# Effectiveness of Remediation Processes in Eutrophic Water Conditions of Crystal Lake, Hennepin County, MN.

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A thesis submitted in partial fulfillment of the requirements of the degree of
Bachelor of Arts
Geology
At
Gustavus Adolphus College
2015

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## Abstract

Runoff in urban freshwater lakes and streams is a growing problem in many Midwestern watersheds due to the growth of residential and agricultural development. This runoff leads to the introduction of excess nutrients into these urban lakes, resulting in eutrophic conditions (nutrient hyper-enrichment). Crystal Lake is a small (89 acres) lake located in the Shingle Creek Watershed of Hennepin County Minnesota, and was placed on Minnesota's list of eutrophic impaired waters in 2002. As a result, a 2009 EPA study assessed the nutrient concentrations in the lake and recommended lake quality remediation. In 2011, a flocculation plant was installed to remove phosphorus from the lake by cycling water out of the lake into holding tanks. Phosphorus in the water was then removed by adding an alum to the water in these tanks, causing a precipitate to form and the bound phosphorus could then be transported out of the watershed. The flocculation plant collected water quality data in the summers of 2012 and 2013 to evaluate the impact of remediation measures. The plant was not in operation in 2014, due to lack of employee personnel from the City of Robbinsdale.

The aim of this study compares water quality data as a function of remediation efforts. Total phosphorus (TP), dissolved oxygen (DO), and water clarity data collected during summer 2014, when the plant was in idle, is compared to water quality data both before remediation and during plant operations to examine the effect of the flocculation plant on water quality parameters. Preliminary analyses suggest that the flocculation plant has positively impacted water quality in the lake and should be considered for continued use.

## Acknowledgements

I would like to thank Richard McCoy, Robbinsdale City Engineer and Public Works Director for allowing me to access Crystal Lake water quality data records. I would also like to thank Jay Morgan, Robbinsdale Utility Supervisor, for introducing me to Richard as well as showing me an in depth look at the Robbinsdale flocculation plant operation. Thank you Jeff Jeremiason for letting me use your sampling equipment. Finally I would like to thank my brother Mark Berger for helping me with my fieldwork in collecting samples.

## Table of Contents

## Figures and Tables

## Introduction

Eutrophication (excessive nutrient levels) is a major issue in urban/suburban lakes due to accelerating growth of cities and farmland, which ultimately leads to alterations in the nutrient balance of these watersheds. Levels of phosphorus in freshwater systems are estimated to be 75% greater in systems subjected to human alterations compared to unaltered systems (Bennet et al.,2001). Phosphorus is considered the limiting agent for plants and algal growth, which can lead to decreases in water clarity as well as dissolved oxygen (Kloiber, 2002). Deep water lake systems with high phosphorus concentrations are often deficient in oxygen because algae have a short life cycle and the introduction of nutrients not only increases algae populations but also increases the amount of decomposition as the algae die and settle to the lake bottom. The decomposition of the algae by bacteria is a process that removes oxygen from the water column, resulting in anoxic zones developing near the lake bottom (Gachter, 1998). Anoxic zones become more prevalent in eutrophic lakes as a result of increased phosphorus levels and algal blooms, creating zones that are uninhabitable for fish and other aerobic organisms. Water clarity is also affected during algal blooms, causing the water to turn green and unpleasant for many recreational uses.

In an urban setting, runoff from residential and agricultural land represents one of the biggest sources of phosphorus in these small water systems. Of secondary importance in these developed settings in the natural phosphorus delivery into lakes and streams from decaying organic material, mainly dead trees and foliage near shorelines. Management of nutrient levels in freshwater systems attempts to bring about long-term improvements by slowing algae growth in these systems, the most common intention aims to reduce nutrient concentrations (Cooke 1986). Keeping healthy nutrient levels within lakes is important for maintaining a functioning ecosystem as well as for developing a pleasing commons for the nearby residents and visitors.

Crystal Lake is one of many freshwater lakes in the Twin Cities that are classified as eutrophic (EPA, 2009). This lake is primarily used for recreational purposes including swimming, fishing, and boating. Excess nutrients in this urban lake have decreased fish populations (MN DNR 2004), and made it unpleasant to use throughout most of the summer, because of the smell and green stained color. Currently, the City of Robbinsdale has implemented storm gardens around the lake as well as protected foliage around the shoreline to help filter out nutrients from runoff and storm water. In 2002 Crystal Lake was listed as an impaired lake under eutrophic conditions by the Shingle Creek Watershed Commission. The Environmental Protection Agency (EPA) analyzed Crystal Lake in 2009 and provided a comprehensive analysis of the lake's health. Because of continual summers in which the lake failed to meet state water quality standards and based on the assessment given in the EPA report, the City of Robbinsdale implemented a nutrient filtration system on the south end of the lake in 2012.

The plant is intended to treat up to 1.3 million gallons of water per day. It uses an alum agent (typically aluminum sulfate) that binds with the phosphorus to form a precipitate. The precipitate can then be transported out of the lake and the purified water can be returned into the lake. There are three pipes that run along the bottom of the lake that pump water into this flocculation plant and the inlets are located at the south end of the lake in about 15 feet of water, the middle of the lake at around 20 feet. of water, and towards the north end of the lake near the deepest portion of the lake. This plant was awarded the: *MPWA Project of the year* 2012, the *ACEC Minnesota Engineering Excellence Grand Award* 2012, and the *MnSPE Severn wonders of engineering award* 2013. The plant cost a total of $1.2 million to build and approximately $90,000 to run per summer. The goal of the filtration system is to reduce the amount of phosphorus within the lake system and to ultimately reduce algal growth, increase water clarity, and stabilize oxygen concentrations in the water column. While operating, the filtration plant collected water quality data for the summers of 2012 and 2013. However, due to lack of personnel, the plant was not in operation for summer 2014 and no water data was collected. Restoring healthy water quality levels in eutrophic lakes is a long multi-year process; therefore, collecting annual water quality data is paramount for ensuring the future of these water systems. The goal of this study is to gather water quality data for the 2014 summer, assess the efficiency of the flocculation plant during the 2012 and 2013 summers, and finally to determine the effect of stopping the plant after two years of use.

## Geologic Setting

Crystal Lake is located in the suburban city of Robbinsdale in Hennepin County, MN. It is a fluvial remnant located in sediment derived from upper western terrace of the greater Mississippi River system. Underlying much of this area is Ordovician aged St. Peter Sandstone (Shingle Creek, 2004). The lake has a surface area of 89 acres and a maximum depth of 39 feet. The Crystal Lake Watershed covers 1,237 acres or approximately 4% of the entire Shingle Creek watershed (Figure 1). The littoral zone, the area where aquatic vegetation grows, is less than 15 feet deep, and covers about 72% of the lake (MN DNR, 2004). There are 15 storm sewer inputs into the lake (WSB & Associates, Inc., 2003). There are no natural outlets for Crystal Lake; storm water treatment is minimal but there is a lift station that pumps storm water into the City of Minneapolis storm sewer system (TMDL, 2009). There are also multiple small ponds and storm gardens surrounding the lake that were put in place to treat some of the storm water that is discharged into the lake. Residential development and parks/recreational areas surround the majority, accounting for 76% of the surrounding land use (TMDL, 2009). Other lakes within this watershed are subjected to similar urban settings and are also experiencing eutrophic conditions (Shingle Creek, 2004)

**Figure 1**

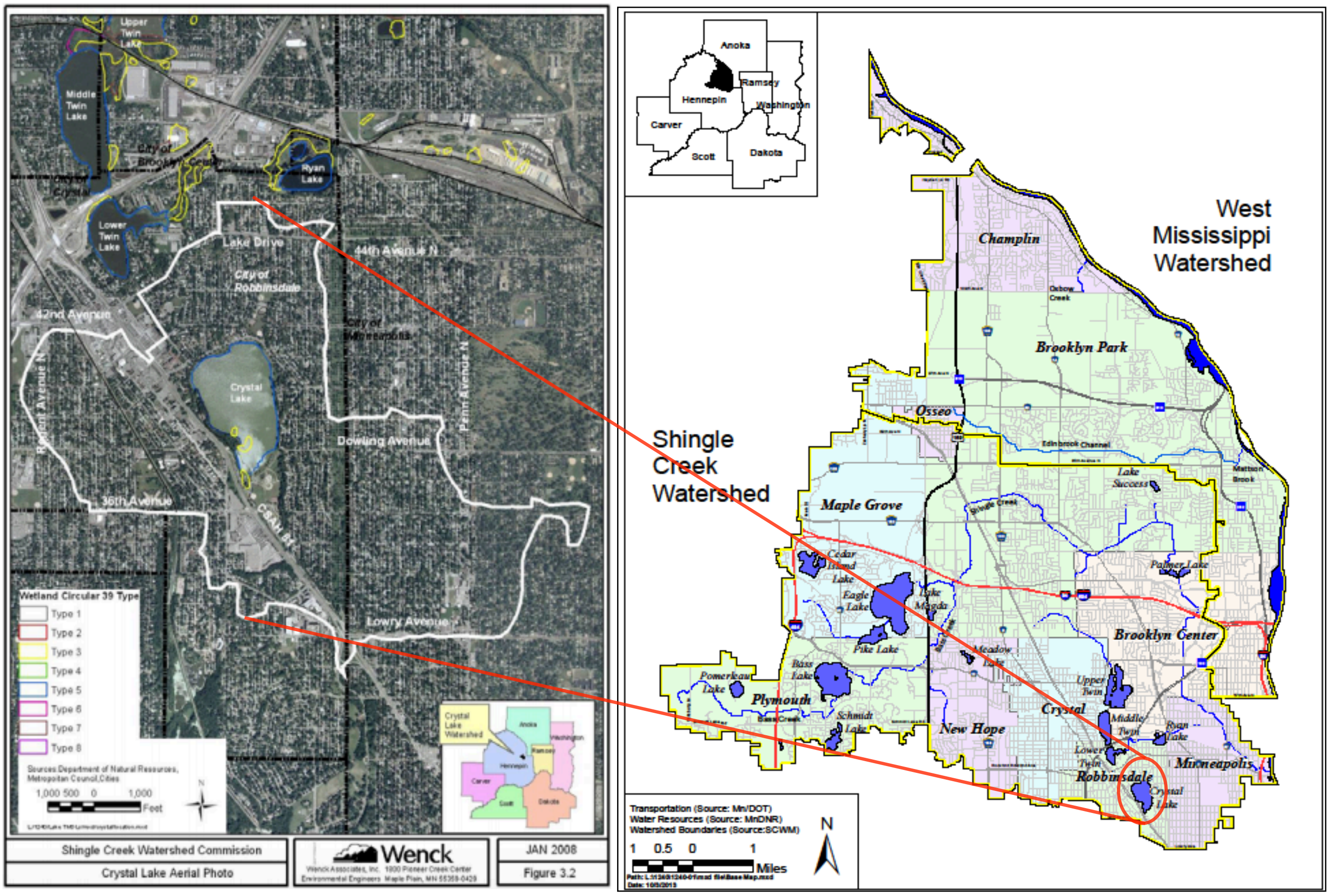


Figure 1: Maps provided by the Shingle Creek & West Mississippi Watershed Management Commissions May 2004.

## Methods

Field work:

Using a GPS with a map of the Crystal Lake bathymetry, a sampling area was marked (45° 1’35.612” N 93° 19.575W) located between previous data retrieval sites marked “Sampling Location 1” and “Sampling Location 2” (Figure 2). This area was chosen because it was towards the middle of the lake and relatively easy to boat out to from shore. It is 20 feet deep in this part of the lake Samples and Hydro Lab Quanta probe data were taken Wednesday nights at 5:00pm from June 21st to July 31st. Water clarity measurements were taken boat side using a Secchi disk. The probe was used to record DO, pH, and water temperature. After those measurements were recorded, water samples were taken just below the surface in 500mL plastic jars, which were dated then stored under refrigerator temperatures.

Lab work:

Total phosphorus was measured using the method of Murphy and Riley (1962). Phosphorus standards of 0.5mg/L, 1.0mg/L, 2.5mg/L, and 5.0mg/L were made by diluting stock phosphorus solution. The samples were then concentrated and digested by adding 1mL of NaOH and .5g of $K_2S_2O_8$ to 100mL of each sample and boiling on a hot plate to a final volume less than 25mL. Samples were diluted with milliQ water to reach 25mL exactly to ensure equal dilutions. The coloring agent in this procedure is a mixture of the following: sulfuric acid ($H_2SO_4$), potassium antimonyl tartrate solution ($K(SbO)C_4H_4O_6{*}0.5H_2O$), ammonium molybdate ($(NH_4)_6Mo_7O_{24}{*}4H_2O$), and ascorbic acid. 1.6mL of the coloring agent was added to 10mL of each digested sample (and standards) and were set aside to react for 10 minutes. The absorbance of the samples was then measured at 880 nm using a Carey 50 spectrophotometer, and concentrations were determined using a calibration curve made from the phosphorus standards.  These data were then compared to rainfall logs from the *Community Collaborative Rain, Hail & Snow Network* (CoCoRaHS) database and field data. The City of Robbinsdale Water Quality Monitoring program for Crystal Lake collected samples from three locations in the lake (Figure 2) during the summers of 2012 and 2013. This study (summer 2014) collected samples at a location between sites 1 and 2 (Figure 2). Data records from 2012 and 2013 were retrieved from the *2011 Water Quality Monitoring Program for Crystal Lake*, WSB project No 1931.

**Figure 2**


Figure 2: Crystal Lake showing locations of 2012-13 sampling (locations 1-3) and location for 2014 ampling (marked Sampling Area). Map provided by Shingle Creek Watershed Management Commission via Crystal Lake Nutrient TMDL, 2009.

## Results

### Previous Data

Water quality data records show that Crystal Lake has continually struggled with meeting water quality standards set by the state of Minnesota. In figure 3 average summer Secchi disk measurements are shown dating back to the summer of 1986. With the exception of 1997, Crystal Lake had not been meeting the state standard for water clarity. In Figure 4, it shows that Crystal Lake was not meeting state standards for total phosphorus as well. It is key to note that in these two figures, the data is represented as yearly averages and does not show variation throughout the summer.

**Figure 3**

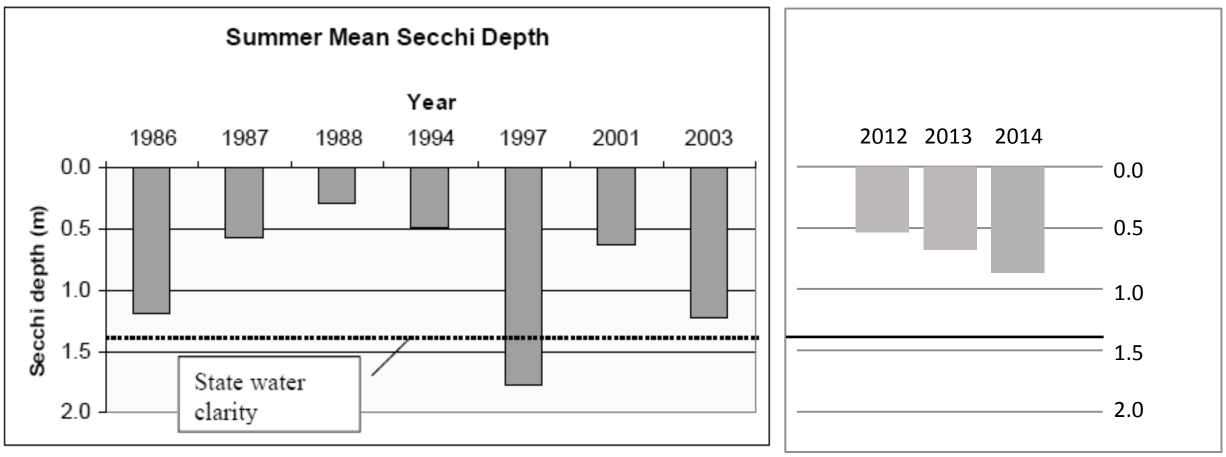


Figure 3: Average annual water clarity measurements gathered from the Shingle Creek Watershed Commission (1986-2013). Average summer mean Secchi measurement data for 2014 was collected separately. The Minnesota state water clarity standard (1.4 meters) is designated by the black line.

**Figure 4**

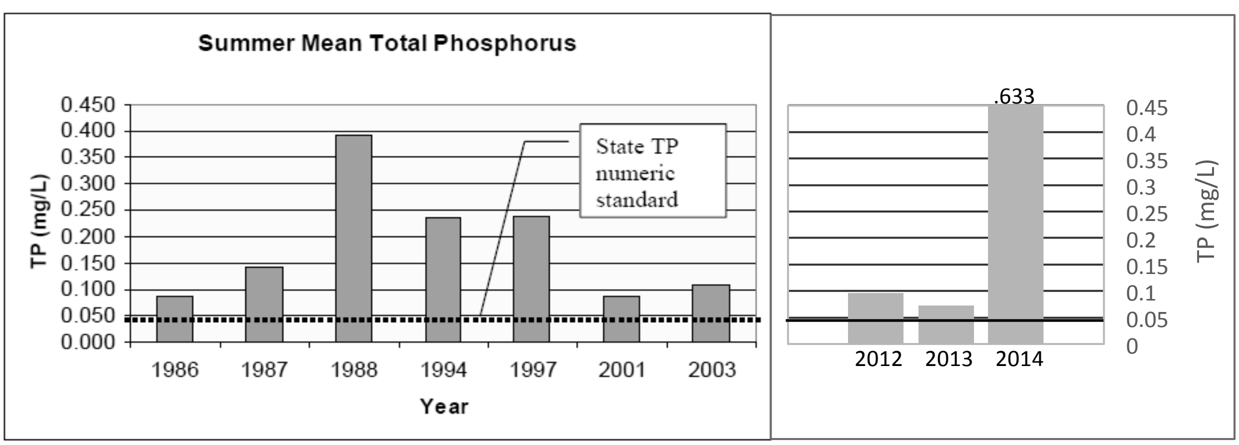

Figure 4: Average annual total phosphorus concentrations (1986-2013) gathered by the Shingle Creek Watershed. Average summer mean total phosphorus data for 2014 was collected separately. Minnesota state standard for total phosphorus concentrations (.04mg/L) is designated by the black line.

**2012-2013**

Following the installation of the flocculation plant, water quality data were collected and archived. In Figure 5 Secchi disk measurements are shown from summers 2012-2014.

**Figure 5**

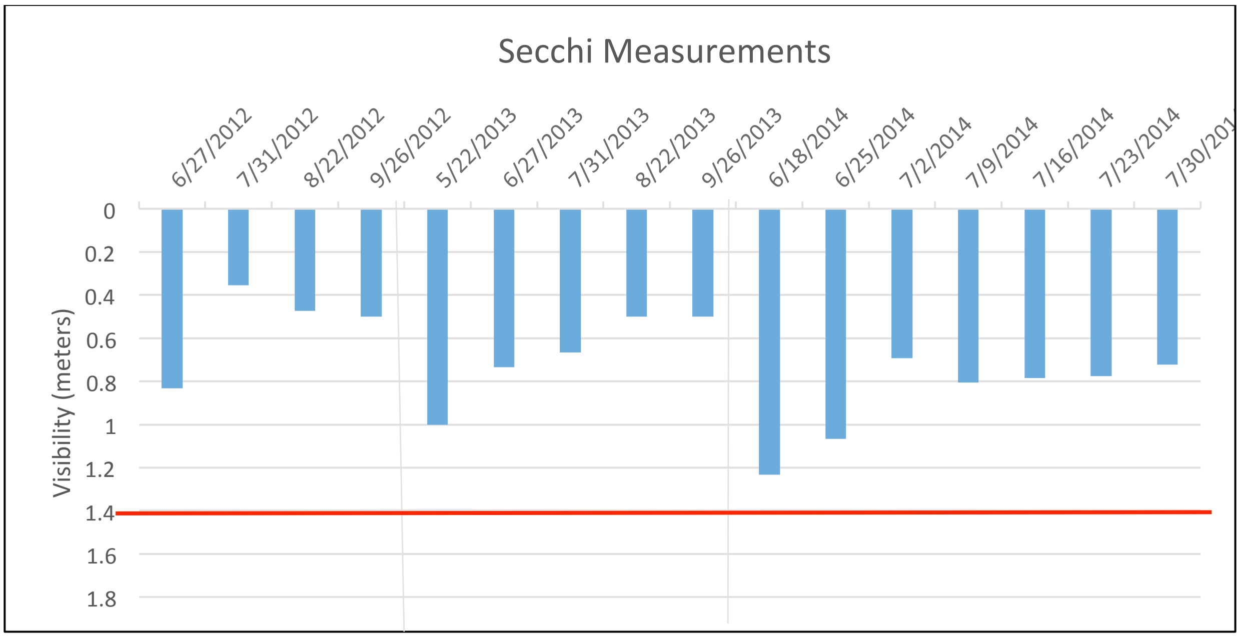


Figure 4.1: Secchi disk measurements from 2012 through 2014. Measurements from 2012 and 2013 are averaged from the three collecting sites each day. Data from 2014 was taken at the given site seen in figure 1.1. The red line displays the Minnesota State water clarity standard (1.4 meters) for this lake.

Total phosphorus data was also collected and recorded seen in figure 4.2. Again the 2014 data is separate from the data collected in 2012 and 2013. It can be pointed out that from the data in 2012 to the 2013 shows a deacrease in total phosphorus concentrations (Figures 3.2 and 4.2). The data ranges between 0.055mg/L TP to 0.143mg/L TP during the summer of 2012. The range of data from 2013 is 0.064mg/L TP to 0.094mg/L TP. It should be noted that TP concentrations ranging from 0.5-0.8 mg/L were reached near the bottom of sampling locations 2 and 3 during late June through September of these summers.

**Figure 6**

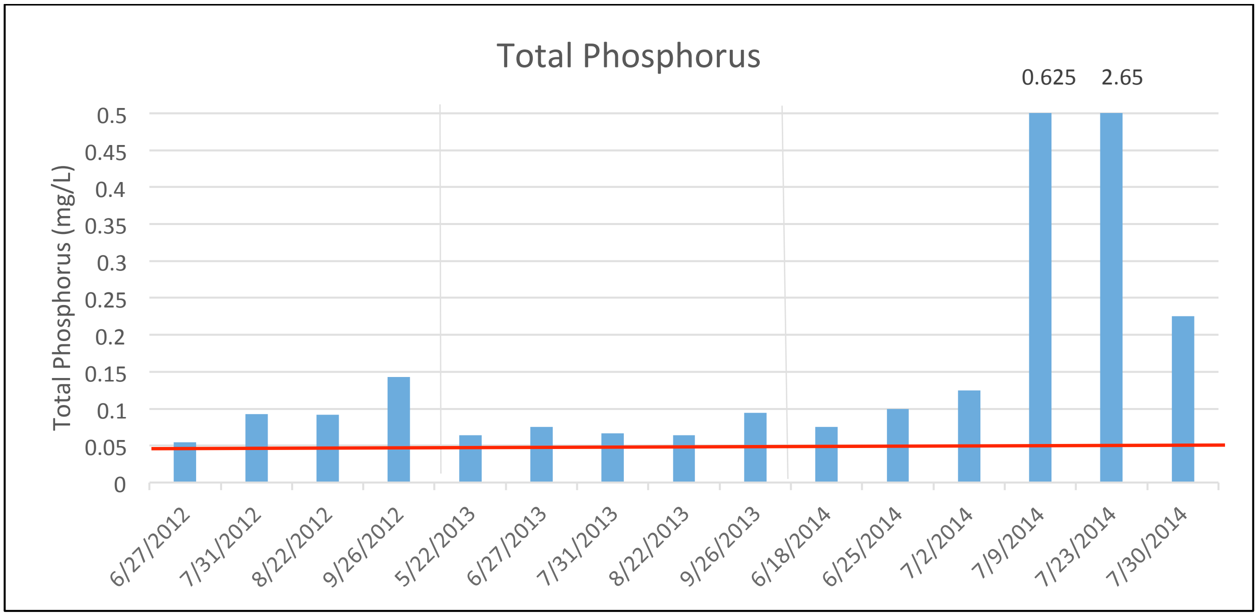


Figure 4.2: Total phosphorus concentrations are displayed. Measurements from 2012 to 2013 are averaged from the three collecting sites each day. Data from 2014 was taken at the sampling site shown in figure 2. The red line displays Minnesota state standard for total phosphorus concentrations (0.04mg/L) for this given lake. TP concentrations for 7/9/2014 and 7/23/14 are off-scale on this diagram; values are given above the bars.

Dissolved oxygen content was also collected during the 2012-2013 summers. This data can be used to help model eutrophic conditions throughout the water column profile and to locate the base of the oxygenated layer. Figure 7 displays average DO content for the 2012 and 2013 summers. The DO quantities are averaged from the three collecting sites (Figure 2). These data show a steep decrease in DO at a depth between 5 and 10 feet during the summer that deepens in autumn. It is typical for eutrophic lakes to develop anoxic zones near the bottom of the lake because of the presence of decaying organic material.

**Figure 7**

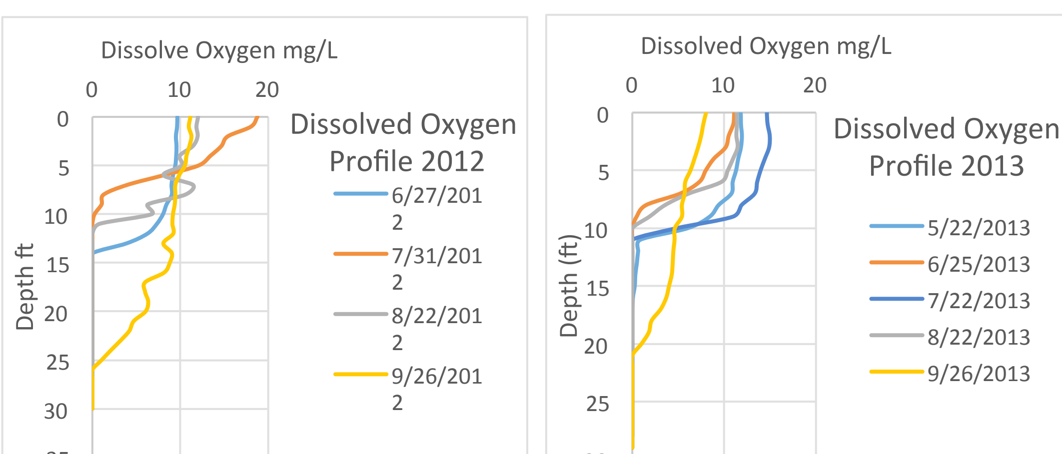

Figure 7: Dissolved oxygen concentrations are displayed in a profile perspective. Measurements from 2012 and 2013 are averaged from the three collecting sites each day.

**2014**

During the 2014 summer, the flocculation plant was not in operation; thus, the city of Robbinsdale did not monitor lake water that summer. As noted in figure 2, data for 2014 was collected as a part of this project from the sampling site between sites 1 and 2 of the previous data collection sites. In Figures 3 and 5 Secchi disk measurements for 2014 are shown. It is easily noticed that these measurements show that the water was much clearer during this summer. In figures 4 and 6 the 2014 TP concentrations are displayed in comparison with previous years.

There were many rain events during this last summer, which is a potential runoff influx into the lake. In figure 8 the total precipitation for the 2014 summer is displayed as well as the corresponding TP measurements and daily high temperature values for each day. Large rain events to pay attention to are the events through late June and July. A total of 14.54 inches of rainfall from 6/1- 7/31 alone, and on 7/12/14 there was a large rain event that totaled close to 2 inches of total rain, this was followed by a dramatic cooling of daily high temperatures. There was a rebound of the temperatures in the next following few days.

**Figure 8**

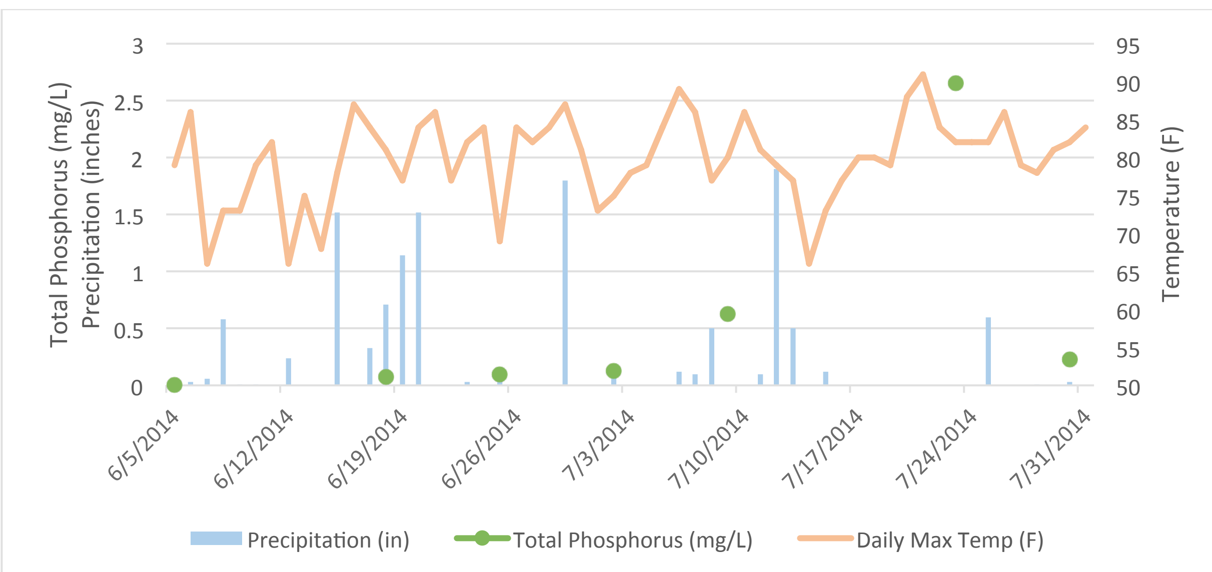


Figure 8: Total phosphorus concentrations, total precipitation, and daily maximum atmospheric temperatures for Crystal Lake in 2014.

Dissolved oxygen concentrations were also gathered at set depths at the 2014 sampling site. Measuring depths were taken at 2.4 feet and 13.2 feet seen in figure 9. Because the data is not continuous throughout the water column the lines connecting the data is generalized and does not show the actual point of anoxic zones seen in figure 4.3 profiles.

**Figure 9**

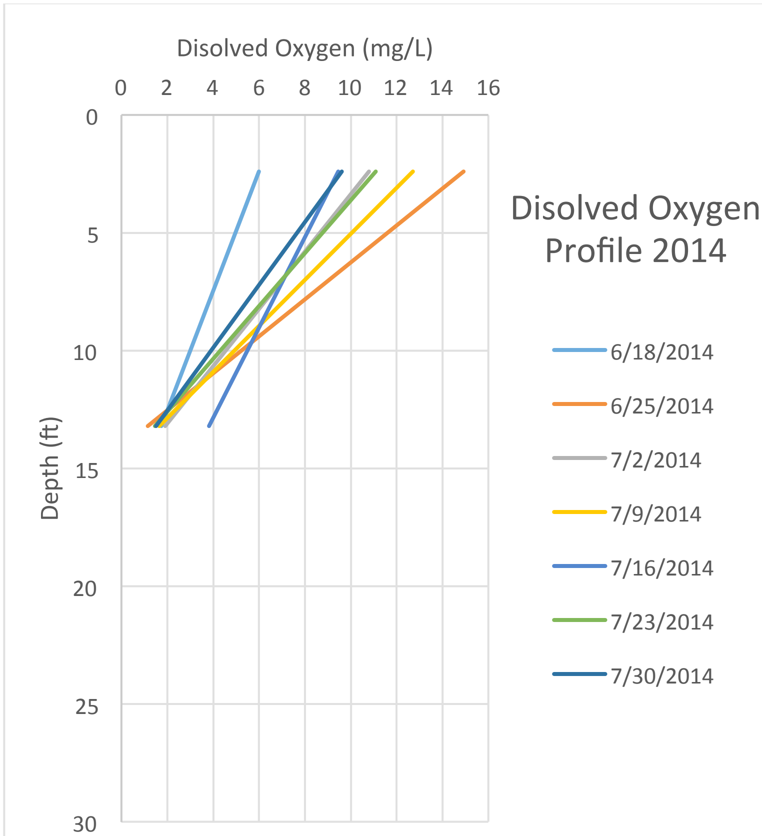


Figure 9: Average dissolved oxygen content for each sampling day. Dissolved oxygen readings were only taken from depths of 2.4 feet and 13.2 feet.

## Discussion

**Previous data**

Crystal Lake has been struggling with maintaining healthy nutrient levels for a long time. Previous analyses show that the lake has failed to meet state standards since measurements began in 1986 (Figures 3 and 4); similar nutrient impairment issues likely began before this. Because this is a relatively deep lake without an outlet, inorganic phosphorus will accumulate, concentrating near the lake bottom, where anoxic conditions cause it to be remobilized into the lower water column (Correl, 1998). Lake remediation is a multi-year process (Sondergaard et. al. 2007) and the historical data (Figures 3 and 4) indicate that Crystal Lake likely requires long-term remediation.

**2012-2013**

Total phosphorus and Secchi disk measurements (Figures 3, 4, 5, and 6) from 2012-2013 show a decrease in amount of total phosphorus and increase in clarity. These records still show that the lake is not meeting the state water quality standards, however, underscoring the idea that lake remediation takes time. The dissolved oxygen profiles (Figure 4.3) show that the lake is strongly stratified and has a prominent anoxic layer. During 2013, the oxycline occurs at a greater depth than in 2012 (data not available prior to 2012), suggesting that productivity and eutrophication in the upper water column may be declining. These measurements indicate that the lake continues to be eutrophic, and that bacterial decay of organic material uses oxygen in the water column, producing lake bottom anoxia and accumulation of inorganic phosphorus towards the lake bottom (Bennion et. al., 2007). The data presented from the years 2012 to 2013 show that there were signs of the nutrient levels beginning to be maintained and are potentially reaching levels that meet the state water quality standards. However, as noted, phosphorus likely continued to accumulate near the lake bottom. If the phosphorus is left unattended it will eventually be reintroduced into the lake system and eutrophic conditions will be exhibited once again (Carpenter et. al. 1978). Lake remediation is a long process; however, water quality did appear to be improving during the two years the flocculation plant was operating.

**Summer 2014**

The flocculation plant was not running during the summer of 2014. Therefore, data collected during the summer of 2014 has the potential to evaluate the effect of a return unremediated conditions. Total phosphorus during the summer of 2014 (Figures 6 and 8)is higher than observed in 2012 and 2013, with an anomalously high spike in July. The 2014 average phosphorus (Figure 4) data is much higher than any previous data recorded. There was also a significant drop in TP shown in 7/30. Causes for this major increase in TP readings may be: large release of inorganic phosphorous from anoxic benthic sediment (Gachter et al.,1998), or large runoff events as a result of the highly concentrated rain events (Figure 8). Even if high rainfall variable summer conditions such as in 2014 are the root cause of the large swings in TP observed, the overall high TP concentrations are robust throughout the summer, indicating a TP increase over 2012 and 2013 measurements.

Secchi disk measurements in 2014 (Figure 5) ranged from 0.7 meters to 1.23 meters of visibility, which is an increase compared the previous two summers. Generally, high TP levels would be expected to correlate with low water clarity. A lack of relationship is likely attributed to a combination of frequent rain events causing a dilution effect and overall lower summer temperature than normal. DO concentrations near the surface of the lake are also higher overall in 2014 compared to 2012-13 (Figure 4.3). Two explanations are possible: First, the sharp increase in TP could have influenced increased algal growth and photosynthetic production of oxygen. Second, higher DO might be attributable to an overall cooler summer, with frequent rain events keeping the surface of the lake oxygenated and mixed.

**Limitations**

An accurate assessment of the effectiveness of the flocculation plant requires additional data. The limited data window, with monthly sampling in one or a few lake locations, is insufficient to draw firm conclusions about the efficiency of the flocculation plant. In addition, the 2014 data may not be comparable to previously acquired data because there could be differences in experimental methodology or sampling methods. Finally, the anomalously high rainfall and cooler temperatures during 2014 might affect our ability to generalize conclusions with future/past annual data.

## Conclusion

Data collected in 2012-13 suggest that the flocculation did result in improved water quality that might ultimately lead to removing Crystal Lake from the impaired water list in the future. Furthermore, the data gathered during the summer of 2014 suggests that cessation of phosphorus removal measures caused an erosion of water quality during that year. These results would suggest that it would be wise to continue plant operations, even in the face of significant operational costs. Remediation in lakes is a slow process but it is necessary in maintaining a healthy ecosystem and a healthy commons for the City of Robbinsdale. After analysis of the data from the past three summers, there is promise for improvement in Crystal Lake's water quality/health with the further continued use of the flocculation plant. If the flocculation plant remains in use and the remediation of Crystal Lake is a success, it would be a great example for possible remediation implements in other suburban lakes throughout the metro that are also suffering from eutrophic conditions.

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