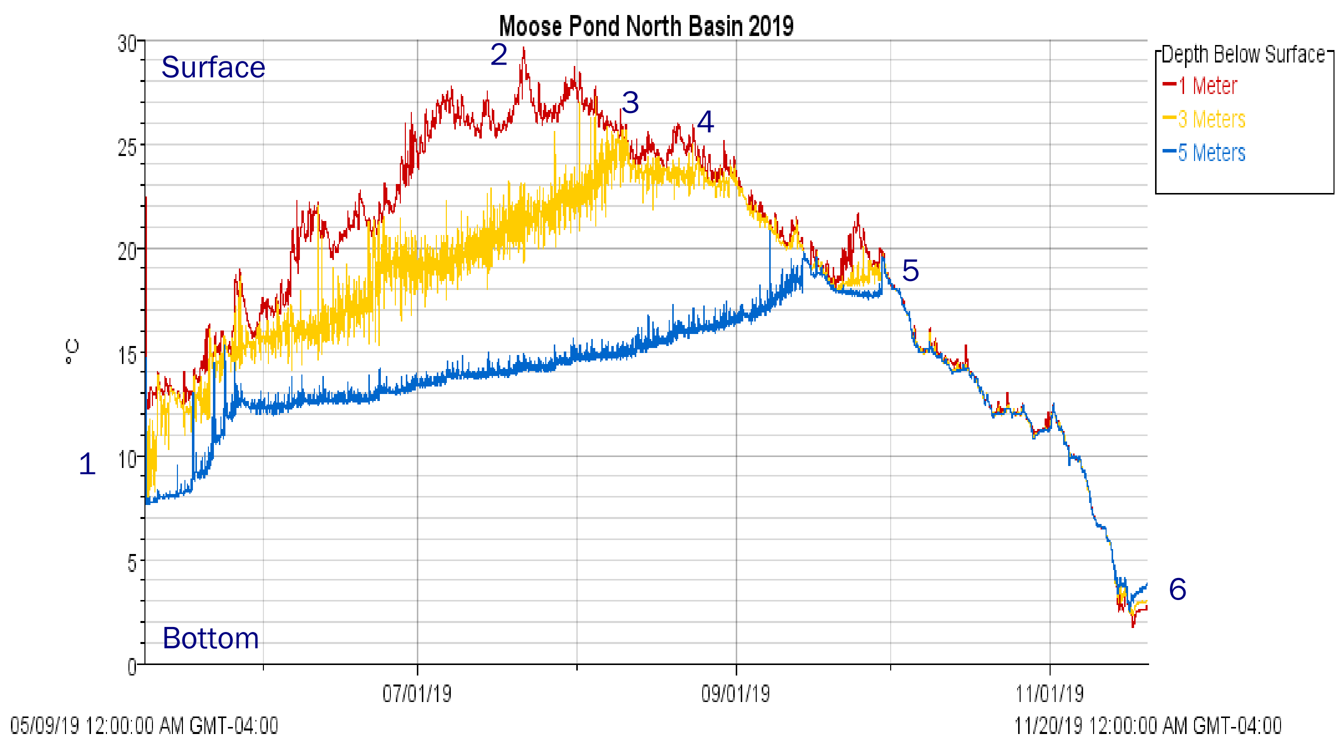
Moose Pond (North Basin)

Summary

The water column of the north basin in Moose Pond distinctly and strongly divided into layers based on temperature (stratified). The temperature in the upper waters (1 meter) increased dramatically following air temperature increases while temperature increases in deep water (5 meters) were much more gradual. However, a large temperature differential still formed, resulting in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. The north basin was weakly stratified when sensors were deployed on May 9.
2. Peak temperature (29.6 C/ 85.3F) was reached on July 21.
3. As surface waters cooled, water temperature between 1—3 meters equilibrated and mixed.
4. Warm spells in late August and September caused waters between 1—3 meters briefly re-stratify.
5. Full mixing occurred on September 29.
6. Winter stratification had already begun when sensors were removed on November 20.



Peak Temperature	Full Mixing
7/21	9/29

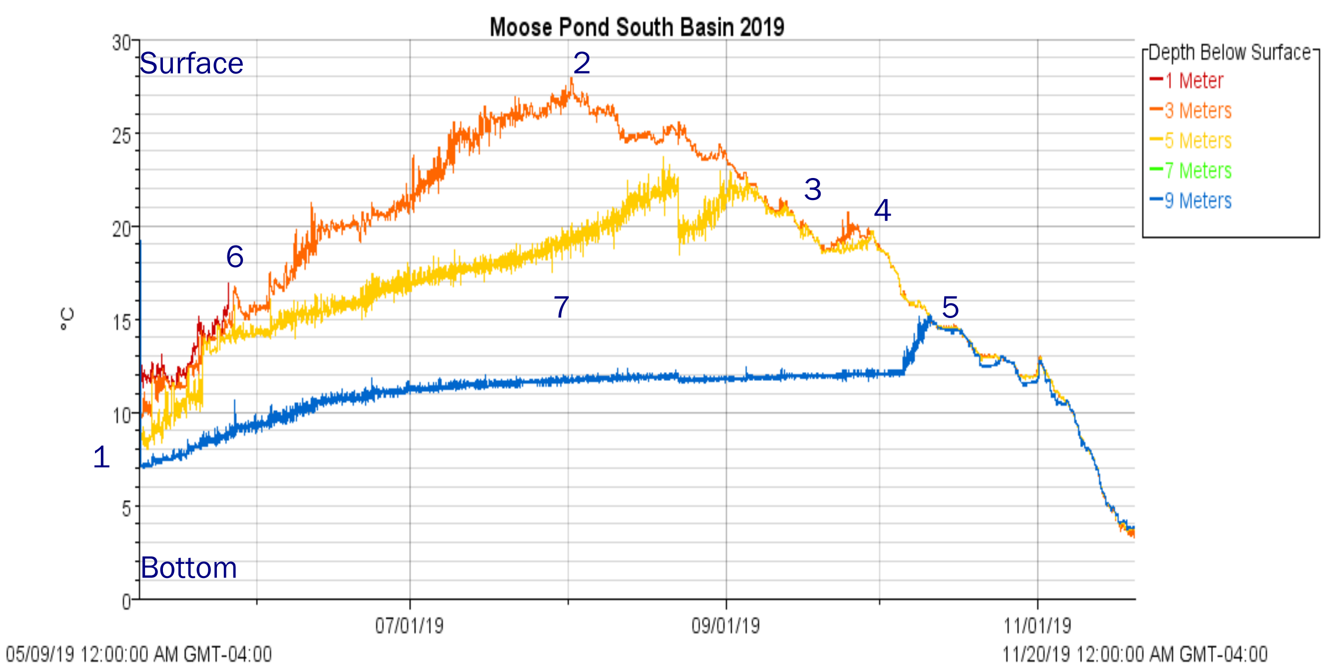
Moose Pond (South Basin)

Summary

The water column of the south basin in Moose Pond distinctly and strongly divided into layers based on temperature (stratified). The temperature in the upper waters (1 meter) increased dramatically following air temperature increases but there was very little change in temperature over the season in the deepest waters (9 meters). Large temperature differentials like this result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. The south basin was weakly stratified when sensors were deployed on May 9.
2. Peak temperature (28.0 C/ 82.4 F) was reached on August 1.
3. As surface waters cooled, water temperature between 1—3 meters equilibrated and mixed.
4. After a warm spell in late September, waters between 1—3 meters briefly re-stratified.
5. Full mixing occurred on November 7.
6. The 1 meter sensor failed in late June.
7. The 7 meter sensor did not function at all during the season.



Peak Temperature	Full Mixing
8/01	11/7

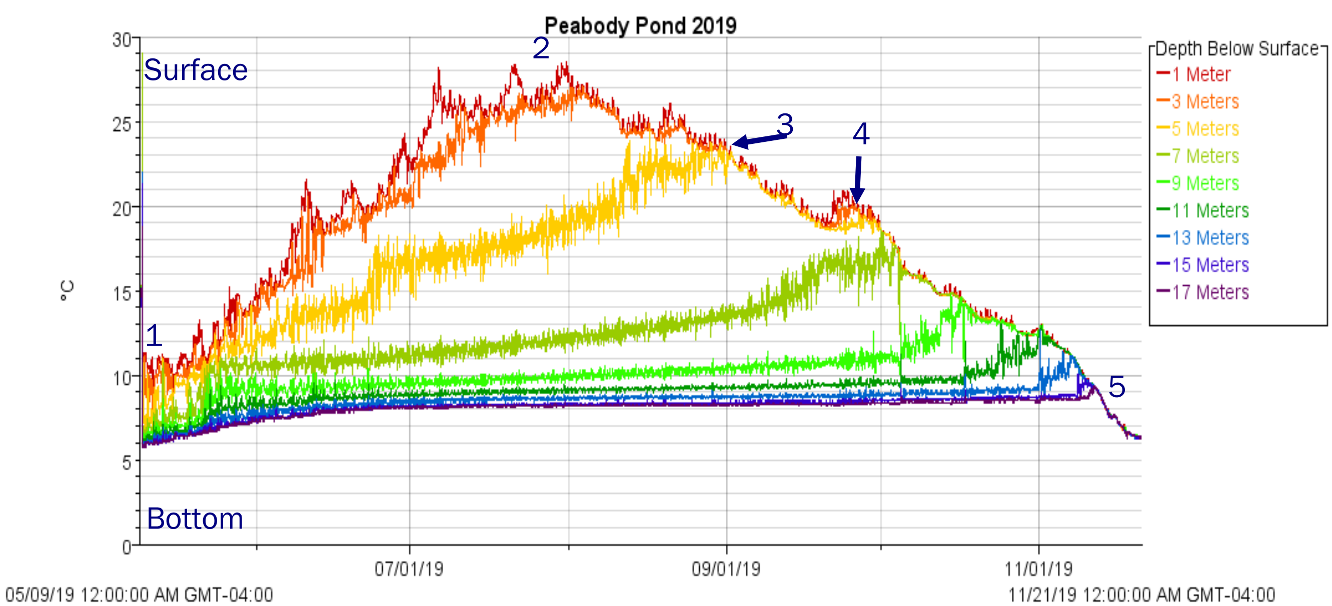
Peabody Pond

Summary

The water column of Peabody Pond distinctly and strongly divided into layers based on temperature (stratified). The temperature in the upper waters (1—3 meters) increased dramatically following air temperature increases, but there was very little change in temperature over the season in the deepest waters (11—17 meters). Large temperature differentials like this result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient rich-deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. Temperature increased uniformly throughout the water column from the time sensors were deployed on May 9 until early June when temperature differences between layers began to widen.
2. Peak temperature (28.6C/ 83.5 F) was reached on July 31.
3. As surface waters cooled, water temperature between 1—3 meters equilibrated mixed.
4. After a warm spell in late September, waters between 1—3 meters briefly re-stratified.
5. Full mixing occurred on November 11.



Peak Temperature	Full Mixing
7/31	11/11

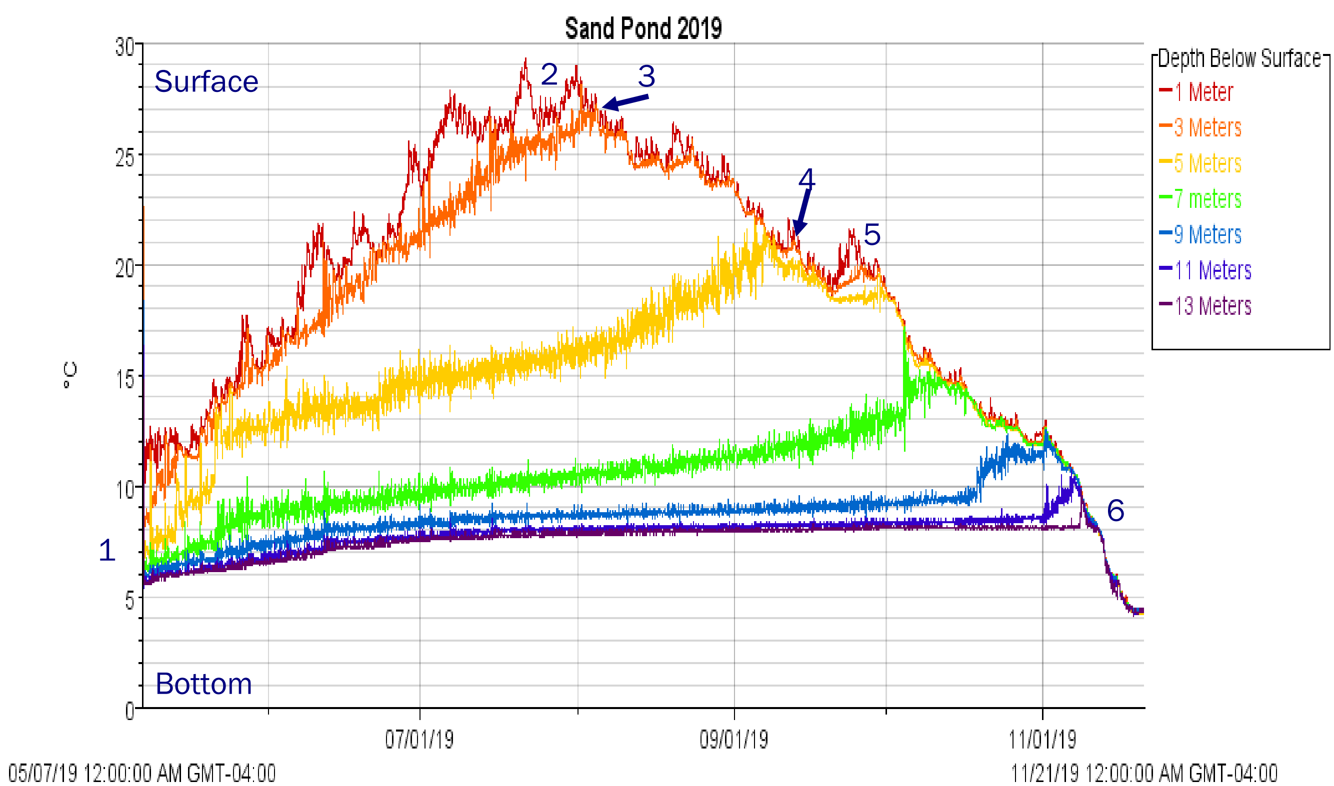
Sand Pond

Summary

The water column of Sand Pond distinctly and strongly divided into layers based on temperature (stratified). The temperature in the upper waters (1— 3 meters) increased dramatically following air temperature increases, but there was very little change in temperature over the season in the deepest waters (9—13 meters). Large temperature differentials like this result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. Sand Pond was weakly stratified when sensors were deployed on May 7.
2. Peak temperature (29.2 C/84.6 F) was reached on July 21.
3. As surface waters cooled, water temperature between 1—3 meters equilibrated and mixed.
4. 5-meter deep water mixes in with the surface waters.
5. After a warm spell in late September, waters between 1—5 meters briefly re-stratified.
6. Full mixing occurred on November 8.



Peak Temperature	Full Mixing
7/21	11/08

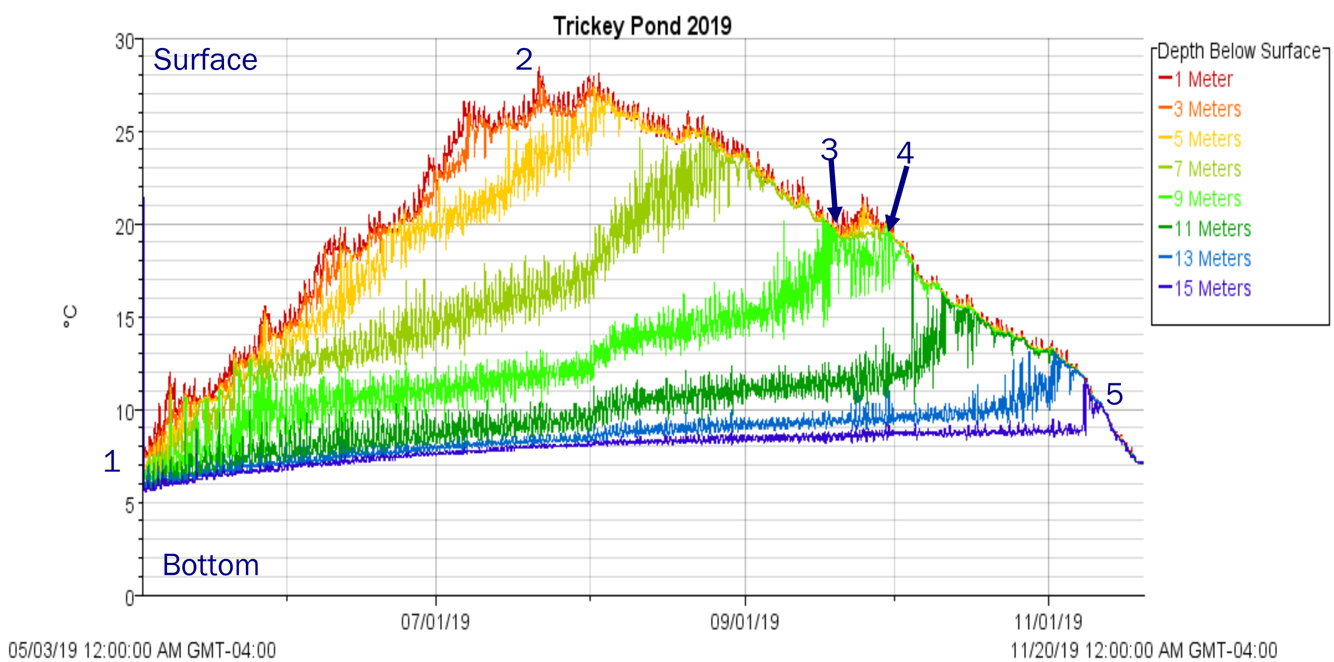
Trickey Pond

Summary

The water column of Trickey Pond distinctly and strongly divided into layers based on temperature (stratified). The temperature in the upper waters (1—5 meters) increased dramatically following air temperature increases, but there was very little change in temperature over the season in the deepest waters (13—15 meters). Large temperature differentials like this result in surface waters that are unlikely to mix with deep waters during the summer months, thus reducing the chance that more nutrient-rich deep water could come to the surface and feed algae.

The following events can be seen in the graph below:

1. There was less than 3 C difference between surface and bottom waters when sensors were deployed on May 3.
2. Peak temperature was reached on July 21 (28.5 C/ 83.3 F).
3. As surface waters cooled, water temperature between 1—9 meters equilibrated and mixed.
4. After a warm spell in late September, waters between 5—9 meters briefly re-stratified.
5. Full mixing occurred on November 11.



Peak Temperature	Full Mixing
7/21	11/11

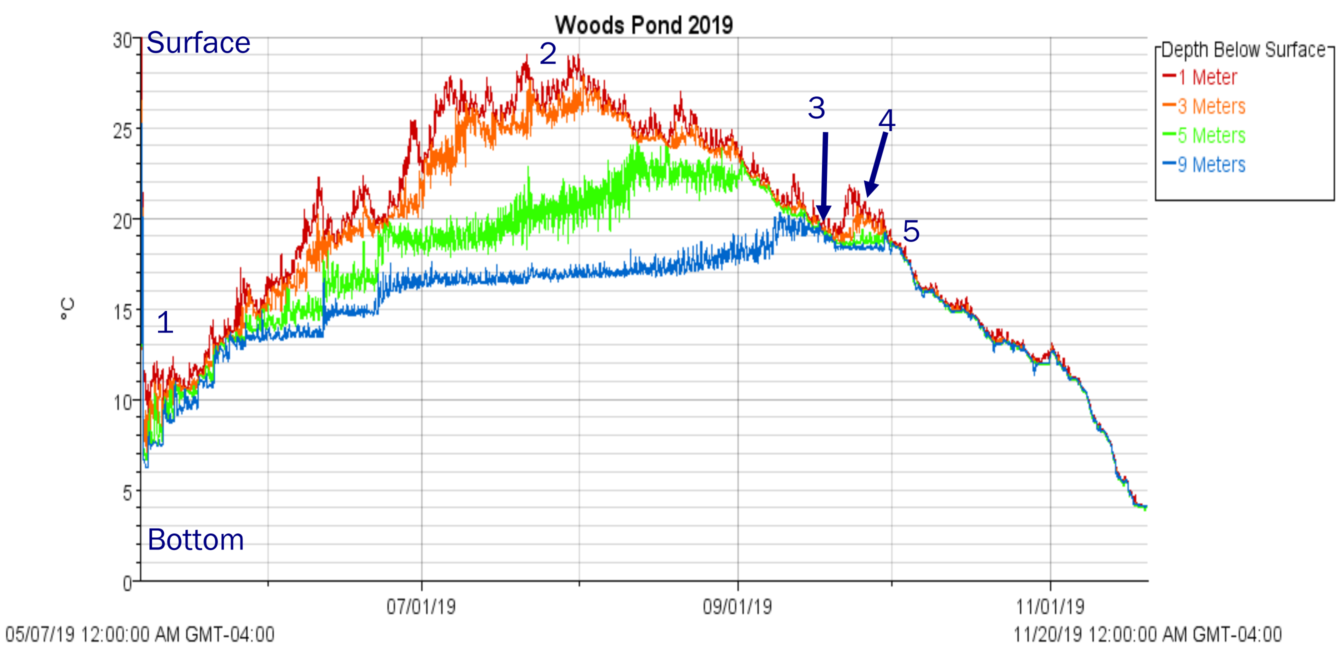
Woods Pond

Summary

The water column of Woods Pond is distinctly divided into layers based on temperature (stratified). The temperature in the upper waters (1—3 meters) increased dramatically following air temperature increases while temperatures in bottom waters (7 meters) gradually increased throughout the season. The temperature differential between surface waters and deep waters was still large enough to limit the introduction of deep water nutrients which, in turn, limits excess nutrients from feeding algae populations during the timeframe that algae is most productive.

The following events can be seen in the graph below:

1. Woods Pond was weakly stratified when sensors were deployed on May 7.
2. Peak temperature was reached on July 21 (28.5 C/ 83.3 F).
3. As surface waters cooled, water temperature between 1—7 meters equilibrated and mixed.
4. After a warm spell in late September, the entire water column briefly re-stratified.
5. Full mixing occurred on November 6.



Peak Temperature	Full Mixing
7/21	11/06