Temperature and Dissolved Oxygen Profiling of Muskrat Lake

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ABSTRACT

A temperature and dissolved oxygen lake profile was completed from June to November 2015 at Muskrat Lake located in Cobden, Ontario. This is the first time that consecutive monthly profiles of the lake have been taken in summer and fall months. Muskrat Lake is a eutrophic lake as it is highly productive and produces a variety of aquatic plants and houses many species of fish including lake trout, an oxygen sensitive species. Muskrat Lake also exhibits a unique negative heterograde curve, or oxygen sag in its metalimnetic layer during the summer months. In June and July 2015, the lake was vertically profiled at 48 sites, and in August, October and November the lake was profiled at 27 sites using YSI 6600 Sonde technology. It was found that the oxygen sag existed from 6 to 10m below the surface from June to August and dissipated in October. In August, the greatest levels of temperature and lowest levels of dissolved oxygen below provincial water quality guidelines were seen throughout the lake. Lake turnover occurred in November having a uniform temperature of 6.7˚C and a uniform dissolved oxygen level of 9.5mg/L throughout the water column. Graphs and maps were generated to showcase dissolved oxygen and temperature data temporally and spatially in Muskrat Lake.

INTRODUCTION

Every lake is unique in terms of morphology and productivity. Therefore, when describing seasonal temperature changes and dissolved oxygen levels in a lake, each lake reaches summer stratification and fall turnover at different times. In addition, each lake experiences various levels of dissolved oxygen, temporally and spatially (Lampert & Sommer, 2007).

Muskrat Lake in Cobden, Ontario is a large and deep lake. As seen in Figure 1, Muskrat Lake's basin is very longitudinal and its trough extends to a deep hole that is approximately 60 meters in depth. The lake covers over 1000 hectares and therefore has an extensive area of water for light penetration and the production of aquatic plants and algae. Furthermore, this lake suffers from eutrophication as it receives higher than normal levels of nutrients such as phosphorous. This process enhances the over-growth of plants and algae. When decomposition occurs, Muskrat Lake channels the decomposing plant and algal material into its deep waters. This amount of decomposition requires a high amount of oxygen, which is why Muskrat Lake suffers from oxygen depletion in the late summer and early fall months. This makes Muskrat Lake an area of special concern because of the local population of lake trout. Lake trout are an oxygen sensitive species and rely on higher amounts of dissolved oxygen. Therefore many lake trout and other species of fish become very oxygen stressed by the end of the summer (Michalski, 2013).

Lake trout prefer a dissolved oxygen value of 7mg/L and juvenile lake trout need at least 7mg/L to survive (Anderson, 1986). Lake trout also prefer an average water temperature of 10˚C, and can tolerate a range from about 4˚C to 18˚C (Ontario Fish, n.d.). As a result of the overall low levels of dissolved oxygen throughout the lake during the late summer, lake trout become very oxygen stressed (Michalski, 2013). To "ensure that the water quality is satisfactory for aquatic life and recreation" the government of Ontario published a report specifying guidelines for dissolved oxygen values. Referring to section 2.0 of this report, provincial guidelines for a cold water system should have dissolved oxygen levels of at least 4-7mg/L. For warm water systems the minimum guideline is 5-8mg/L (Ministry of Environment and Energy, 1994). Cold water systems are those in which the maximum mean monthly water temperature does not exceed 20˚C and is one that can support a year-round population of cold water fish, such as lake trout. Warm water systems can also support lake trout, but they generally do not survive all year. Streams and lakes can be mixed with warm and cold water fish species, as is the case with Muskrat Lake (Anderson, 1986).

Temperature and dissolved oxygen levels vary throughout the year and throughout the water column in Muskrat Lake. In summer and winter months, lakes are stratified into layers. These layers can be seen in Figure 2. The metalimnion layer in a lake, also called the thermocline, is the middle layer. Two other layers in a lake are the epilimnion, which is the top layer, and the hypolimnion, which is the bottom layer. In the fall, the water surface that was once 18 to 22 ˚C from summer warmth, cools to 4˚C. Water is most dense at 4˚C and therefore will sink to the bottom of the lake, forcing the hypolimnion layer to rise, changing over the water. All of the water in the lake mixes and becomes the same temperature at 4˚C. This turning over of water also mixes dissolved oxygen, giving a uniform dissolved oxygen range throughout the water column. In the spring, as the ice melts and temperature rises, the epilimnion layer will reach 4˚C and sink to the bottom of the lake. The water mixes together having the same temperature and density with the same range of dissolved oxygen. This changing of the water in the fall and spring is known as lake turnover. Lake turnover is also affected by a lake's morphology. Deeper lakes, such as Muskrat Lake, will experience a greater turnover event as they have a larger range in temperature from the top to the bottom of the lake compared to shallow lakes (National Geographic, 2015).

It was also discovered that Muskrat Lake experiences a negative heterograde curve or a unique oxygen sag in the metalimnion layer in the summer months. This sag is seen in Figure 3. The reason behind this oxygen sag has not been fully determined, but there are a couple of causal explanations. It is suspected that masses of zooplankton reside at the metalimnion and respire available oxygen producing this sag. Another explanation is that as plant and algal material sink to the denser metalimnion layer, they decompose by bacterial respiration and produce this oxygen sag (Wetzel, 2001).

Typically, eutrophic lakes like Muskrat Lake do not produce a negative heterograde curve, or oxygen sag, as they usually produce a clinograde curve (Figure 4) where dissolved oxygen is progressively reduced in the hypolimnion to the bottom of the lake during summer months. Since oxygen is more soluble in cold water, cooler water tends to hold more oxygen. In this case, however, the temperature curve can be ignored as oxygen is regulated by biological processes. Dissolved oxygen decreases in the hypolimnion since it is cut off from atmospheric oxygen, from oxygen produced from photosynthesis, and also because of oxygen consumption that occurs by aquatic organisms. In unproductive or oligotrophic lakes dissolved oxygen is regulated largely by physical processes. The oxygen content of the hypolimnion is higher because of its cooler temperature from spring turnover and because of the little oxygen consumption that occurs. This produces an orthograde dissolved oxygen curve also seen in Figure 4. The differences between oligotrophic and eutrophic lakes tend to disappear with fall and spring turnover. As water is mixed, this produces uniform temperature and dissolved oxygen conditions throughout the water column (Hebert, 2008).

To understand the spatial and temporal distribution of dissolved oxygen and temperature levels in Muskrat Lake, a Muskrat Lake Profiling project was initiated in June 2015. This is the first profiling project undertaken to complete a monthly profiling analysis of the lake. By using a depth profiling approach, 48 sites were vertically profiled over a 2 day sampling period in June and July by using YSI technology to log dissolved oxygen and temperature data from the bottom to the surface of the lake. In August, October and November, 27 sites on Muskrat Lake were profiled in a one day time period. Site locations are shown in Figure 5. Collected dissolved oxygen data will show where the oxygen sag and hypoxic and anoxic areas of the lake are located throughout the summer and fall months. The collection of temperature data over several months will show summer lake stratification and fall lake turnover, and the movement of the thermocline. Further studies should aim to collect data in the spring and winter months. This would provide a year round visual of temperature and dissolved oxygen data to produce complete spatial and temporal visuals of lake conditions.

To spatially and temporally summarize dissolved oxygen and temperature data over time, Geographical Information System (GIS) mapping and graphs were used. These maps and graphs assist in understanding where and when Muskrat Lake experiences anoxic and hypoxic conditions and when lake turnover occurs. This will foster and support additional research on Muskrat Lake that aims to describe lake dynamics such as eutrophication, the oxygen sag, and deleterious oxygen levels that result in fish stress.

METHODS AND MATERIALS

Refer to the CCME ‘Protocols Manual for Water Quality Sampling in Canada’ for safety in sampling from a boat and protocols for *in situ* measurements of dissolved oxygen and temperature (Appendix B).

Materials for Calibration of YSI:

- YSI 6600 Sonde Instruction Manual
- Calibration Work Sheet and pencil/pen
- YSI Sonde 6600 with calibration cup, Handheld 650 and 4 meter cable
- Large beakers
- Kim wipes
- De-ionized water
- 1413 Conductivity Solution
- Thermometer
- pH 7 and pH 10 solution

Materials for Field Sampling:

- YSI Sonde 6600 and Handheld 650
- 40 meter cable stored in a bucket
- Field laptop
- Handheld 650 computer cable
- Muskrat Lake Sampling Site maps
- 2 GPS units
- Extra C-batteries (at least 12) and AAA-batteries (4)
- Life jackets and First Aid Kit
- Secchi Disk
- Field notes and pencil/pen
- Pontoon boat and gas

Materials for Analysis:

- Laptop with EcoWatch, Excel, ArcGIS mapping software
- YSI Handheld 650 and computer cable

Methods for Calibration of YSI:

1. Follow instructions starting on page 20 of “YSI 6600 Sonde: Instruction Manual”.
2. Gather calibration materials listed above or listed in Instruction Manual.
3. Calibrate in order from page 20, for dissolved oxygen, depth, conductivity, temperature and pH.

Methods for Field Sampling:

1. Enter UTM coordinates of all sites onto GPS units. Have a second GPS unit as a backup and batteries. Enter coordinates before the sampling day.
2. Calibrate YSI before the sampling day and ensure battery life in both Sonde and Handheld is good. Ensure previous data on YSI is already uploaded on a laptop and deleted off the Handheld.
3. Bring all materials listed above on the boat.
4. Attach the 40 meter cable onto the YSI Sonde and Handheld 650. Remove the storage/calibration cup on the Sonde and replace with the probe guard.
5. Use the GPS with site location UTMs stored and locate the first site with the aid of the sampling map. Use a compass option on the GPS unit to better orientate to the site.
6. Turn the YSI on – press the power button, press 'Sonde run'. Check to make sure readings are looking correct (they should after calibration).
7. At the sampling site have one person lower the Sonde into the water as another person monitors the Handheld for a depth reading.
8. When the depth reading stabilizes, the Sonde has reached the bottom of the lake.
9. The person lowering the Sonde waits as the Handheld is initialized to start logging (from the Handheld press 'Start Logging' and enter site number as the file name and the date as the file description, press 'ok').
10. Sonde is pulled slowly up in a steady pace to the surface of the water.
11. Check turbidity to make sure it is low. A high turbidity may indicate the Sonde is in the sediment. If there is a high turbidity at the bottom of your pull, bring the Sonde up and let it fall back down to help remove sediment. This data can be cleaned up later in analysis.
12. Once the Sonde is completely out of the water press 'Stop Logging' on the handheld.
13. Store the Sonde in a safe place while you are navigating to your next sampling location by using the GPS and maps. Repeat steps 7-12. Sonde can be left on throughout the day. Turning it on and off between sampling sites can lessen the battery life.
14. If YSI memory space becomes full, data must be uploaded to the field laptop before more sites can be completed. It is suggested that the YSI memory storage be emptied before the sampling day so this does not need to be done in the field. Sonde files can only be deleted all at once on the Handheld. Follow analysis instructions for uploading files onto EcoWatch.

Methods for Analysis:

1. YSI data files are transferred from the Handheld to the field laptop (or a computer with EcoWatch software). Attach the Handheld to the laptop with the cord.
2. If using Environmental Technician program field laptop, must log in as Sarah Hall with password obtained from Sarah.
3. Open EcoWatch and click on the Sonde icon.
4. Turn on the Handheld, go to 'File', then 'Upload to PC'. Select files individually to load onto EcoWatch.
5. Through the EcoWatch software, transfer the data files from .dat to .dbf.
6. Open .dbf files through Excel to clean up the data by eliminating discrepancies (high turbidity data logs and out of water logs). Save the files as .xlsx.
7. Filer this data using a built formula created in Excel. Filtering finds the closest depth to 1m, 2m, 3m etc., and it's associated dissolved oxygen and temperature data point.

8. After all sampling site files are cleaned and filtered, create a summary file for each month that contains the sampling site number, their UTM coordinates, depth, dissolved oxygen and temperature data points.
9. Create maps and graphs by using ArcGIS and Excel based on analysis goals.

RESULTS AND DISCUSSION

Our results found that there was an oxygen sag and low levels of dissolved oxygen in Muskrat Lake throughout the summer months of June, July and August. In October, the oxygen sag disappeared and the thermocline layer of the lake began to break down. Complete lake turnover was seen in late November. This section will further detail temporal and spatial dissolved oxygen and temperature levels across Muskrat Lake by displaying and interpreting results in graphs and maps.

Muskrat Lake experienced the warmest temperatures in the month of August, followed by July and June. Water temperature cooled down in October to eventually reach turnover by November. Temperature levels were mapped with data collected on August 19th 2015. These maps are one way of demonstrating how profiling data can be displayed in a map format. As seen in August, temperature at the lake surface is at its warmest ranging from 22 to 28˚C (Appendix C - Figure 6). At a depth of 5m, temperature ranges from 16 to 25 ˚C (Figure 7). At 10m, shown below, temperature ranges from 7 to 22 ˚C (Figure 8). As lake trout prefer cooler water at 10 ˚C, we could hypothesize that lake trout would prefer a habitat at this depth. They could also live at a depth of 15m as temperature ranges from 7 to 10 ˚C (Figure 9).

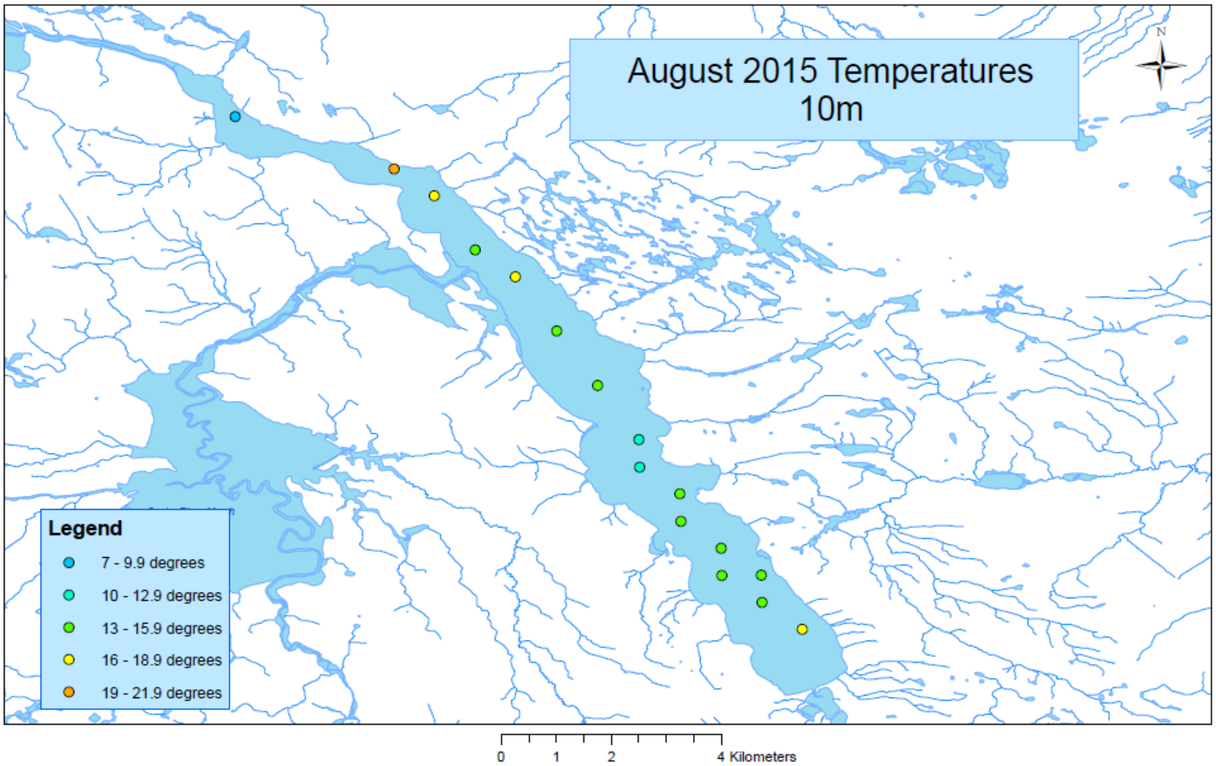

Figure 8. August temperature levels at 10m below the surface of Muskrat Lake.

Temperature data was also displayed in graphs. Profiling sites that are deepest were chosen to be graphed so that changing temperature levels could be seen throughout the Muskrat Lake water column. The graph shown below displays temperature data at site 21 in the months of June, July, August and October (Figure 10). As seen below, the lake surface is warmest by the end of summer in August, followed by July and June. In October, the breakdown of the thermocline layer in the lake is occurring. This is indicative that Muskrat Lake is close to turnover, but not quite yet at this point as uniform temperature from the surface to the bottom of the lake is not seen. It is also obvious that deep water temperature throughout the summer and fall remains relatively constant around 5 to 6 ˚C. Site 10 and 19 are also included in Appendix C (Figure 11 and 12). These sites, along with all other deep sites ranging from 20 to 40 meters in the lake, show the same pattern in changing temperature levels from June to October.

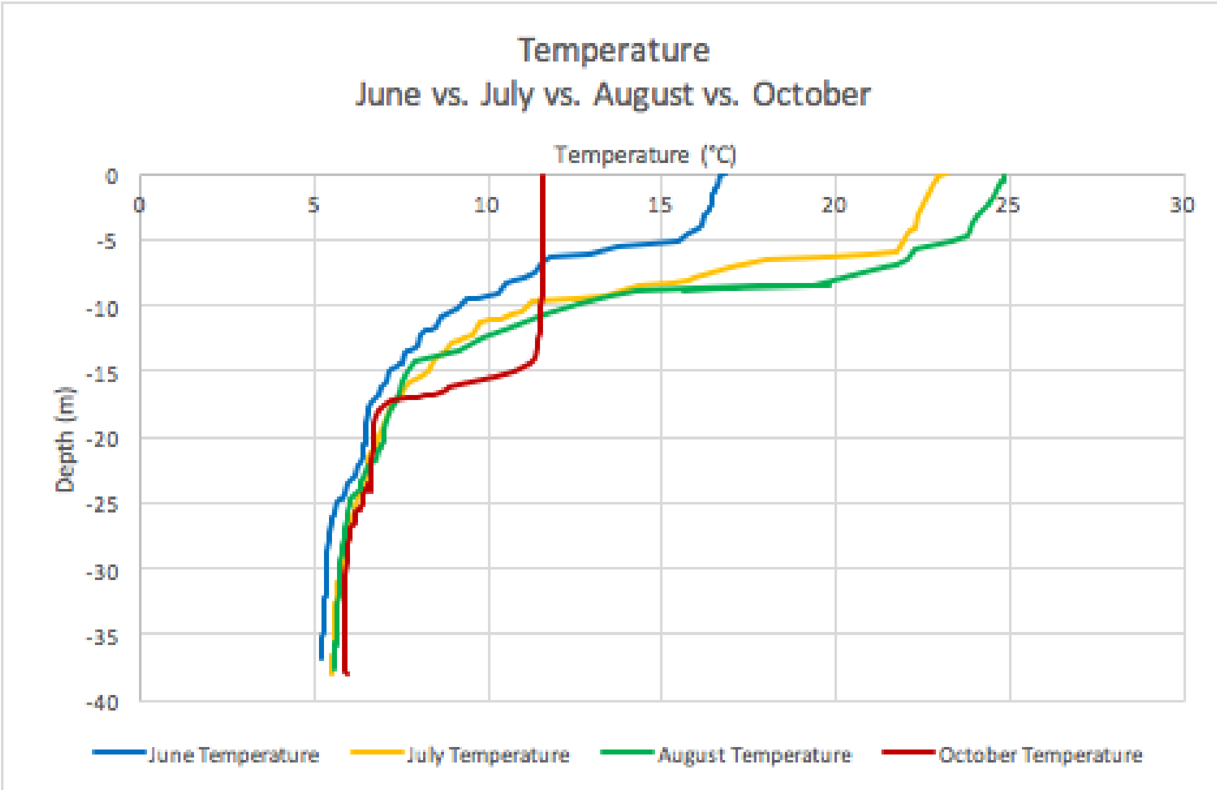

Figure 10. Temperature levels by depth at site 21 in June, July, August and October in Muskrat Lake.

Dissolved oxygen data was mapped for the month of August as well. The map shown below displays dissolved oxygen data on August 22nd at a depth of 10m. As hypothesized, lake trout would be residing at this depth since this is where their preferred level of temperature is found at 10˚C. However, as shown in Figure 13, at a depth of 10m there is a severe depletion of oxygen. Oxygen ranges from less than 2 to 5 mg/L which is below the preferred level of 7mg/L of oxygen for lake trout. This leads to the conclusion that the lake trout population in Muskrat Lake are stressed, and have a hard time finding a suitable habitat during the summer months, specifically in August. This map also shows dissolved oxygen levels that are less than 3mg/L at the Muskrat River inflow and outflow and at the Snake River inflow. This is most likely due to the high plant and algae growth in these areas. These areas are shallow for light penetration to occur to promote aquatic plant growth and because of existing eutrophication, this growth is exacerbated specifically in these areas. By August, decomposition is occurring in the metalimnion layer, or at this 10m depth, and oxygen is consumed by bacterial respiration.

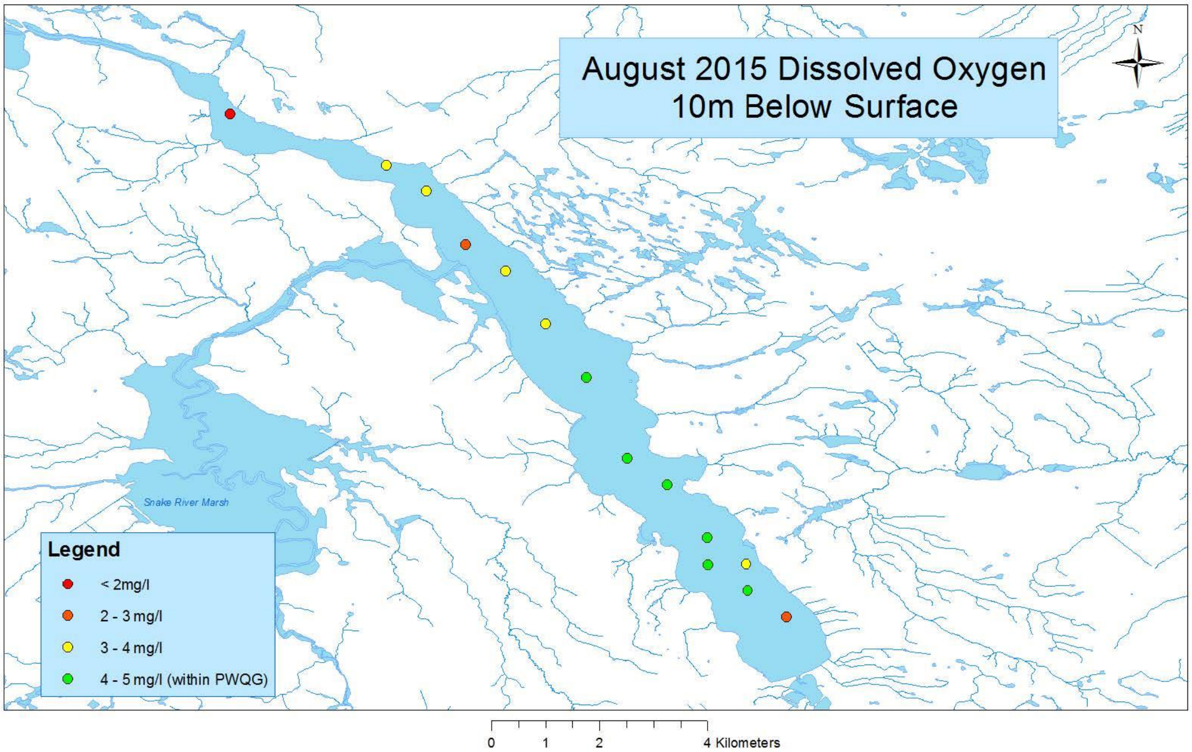

Figure 13. August dissolved oxygen levels at a depth of 10m below the surface of Muskrat Lake.

The graph below (Figure 14) also represents data from site 21 at Muskrat Lake in June, July, August and October, but for dissolved oxygen. This graph displays the oxygen sag that occurs in Muskrat Lake in the summer months during summer stratification. The oxygen sag is present around 5 to 10m, and it is apparent that August experiences the largest oxygen sag. As stated in the introduction in this report, the reason behind the oxygen sag is unknown, but could be due to zooplankton consuming oxygen in this metalimnion layer, or decomposition of aquatic plants being held in this layer and oxygen being consumed by bacterial respiration. The sag also disappears in October as this is when the thermocline layer is breaking down before lake turnover. Levels of dissolved oxygen are higher in June and July, especially in June. Lake trout would have no issue in locating a suitable habitat with their preferred dissolved oxygen level of 7mg/L. In August however, this level of dissolved oxygen is only found at the surface of the lake. Once again, this demonstrates that lake trout would be stressed because of difficulty finding suitable habitat in August. In October, levels of dissolved oxygen start to climb upwards since the thermocline layer in the lake is breaking down. Site 10 and 19 dissolved oxygen graphs are found in Appendix C (Figures 15 and 16). These graphs demonstrate that the oxygen sag is consistent throughout Muskrat Lake's deep sites throughout the summer months. Seen in these figures as well, the thermocline layer is breaking down in October.

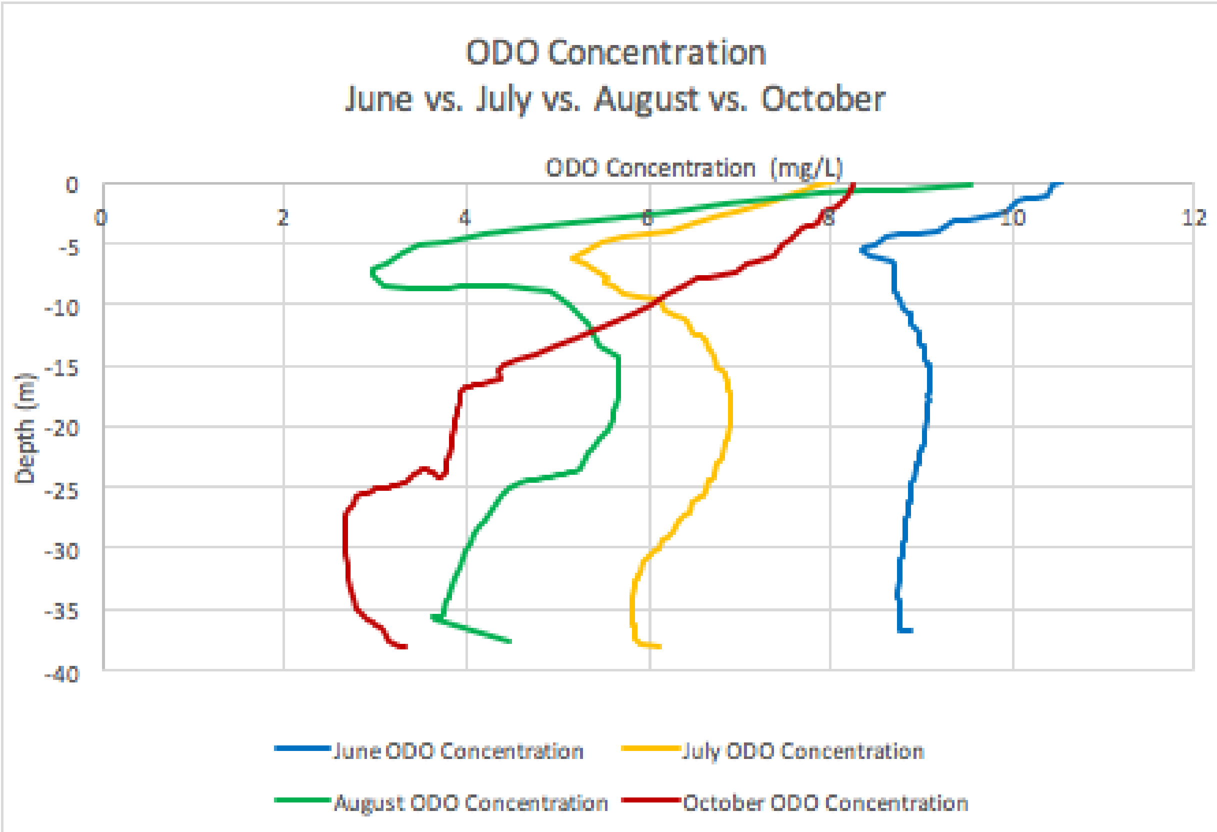

Figure 14. Dissolved oxygen levels by depth at site 21 in June, July, August and October in Muskrat Lake.

Lake turnover was seen on November 26th, 2015 on Muskrat Lake. The graph provided below (Figure 17) displaying data from site 21 shows that dissolved oxygen and temperature levels are uniform throughout the water column. Dissolved oxygen is consistent around 9.5mg/L and temperature is around 6.7 ˚C. These conditions are much more suitable for the lake trout population in Muskrat Lake as high amounts of dissolved oxygen are available and an optimal temperature is reached from the turning over of the lake. Lake turnover occurred with these levels of dissolved oxygen and temperature throughout the lake. Site 10 and 19 graphs are provided in Appendix C (Figures 18 and 19) to demonstrate this.

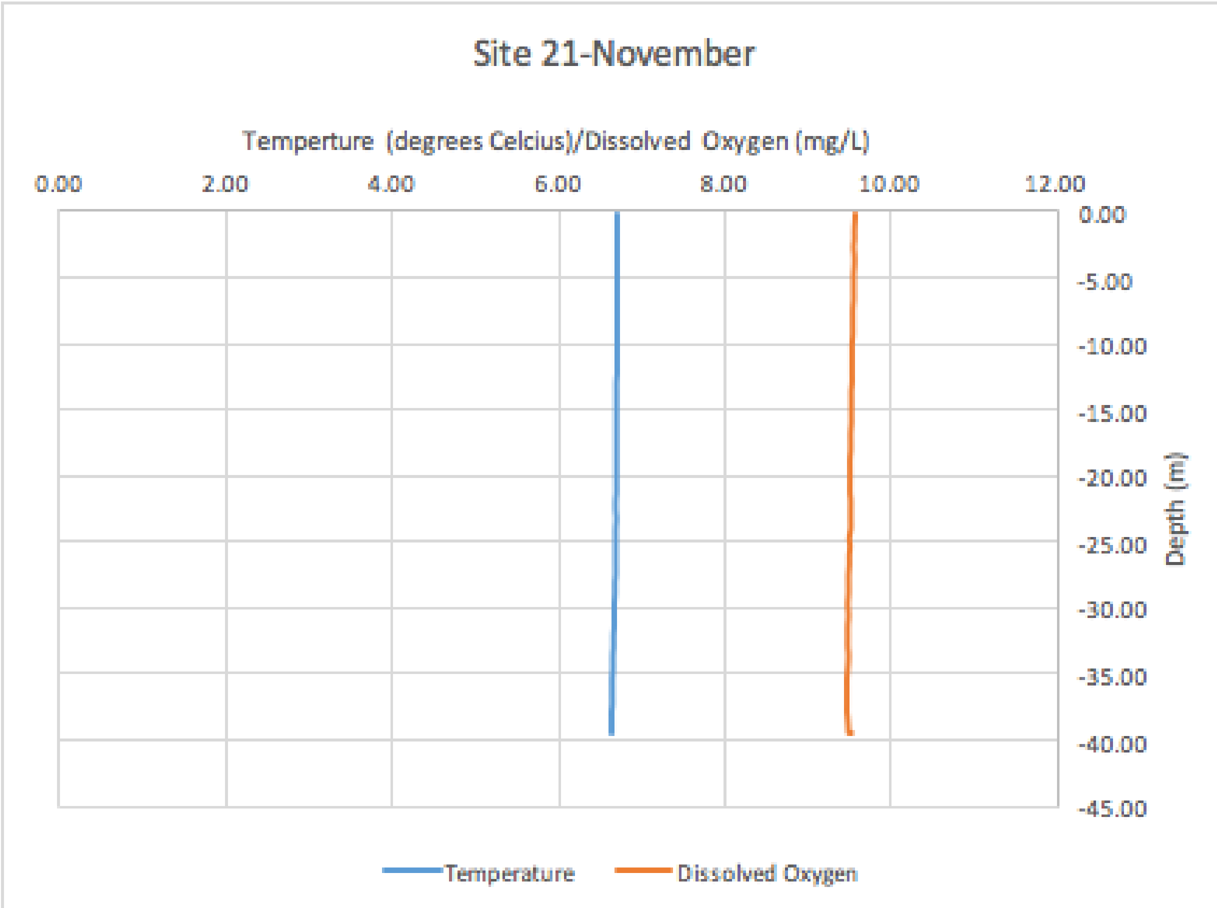

Figure 17. Lake Turnover in November at site 21 on Muskrat Lake.

CONCLUSION

By August, most sites on Muskrat Lake fell below dissolved oxygen guidelines of 5 to 8mg/L. Very low levels of dissolved oxygen, below 3mg/L, were seen at the Snake River inflow and the Muskrat River inflow and outflow. These late summer dissolved oxygen levels throughout the lake create stress for all species of fish in Muskrat Lake, but specifically for the lake trout population, as it is hypothesized they would have trouble locating a habitat with 7mg/L of dissolved oxygen and a 10˚C temperature. Also, an oxygen sag is present throughout the summer months which could indicate the presence of zooplankton at the metalimnion layer or decomposition being held in this layer that would require the consumption of oxygen. Finally, lake turnover occurs in late November, which provides a suitable dissolved oxygen and temperature habitat for the lake trout population and other species of fish.

This profiling of dissolved oxygen and temperature with data interpretation in the form of maps and graphs will help to foster and support additional research on Muskrat Lake. Specifically, research should aim to describe hypoxic and anoxic areas, the oxygen sag, fish stress and eutrophication in Muskrat Lake.

ACKNOWLEDGEMENTS

We would like to thank the Cobden Civitan Club for helping fund this research. A huge thank you to Andrew Laird. Andrew was our community partner and is a member of the Muskrat Watershed Council. We would also like to thank Ted Barron for the use of his boat and Everton Spuldaro for assembling data over the summer months. Finally, we would like to thank Sarah Hall, Julie Sylvestre, Shandy Labine and Jodi Bucholtz for their support throughout this research project.

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Appendices

Appendix A – Introductory Material

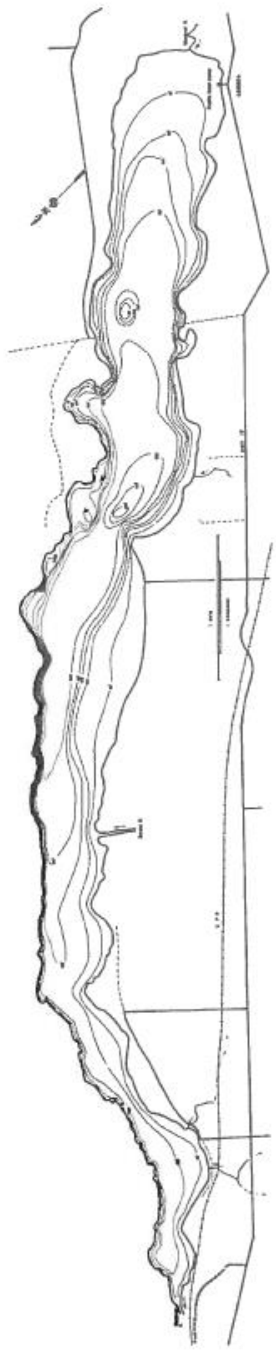

Figure 1. Morphometry of Muskrat Lake (Michalski, 2013).

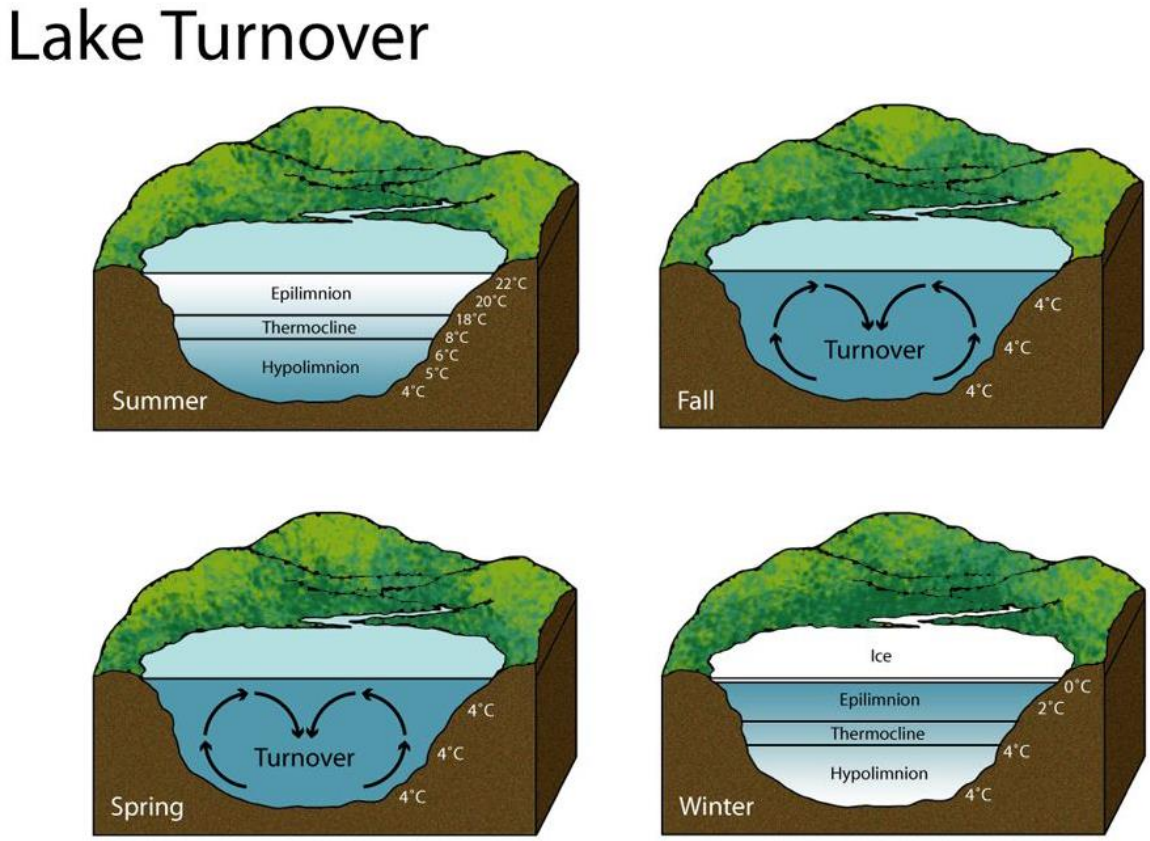

Figure 2. Lake Layers during turnover (National Geographic, 2015).

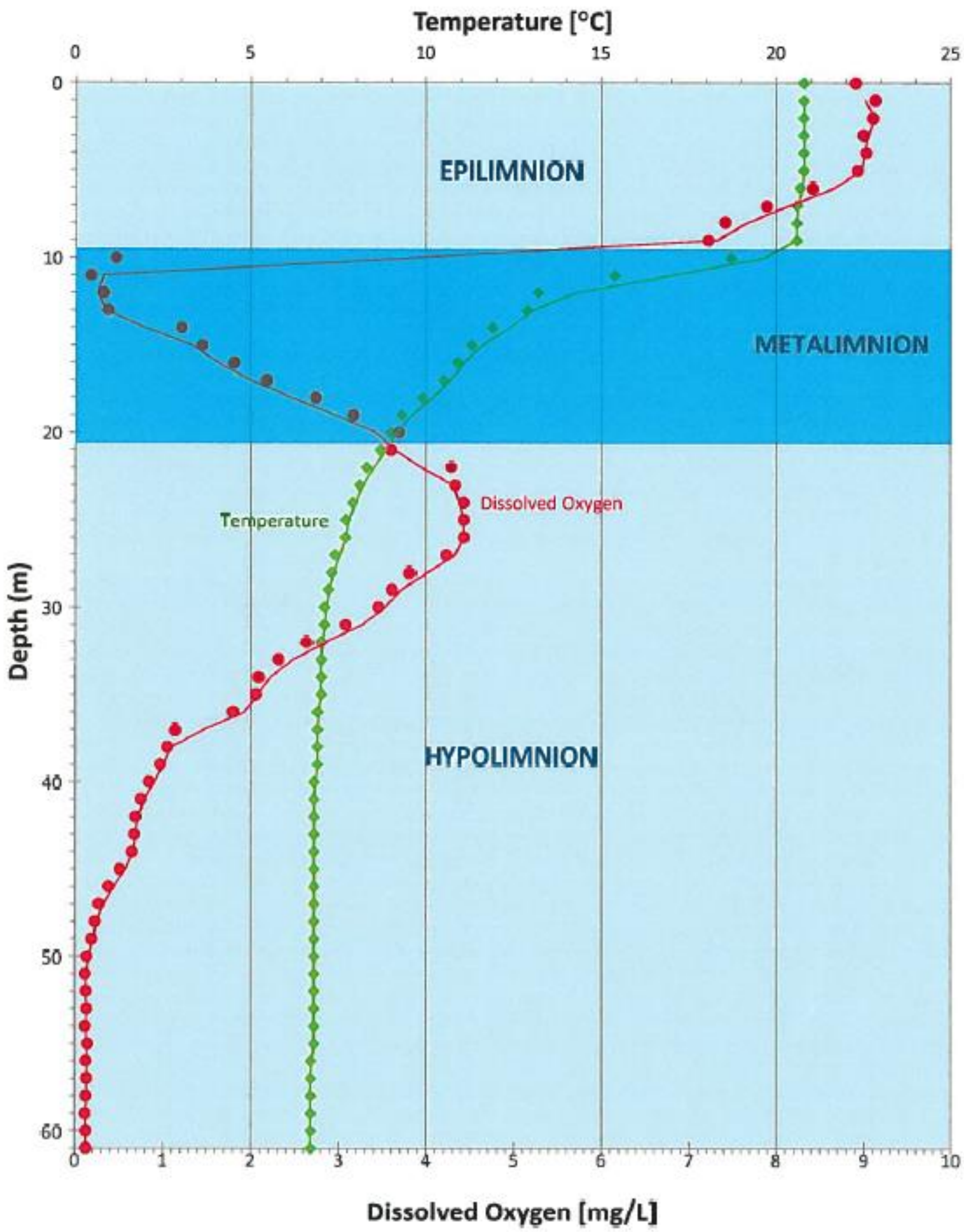

Figure 3. Temperature and Dissolved Oxygen Profiles on Muskrat Lake in September 2004 (Michalski, 2004).

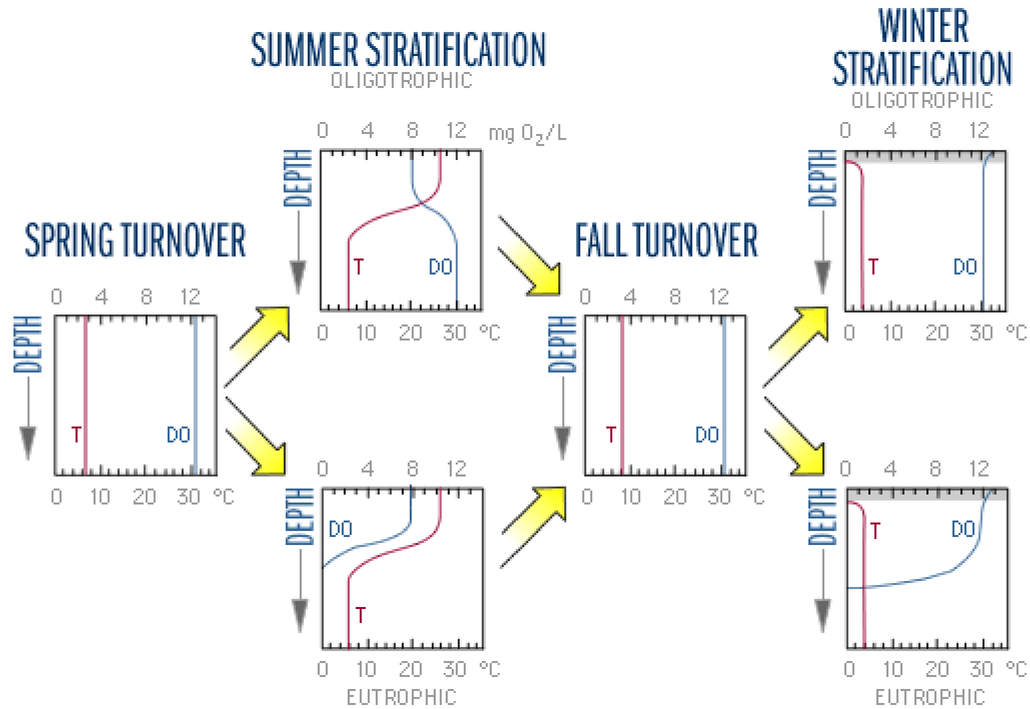

Figure 4. Dissolved oxygen and temperature curves shown in spring, summer, fall and winter months in both eutrophic and oligotrophic lakes. Clinograde dissolved oxygen curve shown in eutrophic summer stratification graph and orthograde dissolved oxygen curve shown in oligotrophic summer stratification graph (Lake Access Project, n.d.).

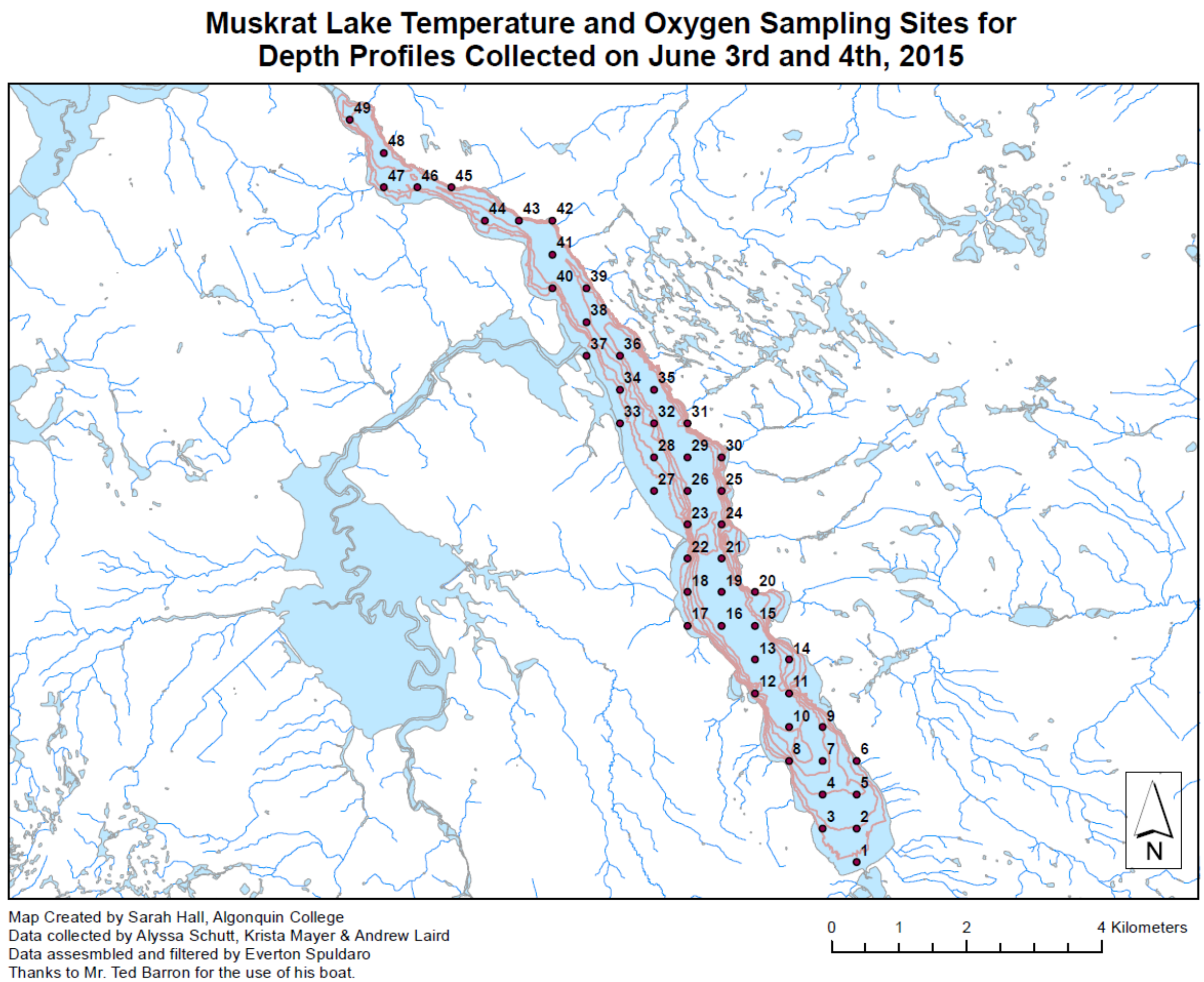

Figure 5. Sampling Sites on Muskrat Lake (map created by Sarah Hall).

Appendix B – CCME Protocols for sampling from a boat and taking in-situ measurements of dissolved oxygen and temperature

2.1 PROTOCOL FOR SAFETY IN SAMPLING FROM BOATS AND AIRCRAFT

Overview

When sampling from aircraft, the pilot has final say regarding operational details such as loading of equipment, weather conditions under which the trip can be performed safely, safety information and deplaning procedures. A personal flotation device (PFD) should always be used. When sampling from a boat or aircraft, you should perform a visual inspection of the surroundings paying close attention to wave height and direction. Individuals should move within the boat using slow, calculating motions, thereby minimizing risk and should not stand in the boat to obtain the water sample. The boat must be maintained in a safe condition and aircraft safety and maintenance records should be inspected.

Sources

Alberta Environment (2006 a), Environment Canada (1999 Draft), Environment Canada (2001), EMAN-N (2005)

At a glance

boat and aircraft positioning

1 Prior to collecting a sample, it must be ensured that the anchor is secure and the boat is pointed into the wind. For aircraft, it must be ensured that the rotors and engines are still and the aircraft is pointed into the wind. Do not go forward from the red line on the float.

boat safety

2 When sampling from a boat, be aware of other boat traffic and natural hazards. All power-driven vessels must yield the right-of-way to those not operating under power such as canoes. Two paddles, a bailer and an anchor must be on board. All Transport Canada regulations regarding equipment required relative to the type/size of boat being used should be adhered to.

moving within the boat

3 Samplers should position themselves securely on the floor of the boat or on one of the seats. Move within the boat using slow, calculating motions, thereby minimizing risk to oneself as well as others in the boat. Do not stand in the boat to obtain the water sample. Position yourself securely on the floor of the boat or on one of the seats. Prior to collecting a sample, the other crew members in the boat should be informed that a sample is going to be collected and they should counter balance the boat by positioning themselves on the opposite side to which the sample will be collected.

link between pilot and sampler

4 The rear door of fixed-wing aircraft (e.g., the Cessna 206, with its long, broad tail section) should be tied open. Direct or headphone communication with the pilot is essential. The pilot may need to communicate the difficulty of keeping the aircraft stable on the water, or the fact that wind, wave or fog conditions are making it too dangerous to continue with sampling. It is much safer to have a third person to help with communication between the sampler and the pilot. Relatively busy "air traffic" in popular lake areas may mean additional safety risks, forcing workers to work quickly and efficiently.

footing on pontoons

5 Ensure that footing is secure on aircraft if sampling from pontoons. Pontoons become wet and possibly slippery when landing. Samplers on pontoons should be tethered to the aircraft and should be wearing a PFD as well as rubber boots. The PFD should not be worn in the aircraft unless it is the manual inflation type.

leaving a helicopter

6 For helicopters, never leave from the rear of the helicopter as the tail rotors are dangerous. If it is absolutely necessary to depart a helicopter with the engine running such as during winter sampling, leave the helicopter in a crouched position.

7 After the sample has been collected, the crew members should return to their regular positions in the boat or aircraft.

5.1 PROTOCOL FOR CONVENTIONAL FIELD MEASUREMENTS

Overview

In situ measurements of parameters such as pH, dissolved oxygen, temperature, conductivity, turbidity, and redox potential are routinely taken at the time of sampling. These measurements are taken *in situ* in the water body just below the surface, at mid-depth or at discrete depths depending on the sampling objective and the depth of the sampling site, using electronic single or multi-probe meters.

The proper maintenance and calibration of instruments is a very important part of any water quality program. The instruments must be in good working condition in order to get accurate results. Field personnel must understand the calibration and use of any instrument they are using in the field. Maintenance and calibration log books should be kept up to date to track the performance of the meter. The meter probes should be calibrated daily under field conditions and temperatures, and periodically throughout the day if required (e.g., dissolved oxygen at sites of different altitudes or every five samples if water quality changes dramatically from site to site). The exceptions are: temperature (check in laboratory monthly with a certified mercury thermometer), conductivity and turbidity (calibrate at the beginning of the sampling trip), and redox potential (calibrate once every six months).

Review the water quality data on-site during sample collection to prevent the measurement and/or recording of false measurements. Re-measure and double check any dubious readings before leaving the site. It may also be worthwhile doing verifications at the end of the day for some key parameters (not re-calibrations) to check if the meter has drifted or is malfunctioning. Meter readings should be checked in standard solutions and recorded in the log/field book. This ensures that the meter has been working properly throughout the day.

Sources

Environment Canada and B.C. WLAP (2005 c), Alberta Environment (2006 a), EMAN-N (2005)

At a glance

1 If taking field temperature measurements with a thermometer, remove the cover and place it in the shade, out of the wind, preferably about 1 metre above the ground to minimize the heat influence from anything other than ambient air temperature. Leave the thermometer for five to ten minutes or for the time it takes to collect the water samples. Record the air temperature to the nearest 0.5 degrees Celsius. Temperature measurements of the water must be taken in the field immediately upon obtaining a sample or preferably *in-situ*, by means of automated temperature probes.

calibration

2 Calibrate the multi-probe/meter prior to daily sampling for pH and DO. Conductivity and turbidity can be calibrated at the beginning of the sampling trip and redox potential should be calibrated every six months. Temperature should be calibrated every month with a certified thermometer.

3 *In situ* measurements at sites <2m deep should be taken just below the surface of the water (0.1 m depth).

4 *In situ* measurements at sites >4m deep, should be taken just below the surface of the water (0.1 m depth) and at 1 m intervals down to 1 m above the lake bottom. At sites $\leq$ 2 m deep, one set of measurements at mid-depth might be considered appropriate. At sites between 2 and 4 m deep, two measurements can be taken 0.25 m below the surface and 0.25 m above the lake bottom. It is preferred to take field water quality readings from the body of water itself (*in situ*) but on some occasions it may be necessary to take the measurements from a sub-sample of water. In this case take separate water samples for these field measurements and never take field water quality measurements from samples to be submitted to the laboratory for analysis.

let the instrument stabilize at each depth

5 Let the instrument stabilize at each depth (usually 1-2 minutes) and record the readings in a field sheet/book. Also, if possible store readings at each depth in a datalogger. On deep profiles and where approved by the project manager, it may be acceptable to proceed at 5 m intervals if there is little change in readings at 1 m intervals. When change is detected (thermocline, chemocline, etc.), then define the area of change at 1 m intervals. **6** Bring the probe/sonde back up to 1 m, allow to stabilize and record readings at that depth. (Note: redox will probably not stabilize quickly at the surface.) This acts as a field check on the instrument and verifies the accuracy of the first reading.

7 New **conductivity** meters may use different types of probes. Follow the manufacturer's instructions for use. Conductivity meters are also available for "pure water" (i.e., conductivity from 0 – 100 µS/cm) and for high conductivity waters (100 – 1000 µS/cm). The sampling circumstances may need both ranges.

8 **pH** should be measured after the conductivity measurement using a pH meter. Adjust the temperature reading (if needed) to the temperature of the field sample. Shake the sample and rinse the electrode with sample. Place the electrode in the sample. Select pH measurement mode. Swirl the sample and measure the pH. Allow sufficient time for the meter to stabilize. Be sure to rinse the electrode with de-ionized water before storage. Store the electrode in a potassium chloride (KCl) storage (long-term) solution according to the manufacturer's instructions. pH

Electrode sensors should be kept wet with sample water or with tap water, and not in a standard solution, at all times during sampling.

9 **Dissolved oxygen** can be measured using multi-meter DO sensors that have appropriate membranes and are properly calibrated. The meters measure the level of dissolved oxygen in both milligrams per litre and percent of oxygen saturation. Follow the manufacturer's instructions for measuring DO, calibrating the meter and keeping the probe clean. One water sample taken at one profile depth per water body can be subjected to a Winkler analysis as a further check of the accuracy of the DO meter measurement, preferably at a depth where oxygen appears stable. A meter DO measurement within ±0.5 mg/L of the Winkler DO measurement is generally considered acceptable, however USGS (2005) recommended that meter and Winkler DO measurements should be within ± 0.05 mg/L DO.

10 **Turbidity** is measured as follows**.** Fill a ***cuvette*** with shaken field sample to the line marked on the cuvette. Dry the cuvette with a clean, lint-free, laboratory-grade paper towel. Place the cuvette with the orientation mark facing forward in the chamber. Note: Handle the cuvette with care and do not touch the area of the cuvette below the line. Keep the cuvettes absolutely clean. Measure the turbidity of the sample. Rinse the cuvette with de-ionized water before storage

Appendix C – Results

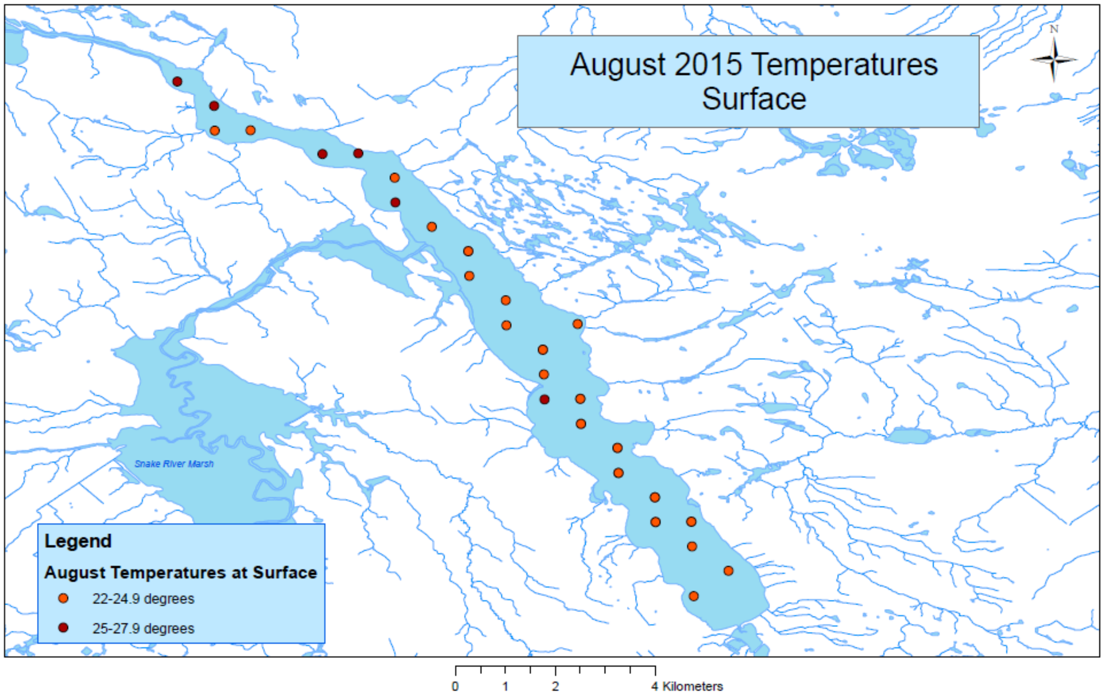

Figure 6. August temperature levels at the surface of Muskrat Lake.

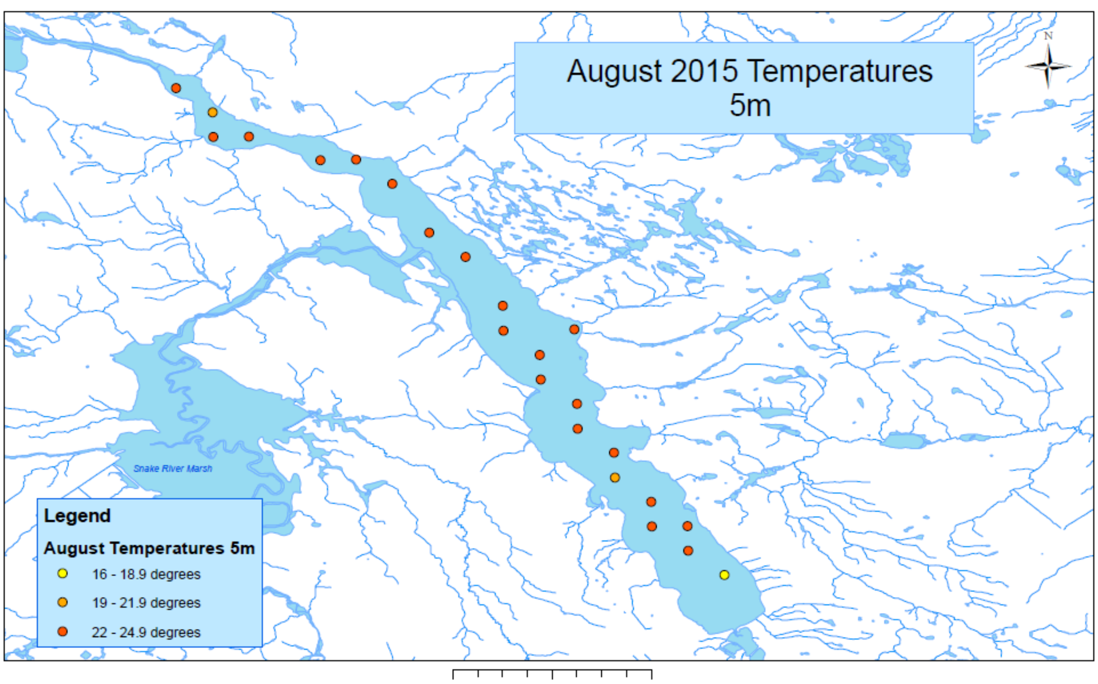

Figure 7. August temperature levels at 5m below the surface of Muskrat Lake.

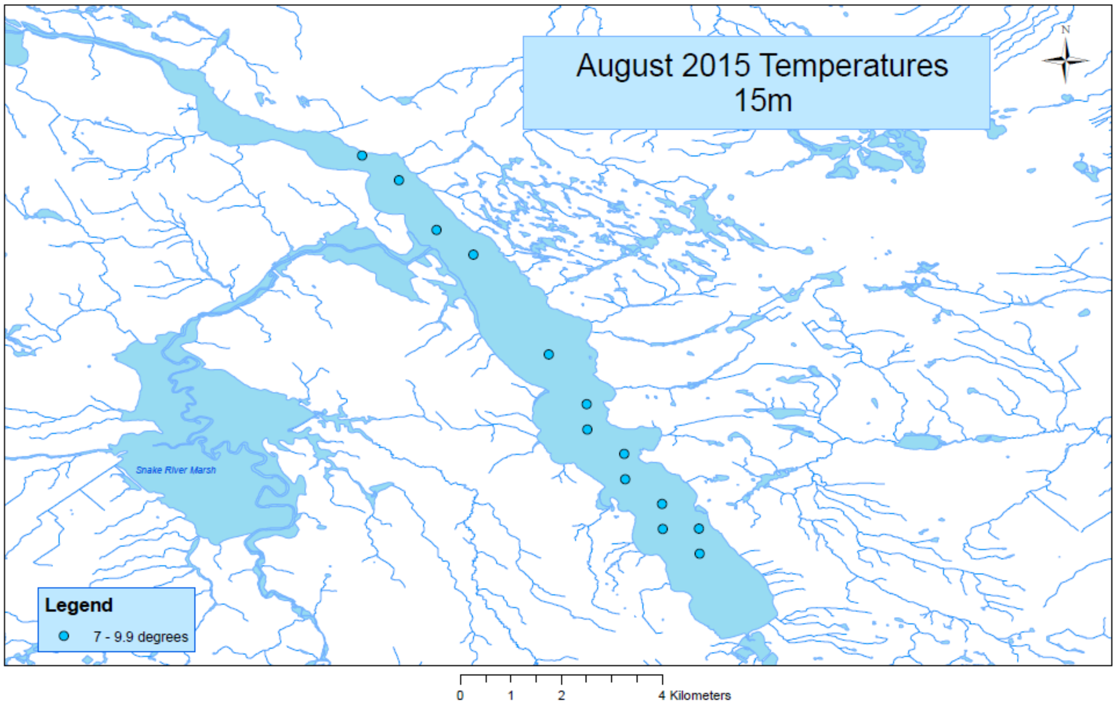

Figure 9. August temperature levels at 15m below the surface of Muskrat Lake.

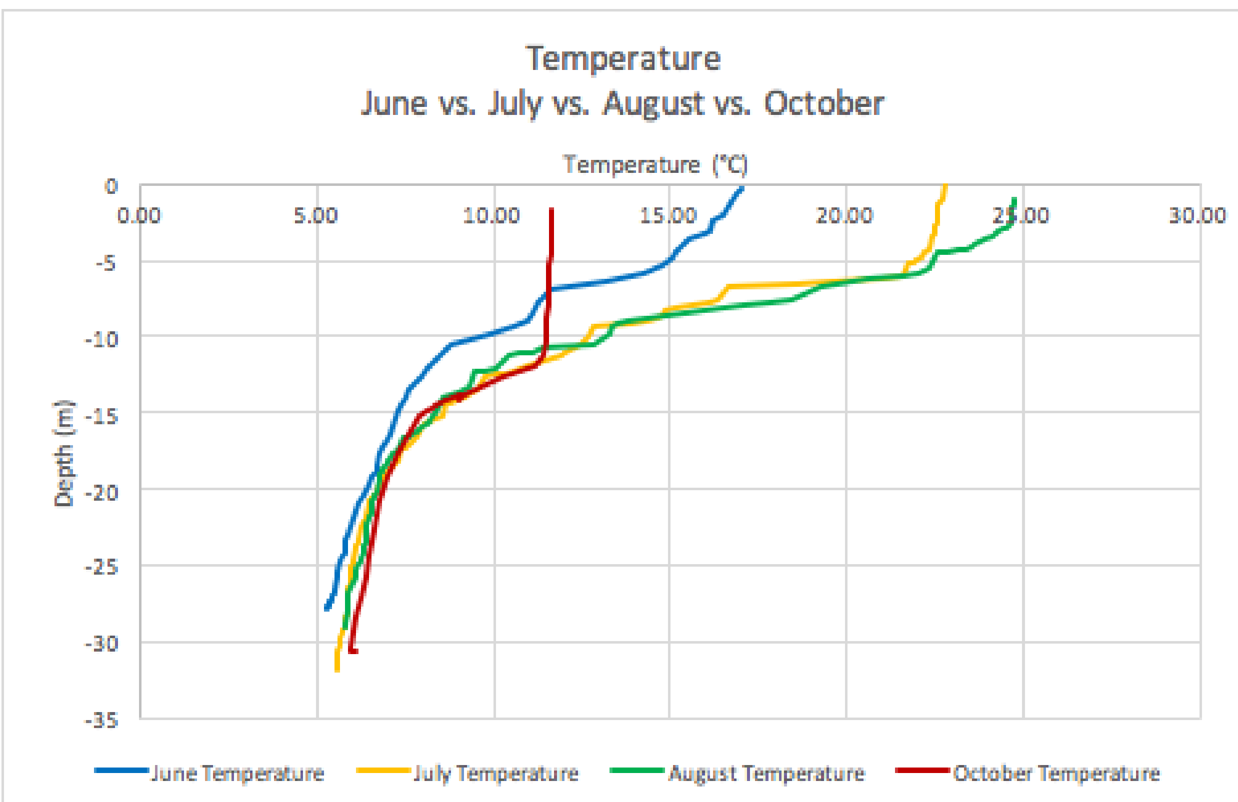

Figure 11. Temperature levels by depth at site 10 in June, July, August and October in Muskrat Lake.

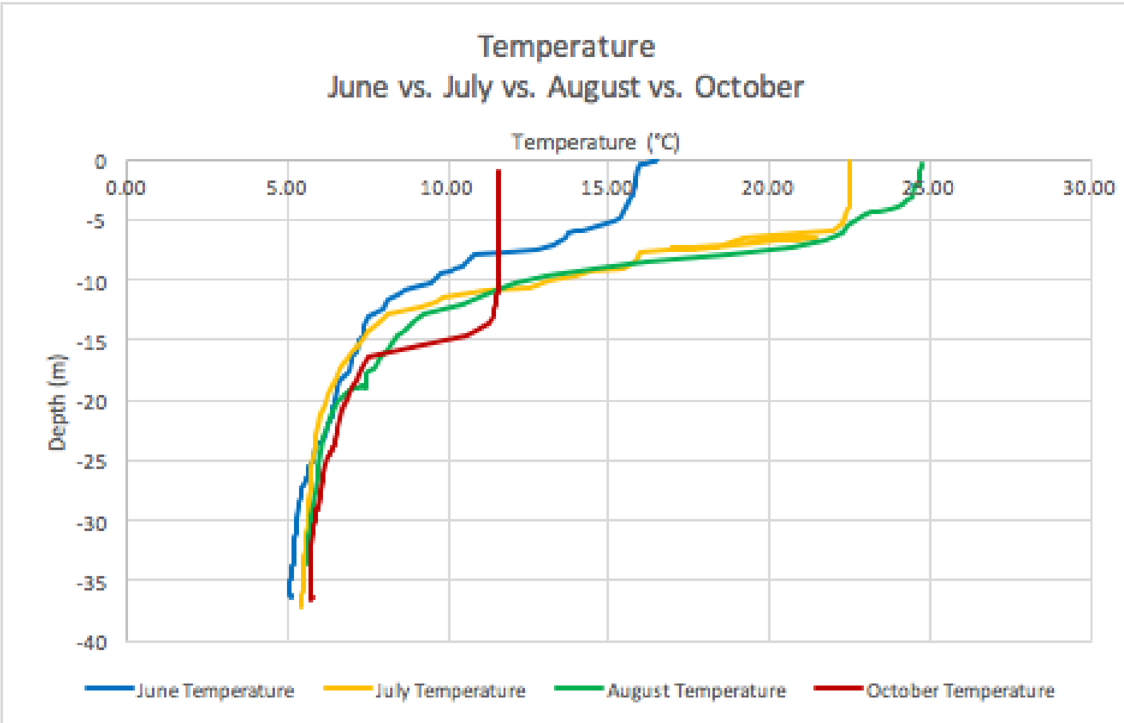

Figure 12. Temperature levels by depth at site 19 in June, July, August and October in Muskrat Lake.

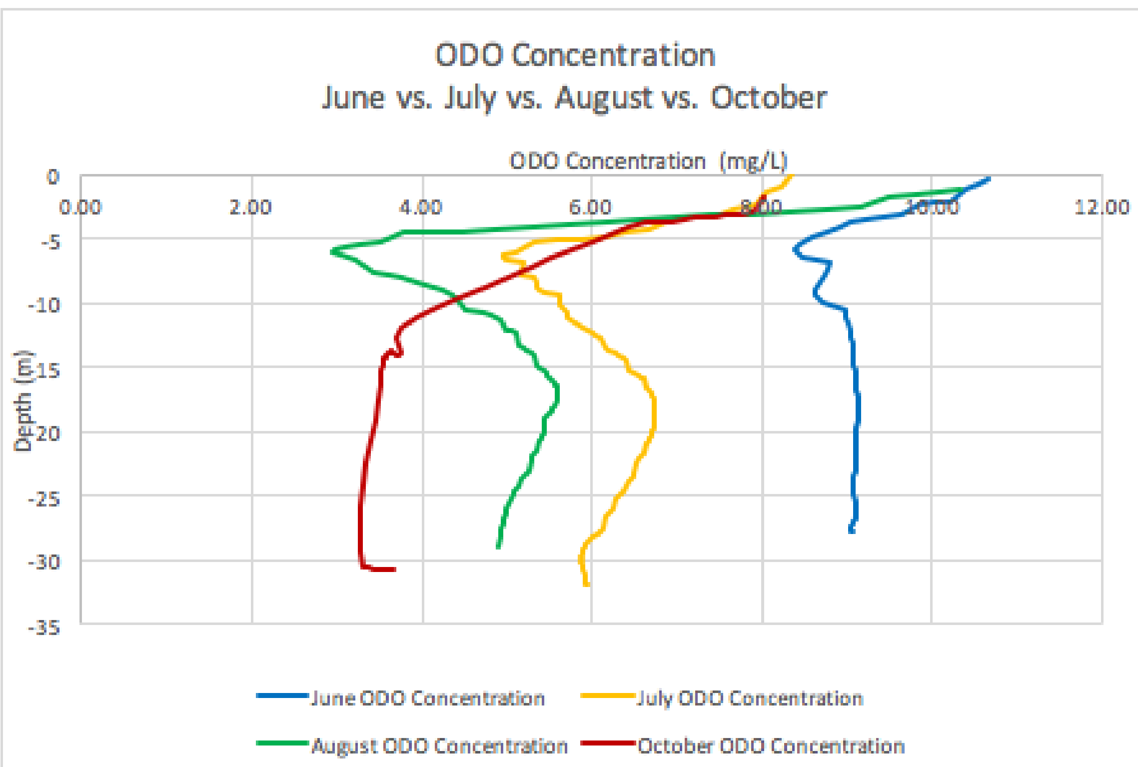

Figure 15. Dissolved oxygen levels by depth at site 10 in June, July, August and October in Muskrat Lake.

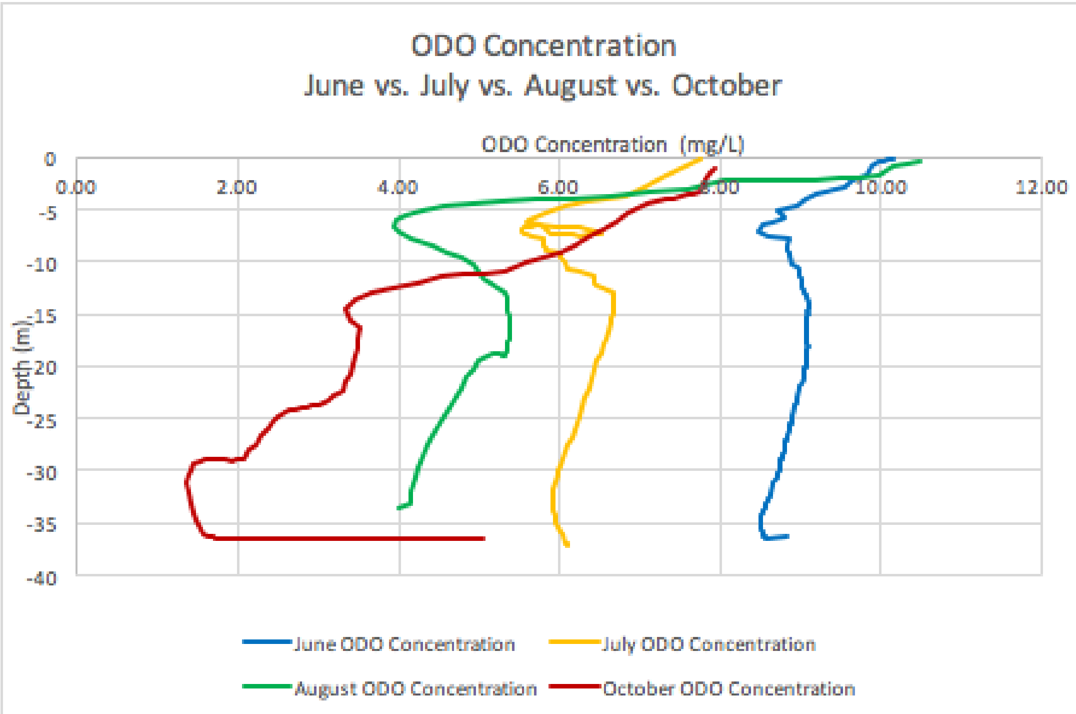

Figure 16. Dissolved oxygen levels by depth at site 19 in June, July, August and October in Muskrat Lake.

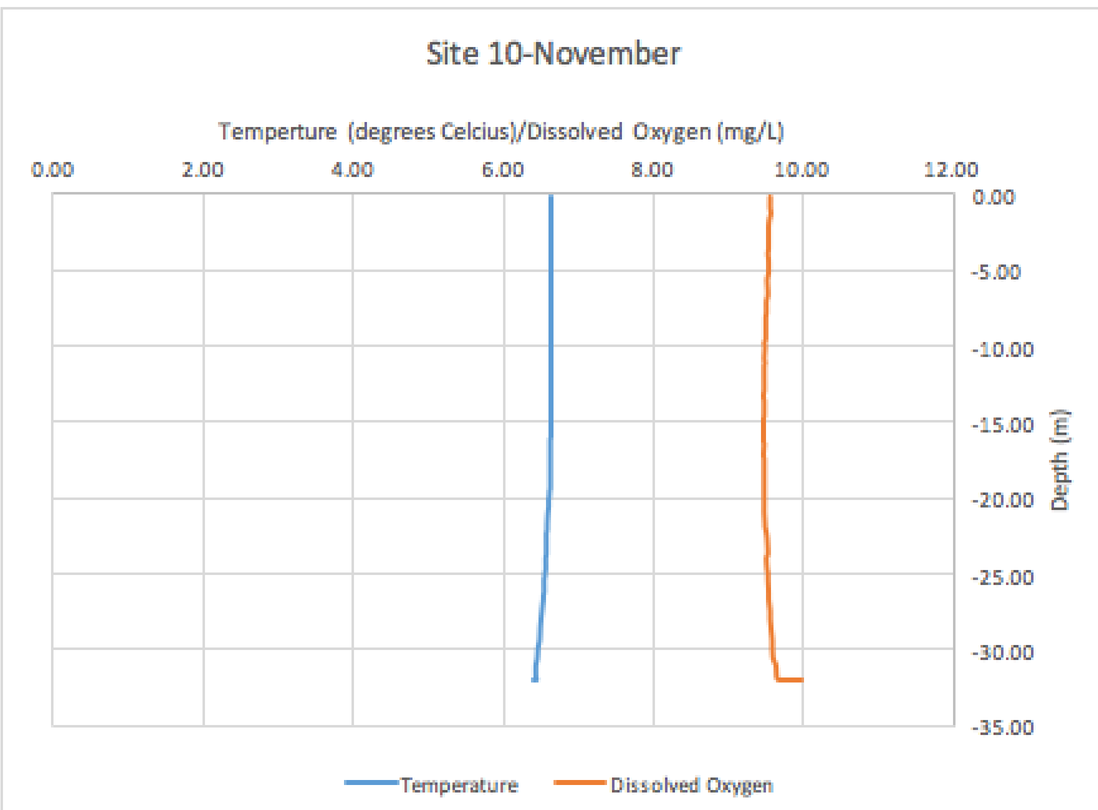

Figure 18. Lake turnover in November at site 10 on Muskrat Lake.

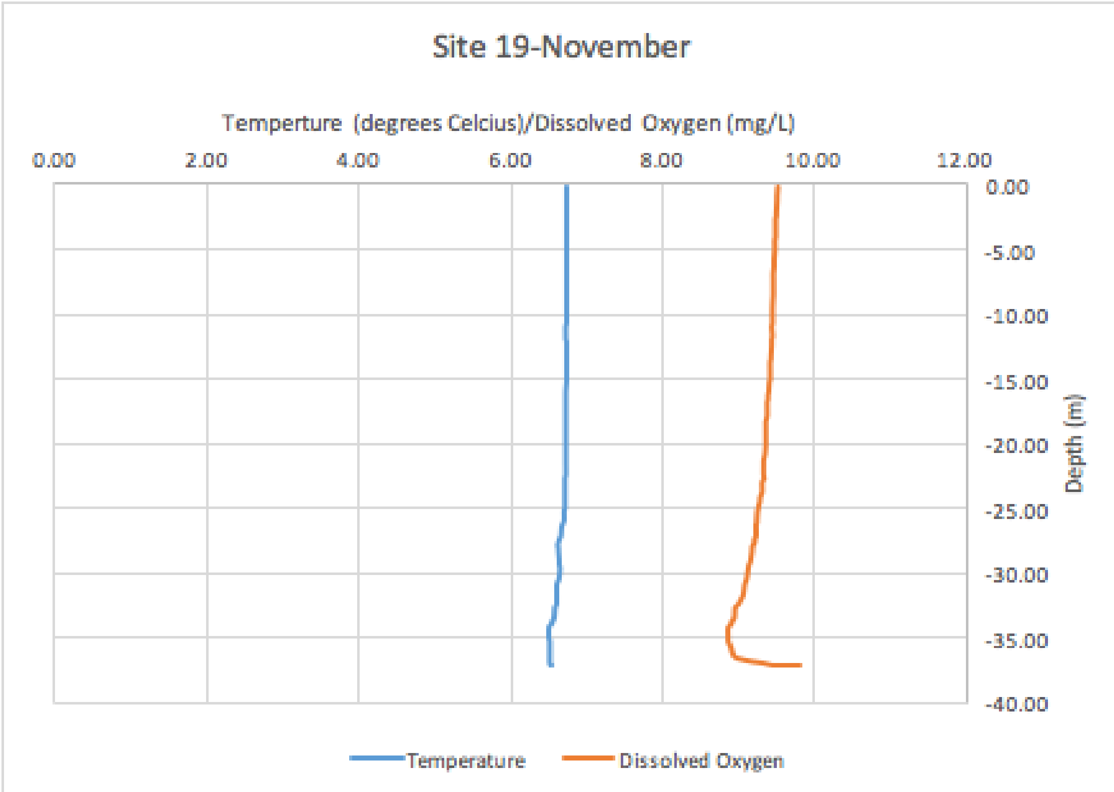

Figure 19. Lake turnover in November at site 10 on Muskrat Lake.