Using temperature sensing equipment to detect groundwater and surface water interactions in Long Lake, New Brighton, MN

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Dedication

I would like to dedicate this thesis in memory of my father, Jim Chermak, who I know in my heart would be immensely proud of everything I have accomplished in life. The support of my mom, Colleen Chermak, and dad has been the driving force in my academic and professional success.

Abstract

Temperature sensing equipment is a cost effective way to determine areas in water bodies where groundwater may be seeping into the surface waters. Data records of noticeable temperature differences can indicate points where groundwater may be mixing with the surface water. Identifying these areas can help in many studies including determining pollutant loading and water level fluctuations.

The research reported in this manuscript used Dallas Thermochron DS1922L-F5 temperature loggers to map the south lobe of Long Lake, which is a deep, urban lake. Based on this sampling event a few areas were identified for possible groundwater inputs. These areas include the connection to the north lobe of Long Lake, the east cove north of the beach, and at the south end of the lake. The results demonstrate the successful aspects of this method of my study. This method could be used as a developmental tool for future projects hoping to accomplish a similar result.

Table of Contents

List of Figures

1. Introduction

Long Lake is located in New Brighton, Minnesota and within the borders of Ramsey County. It is positioned in the northwest quadrant of Interstate Highways 694 and 35W. Long Lake is in the Rice Creek Watershed District (RCWD) and is regularly monitored by the staff for a variety of water quality parameters.

The Minnesota Department of Natural Resources (MN DNR) Lake Identification number for Long Lake is 62-0067 (MN DNR, 2009). The most current lake characteristics available from the DNR's Lake Finder website include the total lake area as 172.62 acres, of which 110 acres is littoral area. The lake has both a northern and southern basin with a narrow channel connecting them. The southern basin has a direct connection to Pike Lake to the west while the northern basin is stream-fed from Rice Creek to the north. The maximum depth is 30 feet and maps identify two deep pockets in both the north and south basins that achieve that maximum depth. The water clarity is 4.5 feet (MN DNR, 2009). Historically, Long Lake has been identified as having an abundance of native aquatic plants although recent surveys by Ramsey County Lake Management and Ramsey Conservation District have not found supporting evidence in the past two years (Ramsey Conservation District, 2008).

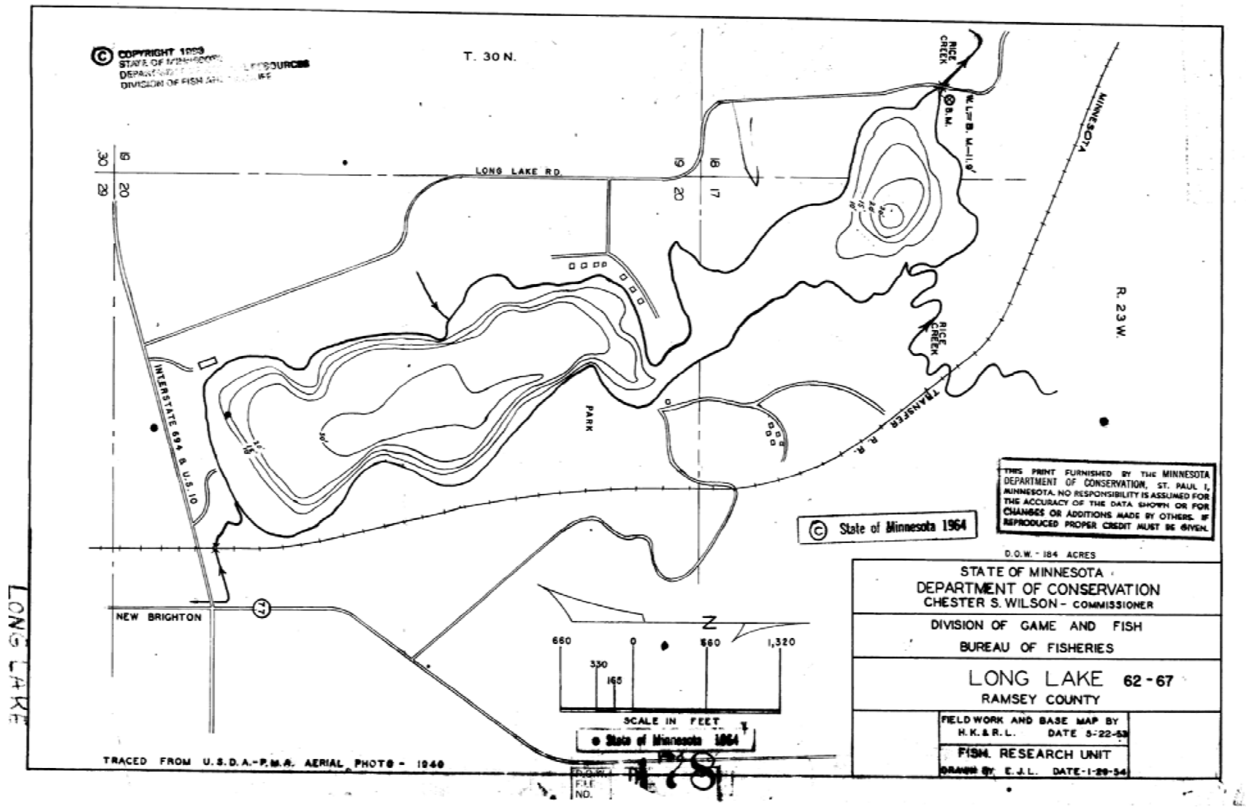


Figure 1.1. Bathymetric contours of Long Lake *File credit: MN DNR Lakefinder, 2009*

Long Lake is widely used for fishing and swimming. It is surrounded by a very urbanized watershed which in the past had significant industrial activity, some of which handled solvents, degreasers, and petroleum products (Minnesota Pollution Control Agency, 2008). According to the Minnesota Pollution Control Agency (MPCA), the lake has a normal water elevation of 863.1 feet above sea level (Minnesota Department of Health, 2008). Long Lake has been the focus of many studies, led by the MPCA and Minnesota Department of Health, researching volatile organic carbon contamination, macrophyte studies, and ground water inflow. It is also identified by the city of New Brighton in their Surface Water Management Plan as a point of interest. The plan states New Brighton's request that, “RCWD set its water quality goal for Long Lake to be TSIS (Trophic Status Indicator Secchi) = 50 to reflect use as a swimming lake. Also, we request that RCWD classify and formally recognize Long Lake as a Tier II lake" (City of New Brighton, 2000). A report done by Rice Creek Watershed District in 2008 titled, *State of the Lakes*, grades Long Lake a "C" in water quality. This rating is related to the phosphorus and chlorophyll-a concentrations that exceed the state standards (RCWD, 2008). As a result, Long Lake remains a target of water quality monitoring.

Temperature sensing technology has been explored previously using fiber-optic cable in a method called Fiber-Optic Distributed Temperature Sensing (FO-DTS). An example of previous studies can be found from the U.S. Geological Survey (USGS) website. The USGS summarizes the FO-DTS method as "measurements that involve sending laser light along a fiber-optic cable. Photons interact with the molecular structure of the fibers, and the incident light scatters. Analysis of Raman backscatter for variation in the optical power allows the user to estimate temperature" (USGS, 2011). The spatial and thermal resolutions of the FO-DTS method are comparable to that of the Dallas Thermochron sensors (Dallas/Maxim, 2011) used in this study.

A study titled, *Monitoring Submarine Groundwater Discharge Using a Distributed Temperature Sensor, Waquoit Bay, Massachusetts*, by F.D. Day-Lewis details the use of FO-DTS to map fresh submarine groundwater discharge. The findings of this study were threefold: The first being the discovery of a cold zone 15 ft offshore of the bay, secondly a positive correlation between bay floor temperature and the tidal level and lastly a positive correlation between bay floor temperature and bay water temperature (Day-Lewis et al., 2006).

Dr. Donald Rosenberry is a hydrologist with the U.S. Geological Survey. Rosenberry has studied groundwater and surface water interactions. Hydrologists and ecologists interact to understand the impact of ground water on aquatic ecology (Hayashi et al., 2002). Groundwater exchange can be a large component of water flux in lakes, but it is difficult to measure accurately and is often calculated as the residual of the hydrologic budget or sometimes ignored (Winter, 1981; Hunt et al., 1996).

One of Rosenberry's methods was using stable isotopes to evaluate flow direction and source of groundwater (Schuster et al., 2003). Water stable isotopes can be used to describe water movements, but they are typically only effective in lakes with long water residence times (Stets et al., 2010). Stets et al. concluded that their isotope model performed well in the open-basin lakes, providing that an adequate number of lake surface water samples were collected (Stets et al., 2010).

Three of the most commonly used methods to either calculate or directly measure flow of water between surface-water bodies and the ground-water domain include: measurement of water levels in a network of monitoring wells, the use of portable piezometers to measure gradients, and seepage meters to measure directly flow across the sediment-water interface at the bottom of the surface-water body (Rosenberry et al., 2008). Selection of the appropriate methods of calculation and measurement if one of the most important decisions to be made when quantifying exchange between ground water and surface water (Rosenberry et al., 2008). Of the three methods for measuring flow of water, each has advantages and disadvantages (Rosenberry et al., 2008). The selection of the method used must be relevant to the study area of interest (Rosenberry et al.,2008). It is not possible to anticipate all situations in a field study but one can generally look at the conditions you may encounter.

2. Methods

The set up for my methods was modeled with the help of Bill Olsen, a hydrogeologist for Dakota County Water Resources department. Bill Olsen's 2007 work titled, *High Resolution Longitudinal Temperature Survey of the Vermillion River*, was the basis for my methods and set up. Olsen and his survey partners used Dallas Thermochron DS1922L-F5 temperature loggers to record temperatures along several reaches of the Vermillion River as part of an Environmental Protection Agency (EPA) Thermal Trading Project (Olsen et al., 2008). Several adjustments were made to his procedure since the characteristics of the Vermillion River and Long Lake are very different. The Vermillion River is fairly consistent in its grade and is shallow enough that several members of the survey crew were able to wade the shores for long distances to acquire data. Long Lake is larger in size and has two steep drop offs; one in the north basin and one in the south basin, which are 30 feet in depth. Also, the shoreline of Long Lake has inconsistent bathymetric contours which would not be conducive to sampling on foot.

The first part of this method involved setting up a sampling apparatus. A 16 foot flat bottomed John boat with a 15 HP Honda motor was used to navigate the water. A ten foot length of schedule 80 PVC pipe was strapped to a four foot section of 2 x 4 to affix it to the boat. Schedule 80 PVC pipe was chosen because it is thicker and stronger than standard grade PVC pipe. There was concern over the strength of the sampling arm given the drag from the water and aquatic plants. The four foot length of 2 x 4 was cut to the exact measurement of the boat's width. The board was then secured to the boat with five inch lag bolts and lock nuts through the oar locks. The sampling bags were attached to rope and the rope was then connected to the pipe. On the board, seven loop screws were attached at even intervals to thread the corresponding rope from the seven individual sampling bags. The ten foot length of schedule 80 PVC pipe was secured to the 2 x 4 board as a way of making the unit easy to transport and have it safely attached to the boat while sampling the lake. Several ratcheting tie down straps were used to secure the PVC to the board. Tie downs were preferred since they are easily removed if there was a need to quickly release the sampler while out in the field. The PVC was drilled with seven equidistant holes and attached with four inch lag bolts and lock nuts.

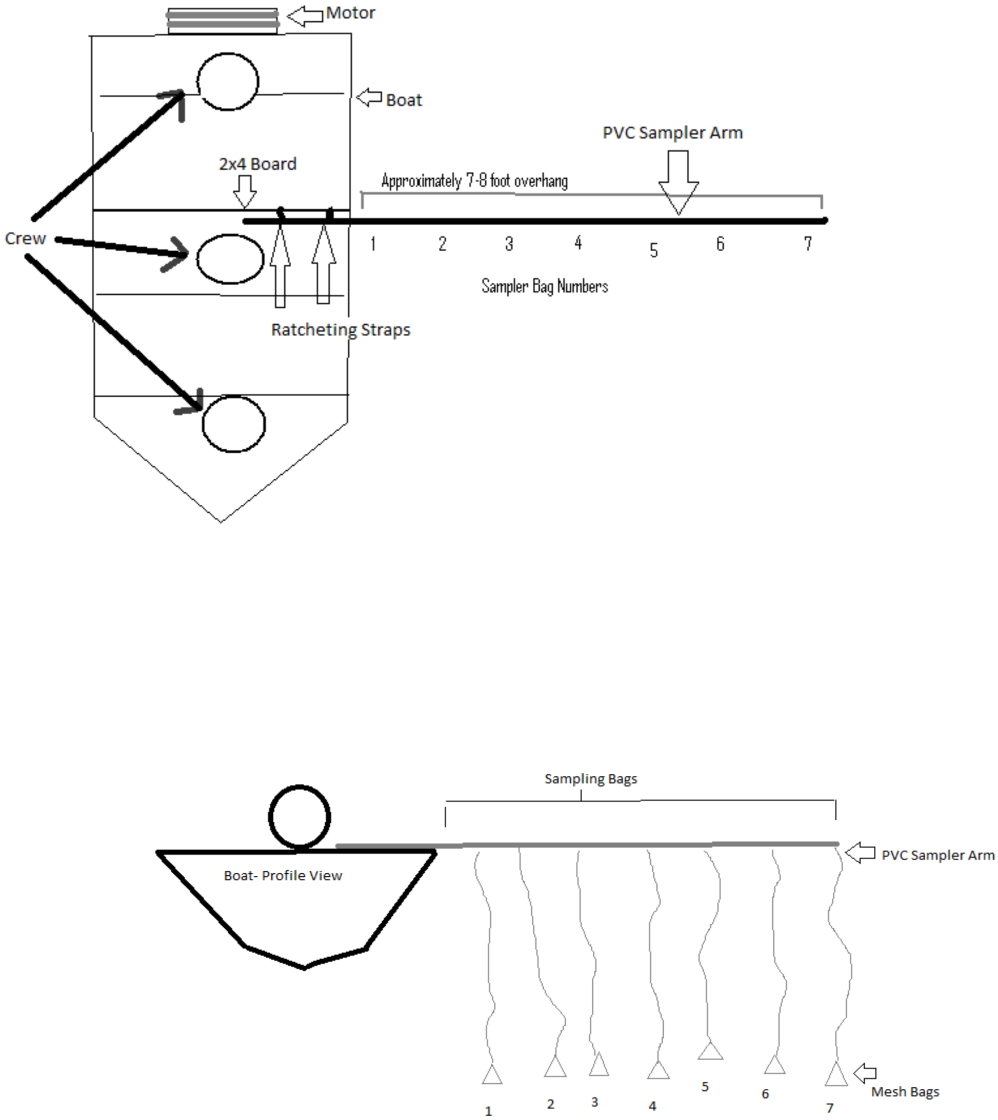


Figure 2.1. Sampler set up diagram

Figure 2.2. Photograph of Sampling Boat and Apparatus

The temperature loggers were borrowed from Dakota County Water Resources department. Their staff's past experience recommended using wire mesh bags made of 60 mesh brass screen and attached to string or poles and sealing the Dallas Thermochron temperature loggers into the wire mesh bags for the duration of the sampling. The temperature loggers are a little bigger than a watch battery. Since the Dallas Thermochron temperature loggers are water resistant but not waterproof, they were sealed into small two inch by three inch resealable plastic bags inside the wire mesh sampling bags. To ensure that the temperature loggers stayed inside the sampling bags, flexible metal tape secured the open edge. The wire loop on the bags was tied with a 20 foot length of rope. As an extra precaution, electrical tape was wrapped around the rope knot and wire loop on the mesh bags in case frayed rope caught on branches or aquatic plants. It was very important that the sampling bags be tied securely to the sampling apparatus because each Dallas Thermochron temperature logger is very expensive.

The length of rope attached to each wire mesh sampling bag was first strung through the eye loop bolts evenly spaced through the holes of the PVC pipe. Next, the rope was brought through the eye loop screws mounted to the four foot section of 2 x 4 secured to the boat. As an extra security measure, ¾ inch flat washers were knotted to the ends of the rope and secured with electrical tape after being strung through the eye loop bolts. This was done in case the person handling the ropes accidently lost grip of the rope’s end. Lastly, fluorescent marking tape was flagged on the rope four feet from the top of the wire mesh bag. In the event that a rope was lost in the lake, the idea was that the fluorescent tape would make it visible.

Two of the ten feet of the schedule 80 PVC pipe was attached to the 2 x 4 clamped to the boat, which allowed for roughly eight feet to overhang the side of the boat. The spacing for each sampling rope was about 11 to 12 inches between sampling bags. The sampling bag that was closest to the far end of the PVC pole was number seven. The boat traveled in reverse in a counterclockwise manner starting from the south end so sampling bag seven was closest to the shoreline. The sampling bag closest to the boat’s edge was number one. This was closest to the center of the lake. The number of Dallas Thermochron temperature loggers placed in each wire mesh sampling bag was 5, 3, 4, 4, 4, 4, and 4 for sampling bags 1 through 7, respectively. Multiple loggers were used in each bag in case a logger malfunctioned and to have a larger data set.   The loggers were numbered in permanent ink and those numbers were recorded in the field book along with the sampling bag number. The Dallas Thermochron temperature loggers have the ability to be preset prior to our sampling. A USB dock that snaps the logger into the port and the compatible program for the system is loaded on a computer. By calculating the minutes until the loggers were to be deployed from the current time, they were preset to the desired sampling start time. For example, if you wanted to begin sampling at 9:30 a.m. and you were presetting the loggers at 8:00 a.m., you would set them to begin sampling in 90 minutes.

Figure 2.3. Long Lake Sampling Path

Once the sampling bags were lowered to begin our sampling route (See Figure 2.3), they were kept near the lake bottom. The boat was launched at the south end of the lake by the boat ramp and started to the east in a counterclockwise pattern around the southern lower basin. The boat stayed as close to shore as possible but that distance varied. The boat motor went in reverse to achieve the slowest possible speed. Going in reverse also allowed for the sampling ropes to drag in the opposite direction of the motor propeller blade so the rope would not get caught in the blades. A Trimble GeoXH GPS handheld unit was used to record our position. The accuracy of the Trimble GPS unit is three feet or less. The GPS unit was set to continuously take a location point every second. A temperature probe was used to randomly check sediment temperature at various points along the sampling route. To record those data points, the time and reading were noted in a field book. Three people were needed for this sampling operation: one person was in charge of steering the boat, another person in charge of handling the sampling rope and apparatus, and the last person to record temperature readings and control the GPS unit.

Prior to the main sampling event, a trial run was conducted with Bill Olsen on April 5, 2009. We spent a couple hours on the lake and revised our sampling plan. At that time, ice was still present on much of the lake. The day of the main sampling event was April 8, 2009 when the ice was significantly reduced. This factor allowed the sampling crew to easily navigate to all of the lake. The weather on April 8th was sunny with a moderate breeze. The wind was part of the reason that the ice cover had decreased within the past few days. The wind was helpful in that manner but it made keeping a consistent sampling path more challenging.

My objective for this sampling event was to get an accurate reading of the groundwater temperature right after ice out, so timing was crucial. If the wait was too long, the surface water temperature would not be varied enough from the groundwater inputs and thus be difficult to detect where the groundwater is exfiltrating. In the early spring the surface water is colder than the groundwater. In late summer the surface water would be warmer while the groundwater would be cooler.

The temperature loggers were downloaded to the computer and into a Microsoft Excel (2007) spreadsheet from the USB connection and docking station. Microsoft Excel was the primary way these data were organized and interpreted. Once every temperature logger was recorded into Microsoft Excel, these data were ready for interpretation. The temperature loggers were preset to take a reading every second in degrees Celsius. The spreadsheet was organized to separate the data by logger number and by bag number into their own tab. The first column in the Microsoft Excel spreadsheet reflects the time in hour, minute, second format. The columns next to the time show the temperature as recorded by the Dallas Thermochron loggers, to four significant digits. According to the manufacturer, the DS1922L-F5 loggers have a thermal resolution of 0.0625°C and a range from -10°C to +65°C. Each of the Dallas Thermochron logger temperature readings were paired into successive columns and arranged by sampling bag. Then, the average and standard deviation for each sampling bag was calculated. Once this was completed, these averages and standard deviations were compared one to another. An overall average of all seven bags' averages and standard deviations was calculated in the next step. Lastly, the GPS data was transferred into ESRI ® ArcMap™. This spatially mapped the several thousand data points collected in the field onto an aerial map of the lake. Using these GPS positions, data from the temperature loggers was correlated to the spatial position. Plotting the overall average and standard deviation on the ESRI ® ArcMap™ file visually showed the GPS points taken at each coordinating data point.

A grid diagram was created with lettered columns and numbered rows to overlay on an aerial map of the lake to illustrate a better visualization of the data. See Figures 3.2, 3.3, and 3.4 for grid illustration. Describing different areas of the sampling route is easier when one can assign a quadrant to the area of interest. The data values started at the northeast portion and ended at the southwest portion of the southern basin.

3. Results

Of the 28 Dallas Thermochron data loggers deployed, 26 yielded results. One logger from bag one malfunctioned and another logger from bag two did not produce any results. When working with the data points in ESRI ® ArcMap™ 10.0 software, there were several processes for interpreting these data. A graduated color ramp was used to show the standard deviations in five color ramp ranges using the Natural Breaks (Jenks) method in ESRI® ArcMap™. The lowest ramp color was red which depicted the standard deviation between 0.031001- 0.047439 degrees. The next greatest change color was orange which depicted 0.047440-0.058783 degree temperature change. The next color was light green as showing temperature changes between 0.058784- 0.081432 degrees. After that was bright blue as showing a change in temperature between 0.081433- 0.126404 degrees. Lastly, the dark blue color showed the greatest temperature change between 0.126405- 0.554847 degrees.

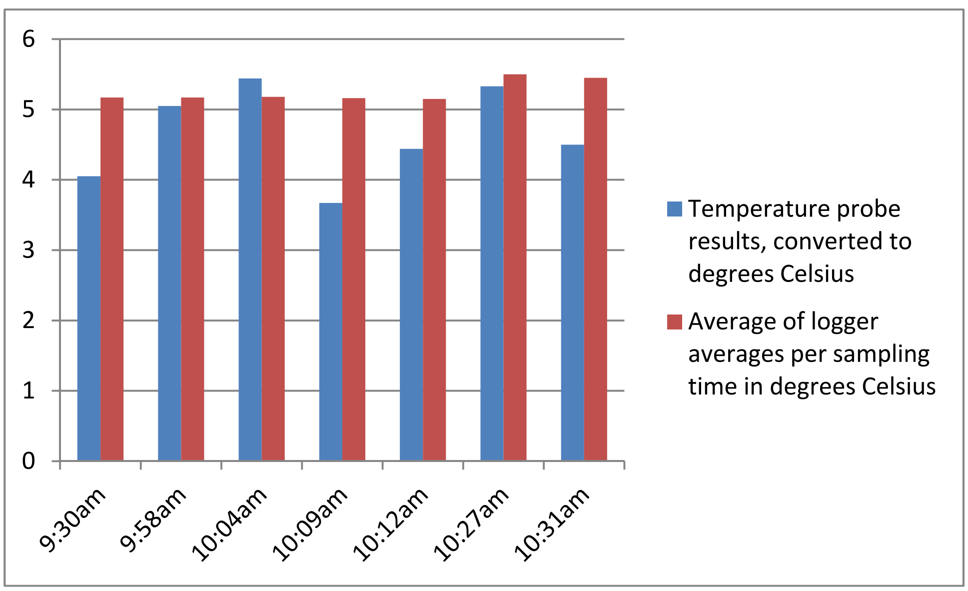
The overall data averages were similarly calculated and plotted using a color ramp from pink to dark blue in the Natural Breaks (Jenks) method (See Figure 3.1). The lowest temperature average was 4.82614- 5.23821 degrees Celsius and was colored pink. The next greatest temperature average was 5.235071- 5.351857 degrees and was peach colored. Next were 5.354071- 5.459536 degrees which was lime green color. Next greatest temperature average was 5.461643- 5.582964 degrees and dark green in color. Lastly, the greatest temperature change was 5.585143- 5.782607 degrees depicted by a dark blue dot.

The background lake water temperature was taken intermittently with the temperature probe in Fahrenheit degrees. The lake temperature registered around 39 degrees Fahrenheit which converts to around 3.8 degrees Celsius.

3.1. Temperature Probe Data

Incorporating the manually collected bottom sediment temperature probe data against the automatic temperature results from the loggers involved entering the field notes into the Microsoft Excel spreadsheet. A separate tab was created and the data was transcribed from the field book with the date, time, degree reading in Fahrenheit, and any comments. The time was less accurate than the loggers' recordings since we used a clock without a second hand. To compensate for this, all the average recordings in the overall average tab for that time frame were averaged. This reduced the readings taken every second into one average for that minute in time. The temperature probe readings were converted from Fahrenheit to Celsius. The Celsius result was graphed against the averaged logger reading.

Figure 3.1. Comparison of manual bottom sediment temperature probe results against automatic temperature logger results.



3.2. Average Comparisons

After averaging the data values of the sensors per bag and then plotting them, some minor trends were found. The general trend from the first sampling point was an increase in average temperature in the east cove past the beach and near the channel connection to the north lobe. The average temperature dropped drastically on the west near the Pike Lake connection then slowly increased near the south end of the lake. The first slight temperature increase happened in the upper corner of quadrant C2 (See Figure 3.2). The next slight increase occurred at the point where the north and south lobe of the lake connect in quadrants C1 to A2. This occurrence could be from slightly warmer water from the north lobe entering the south lobe. The slight decrease to more drastic decrease was on the west side of the lake around quadrant A3 to A6. From that point in the sampling path the temperature average slightly increases ending with a slightly higher temperature at the end of the sampling route in quadrant C12.

Since the data points were so clustered and not easy to read, a moving average of the average points was calculated so the points were better depicted on the map. A moving average is defined as one of a succession of averages of data from a time series, where each average is calculated by successively shifting the interval by the same time period (Merriam Webster, 2011). The total number of data point values from the samplers was 4,096. By dividing 4,096 by 60, since one point was taken every second to round it out to an even minute marker, the result was 68 intervals. The existing average shapefile was exported as a data file in ESRI® ArcMap™ and modified to include the new moving averages. When that was completed, the new moving averages shapefile was spatially displayed on the map by graduated color symbology display (See Figure 3.3). The result was data points that are more spread out and easy to distinguish from adjacent data points.

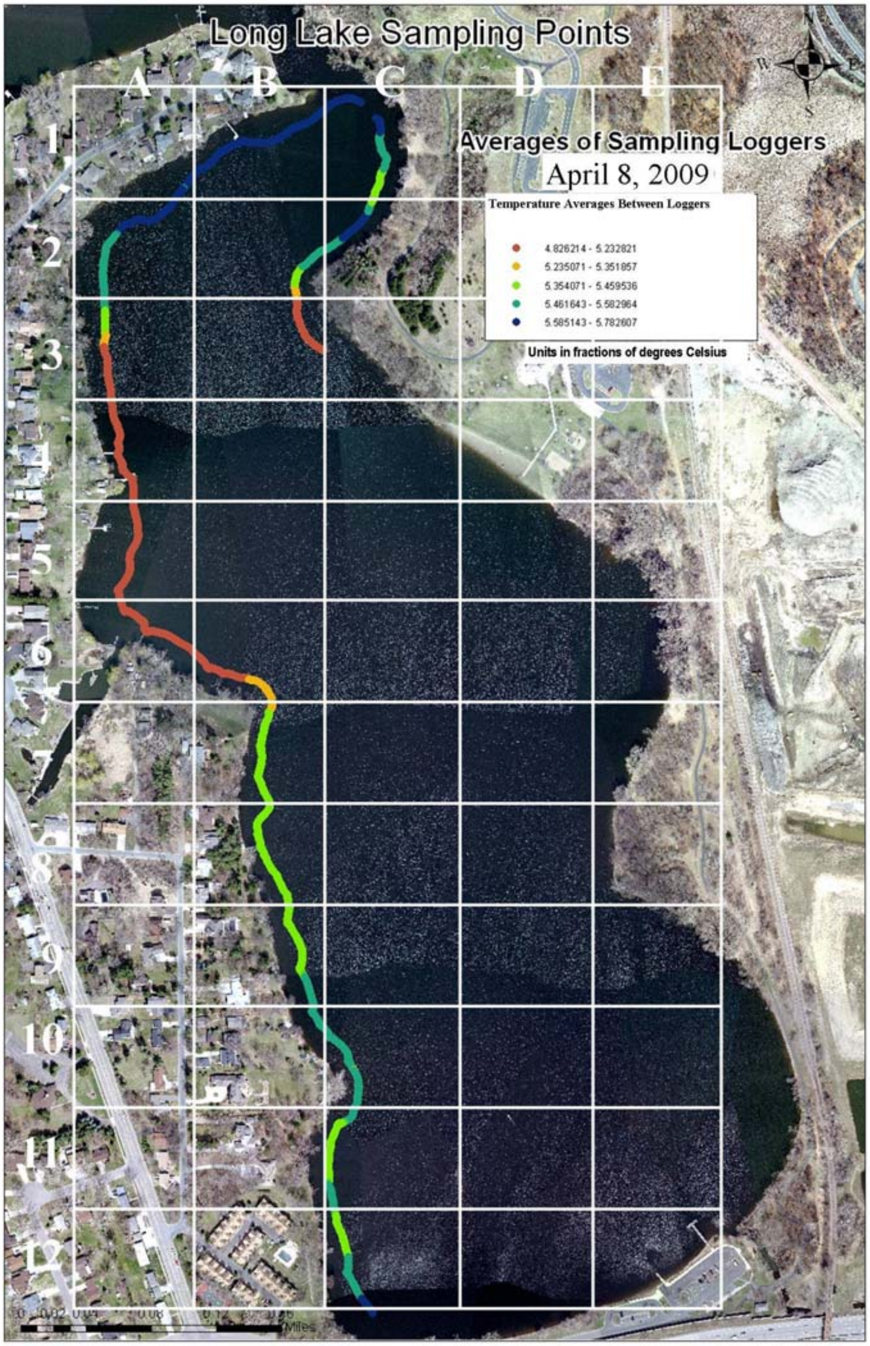


Figure 3.2. Distribution of sampling point averages.

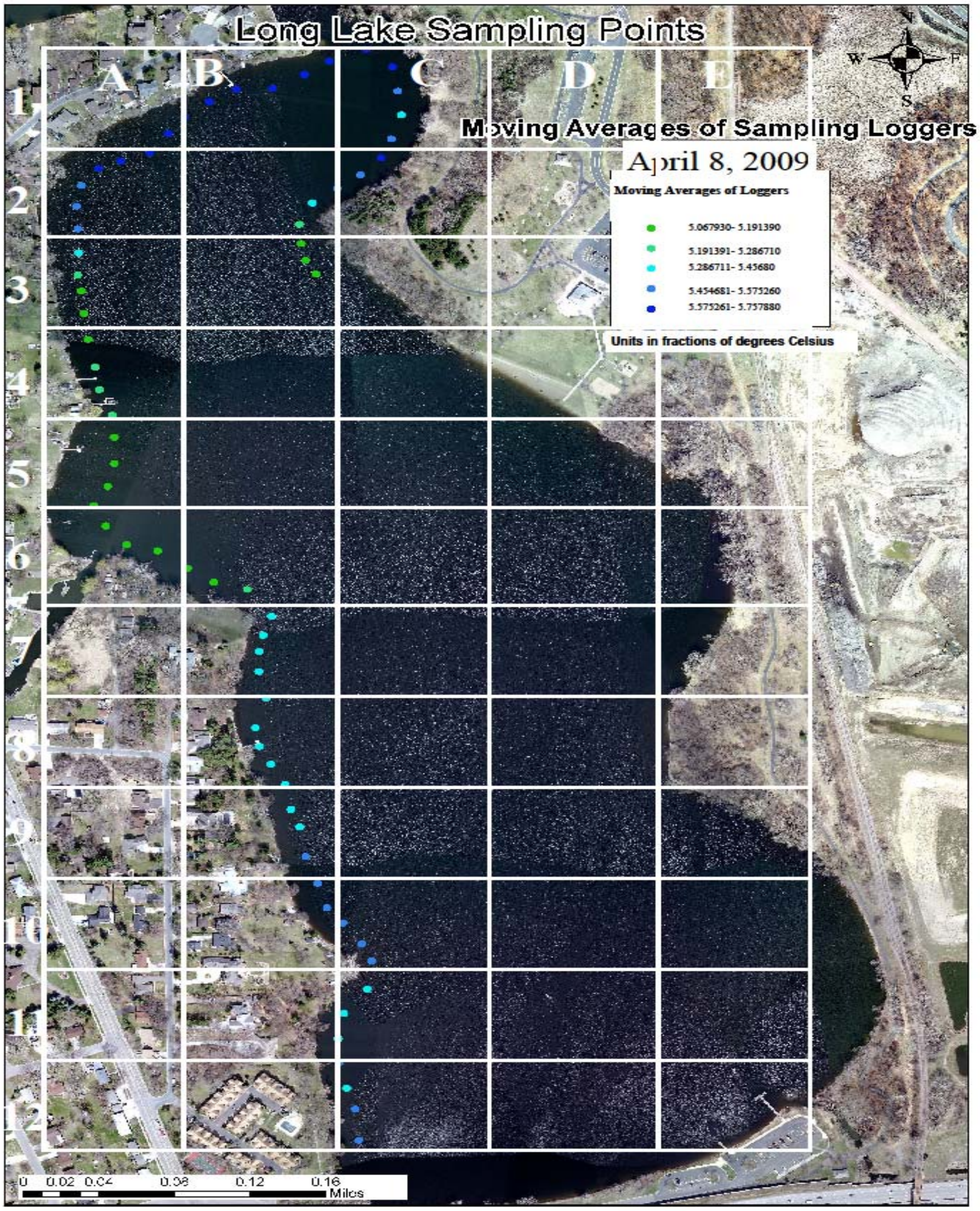


Figure 3.3. Distribution of sampling point moving averages.

3.3. Standard Deviation Comparisons

The trends among the standard deviation averages were minor compared to the data point averages. The values first took a slight decrease in deviation change and then a large increase from the starting location (See Figure 3.4). As the data plots continued, the values took two large decreases before increasing just past the north lobe connection. Towards the middle of our sampling event, many of the values showed little change or decreased slightly. The trend continued until a few additional small increases. One significant increase was at the Pike Lake connection, which may be a result of the channel inflow. Also, in quadrant B6 a sampling location appeared where it doubled in standard deviation temperature value from the surrounding sampling locations. The last increase was in quadrant C10 where two locations in close proximity to one another doubled in standard deviation temperature value within three sampling seconds.

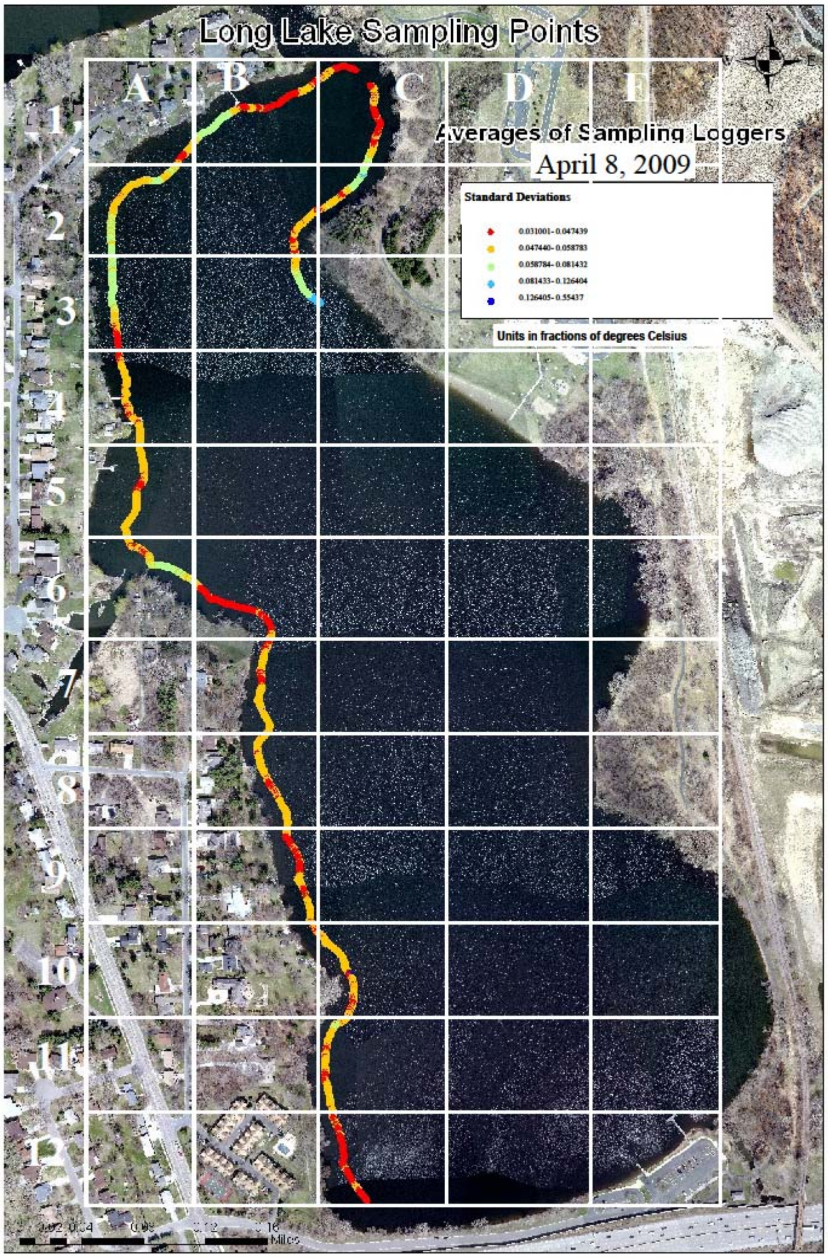


Figure 3.4. Distribution of sampling point standard deviations.

4. Discussion

Several factors worked well in this field survey. First, the method of deploying the Dallas Thermochron temperature sensors was well done. The method of attaching them in mesh bags and secured by electrical tape was very successful to get accurate results when in contact with the water temperature and also a safe way to deploy them into the test area without loss of equipment. Another item that worked well was using an accurate GPS handheld unit to record positions in frequent intervals. Processing these data was made simpler with the help of a spatially referenced map. I also feel that the results from our particular GPS unit were very accurate, so this model would be recommended. The last positive aspect of this experiment is that the Dallas Thermochron temperature sensors are a less expensive alternative for temperature studies than more costly methods such as the remote fly over analysis that will be used on the White Bear Lake groundwater study. If a study similar to this was being considered as part of a cost-benefit analysis, this method would have the most value. It would yield accurate results at a great value as a greater management decision for your study.

Some limitations to this project design include the method of sampling the lakeshore. Using a motorboat to sample closest to the shore was the best method available to our group but there are some limitations to where you can safely travel. For example, near residential docks and where trees and shrubbery extend over the water. The variations in the shoreline depth were also problematic as there were many bathymetric changes over the sampling course. Another limitation of this setup is that using a large sampling apparatus can be a little unwieldy and harder to quickly manipulate than hand sampling by foot.

Why did the results appear as shown? My hypothesis is the moving average results were higher at the mouth where the north lobe met the south lobe because the average water temperature in the north lobe was warmer than that of the south lobe. One suggested modification would be to get some data points from the north lobe to make a comparison study. If we had done several sampling events in both the spring and fall, the larger data set may have shown more conclusive results. Adding seasonal sampling days would be one adaptation to this study method. The sampling apparatus that the sampling equipment was attached to could be improved the next time around. The string of the samplers, when used in a heavily vegetated aquatic area or one where lots of debris resides, could become problematic for damage to the sampling apparatus. A better design of the way the samplers were carried through the water could lead to better results.

5. Conclusions and Recommendations

The results of the temperature logger survey showed mixed results. An adaptation of the methods could be beneficial for future studies and monitoring of similar sites. Recommendations for improvements to this project would include additional sampling staff, especially for larger and more time intensive sites. Additional staffing could also improve the data gained from the manual temperature probe results. A single person solely controlling the temperature probe would give more accurate and better spaced data results. Sampling over a period of multiple days would yield more data results and thus a better chance to find a data trend.

If further studies were to be completed from the results found in this report, researchers could focus their sampling efforts to two locations; at the north end where the two basins connect upwards from the beach and at the south end. These results showed slight temperature increases at those two locations which would benefit from further sampling.

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