2013 Tulaby Lake Hydrologic Investigation

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Tulaby Lake

Tulaby Lake is located in the pristine forested region of northern Minnesota. It is located 35 miles northeast of Detroit Lakes, MN. Tulaby Lake is considered impaired for recreational use due to excessive phosphorous levels. Past monitoring efforts have documented a seasonal phosphorus dynamic that typically results in a late-August to early-September blue-green algae bloom. For the purposes of this report, Tulaby Lake (43 foot maximum depth) was considered a "deep" lake. Tulaby Lake is expected to have similar characteristics to other "deep" lakes located in the forested regions of northern Minnesota.

The purpose of the study of Tulaby Lake is to understand its water quality dynamics. The hydrologic investigation began by reviewing previous findings from Bruce Paakh, The Tulaby Lake Association, Joe Magner, the White Earth Band of Ojibwe, and RMB Environmental Laboratories (RMB). The Tulaby Lake Report by Moriya Rufer from RMB provided an excellent source of information on Tulaby Lake. The review includes the examination of the area's land use, underlying hydrology, geology, and historic water quality data. The historical data was used in conjunction with an isotope analysis and laboratory analysis of water samples collected from 2011 to 2013 (1).

Land Use

Tulaby Lake Watershed is primarily comprised of forests, waters, and wetlands. (Table 1). Based on the land use data from the University of Minnesota Remote Sensing and Geospatial Analysis Laboratory urbanization is not prevalent in the Tulaby Lake watershed as seasonal and year round lake homes making up less than 3% of the total watershed area. During the period from 1990 to 2000 residential development only increased 1.5%. The small agricultural component decreased 14.3% during this same period. Impervious surfaces within the watershed are primarily rooftops with some paved driveways and these areas comprise a relatively small percentage (1%) of the total watershed area (2).

The dataset indicates that one significant change that has occurred is the decrease of wetlands, grasses, and shrub by 45.1% from 1990 to 2000. This loss appeared to be isolated to the Tulaby

Lake Watershed as the entire Wild Rice River Watershed experienced a slight increase of 4,815 acres of grasses, shrubs, and wetlands from 1990 to 2000. This loss of grasses, shrubs, and wetlands from 617 acres to 339 acres appears to be due to changes in aerial photo interpretation and not a watershed change. In speaking with long-time Tulaby resident Irv Kallin, Irv indicated that there has been no significant loss in grasses, shrubs, and wetlands within the watershed. The shift appears to be due to an associated increase in land classified as forest (2).

	1990		*2000*		*Percent Change*
Land Cover	**Acres**	**Percent**	**Acres**	**Percent**	*1990 to 2000*
Forest	5013	73.09	5342	77.88	6.6% Increase
Water	**958**	**13.97**	**913**	**13.31**	**4.7% Decrease**
Grass/Shrub/Wetland	617	9	339	4.94	45.1% Decrease
Urban	**198**	**2.89**	**201**	**2.93**	**1.5% Increase**
Agriculture	70	1.02	60	0.87	14.3% Decrease

Table 1. Tulaby Lake's percent change from 1990 to 2000 (http://land.umn.edu)

Historic Review of Climate and Isotopic Response

Dr. Joe Magner began work on Tulaby Lake in 2011 by collecting water samples for stable isotope analysis. The following section outlines the historic climatic data and lake response.

Historic Climate Data

Annual Precipitation and Average Yearly Temperature

The average mean precipitation and temperature records for the Tamarac National Wildlife Refuge just south of Tulaby Lake were obtained from Midwestern Regional Climate Center. (Figure 1). From 1985 to 1989 the area experienced a period of significantly lower levels of precipitation. A heavy rainfall on the 14th and 15th of July 1993 ended the previous dry period and began a 20 year stretch of unusually wet weather with the exception of a few dry years that include 2003 and 2011. Average annual temperatures have remained slightly higher than average since 2010 (3 & 4).

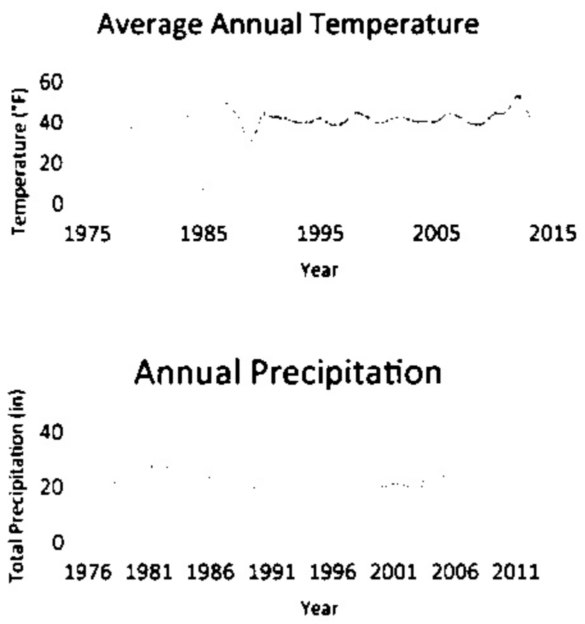

Figure 1. A) Annual temperature **B)** Annual precipitation

(Summary Tables for both the Total Precipitation and Average Mean Temperature can be found in Appendix A.)

Water Levels

The Ordinary High Water Level (OHW) elevation, which is a measurement of lake depth relative to elevation, for Tulaby Lake is 1530.8 feet. (Figure 2). The highest recorded level of 1531.01 feet was recorded on July 15, 1993. The lowest recorded level of 1528.57 feet was recorded on June 16, 1997. Figure 3 shows the lake level data from 2004 to 2013 (5).

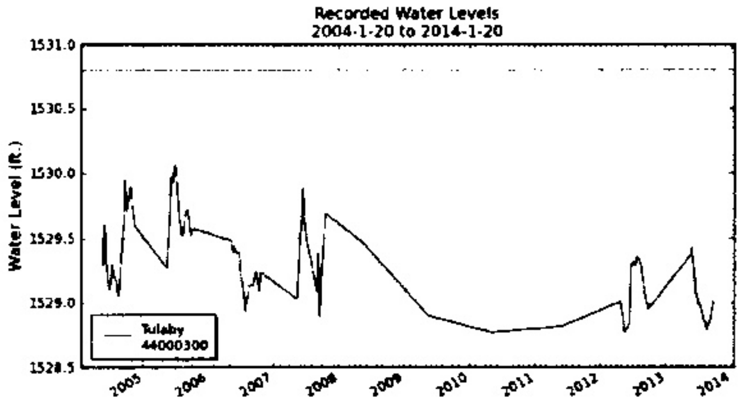

Figure 2. Water levels for Tulaby Lake (2005-2014).

Isotope Data

Isotope data was collected from Tulaby Lake in 2011. Figure 3 is a plot of the stable isotope $\delta^{18}O$ (‰) vs the stable isotope δD (‰) for Tulaby Lake. The stable isotope $\delta^{18}O$ is a ratio of two stable isotopes of oxygen ($^{18}O/^{16}O$). The stable isotope δD is ratio of deuterium and hydrogen defined as D/H ($^{2}H/^{1}H$).

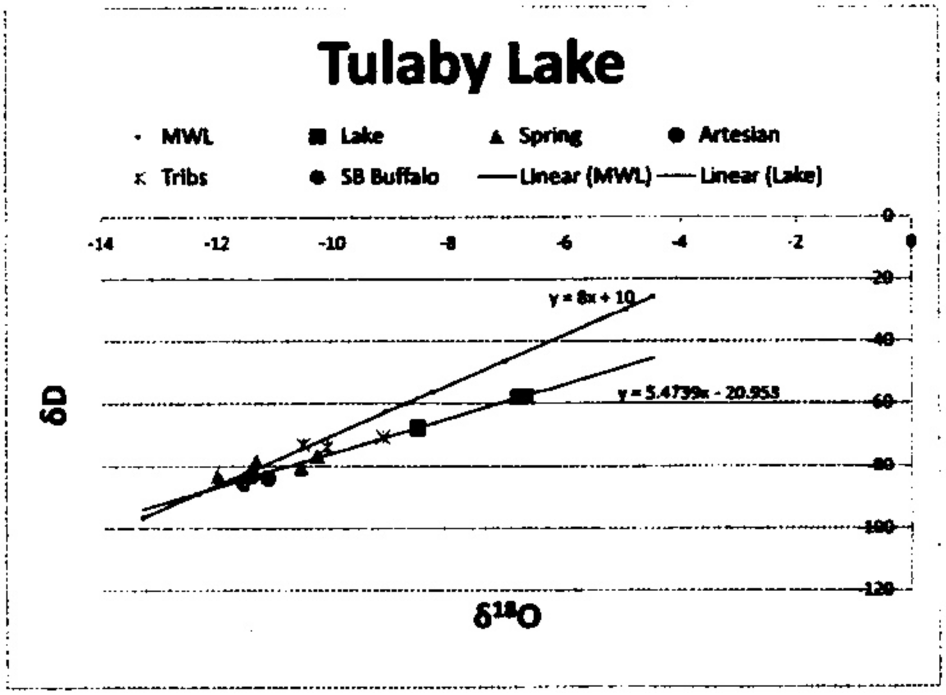

Figure 3. 2011 isotope analysis for Tulaby Lake.

The data indicated an evaporative signature for Tulaby Lake. The data plotted to the right of the meteoric water line (MWL) indicates that evaporation surpasses precipitation. This suggests that this interaction has been sustained for longer that just one year. This also indicates that groundwater from wetlands and small springs are the primary source of water for Tulaby Lake.

The data also indicates that the groundwater sources contain a mixture of precipitation and regional snow melt.

Floyd Lake and the South Branch of the Buffalo River plot along the evaporative line and intersect with the MWL at $\delta^{18}O$ -12 and δD -83, thus making the evaporative line the regional line. This represents the mean annual value for the subsurface snow melt recharge. This is most likely the result of a decade long snow melt to subsurface interaction.

Investigative Work Spring, Summer, and Fall of 2013

In the spring, summer, and fall of 2013 a group of students from the University of Minnesota headed by Dr. Joe Magner partnered with Bruce Paakh (MPCA) and the Tulaby Lake Association to investigate the changes in Tulaby Lake's water quality. The University made a total of three trips to Tulaby Lake: June 8, July 13, and September 21, 2013. The group was split into two teams: an in-lake and shoreline team headed by Jennifer Soltys and a wetland/wetland stream team headed by Mark Greve and Rachel Rausch.

In-Lake Methodology

Lake water quality readings and samples were taken at two locations. The first site, site 202 is about 35 feet deep or 10.5 meters and is the deep centrally located site in the lake. This site is considered the primary site for water quality condition monitoring in Tulaby Lake (6).

The second site (site 203) is 43 feet or 13 meters deep and is the deepest spot in the lake located near the north end of the lake. This site is used for monitoring internal loading and deep oxygen levels that can signal when internal loading begins to take place. The site is located across from a white cabin on a bluff between two reddish-brown cabins (6).

Surface (0 to 2 meter integrated) and deep grab samples (about 1 to 2 feet off the bottom) are taken at each site. To distinguish between surface samples and bottom samples, a D is written after the site number for the deep water samples. Samples were collected for the stable isotopes of H and O, reactive phosphorous, total phosphorous and ferrous iron. Water clarity measurements were taken with a Secchi disk. In addition, a YSI water quality sonde was used to collect a dissolved oxygen/temperature profile as well as, conductivity, and pH at each site (6).

Shoreline Methodology

Sites that likely provide groundwater infiltration into the lake were identified using a temperature probe. The temperature of the surface water was compared to the ground water temperature about two feet under the aquatic sediment. Areas where the groundwater is infiltrating the lakebed will have a greater temperature difference. Another indicator of possible ground water infiltration is a slight change in color of the aquatic sediment along the shore. The sediment with iron present will have a reddish/orange tint that differentiates it from the surrounding sediment. A peristaltic pump and groundwater sampler were used to obtain groundwater samples. It should be noted that while a lakebed groundwater source was identified, samples were unable to be obtained at that time and the location due to a lack of the necessary equipment (6).

Stream Methodology

There are a number of streams discharging directly into Tulaby Lake which have been identified. The primary stream of interest has an uncapped artesian well dispersing high volumes of groundwater into the stream approximately 20 feet from its lakeshore delta. Grab samples were taken from the flowing well (Figure 4) and from a site upstream of the well (6).

(For complete In-Lake and Shoreline Methodology see Appendix B).

Figure 4. Flowing Artesian Well

Wetland and Wetland Streams Methodology

One of the initial tasks was to identify the groundwater sources for the tributaries and surrounding wetlands. Team members hiked up the main branch of the stream that drains the wetland. Once a groundwater source was located, a PVC access tube (well) was installed using hand-held augers. In order to determine the placement of a well, iron stains were used as possible indicators of upwelling groundwater. Moving water was also used to distinguish between stagnate and flowing water. Four wells were installed in locations which met these criteria.

For the initial sampling of each well, the well was first allowed to acclimate. Then, temperature readings and samples were obtained. The well was then dewatered with a peristaltic pump. Temperature, depth, specific conductance, and dissolved oxygen readings were obtained after the well recharged with groundwater. Time zero was set when the well was pumped dry, and the time of equilibrium (when the measurements and samples were obtained) were recorded for each well. Upon subsequent sampling trips the following procedures was followed. First, temperature readings and samples were obtained. The well was then dewatered with a peristaltic pump. Then temperature, depth, specific conductance, and dissolved oxygen readings were obtained, as with the initial testing (7).

(For complete Wetland and Wetland Streams Methodology see Appendix D.)

Sampling and Data Collection

Grab samples were retrieved for all sites (lake, well, stream and wetland) during each of the three monitoring trips, when conditions allowed. After collection, the samples were placed in a cooler with ice packs. Samples which were being lab-tested for ferrous iron were preserved with nitric acid and total phosphorus samples were preserved with sulfuric acid. Isotope samples were stored in a refrigerator until sent for testing (6). Sample preservation protocols were following according to EPA standard methods.

Stream surface samples were all obtained using the following method. The sampling container is placed into the stream upside down at the sample site. The container is then inverted underwater and filled. The sample is then capped under water. Water samples are taken from the surface to test for isotopes, total phosphorus, and reactive phosphorous (6).

Deep lake water samples were obtained using a Van Dorn sampler approximately one to two feet off of the bottom at each lake site. Care was taken not to disturb the bottom sediments as this can greatly impact the sample results. Deep water samples were tested for phosphorous (total and reactive) and ferrous iron (6).

The integrated sample was used to collect a surface sample from zero to two meters. The sample is poured into a chlorophyll bottle. These samples were tested for Chlorophyll-a, ferrous iron, and phosphorous (total and reactive) (6).

Samples from the wetland wells were collected directly from the pump. Bottles were rinsed briefly with water from the well before being filled. Any air bubbles were removed and the water was filled to the top to minimize headspace. (7).

Summary of Water Quality Findings Summer and Fall of 2013

In-Lake

Water quality data was collected for two in-lakes sites on June 8, July 13, and September 21. Based upon the collected data, dissolved oxygen and temperature profiles were created for sites 202 and 203. The dissolved oxygen concentrations in the water column are important for the fishery as well as they indicate the timing and potential for internal phosphorus loading from the lake bottom sediments. When DO levels decrease below about 1 mg/L the breakdown of organic bottom sediments by bacteria changes from aerobic (with oxygen) to anaerobic (without oxygen). Sediment bacteria have a significant role in uptake, storage and release of phosphorus including anaerobic release of iron-bound phosphorus. On June 8, 2013, the DO levels began to decrease at 7 meters for site 202, and the DO began to drop at a depth of 9 meters for site 203. On July 13, 2013, the DO levels dropped to 0.7 mg/L at a depth of 7 meters for site 202 and dropped to 0.6 mg/L at a depth of 7 meters at site 203. On September 21, 2013, the DO levels do not drop more than 1.24 mg/L for the total 10.25 meter depth at site 202. However, at Site 203, the DO dropped to 0.22 mg/L at a depth of 12 meters on September 21, 2014.

(Data sets and Graphs are found in Appendix C.)

Stream

Data was collected from stream site 515 and from the artesian well on June 8, July 13, and September 21, 2013. There was not enough data collected to generate any correlation between phosphorous, iron, and ground water. However, the isotope sampling did reveal significant results. Please see Isotope section below for additional details.

Shoreline

On July 13, 2013 two student volunteers (Hanna Rollin and Jennifer Soltys) walked portions of the shoreline in an attempt to locate groundwater inflowing through the aquatic sediment. One site was located and verified with a temperature probe. One other potential site was located, but not verified. The site was not able to be verified to do lack of proper equipment. No samples were collected due to a lack of the proper equipment. Samples could have been obtained using a groundwater extractor and pumping system.

Wetlands

The research into understanding the role that groundwater plays in the lake and watershed phosphorus dynamics includes collecting groundwater samples from the wetlands surrounding Tulaby Lake. To accomplish this, groundwater sources/springs in the wetlands needed to be found and small wells established in the springs for sample collection. Potential sites were located using wetlands and elevation maps generated in GIS. Crews then attempted to locate potential site on the ground. Potential sites were located on June 8 and July 13, 2013. The sites were tested and found to be in the inappropriate locations. On September 21, 2013 potential well sites were located, tested, and verified to be in the correct location. Only one useful data set of this system was generated for the summer and fall of 2013. With groundwater sources identified in the wetlands surrounding Tulaby Lake, future testing is expected to generate more useful data.

(Data sets are found in Appendix E.)

Isotope

Isotope samples were collected from the in-lakes sites 202, 203 (surface and deep samples); artesian well 515; and from stream 115 on June 8, July 13, and September 2013. Isotope samples were also taken from the preliminary wetland wells on June 8, July 13, and September 2013. However, only the September samples were retrieved from confirmed groundwater sources and able to be included in the analysis. The samples collected in 2013 were plotted alongside the isotope samples collected in 2011 and 2012. (Figure 5).

The isotope data collected over 3 years now provide a clear trend. The results show no trend with the deep confined groundwater. This water shifts to the right of left depending on the temperature of snow-melt at the time water recharged the aquifer. The data slope is -.086.

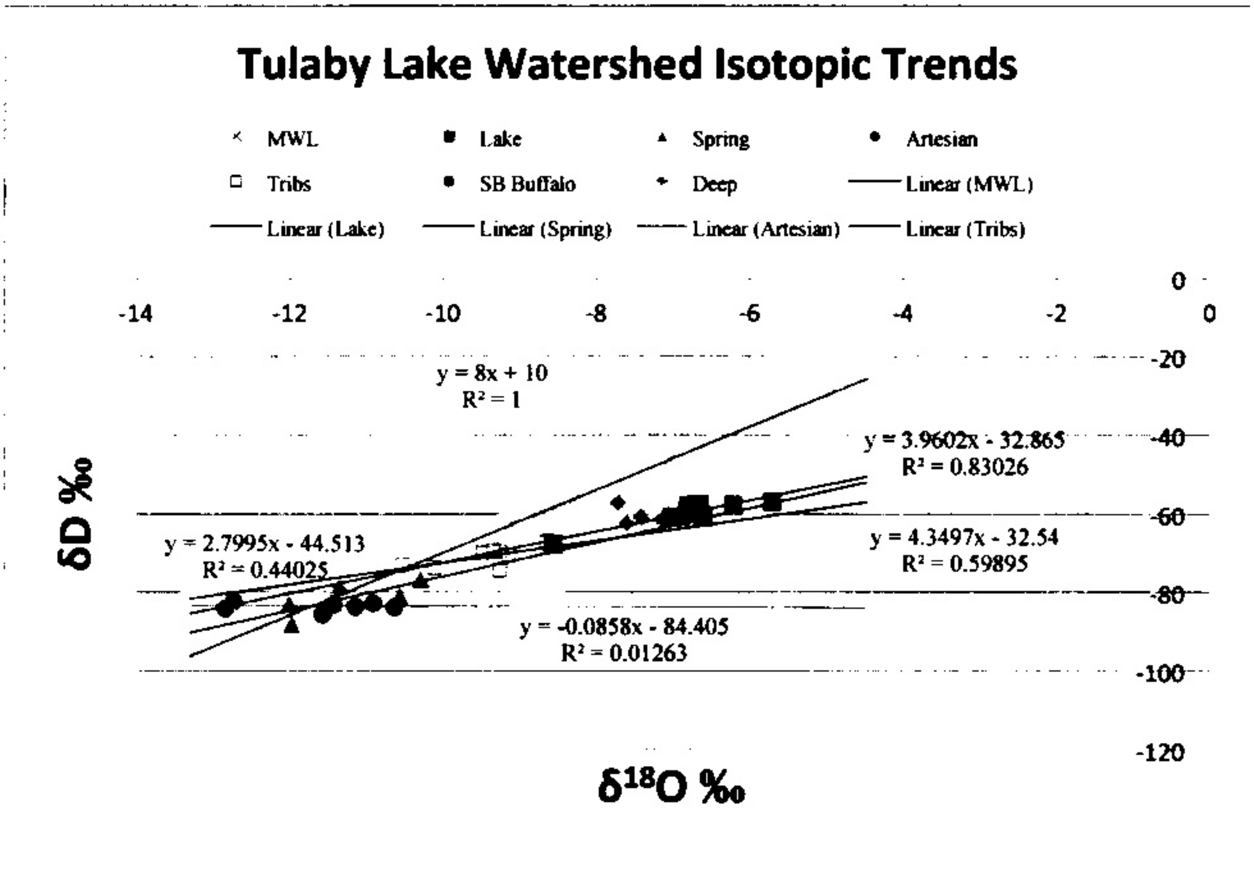

Figure 5. 2011, 2012, and 2013 Tulaby Lake Watershed Isotopic Trends

The lake water shows little influence from the deep groundwater. There is a trend linking upper-till spring discharge and tributary discharge to the lake. The spring water is contained below the ground surface and plots around the Meteoric Water Line (MWL) as shown by triangles. The tributary water plots above the spring data (to the right of the triangles) as shown by the open boxes between the lake water which plots off the MWL in closed boxes. The slopes and intercepts show similar patterns with reasonable R-squared values compared to the artesian water. Because the lake water (includes deep water samples) plots much further to the right with a tight R-squared (.83), the lake hydrology is not dominated by watershed inputs.

Mean hydraulic residence can then be calculated if the seasonal waters are considered in steady state and well mixed with an exponential distribution of residence time as:

$$\tau = \omega^{-1} [(A/B)^{2} - 1]^{1/2}$$

Where τ is the estimated hydraulic residence time, in days, ω the angular frequency of variation ($2\pi/365$ days) or (0.07172), A the input amplitude for precipitation and B the output amplitude reflected in the composite lake mean $\delta^{18}O$.

The lake hydraulic residence time (HRT) ranges from over one year, up to ten years with a mean average around 2-3 years depending on the input A values used in the equation above. If groundwater inflows comprised a larger portion of the in-lake $\delta^{18}O$ content then HRT would be more like 5-7 years. Given the relative heaviness of the lake $\delta^{18}O$, summer precipitation appears to be the strongest lake inflow.

Based on this information it appears that some combination of summer rain and internal loading of P is likely driving lake water quality. Because the lake has slowly degraded over time, atmospheric sources of P should be further investigated.

Lab Analysis

Water samples were collected through the spring, summer, and fall of 2013 from three different areas in an around Tulaby Lake. Samples were collected from in-lake sites 203 and 202, stream sites around the lake, the artesian well, and from the groundwater well sites within the surrounding wetlands. In-lake samples were analyzed for chlorophyll and phosphorous (as total P) for all of the sampling trips. Iron tests were not performed on every sampling date. The May 27, June 8, and July 13, 2014 samples were analyzed for orthophosphate (as dissolved P). The stream (site 115) and the flowing well samples were tested for iron, orthophosphate (as dissolved P), and phosphorous (as total P). On June 8 2013, the stream (site 115) and the flowing well were only tested for phosphorous (as total P). The wetlands were sampled for orthophosphate (as dissolved P) and phosphorous (as total P) on September 9, 2014 because the correct wetland sites were not able to be identified until this data was available. All of the samples were sent to RMB Labs in Detroit Lakes for analysis. (The complete date set can be found in Appendix F.)

The data was analyzed using a primary component analysis (PCA) and a total missing data analysis. The PCA suggested a possible relationship between orthophosphate and iron, orthophosphate and chlorophyll, phosphorous and iron, phosphorous and chlorophyll, and orthophosphate and phosphorous. The total missing data analysis indicated that orthophosphate was the only component with sufficient data for further analysis. (PCA and total missing data analysis results are found in Appendix F).

Conclusion and Recommendations

Analytical Findings

Based upon the PCA and total missing data analysis, additional data samples would be required to obtain an accurate correlations between iron, phosphorous (as total P), orthophosphate (as P dissolved), and chlorophyll a. The analysis suggests that consistent tests for each of these constituents should be taken at regular intervals. Continued testing at sites 202, 203, 115, 515, and at the newly identified wetland, which test for each constituent of concern on each trip, would enable the identification of relationships between constituents if any exist.

Isotope Analysis

The isotope analysis found that precipitation is the apparent driving force behind Tulaby Lake's phosphorous load. Groundwater interactions within the lake were not found to be substantial. While the 2011 and 2012 isotope analysis suggested that ground water was a key factor for lake volume, the combined 2011, 2012, and 2013 analysis did not confirm this assumption. Rather, the isotope sample from 2012 which had suggested a strong groundwater interaction was determined to either be an outlier or an erroneous sample. The complete isotope analysis from 2011, 2012, and 2013 found that precipitation rather than groundwater was the driving force behind Tulaby Lake's hydrology.

Precipitation Analysis

The annual precipitation data was compared to both the phosphorus and chlorophyll a concentrations found in Tulaby Lake. These comparisons can be viewed in Figures 6, 7, 8, and 9 under the Historic Data section. The analysis of phosphorous data found the phosphorus levels were highest during both the dry and wet conditions. The phosphorus was lowest during the moderately moist conditions. It is important to note that the dry conditions occurred during the period of spring runoff. This suggested that the phosphorus loading is coming from two main sources, spring snow melt and precipitation. Chlorophyll a levels were highest during the wet conditions. This suggests that precipitation is affecting the water quality for Tulaby Lake.

Land Use Analysis

The land use data analysis found that Tulaby Lake Watershed has lost approximately 45% of its wetlands from 1990 to 2000, however this information. This reduction of area wetlands is likely a contributor to increase runoff water finding its way into the streams and wetlands feeding into Tulaby Lake. If these wetlands were holding excess phosphorus, they could potential be a phosphorous source. This has not been verified, and may warrant further study. Tulaby Lake does not appear to be affected by any "man-made" sources of nutrients except for shoreline development or wetland loss according to the statement above.

Recommendations

Based on the limited isotope data analysis, precipitation appears to be the primary source of phosphorous coming into Tulaby Lake. It is recommended that the influx of phosphorous be compared to the precipitation for Tulaby Lake Watershed. It is our recommendation that precipitation from various rainfall events be collected and analyzed for phosphorous. It is also recommended that further testing of the adjacent wetlands continue. Wetland testing should continue in the area that was identified as a ground water source during the trip on September 21, 2013.

The analysis of trends or correlations between constituents such as iron, phosphorous (as total P), orthophosphate (as P dissolved), and chlorophyll a would benefit from continued testing at sites 202, 203, 115, 515, and at the newly identified wetland site.

The primary human impacts to Tulaby Lake appear to be accelerated nutrient export rates from shoreline development, flowing wells that discharge groundwater with relatively high phosphorus levels to the lake, and beaver dam removal that results in slugs of high phosphorus water entering the lake. Protecting natural shoreline and restoring developed (lawn) shoreline areas is a sound strategy for reducing phosphorus loading to the lake. Protecting wetland areas from filling or degradation should also be a priority for lake protection purposes. The disposal of lawn clippings, leaves and brush should not be done within wetland areas that contribute to the lake.

Literature Cited

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(5) Minnesota Department of Natrual Resources. 2013. Lake water level report: Tulaby. 18, January, 2014 <http://www.dnr.state.mn.us/lakefind/showlevel.html?id=44000300>.

(6) Soltys, J. & Paakh, B. 2013. Tulaby Lake In-Lake and Shoreline Water Monitoring Plan.

(7) Greve, M. & Rausch, R. 2013.

Appendix A

Total Precipitation (in) for Tamarac Wildlife Refuge (MN) USC00218191

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1977	M	M	M	M	M	3.31	2.98	M	7.9	2.83	4.09	0.66	*21.77
1978	0.16	0.21	0.35	2.13	2.46	3.33	3.93	1.23	3.54	0.51	0.95	0.36	19.16
1979	0.64	1.84	1.91	3.01	1.53	6.87	2.34	1.92	0.41	3.94	0.71	0.22	25.34
1980	1.17	0.81	M	T	0.34	3.45	3.13	M	2.88	2	0.49	0.29	*14.56
1981	0.17	M	0.83	1.4	0.6	5.91	5.7	4.22	2.23	4.02	0.47	0.66	*26.21
1982	0.84	0.58	1.66	0.77	5.14	1.57	6.33	2.11	1.38	4.25	0.18	0.28	25.09
1983	0.76	0.14	1.01	0.24	1.69	6.84	7.77	1.46	2.91	2.31	1.31	0.47	26.91
1984	0.3	0.55	0.45	1.66	0.86	6.85	1	1.55	1.61	6.75	0.2	0.83	22.61
1985	0.17	0.13	M	M	M	M	M	M	M	M	M	0.96	* 1.26
1986	1.55	M	M	4.43	2.23	2.18	4.44	2.77	5.58	M	M	M	*23.18
1987	M	M	0.99	T	4.78	1.23	M	2.46	M	0.86	M	0.98	*11.30
1988	1.86	0.09	0.72	0.06	1.12	1.17	2.88	4.1	2.65	0.59	0.76	1.12	17.12
1989	1.92	0.21	0.92	0.13	M	M	M	7.85	3.44	0.75	1.29	0.2	*16.71
1990	0.23	0.43	2.75	2.22	0.93	3.6	2.35	2.35	1.42	3.4	0	0.86	20.54
1991	0.52	1.32	1.45	4.31	2.93	3.28	3.38	1.64	3.2	1.29	0.78	0.64	24.74
1992	0.49	0.35	1.37	1.71	1.16	5.03	4.91	3.9	2.56	0.95	1.45	0.64	24.52
1993	2.03	0.1	0.49	2.44	3.97	6.17	13.27	3.18	1.52	0.57	1.98	0.55	36.27
1994	0.97	0.3	0.86	2.78	1.41	5.72	3.08	2.83	2.53	4.55	1.33	0.23	26.59
1995	0.92	0.51	1.06	0.24	2.02	1.25	4.37	5.42	2.14	3.42	0.66	0.85	22.86
1996	0.51	0.38	0.56	0.18	1.87	4.05	2.57	3.2	4.58	1.4	0.85	M	*20.15
1997	1.12	0.07	1.07	0.01	2.82	5.01	3.3	3.05	3.23	2.72	0.92	0.24	23.56
1998	0.4	0.32	0.88	0.55	4.17	7.76	3.52	1.87	3.37	4.8	1.25	0.53	29.42
1999	0.82	0.13	1.06	0.77	4.49	3.27	4.01	5.25	3.48	1.47	0	0.04	24.79
2000	0.07	0.28	1.27	0.73	3.21	5.34	2.1	M	1.59	3.99	M	0.8	*19.38
2001	0.29	1.13	0.03	1.58	3.81	2.53	2.87	2.2	2.58	2.84	0.21	0.19	20.26
2002	0.03	0.01	0.44	1.33	1.82	5.45	3.81	2.6	2.12	1.35	0.78	0.17	19.91
2003	0.17	0.05	0.24	0.99	3.03	6.56	1.69	0.36	1.65	1.02	0.21	0.29	16.26
2004	0.97	0.55	1.7	0.22	5.91	1.84	2.04	1.8	8.24	3.55	0.83	0.35	28
2005	1.17	0.18	0.06	1.61	3.94	6.23	M	3.29	2.08	1.97	2.2	0.72	*23.45
2006	0.18	1.19	1.41	M	3.09	2.57	1.93	3.45	4.69	0.99	0.01	0.81	*20.32
2007	0.03	1.16	0.41	2.62	4.4	4.85	2.5	2.13	2.54	3.49	0.13	1.27	25.53
2008	0.03	0.5	0.73	2.18	1.04	5.28	1.27	1.65	3.23	5.55	0.89	0.99	23.34
2009	0.14	0.73	3.95	1.21	1.76	4.51	2.92	2.72	2.09	4.32	1.03	0.68	26.06
2010	1.08	0.59	0.75	1.68	2.61	3.15	8.26	4.03	4.21	2.75	0.42	0.58	30.11
2011	0.66	0.27	1.38	M	0.51	2.5	2.54	2.07	0.72	M	M	M	*10.65
2012	0.26	0.49	1.62	2.82	2.41	3.51	4.68	1.51	0.31	2.49	M	M	*20.10
2013	1.33	0.13	1.77	1.62	4.79	3.59	2.18	0.5	3.44	M	M	M	*19.35
2014	M	M	M	M	M	M	M	M	M	M	M	M	M

Count:	**35**	**33**	**33**	**33**	**34**	**35**	**33**	**33**	**35**	**33**	**30**	**32**
Average:	0.68	0.48	1.1	1.44	2.61	4.16	3.76	2.75	2.92	2.66	0.88	0.58
Median:	0.52	0.35	0.99	1.4	2.44	3.6	3.08	2.46	2.58	2.72	0.78	0.61
Low Value:	0.03	0.01	0.03	0	0.34	1.17	1	0.36	0.31	0.51	0	0.04
High Value:	2.03	1.84	3.95	4.43	5.91	7.76	13.27	7.85	8.24	6.75	4.09	1.27

M = Missing
T = Trace
* The annual data is incomplete. and not used for the calculation of the summary statistics.

Table 2. Total Precipitation (in) for Tamarac Wildlife Refuge (MN) USC00218191

Annual Mean Temperature (F) for for Tamarac Wildlife Refuge (MN) USC00218191

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**	**Annual**
1977	M	M	M	M	M	63.9	69.3	M	56.7	45.8	25.4	7.1	44.7	* 44.7
1978	0.1	5.9	24	41.1	59	61.6	65.9	66.4	59.8	44.9	22.5	6	38.1	38.1
1979	-4.6	0.2	22.1	34	47.1	61.1	66.5	62.1	57.5	41.4	26.2	20.5	36.2	36.2
1980	5.3	8.2	M	46.5	62.9	63	68.1	M	54.5	42.6	32.2	12.4	39.6	* 39.6
1981	12.1	19.1	32.6	44.4	53.5	62.3	68.2	67.5	56.7	43.8	36.8	13.7	42.6	42.6
1982	-8.6	10.8	19.4	37.4	58.2	58.9	69.2	65.3	55.5	46	23.9	18.4	37.9	37.9
1983	13	20.7	29.4	40.6	52.1	63.4	71.5	71.3	57.1	44.6	29.7	-2.4	40.9	40.9
1984	6.6	23.3	21.2	45.4	53.8	65.1	69	70.6	51.9	48.6	28.3	10.4	41.2	41.2
1985	5.9	9	M	M	M	M	M	M	M	M	M	0.8	5.2	* 5.2
1986	14.5	M	31.5	44.7	56.5	66.1	69.9	63.1	55.1	M	M	M	50.2	* 50.2
1987	M	M	32.1	50.4	60.3	67.5	M	64.6	M	41.1	M	21.2	48.2	* 48.2
1988	0.9	3.8	26.3	43.5	62.3	70.1	73.3	68.9	59.9	43.2	28.1	12.8	41.1	41.1
1989	11.2	0.9	13.5	42.9	M	M	M	69.6	57.5	44.3	21.9	-2.6	28.8	* 28.8
1990	20.6	17.5	29.7	39.8	52.9	65.9	67.3	68.4	62.1	44.7	32.9	8.3	42.5	42.5
1991	3.4	17.5	28.9	45	59.2	68.1	67.7	70	55.9	41.7	23.1	16.5	41.4	41.4
1992	16.5	20.9	29.4	38.5	58.4	61.2	61.8	62.7	55.7	45.7	26.4	11.8	40.8	40.8
1993	8.7	9.8	26.7	41.8	55.5	60.5	65.3	66.9	50.3	42	22.5	13.3	38.6	38.6
1994	-7.8	-1	25.5	40.5	56	64.5	64.9	63.3	59.1	48.4	32.8	19.8	38.8	38.8
1995	7.9	6.7	25.9	35.5	51.7	68.3	65.3	68	55.8	43.1	18.8	M	40.6	* 40.6
1996	-3.9	6	13	33.6	50.9	64.5	65.7	68	57.1	42.9	16.5	M	37.7	* 37.7
1997	0.8	11.8	20.5	33.5	47.7	66.2	67.2	64.2	59.3	44.4	21.1	22.4	38.3	38.2
1998	10.5	26.1	24.7	44.6	59.1	61	68.2	68.2	62.1	45.5	29.8	18.2	43.2	43.2
1999	3	18.4	27.4	44.3	54.3	63.6	69.7	66.3	53.9	41.2	37.5	19.9	41.6	41.6
2000	6	19.7	31.6	41.2	55.4	60.6	66.9	M	55.7	47	M	-1	38.3	* 38.3
2001	13.1	1.4	22.4	38.3	M	64.9	68.1	69.1	56.8	43.6	38.9	23.1	40	* 40.0
2002	M	20.2	15.2	35.9	47.9	64.7	69.6	66	60	35.8	25.4	18.3	41.7	* 41.7
2003	6.5	4.8	19.4	43.4	54.4	62.6	67.6	70.5	56.6	47.7	22.2	15	39.2	39.2
2004	-0.3	9.5	26.6	44	49.7	58.5	65.7	61	61.1	44.5	34.9	15.9	39.3	39.3
2005	4.8	16.3	22.4	46.5	51.7	M	70.9	65.1	60.2	46.9	31.4	14.5	39.2	* 39.1
2006	21.7	8.6	27.5	47.3	56.6	64.6	72.3	67.1	55.4	41.3	31	22.4	43	43
2007	13.6	6.5	29.3	39	57.9	66.3	70.8	65.8	59.7	47.4	30.6	10.7	41.5	41.5
2008	5.4	7.2	21.3	37.7	52	61.2	68.2	67.4	57.8	44.7	30.3	2.7	38	38
2009	-1.2	9.1	21.3	39	51.5	61.1	63.7	63.2	62.1	38.3	37	10.6	38	38
2010	6	9.2	32.9	50.5	53.3	63.8	70.8	70.2	54.7	49.4	M	11.2	42.9	* 42.9
2011	5.2	7.6	20.3	40.8	54.5	62.2	72.7	69.5	58.3	M	M	M	43.5	* 43.5
2012	M	19.3	37.5	44.8	57.5	66	73.8	68	55.6	42.2	M	M	51.6	* 51.6
2013	10.8	8	13.7	29.6	53.5	62.9	71	67.1	61	M	M	M	42	* 41.9
2014	M	M	M	M	M	M	M	M	M	M	M	M	M	M

Count:	**33**	**34**	**34**	**35**	**33**	**34**	**34**	**33**	**35**	**33**	**29**	**31**
Average:	6.3	11.26	24.86	41.32	54.75	63.72	68.41	66.83	57.39	44.08	28.22	12.64
Median:	6	9.14	25.7	41.24	54.35	63.69	68.2	67.11	57.05	44.39	28.32	13.33
Low Value:	-8.59	-1.03	13.05	29.61	47.14	58.48	61.84	60.98	50.27	35.83	16.52	-2.62
High Value:	21.71	26.05	37.45	50.48	62.85	70.12	73.75	71.31	62.13	49.38	38.93	23.15

M = Missing
T = Trace
* The annual data is incomplete, and not used for the calculation of the summary statistics.

Table 3. Annual Mean Temperature (F) for for Tamarac Wildlife Refuge (MN) USC00218191

Appendix B

Methodology

Water quality Sonde readings and samples are taken at two locations. The first site, site 202 is about 35 feet deep or 10.5 meters and is the deep centrally located site in the lake. This site is considered the primary site for water quality condition monitoring in Tulaby Lake.

The second site (site 203) is at 13 meters deep and is the deepest spot in the lake located near the north end of the lake. This site is used for monitoring internal loading and deep oxygen levels that can signal when internal loading begins to take place. The site is located across from a white cabin on a bluff between two reddish-brown cabins.

Surface (0 to 2 meter integrated) and deep grab samples (about 1 to 2 feet off the bottom) are taken at each site. To distinguish between surface samples and bottom samples, a D is written after the site number for the deep water samples. Samples are for isotopes, reactive phosphorous, total phosphorous, ferrous iron, and water clarity with a Secchi disk. In addition, a YSI water quality sonde is used to collect a dissolved oxygen/temperature profile at each site and conductivity and pH are also recorded.

In-Lake Site Sampling

1. Locate the site of interest.
    a. Special care should be taken to locate each of the site of interest before beginning sampling.
    b. The site is located with a depth find on the pontoon.
2. Carefully place the anchor upwind from the site.
    a. At each site location, the pontoon is carefully anchored upwind of the site to prevent any disturbance of the sample water by the anchor.
3. Take Secchi disk measurement.
    a. The Secchi Disk is lowered until it disappears and the depth is noted. Then the disk is pulled upward until it reappears. The average of the disappearance and reappearance depths is the Secchi depth.
4. Obtain 0 to 2 meter integrated water sample
    a. Triple rinse the integrated sampler with lake water at the site away from where you intend to collect the sample.
    b. Remove the stoppers from both ends of the integrated sampler and lower it verticlally into the water column until it is nearly submerged.
    c. Insert the top stopper and raised the sampler up and immediately insert the lower end into the chlorophyll bottle.
    d. Mix the sample in the chlorophyll bottle and pour off other samples from this bottle. Dump out the remaining water in the chlorophyll bottle and resample to fill it.

    e. Store the samples which are not being tested right away in a cooler with a cold packs or ice. Add the nitric acid preservative to the Fe sample and sulfuric to the TP samples.
5. Obtain deep grab samples.
    a. A Van Dorn sampler is used to take water samples approximately one to two feet off of the bottom at each site. Care must be taken to not disturb the bottom sediments with the sampler as this can greatly impact the sample results.
        i. Collect the sample with the Van Dorn sampler and transfer the samples to the appropriate container.
        ii. Store the samples which are not being tested right away in a cooler with a cold pack. Add the nitric acid preservative to the appropriate samples.
6. Take YSI water quality Sonde measurements.
    a. The YSI Water Quality Sonde instrument is used to test for temperature, DO, pH, conductivity, and turbidity. The Sonde is carefully lowered to take the first reading of the surface water. It is important to wait until the reading on the screen stabilizes. The results should then be recorded. Subsequent readings are taken in one meter increments to the bottom. The final reading should be taken at approximately one to two feet from the bottom.
7. Test for iron and phosphorus using the Hach field chemistry set.
8. Obtain water sample for isotope testing
    a. Sample should be kept in the small bottles and labeled appropriately.

Shoreline Sampling

1. Possible sites of groundwater infiltration in to the lake are identified.
    a. There will be a slight change in color of the aquatic soil along the shore. The soil will change from a normal coloring to having a reddish tint. This may indicate an area of infiltrating ground water.
2. The temperature probe is used to compare the temperature of the surface water to the temperature approximately few feet under the aquatic soil.
    a. Areas where the groundwater is infiltrating will have a greater temperature difference.
3. Use the groundwater sampler to access the ground water.
    a. The groundwater sampler has a pounder used to insert the sampler into the soil.
    b. Once the groundwater sampler is at an appropriate depth, gently use the pounder to back out the sampler slightly.
        i. This will open up the groundwater sample's filter and allow a sample to be obtained.
    c. Connect the ground water to the small sub-pump.
        i. The sub-pump will need to be connected to a battery.
        ii. Allow the first portion of the sample to rinse out the tubing.
        iii. Collect the sample in the appropriate container.
        iv. Store the samples which are not being tested right away in a cooler with a cold pack. Add the nitric acid preservative to the appropriate samples.

Artesian Well and Stream Sampling

1. Obtain a water sample from the artesian well.
    a. The well is located near the outlet of the small stream that flows into Tulaby Lake. The shoreline of the area has been reddened by iron from the well. The area has a line of reddened rocks near a dock.
        i. Take caution when near the dock. There is a pipe which extends underwater near the front of the dock.
    b. Insert the sample bottle into the flowing well. Rinse a few times and collect the sample.
        i. Store the samples which are not being tested right away in a cooler with a cold pack. Add the nitric acid preservative to the appropriate samples.
2. Obtain a sample from the stream.
    a. The stream flows into Tulaby Lake in an area of the shoreline which has been reddened by iron from the flowing artesian well. The area has a line of reddened rocks near a dock.
    b. The sample areas for the stream are on either side of the culvert which passes under a driveway.
    c. The sampling container is placed upside down at the sample site.
    d. Invert the container underwater.
    e. Cap the sample under water.
    f. Place the samples in a cooler with cold packs. Samples which are being lab-tested for ferrous iron and not being tested immediately with the Hach field chemistry set need to be preserved with sulfuric acid.

Sampling

Surface Sample

Water samples are taken from the surface to test for isotopes and reactive phosphorous. The sampling container is placed upside down at the sample site. The container is then inverted underwater. The sample is then capped under water. The sample is then placed in a cooler with cold packs. Samples which are being lab-tested for ferrous iron and not being tested immediately with the Hach field chemistry set need to be preserved with sulfuric acid.

Deep Water Samples

A Van Dorn sampler is used to take water samples approximately one to two feet off of the bottom at each site. Care must be taken to not disturb the bottom sediments with the sampler as this can greatly impact the sample results. The sample is then placed in a cooler with cold packs. Samples which are being lab-tested for ferrous iron and not being tested immediately with the Hach field chemistry set need to be preserved with nitric acid.

Integrated Samples

The integrated sample is used to collect a surface sample from zero to two meters. The sample is poured into a chlorophyll bottle. The sample is then placed in a cooler with cold packs. Samples which are being lab-tested for ferrous iron and not being tested immediately with the Hach field chemistry set need to be preserved with sulfuric acid.

Isotope Testing

Water samples are taken from approximately one to two feet off of the bottom and at the surface to test for isotopes. The water does not require preservatives or need to be temperature controlled for this test.

Isotope samples will also be taken from the uncapped artesian well near the outlet of the small stream where the pipe and surroundings rocks are orange. Isotope samples will also be taken from the wetland that flows into the lake.

Phosphorus Testing

Water samples are taken from about one to two feet off of the bottom and at the surface to test for Reactive Phosphorous. The Hach field chemistry set is used for this test (Hach Company, 2013).

1. Enter the stored program number for the reactive phosphorous, ascorbic method on the DR/890 Colorimeter.
    -Press PRGM ?
    - Press 79 Enter
        - The display will show mg/L, PO4, and the ZERO icon.
2. Fill a sample cell with 10 mL of water sample for the blank.
3. Place the blank sample into the cell holder. Tightly cover the water sample cell with the instrument cap.
    - Press ZERO
        - Wait until the screen shows 0.00 mg/L PO4
4. Fill another sample call with 10 mL of sample water.
5. Add the contents of on PhosVer3 Phosphate Powder Pillow and shake for 15 seconds.
6. Press: TIMER ENTER
    - A two-minute reaction time will begin
7. After the timer beeps, place prepared sample into the cell holder. Tightly cover with the instrument cap.
8. Press READ
    - The screen will display results in mg/L (PO4^3-).

Iron Testing

Water samples are taken from about one to two feet off of the bottom and at the surface to test for Ferrous Iron. The Hach field chemistry set is used for this test (Hach Company, 2013).

1. Enter the stored program number for Ferrous iron (Fe^2+)- powder pillows on the DR/890 Colorimeter.
    -Press PRGM ?

- Press 33 Enter
    - The display will show mg/L, Fe, and the ZERO icon.

2. Press ZERO
    - Wait until the screen shows 0.00 mg/L Fe
3. Fill another sample call with another 25 mL of sample water.
4. Add the contents of on Ferrous Iron Reagent Powder Pillow and shake for 15 seconds.
5. Press: TIMER ENTER
    - A three-minute reaction time will begin
6. After the timer beeps, place prepared sample into the cell holder. Tightly cover with the instrument cap.
8. Press READ
    - The screen will display results of ferrous iron in mg/L.

Monitoring Schedule

Lake Monitoring

1 - Total Phosphorus (TP) & Chlorophyll a   Twice per month at Site 202

2 - Secchi Disk   Weekly at Site 202

3 - TP, Cond, Temp, DO, pH After rain events of ¾" and following long dry periods the mini well inlet and GW sites in lake. (To be established.)

Stream & Flowing Well Monitoring

4 - T –Tube, Cond, Temp, DO, pH   After rain events of ¾" and following long dry periods at established sites

5 - Total Phosphorus during heavy rain events > 1" at established sites

6 - Isotopes   After rain events and following long dry periods at established sites

MPCA – will conduct items 3 and 6 including both sampling and analyses.

Tulaby Lake Association – will conduct items 1, 2, 4 and 5.

Appendix C

In-Lake and Shoreline Field Data Spring and Fall of 2013

Artesian Well and Stream

Date	Time	Site	Name	Temp (°C)	Con (mS/cm^3)	pH	DO (mg/L)	Turbidity (NTU)
7/13/2013	12:02 PM	115	Flowing Well	6.35	0.576	7.46	4.71	n/a
7/14/2013	12:05 PM	515	Stream	18.39	0.599	7.85	7.5	n/a
9/21/2013	1:22 PM	115	Flowing Well	6.39	557	7.01	0.28	n/a
9/21/2013	12:05 PM	515	Stream					n/a

Table 4. Table artesian well and stream

In-Lake Sample Data for Sites 202 and 203

Date (2013)	Site	Bottom Depth (m)	Depth (m)	Temp (°C)	Con (mS/cm^3)	pH	DO (mg/L)	Turbidity (NTU)
18-Jun	202	10.6	sfc	14.53	327	8.48	11	1.5
			1	14.54	327	8.52	11.12	1.4
			2	14.51	327	8.52	11.21-11.22	1.6-1.7
			3	14.49	327	8.52	11.23-11.25	1.5-1.6
			4	14.47	327	8.54	11.24	1.6
			5	14.44	327	8.55	11.2	1.5
			6	14.4	328	8.55	11.12	1.7
			7	14.06	330	8.48	9.81	1.8
			8	13.66	332	8.37	8.9	1.7
			9	13.27	336	8.25	6.73	2.4
			10	13.19	336	8.14	5.49	2.9
			11	12.52	341	7.96	2.48	4.7
18-Jun	202	13.5	sfc	14.79	326	8.47	11.32	1.4
			1	14.76	327	8.46	11.47	1.7
			2	14.75	326	8.46	11.51	1.5
			3	14.76	326	8.47	11.51	1.5
			4	14.68	327	8.48	11.47	1.5
			5	14.68	327	8.49	11.45	1.6
			6	14.68	327	8.51	11.42	2
			7	14.63	327	8.51	11.35	1.6
			8	14.62	327	8.52	11.28	1.7

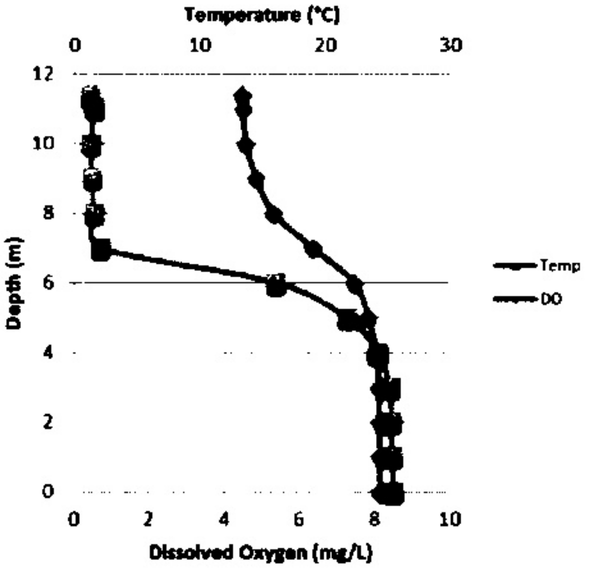
Date (2013)	Site	Bottom Depth (m)	Depth (m)	Temp (°C)	Con (mS/cm^3)	pH	DO (mg/L)	Turbidity (NTU)
			9	13.66	332	8.36	8.84	1.9
			10	13.41	333	8.19	6.84	2.2
			11	13.22	335	8.07	5.32	2.2
			12	12.8	338	7.99	4.28	2.5
			13	12.62	340	7.86	2.12	2.9
13-Jul	202	10.6	sfc	24.46	328	8.63	8.51	n/a
			1	24.45	328	8.62	8.47	n/a
			2	24.4	328	8.62	8.45	n/a
			3	24.34	328	8.62	8.41	n/a
			4	24.17	329	8.57	8.09	n/a
			5	23.49	334	8.47	7.25	n/a
			6	22.33	343	8.23	5.37	n/a
			7	19.04	352	7.75	0.7	n/a
			8	15.88	356	7.66	0.53	n/a
			9	14.53	364	7.61	0.48	n/a
			10	13.71	372	7.58	0.45	n/a
			11	13.47	377	7.57	0.53	n/a
			11.4	13.42	378	7.54	0.41	n/a
13-Jul	203	14	sfc	24.44	329	8.62	8.36	n/a
			1	24.44	329	8.62	8.42	n/a
			2	24.4	330	8.61	8.37	n/a
			3	24.26	330	8.59	8.07	n/a
			4	24.15	332	8.54	7.68	n/a
			5	23.87	333	8.51	7.34	n/a
			6	22.64	341	8.29	5.57	n/a
			7	18.1	354	7.69	0.6	n/a
			8	15.88	355	7.64	0.5	n/a
			9	14.53	362	7.62	0.46	n/a
			10	13.92	367	7.61	0.44	n/a
			11	13.72	371	7.6	0.42	n/a
			12	13.41	377	7.58	0.42	n/a
			13	13.38	378	7.58	0.41	n/a
			13.6	13.38	378	7.53	0.41	n/a
21-Sep	202	10.5	sfc	17.57	298	8.34	7.76	n/a
			1	17.64	298	8.35	7.76	n/a
			2	17.54	298	8.31	7.6	n/a
			3	17.48	298	8.28	7.31	n/a
			4	17.46	298	8.26	7.17	n/a
			5	17.44	298	8.26	7.19	n/a
			6	17.39	298	8.24	7.2	n/a
			7	17.31	298	8.25	7.2	n/a
			8	17.28	299	8.24	7.13	n/a
			9	17.27	299	8.23	7.03	n/a
			10	17.25	300	8.2	6.88	n/a
			10.25	17.23	300	8.12	6.52	n/a

Date (2013)	Site	Bottom Depth (m)	Depth (m)	Temp (°C)	Con (mS/cm^3)	pH	DO (mg/L)	Turbidity (NTU)
21-Sep	203	13-14.5	sfc	17.46	297	8.38	7.57	n/a
			1	17.53	298	8.39	7.53	n/a
			2	17.55	298	8.39	7.48	n/a
			3	17.55	298	8.39	7.46	n/a
			4	17.55	298	8.38	7.42	n/a
			5	17.55	298	8.38	7.37	n/a
			6	17.55	298	8.35	7.35	n/a
			7	17.54	298	8.34	7.35	n/a
			8	17.54	298	8.33	7.31	n/a
			9	17.54	298	8.32	7.25	n/a
			10	17.42	305	8.11	5.75	n/a
			11	17.17	324	7.76	2.9	n/a
			12	16.06	400	7.26	0.22	n/a
			13	15.47	419	7.19	0.21	n/a
			14	14.49	419	7.15	0.15	n/a
			14.5	15.32	425	7.15	0.12	n/a

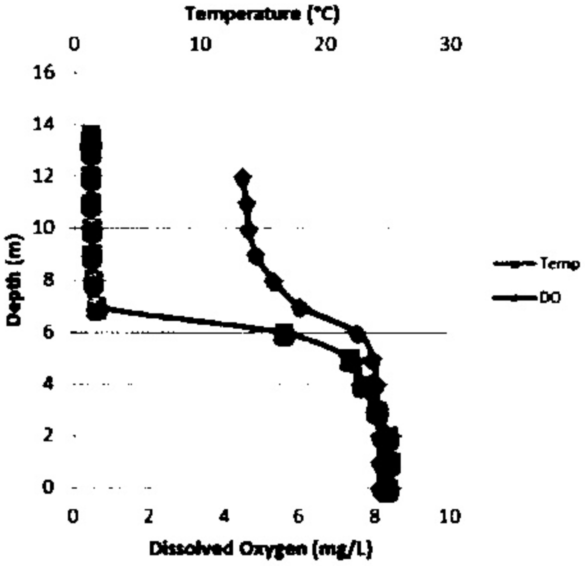
Table 5. In-Lake sample data for sites 202 and 203

Dissolved Oxygen Profiles

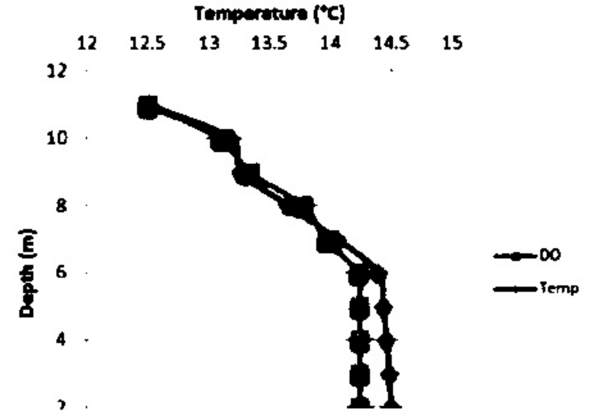
July 13, 2013 Dissolved Oxygen and Temperature Profile for Site 202



July 13, 2013 Dissolved Oxygen and Temperature Profile for Site 203



June 8, 2013 Dissolved Oxygen and Temperature Profile for Site 202



Sept 21, 2013 Dissolved Oxygen and Temperature Profile for Site 203

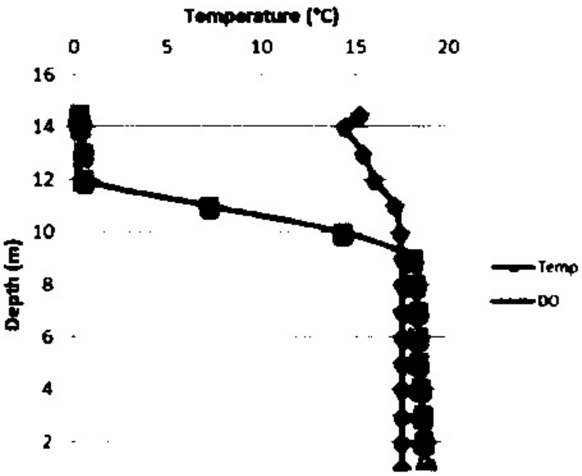


Figure 6. June 8, 2013 Dissolved oxygen profile for **A)** Site 202 & **B)** Site 203

Appendix D

Outline of the Wetland and Shoreline Monitoring Plans

Mark Greve and Rachel Rausch

Wetland Monitoring Plan:

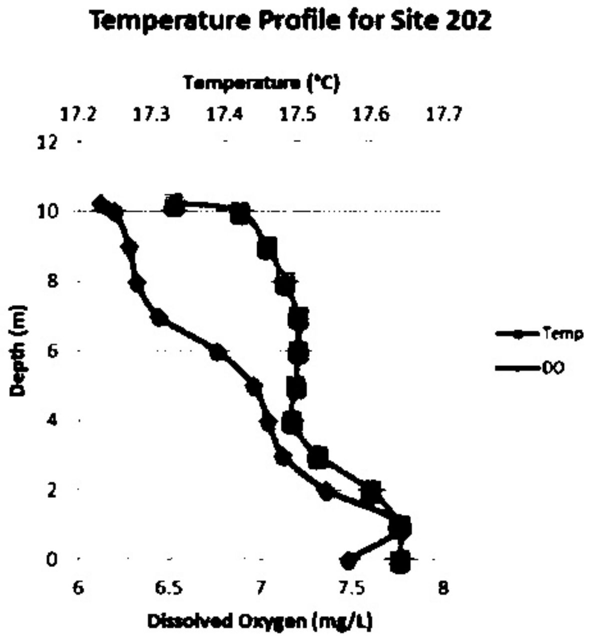
- **Locate Groundwater inlets**

  This method was described by Dr. Magner and involved hiking up the main branch of the stream that drains the wetland. Tributaries to this main branch were located and followed to their source, which is most likely a groundwater inflow point.

  Goals:
  - Walk up tributary or tributaries, find source(s)
  - Install the PVC wells using augers
  - Allow wells to equilibrate for a few hours then take temperature, depth, specific conductance, and dissolved oxygen readings. Also evacuate the well using a peristaltic pump and determine the flow rate into the well by timing the refill.

Locating these groundwater inlets using the easily collected temperature and specific

Figure 8. September 21, 2013 Dissolved oxygen profile for **A)** Site 202 & **B)** Site 203



For the July monitoring trip, 4 new wells were installed in a second wetland at spots of potential groundwater inflow.

- **Checked and relocated existing wells**
  - No evidence that initial placement was in groundwater
- **Explored a second wetland and added 4 wells**
  - Locations were chosen based on rust stains from upwelling groundwater
  - Due to time constraints, minimal data was collected in July
  - Data was collected for an initial conductivity, temperature, and dissolved oxygen readings both inside and outside the wells
  - Data collection was repeated in September. Initial measurements were taken and well was pumped dry, with some of the water being saved for testing. The wells were allowed to recharge and sample and data collection was again repeated.

- **Grabbed water samples along a second tributary to create a sample profile**

Appendix E

Wetland Field Data Spring and Fall of 2013

Well 1

Date	8-Jun
Total Well Depth (ft)	7.04
Start Time :	12:20 PM
End Time:	4:22 PM
Depth of Inner (ft):	4.75
Depth of Outer (ft):	2.85

Surface	
Temperature (°C)	16.4
Sp. C (µS/cm)	0.349
DO (mg/L)	3.51

Surface (2)	
Temperature (°C)	13.9
Sp. C (µS/cm)	0.37
DO (mg/L)	1.33

In Well	
Temperature (°C)	10.6
Sp. C (µS/cm)	0.365
DO (mg/L)	~0

Table 6 June 8, 2013 date for Well 1

Well 2

Date	8-Jun
Total Well Depth (ft)	7.04
Surface Depth (ft):	1.13
Start Time :	12:44 PM
End Time:	4:26 PM
Depth of Inner (ft):	5
Depth of Outer (ft):	4.85

Surface	
Temperature (°C)	13
Sp. C (µS/cm)	0.3334
DO (mg/L)	<1

Surface (2)	
Temperature (°C)	11
Sp. C (µS/cm)	
DO (mg/L)	

In Well	
Temperature (°C)	7.5-8.2
Sp. C (µS/cm)	0.382
DO (mg/L)	<1

Table 7. June 8, 2013 date for Well 2

*Note - It was determined that Well 1 and Well 2 were likely placed in the wrong locations. New wells were located for subsequent trips.

Appendix F

2013 Lab Analysis for Tulaby Lake from RMB Environmental Laboratories, Inc.

Lab Code (ID)	*Description*	*Date*	*Time*	*Chlorophyll A*	*Iron*	*Orthophosphate, as P (dissolved)*	*Phosphorus, Total as P*
200430	**515 well**	**7/13/2013**	**1202**		**4.70**	**0.01**	**0.25**
206779	115 Flowing Well	9/21/2013	1322		4.60	0.01	0.26
197146	**515 WELL**	**6/8/2013**	**1646**				**0.25**
200429	115 stream	7/13/2013	1205		0.82	0.03	0.06
197145	**115 STREAM**	**6/8/2013**	**1646**				**0.02**
198202	Stream 115c	6/18/2013	623		0.41	0.03	0.02
198201	**Nelson Well**	**6/18/2013**	**624**		**6.20**	**0.01**	**0.19**
193928	Tulaby 202 S	5/2/2013	1105			0.01	0.02
195859	**44-0003-00-202 TULABY**	**5/27/2013**	**930**	**17**			**0.03**
195857	44-0003-00-202 Tulaby	5/27/2013	1000				0.03
197140	**Tulaby 202**	**6/8/2013**	**1030**	**11**		**0.00**	**0.03**
198678	44-0003-00-202 TULABY	6/23/2013	1300	5			0.03
199520	**44-0003-00-202 TULABY**	**6/30/2013**	**1600**	**6**			**0.02**
200427	44-0003-00	7/13/2013	1000		1.30	0.03	0.17
200426	**44-0003-00-202 TULABY**	**7/13/2013**	**1000**	**6**			**0.02**
201979	44-0003-00-202 TULABY	7/28/2013	1400	5			0.02
201980	**44-0003-00-202 TULABY**	**7/28/2013**	**1400**				**0.49**
203212	44-0003-00-202 TULABY	8/11/2013	1415	8			0.02
203217	**44-0003-00-202 Tulaby**	**8/11/2013**	**1415**				**0.20**
204545	44-0003-00-202	8/25/2013	1400				0.38
204544	**44-0003-00-202 TULABY**	**8/25/2013**	**1400**	**10**			**0.02**
206792	44-0003-00-202 TULABY	9/21/2013	1135	13			

206782	44-0003-00-202 TULABY	9/21/2013	1140				0.03
193929	Tulaby 202 9m	5/2/2013	1115			0.01	0.02
193930	Tulaby 202 B	5/2/2013	1110			0.01	0.02
197141	202 D	6/8/2013	1035		0.18	0.00	0.04
199518	44-0003-00-202 Tulaby 33ft	6/30/2013	1500				0.11
206783	Tulaby 202 D	9/21/2013	1140		0.16	0.00	0.03

Lab Code (ID)	*Description*	*Date*	*Time*	*Chlorophyll A*	*Iron*	*Orthophosphate, as P (dissolved)*	*Phosphorus, Total as P*
197142	Z MAX	6/8/2013	1115			0.00	0.02
206780	Tulaby 203 (z max)	9/21/2013	1020	14		0.00	0.03
197143	Z MAX D	6/8/2013	1115		0.10	0.00	0.03
197144	Z MAX D SPLIT	6/8/2013	1115				0.01
200428	203 D	7/13/2013	1055		2.20	0.02	0.29
206781	Tulaby 203 D	9/21/2013	1020		6.80	0.01	0.47
200431	Spring By Public Landing	7/13/2013	1540		0.03	0.02	0.02
206768	One Wetland 1	9/21/2013	1021			0.12	0.19
206788	Three Wetland 1	9/21/2013	1021			0.03	0.03
206774	Seven - Wetland 1	9/21/2013	1104			0.02	0.02
206784	Six Wetland 1	9/21/2013	1049			0.02	0.03
206789	Eight Wetland 1	9/21/2013	1137			0.04	0.39
206787	Five Wetland 1	9/21/2013	1036			0.03	0.04
206786	Four Wetland 1	9/21/2013	1027			0.03	0.04
206785	Two Wetland 1	9/21/2013	1017			0.04	0.04
206771	Well 1 Wetland 2	9/21/2013	1014			0.03	1.88
206773	Wetland 2 Above B. Dam	9/21/2013	1049			0.01	0.07
206791	Wetland 2 Instream	9/21/2013	1055			0.02	0.57
206769	Wetland 2 W	9/21/2013	1036			0.03	
206775	Wetland 2 Well 1 Sample 2	9/21/2013	1334			0.03	2.43
206770	Wetland 2 Well 2	9/21/2013	1028			0.01	4.99
206772	Wetland 2 Well 2	9/21/2013	1045			0.11	0.28
206778	Wetland 2 Well 2 Sample 2	9/21/2013	1342			0.02	3.74
206777	Wetland 2 Well 3 Sample 2	9/21/2013	1356			0.07	4.16

206790	**Wetland 2 Well 4**	**9/21/2013**	**1036**			**2.55**
206776	Wetland 2 Well 4 Sample 2	9/21/2013	1349		0.03	1.79
197147	**Z MAX SEDIMENT**	**8/13/2014**	**1145**	**18000**		

Table 8. 2013 Lab analysis data for Tulaby Lake (1)

Variable	*Observations*	*Obs. with missing data*	*Obs. without missing data*	*Minimum*	*Maximum*	*Mean*	*Std. deviation*
Sampled Date	**63**	**0**	**63**	**41396.000**	**41538.000**	**41490.704**	**46.224**
Chlorophyll A	63	0	63	5.000	17.000	9.445	2.178
Iron	**63**	**0**	**63**	**-0.660**	**6.800**	**2.336**	**1.444**
Orthophosphate, as P (dissolved)	63	0	63	0.002	0.116	0.025	0.021
Phosphorus, Total as P	**63**	**0**	**63**	**-0.427**	**4.990**	**0.491**	**1.040**

Table 9. 2013 missing data analysis of Tulaby Lake water samples

Variables	*Chlorophyll A*	*Iron*	*Orthophosphate, as P (dissolved)*	*Phosphorus, Total as P*
Chlorophyll A	**1**	**0.000**	**-0.064**	**0.018**
Iron	0.000	1	-0.079	0.052
Orthophosphate, as P (dissolved)	**-0.064**	**-0.079**	**1**	**0.097**
Phosphorus, Total as P	0.018	0.052	0.097	**1**

Table 10. 2013 Primary Component Analysis of Tulaby Lake water samples

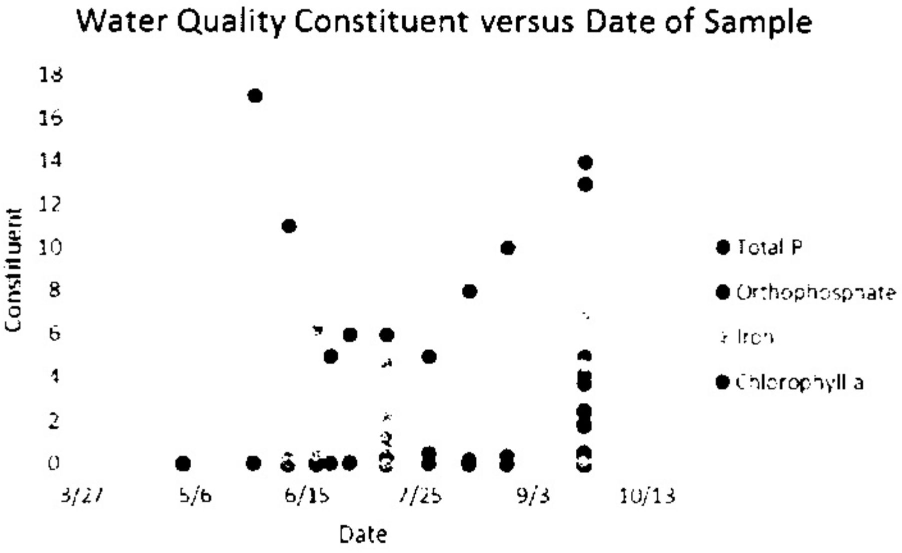


Figure 9. 2012 Primary component analysis

Figure 10. Water quality constituents plotted versus date of sample collection