Technical Memo

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Date: June 14, 2018

Subject: DRAFT Lily Lake Internal Load Study

INTRODUCTION

Lily Lake is a eutrophic, deep lake located in Stillwater, MN. The lake supports recreation such as swimming, boating and fishing and has a beach and public boat ramp maintained by the City of Stillwater. However, Lily Lake has been listed on the MPCA's 303(d) list since 2002 as impaired for aquatic recreation due to excess nutrients. Average total phosphorus concentrations are well above the deep lake standard of 40 ug/L throughout the summer, ranging from 55 ug/L in May to 108 ug/L in August.

A City of Stillwater Lake Management Plan written in 2007 attributed high phosphorus concentrations largely to the lake's 587-acre, fully developed watershed. However, this study acknowledged that one of the primary data gaps was empirical measurements of sediment phosphorus release known as internal loading. The primary goal of this technical memorandum is to evaluate the impact of internal loading to Lily Lake and develop of a cost estimate for an aluminum sulfate (alum) treatment on Lily Lake to reduce internal phosphorus loading.

METHODS

To evaluate internal phosphorus release and sediment chemistry in Lily Lake, a gravity sediment coring device (Aquatic Research Instruments, Hope ID) equipped with an acrylic core liner (6.5-cm ID and 50-cm length) was used to collect sediment in January of 2018 (Figure 1). Three intact sediment cores were collected for determination of P release rates under anaerobic conditions. An additional sediment core was sectioned vertically at 1-cm intervals over the upper 6-cm layer, 2-cm from 6-10 cm and 2.5-cm intervals below 10 cm to evaluate variations in sediment physical-textural and chemical characteristics (Figure 1).

Figure 1. Bathymetry contours (ft.) and sediment coring location on Lily Lake. Note that the lake contours were georeferenced from an image and are added just for reference.

LILY LAKE WATER QUALITY

Summer surface water total phosphorus concentrations in Lily Lake have exceeded the state standard of 40 ug/L for many years, although phosphorus concentrations appear to have improved in recent years, with the state standard met in the two most recent years with data (2013 and 2014; Figure 2).

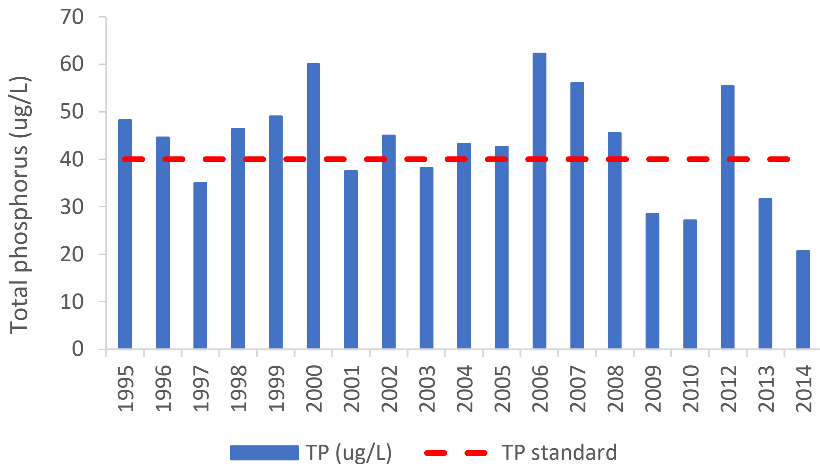

Figure 2. Average annual surface total phosphorus concentrations in Lily Lake.

Over the course of the summer, monthly averages of surface total phosphorus concentrations are consistently above the standard (Figure 3). The highest total phosphorus concentrations appear in August and September, which is a characteristic of lakes impacted by sediment phosphorus release. Conversely, lakes highly impacted by watershed loading would have higher total phosphorus concentrations in the spring since watershed loading is typically higher in the spring. These data suggest that internal loading is driving poor water quality in the late summer even if annual total phosphorus concentrations have improved.

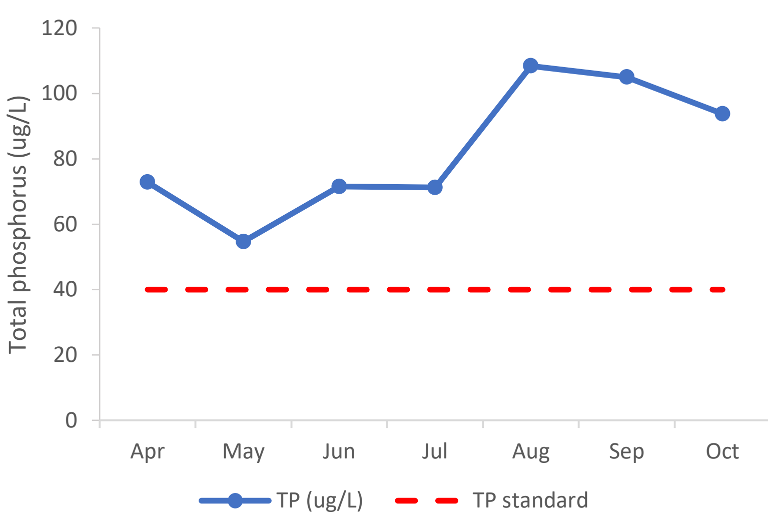

Figure 3. Average monthly surface total phosphorus concentrations in Lily Lake.

Further evidence that internal loading is driving poor water quality in Lily Lake comes from hypolimnetic data. Lily Lake stratifies in the summer, so in 2008, water samples were taken not only from the surface, or the epilimnion, but also from the lower layer, or hypolimnion. Hypolimnion sampling demonstrated that total phosphorus concentrations steadily increase over the course of the summer (Figure 4). From May to August of 2008, total phosphorus in the hypolimnion increased from 200 to almost 900 ug/L. Hypolimnion samples were also taken in 2009 and show a similar sequence. This accumulation of phosphorus in the bottom waters is a clear indication that sediments in Lily Lake release phosphorus into the water column as water temperatures warm and become anoxic.

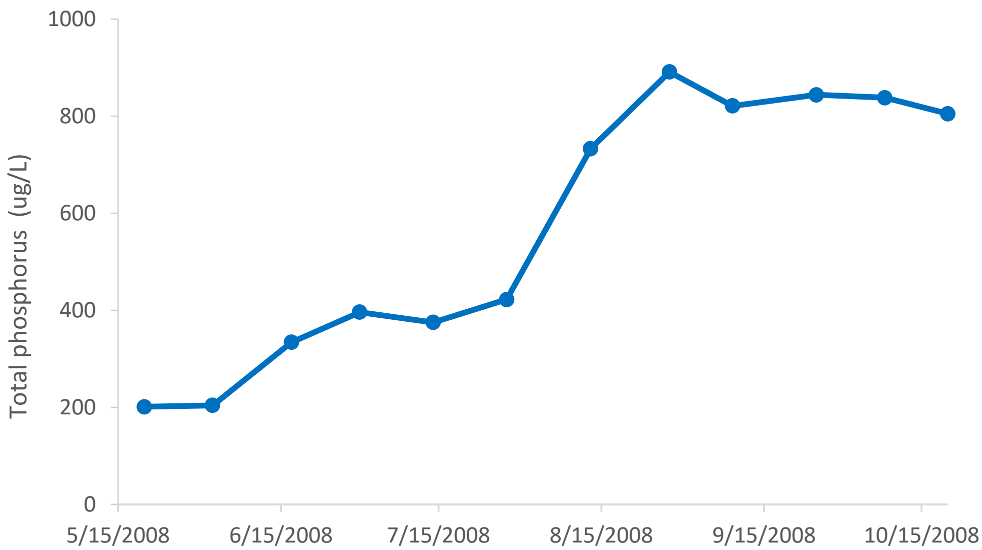

Figure 4. Total phosphorus concentrations in the hypolimnion of Lily Lake in 2008.

Dissolved oxygen profiles confirm that the hypolimnion becomes anoxic in the summer (Figure 5), a factor that causes microbial processes in sediments to release phosphorus. Dissolved oxygen profiles also show that the oxycline is shallowest in July and becomes deeper through October as the water column mixes (Figure 5). Because mixing begins in July, mixing occurs when hypolimnetic total phosphorus levels are at their highest (Figure 4). This explains why surface total phosphorus levels increase in late summer (Figure 3) and indicates that high hypolimnetic phosphorus concentrations do not merely stay in the hypolimnion, but impact surface waters.

Surface chlorophyll concentrations further convey this impact. Increases in surface chlorophyll levels track increases in surface phosphorus levels, suggesting that sediment release of phosphorus is not only making its way to surface waters, but also affecting algal growth. This algal growth, measured as chlorophyll concentration, exceeds the state standard in August and September (Figure 6). The state standard for chlorophyll concentration in Lily Lake is 14 ug/L, while the average August and September chlorophyll concentrations are 20 ug/L and 16 ug/L, respectively (Figure 6).

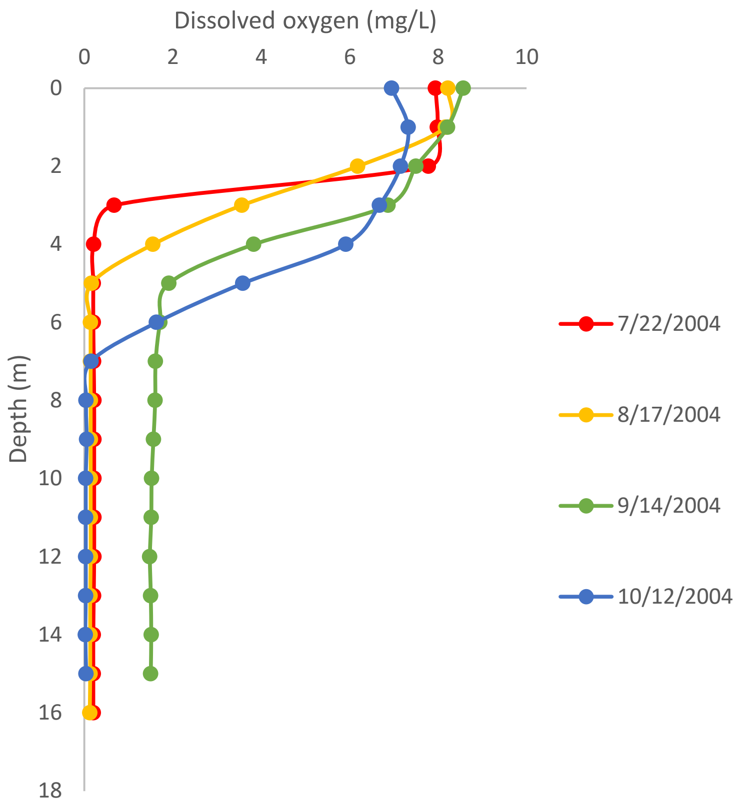

Figure 5. Dissolved oxygen profiles from July to October of 2004 show typical dissolved oxygen levels in Lily Lake and show that mixing begins in July/August.

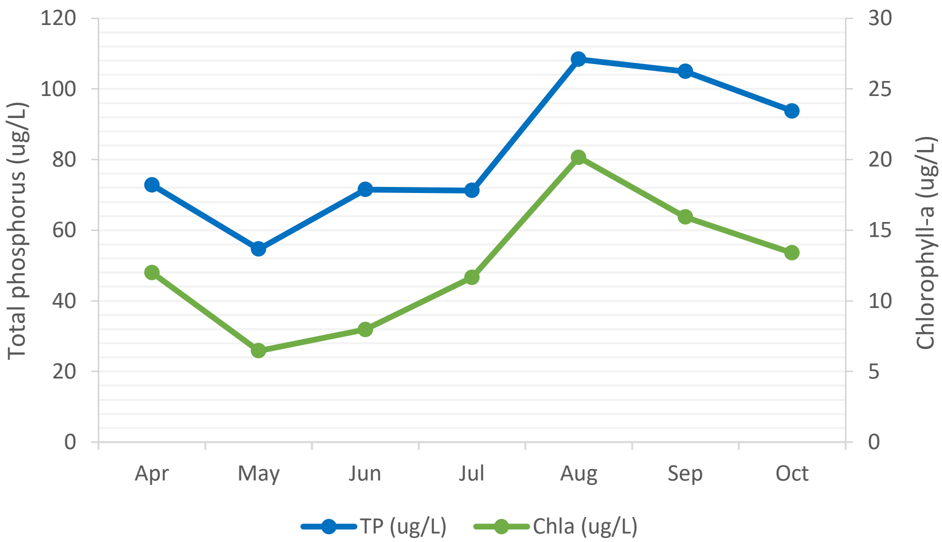

Figure 6. Average monthly surface chlorophyll concentrations track average monthly total phosphorus concentrations throughout the summer in Lily Lake.

PHOSPHORUS RELEASE AND INTERNAL PHOSPHORUS LOADING

One of the primary data gaps listed in the City of Stillwater's 2007 Lake Management Plan is that no sediment release rates were measured while assessing loading to Lily Lake. Therefore, in this study, Wenck measured anaerobic phosphorus release rates from Lily Lake sediment, which averaged 5.71 $mg/m^2/day$ (Table 1). This release rate is considered moderately high and falls at about the 55th percentile of sediment phosphorus release rates measured in the Twin Cities Metropolitan Area. This release rate alone does not suggest that an internal load reduction would have a substantial impact on the nutrient budget of Lily Lake. However, this release rate is clearly driving hypolimnetic phosphorus concentrations.

Table 1. Mean phosphorus release rate under anaerobic conditions for intact sediment cores collected at the deep hole in Lily Lake.

Station	Anaerobic P Release ($mg/m^2/day$)	Standard Error
1	5.71	0.70

SEDIMENT CHEMISTRY

Vertical sediment chemistry profiles were measured in Lily Lake in addition to sediment phosphorus release rates. In most lakes the primary forms of phosphorus driving internal loading in lakes is phosphorus bound to iron (iron-bound P) and phosphorus contained in labile organic matter (labile organic P). Sediment chemistry analysis indicated that iron-bound P was extremely high in Lily Lake (Figure 7). The median iron-bound P in Twin Cities Metropolitan Area lakes is 0.25 mg/g, and Lily Lake's iron-bound P ranges from 1 to 3 mg/g (Figure 7). Further, a peak of iron-bound P is typically observed within the top 5 to 10 centimeters of sediment, below which little iron-bound P is observed. However, Lily Lake's iron-bound P does not decrease throughout the 20-centimeter core (Figure 7).Regardless, the high levels of iron-bound P in Lily Lake's sediment are likely what is driving sediment phosphorus release in Lily Lake and the resulting water column phosphorus levels.

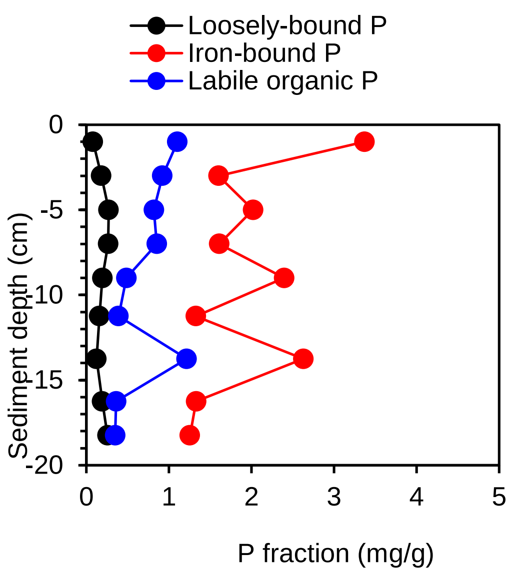

Figure 7. Lily Lake sediment chemistry profiles for the deep coring location.

ALUM DOSE RECOMMENDATIONS OF INTERNAL LOAD REDUCTION

Two factors are typically considered when determining the area that will be treated with alum: redox-P concentration and the average depth of anoxia. Dissolved oxygen data indicate that the deep parts of Lily Lake regularly experience low dissolved oxygen conditions. The minimum depth at which waters are anoxic during the summer is 3 m, while the maximum depth is 9 m. The average anoxic depth is 5.1 m. The area of the lake that has a depth of at least 3 m is much larger than the area of the lake that has a depth of at least 5.1 m or 9 m (approximately 590,700 ft^2 versus 417,00 ft^2 versus 174,900 ft^2, respectively). Therefore, alum doses and associated costs were calculated for each area, after which Wenck assessed which parts of the lake were feasible to treat.

Based on this information, Wenck recommends applying 117 g Al/m^2 to areas with a depth greater than 9 m or approximately 30 ft. (the lake has a maximum depth of approximately 15.5 m or 51 ft.; Figure 1). Wenck recommends splitting this dose into two applications, with the second application occurring two years after the first. Splitting the dose will increase the effectiveness and longevity of the alum application by increasing the time that fresh alum is exposed to the uppermost sediment layer containing high iron-bound P. Splitting the dose will also allow adaptive management in which a larger area of the lake can be treated during the second application if the first application is not as effective as anticipated. Wenck proposes applying the second dose to the same area as the first dose (depths greater than 9 m) if the first dose is effective. If it isn't, Wenck recommends applying the second dose to areas with depths greater than 5.1 m.

Routine monitoring must occur between the alum applications to track the progress of the first application. Wenck recommends measurement of anoxic release rates after the initial alum application to assess if dosing in only the deepest regions of the lake will sufficiently lower internal phosphorus loading. (The focus of the alum application is in the deep region of the lake because these areas have the largest contributions to internal phosphorus loading. It is important to note that shallow regions of the lake may also contribute to internal loading, but to a smaller degree.) Wenck also recommends surface and hypolimnetic water quality monitoring to confirm water quality improvements Lily Lake. The combination of sediment release rate and water quality data will help assess if the second alum application will need to expand into shallower regions of Lily Lake.

The total cost of the recommended alum treatment is $143,000 or $201,250, depending on the area treated in the second alum application. This cost includes bidding, specs, application observation, and follow up monitoring (Table 2). The recommended dose should reduce internal phosphorus loading in deep regions of Lily Lake by an estimated 120 pounds per year. According to the City of Stillwater's 2007 Lake Management Plan, total phosphorus loading to the lake each year is 285 pounds, suggesting the recommended alum treatment has the potential to reduce Lily Lake's phosphorus load by 42 percent.

CONCLUSION

There is little doubt that an alum treatment will positively impact water quality in Lily Lake. However, the magnitude and duration of the impact are more difficult to predict. Lily Lake's high iron-bound phosphorus levels in the sediment suggest alum may be extremely effective, but despite these high levels, the sediment's phosphorus release rates are only moderately high. For this reason, Wenck recommends an adaptive approach in which only half the alum treatment is conducted at once. After this initial dosing, release rates and water quality can be reassessed, and the remaining treatment approach can be planned.

Table 2. Quantities of aluminum sulfate ($AlSO_4$) and sodium aluminate ($NaAlO_2$) and associated costs for the recommended alum application.

Item	Quantity $AlSO_4$ (gal)	Cost of $AlSO_4$ ($/gal)	Quantity $NaAlO_2$ (gal)	Cost of $NaAlO_2$ ($/gal)	Total Cost
Alternative 1 – apply 117 g Al/m^2 > 9 meters	18,350	$1.80	9,176	$5.50	$83,500
Alternative 2 – apply 117 g Al/m^2 > 9 meters and 59 g Al/m^2 between 8 and 9 meters	31,044	$1.80	15,523	$5.50	$141,252
Application observation and monitoring	-	-	-	-	$15,000
Bidding, Permitting, and Specifications	-	-	-	-	$20,000
Follow Up Monitoring	-	-	-	-	$25,000
Total Cost Estimate	-	-	-	-	**$143,500 or $201,250**

Note: Applications should occur in split doses with sediment monitoring in between.

References

Wenck Associates. 2007. City of Stillwater Lake Management Plans—Lily Lake & McKusick Lake.