Technical Memo

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To: Isanti Soil and Water Conservation District
Attn: Tiffany Determan

From: Jeff Strom, Wenck Associates now part of Stantec
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Date: February 5, 2021

Subject: Blue Lake Alum Treatment Feasibility Study

Blue Lake is a deep lake located in southwest Isanti County. While the lake is not currently impaired, average summer growing season total phosphorus (TP) concentrations are close to exceeding State standards and chlorophyll-a concentrations commonly exceed State water quality standards. A recent diagnostic study for Blue Lake (Wenck 2019) found that internal loading from the lake's sediments accounts for a significant portion of the lake's annual phosphorus budget. This technical memorandum assesses the feasibility of an aluminum sulfate (alum) treatment on Blue Lake to reduce internal phosphorus loading and estimated project costs, longevity, and other considerations for the treatment.

Lake and Watershed Information

PARAMETER	BLUE LAKE
Surface Area	263 acres
Max Depth	31 ft
Average Depth	14 ft
Volume	3,652 ac-ft
Average Residence Time	2.3 years
Littoral Area	134 ac
Watershed Size	6,944 ac
Watershed : Lake Area	26:1

Blue Lake is a deep eutrophic lake located approximately four miles northeast of Zimmermann in southwest Isanti County. Blue Lake is a popular destination for fishing, swimming and non-motorized boating. While the lake is located in Isanti County, roughly half of the lake's 6,944-acre drainage area is located in Sherburne County. Blue Lake has a moderate watershed to lake area ratio (26:1). Typically, lakes with watershed to lake area ratios ranging from 20:1 to 30:1 are influenced by both watershed and internal nutrient sources. Average residence time (i.e. flushing rate) of Blue Lake is 2.3 years, which is relatively long given the size of the lake's watershed. The table above summarizes the physical characteristics of Blue Lake and its watershed.

Approximately 75% of Blue Lake's drainage area is developed (i.e. urban/homes and rural cropland) while 20% is considered lowland marsh/wetland and 5% undeveloped and privately owned forested land (Blue Lake Stormwater Retrofit Analysis). Blue Lake's watershed consists of six main tributaries that drain to the lake as well as the direct drainage area surrounding the lake (Figure 1). Isanti SWCD staff monitored flow and water quality in the tributaries draining to Blue Lake from 2015-2018. Results of these monitoring efforts are discussed in more detail in the Blue Lake Diagnostic Study.

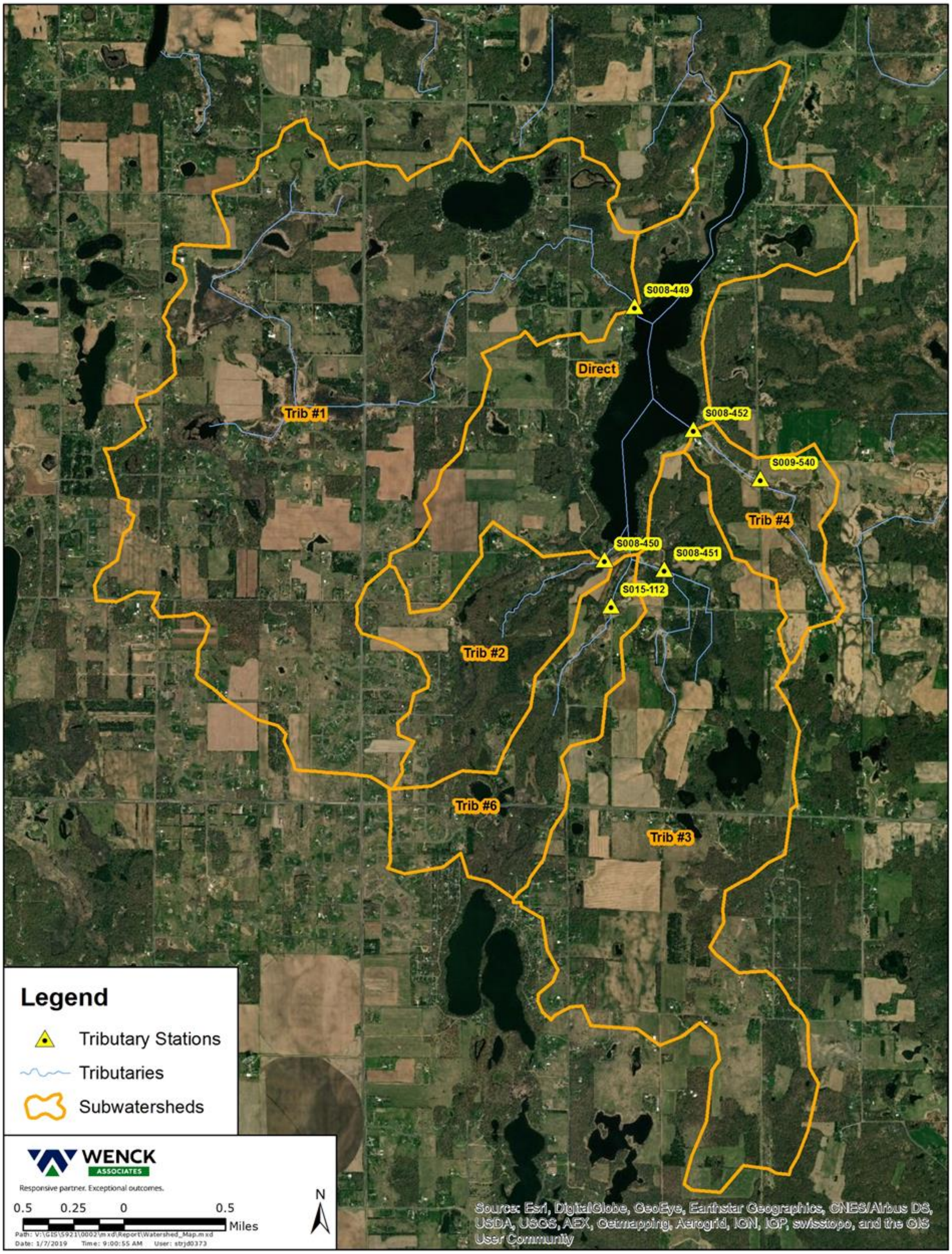

Figure 1. Blue Lake drainage area and tributary monitoring locations (Wenck 2019).

Internal Versus External Load Reductions

The Rum River WRAPS report (MPCA 2017) identified Blue Lake as a Type A (highest priority) protection lake and recommended a surface water total phosphorus (TP) concentration target/goal of 31 µg/L. This target is based on the 25th percentile of the standard deviation of Blue Lake's historical dataset. In 2019, Wenck and the Isanti Soil and Water Conservation District (SWCD) conducted a diagnostic study to better understand phosphorus loading to Blue Lake from external and internal sources (Wenck 2019). The diagnostic study used available in-lake and tributary flow and water quality monitoring data to develop a lake response model and phosphorus budget for the lake. Results of this analysis (Figure 2) suggest that external loading (i.e. drainage areas) to Blue Lake accounts for approximately 38% (508 lbs/yr) of the lake's annual phosphorus load while internal loading accounts for 45% (595 lbs/yr) of the load.

Wenck used the lake response model to estimate TP load reductions (all sources) needed to meet the 31 µg/L in-lake concentration target/goal identified in the WRAPS report. It was estimated that phosphorus loading to Blue Lake will need to be reduced by approximately 360 lbs/yr (27%) to meet the target/goal. The diagnostic study concluded that an alum treatment could reduce internal phosphorus loading to Blue Lake by as much as 500 pounds per year depending on the size of the treatment area and the amount of alum applied.

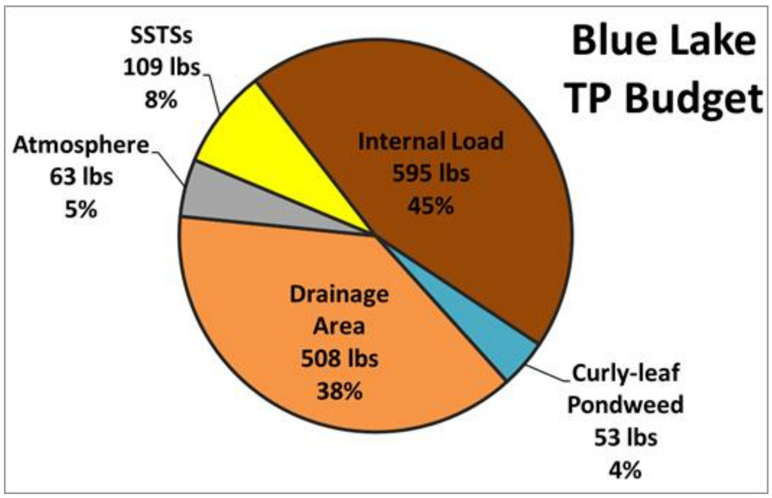

Figure 2. Blue Lake phosphorus budget (Wenck 2019)

History of Projects Completed in the Watershed

In 2017, a stormwater retrofit analysis was completed for Blue Lake which covered the lake's tributary subwatersheds as well as areas draining directly to the lake. This study identified approximately 100 best management practices (BMPs) throughout Blue Lake's drainage area. Eight projects types were identified for the urban area and 97 project types for the rural. Various types of BMPs were sited including: rain gardens, sumps, lakeshore restorations, sand filters, settling ponds, grassed waterways, water and sediment control basins, filter strips, wetland restorations, gully stabilizations, and manure management practices.. 31 of the rural practices have been determined to be unnecessary based on monitoring data. To date, Isanti SWCD and other partners have implemented eight urban BMPs throughout the watershed that were identified in the stormwater retrofit analysis. These projects were the top rated BMPs identified in terms of cost/benefit in the stormwater retrofit analysis and have reduced sediment and phosphorus loads to Blue Lake by approximately 36 lbs/yr and 16,943 lbs/yr, respectively. Below is a summary of the BMPs implemented to date:

- Tiger Street Basins (treats SE inlet)

- Tiger Street Rain Gardens and Sump
- Standford Township Public Boat Access
- 5 separate near-shore stormwater reduction projects

Additionally, several BMPs are under construction or are currently being planned in the Blue Lake watershed that will further reduce sediment and phosphorus loading to Blue Lake. These projects include:

- Additional near shore projects (to be completed with current grant)
- Cover crops and soil health improvement (to be completed with Rum 1W1P implementation funding)
- Enhanced buffers on private ditches (to be completed with Rum 1W1P implementation funding)
- Additional projects identified in the stormwater retrofit analysis (to be completed with Rum 1W1P implementation funding)

Alum Treatment Basis of Design

Anoxia Investigation

Water column processes play an important role in lake nutrient cycling and phosphorus release from the lake sediments. Lake stratification, mixing, and absence of dissolved oxygen (DO) can all affect whether a lake releases phosphorus from benthic sediments. Isanti SWCD, the Blue Lake Improvement District (LID), and other local partners have collected temperature and DO profiles approximately monthly from May through September in 2013-2018 (excluding 2015) in Blue Lake. Anoxia (i.e. DO less than 2.0 mg/L) is prevalent throughout the growing season, showing a stable water column stratification throughout the growing season. Stratification in Blue Lake typically sets up in April to early May and breaks down in late September. The minimum depth of anoxia ranged from 8-20 ft in the middle of summer (Figure 3).

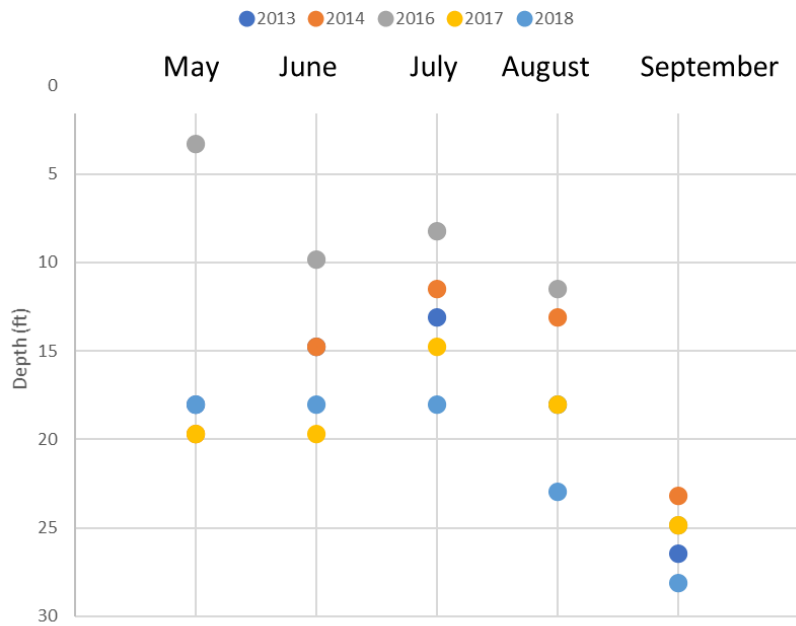

Figure 3. Comparison of minimum depth of anoxia for each month for each monitoring year

Sediment Core Collection

Intact sediment cores were collected at three locations (Figure 4) in Blue Lake in the fall of 2020 using a gravity sediment coring device equipped with an acrylic core liner (6.5-cm ID and 50-cm length). Cores extend radially from the deepest location at 30 ft (st 30), 25 ft (st 25) and 20 ft (st 20). Sediment cores from each station were transported to the University of Wisconsin - Stout Discovery Center Laboratory where they were sectioned vertically at 2-cm intervals over the upper 10-cm to evaluate variations in sediment physical-textural and chemical characteristics, including phosphorus fractionation. Phosphorus fractionation characterizes the different types of phosphorus within the sediment total phosphorus pool. In most lakes, the primary fractions that drive phosphorus release from the sediments are phosphorus bound to iron (iron-bound P) and phosphorus in the sediment porewater (loosely-bound P). Collectively, iron-bound P and loosely-bound P are referred to as redox sensitive phosphorus (redox P) as this is the form of phosphorus that is released during anoxic periods. Lakes with a high fraction of redox P have the potential to release phosphorus at a high rate. Additionally, sediment cores were analyzed in the lab for phosphorus release under anoxic conditions.

Sediment Core Results

Laboratory analyses of the sediment phosphorus fractions indicate redox P concentrations generally increased with depth with st 30 having the highest redox P concentration and st 25 and st 20 having lower concentrations (Figure 5 and 6). Redox P concentrations in the top 0-2 cm ranged from 1.96 mg/g (st 30) to 0.35 mg/g (st 20) (Figure 3). Based on our dataset of over 100 lakes in Minnesota, the median concentration of redox P in lakes is 0.37 mg/g. Generally, we have found that lakes with redox P concentrations greater than 0.37 mg/g have higher phosphorus release rates which is consistent with the release rate results (Figure 7). The cumulative P mass in the top 10 cm (Figure 6) further demonstrates the accumulation of redox P in the deepest contour of the lake (st 30). These data suggest that the sediments analyzed for Blue Lake have accumulated phosphorus that is capable of releasing at a high rate into the water column.

Lab measured anaerobic (anoxic) phosphorus release rates for the three Blue Lake stations ranged from 4.56 mg/m^2/day (St 20) to 9.03 mg/m^2/day (St 25) (Figure 7). These rates are elevated (approx. 75th percentile for st 25 and st 30) compared to other Minnesota lakes in our sediment database. The Blue Lake Diagnostic Study (Wenck 2019) estimated a sediment release rate of 9.8 mg/m^2/day. This estimate was based on the observed rate of change in hypolimnetic TP concentrations during the summer growing season (for years 1988, 1989 and 2014) and is consistent with the lab measured rate results presented here.

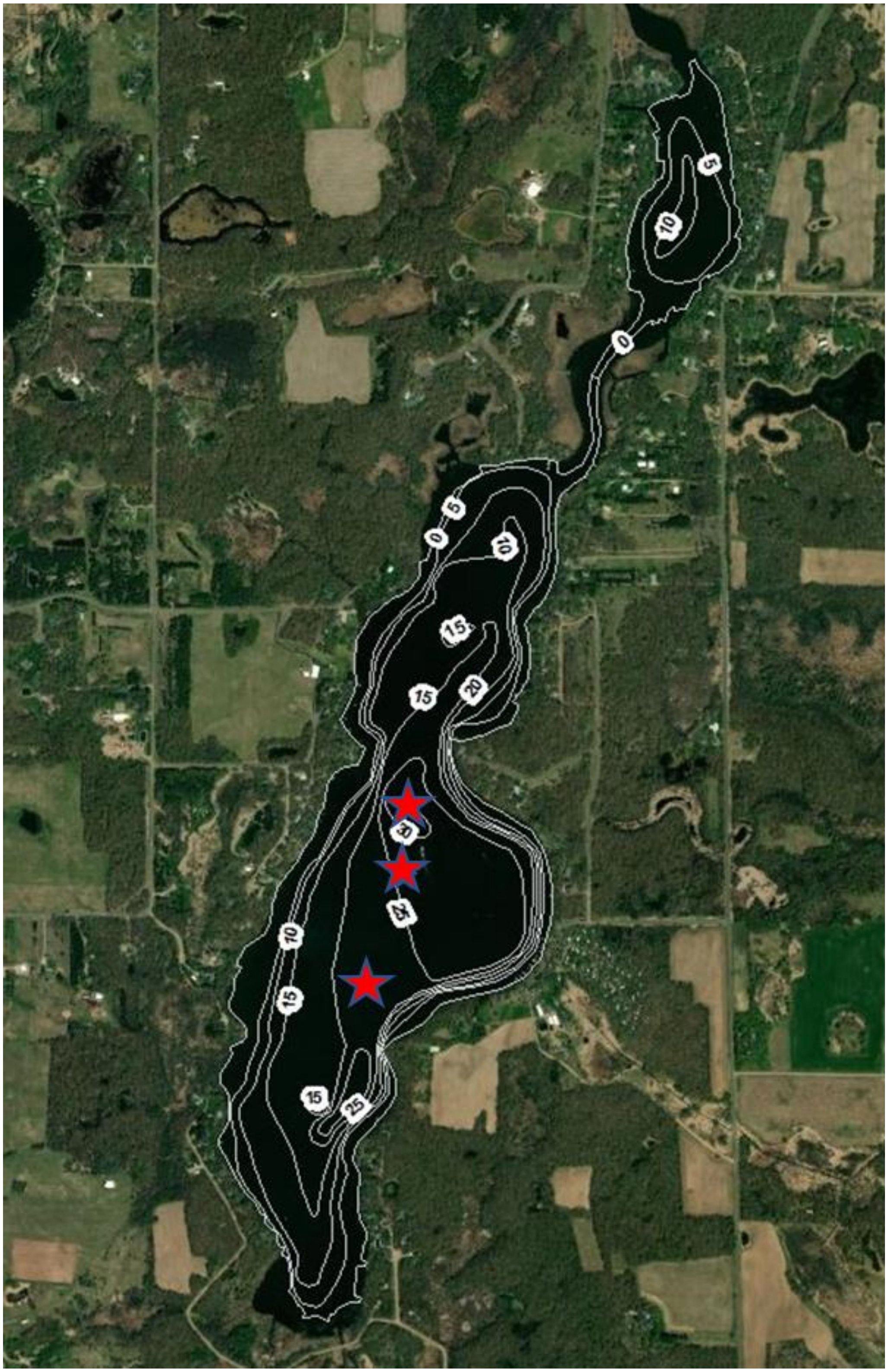

Figure 4. Blue Lake sediment core locations

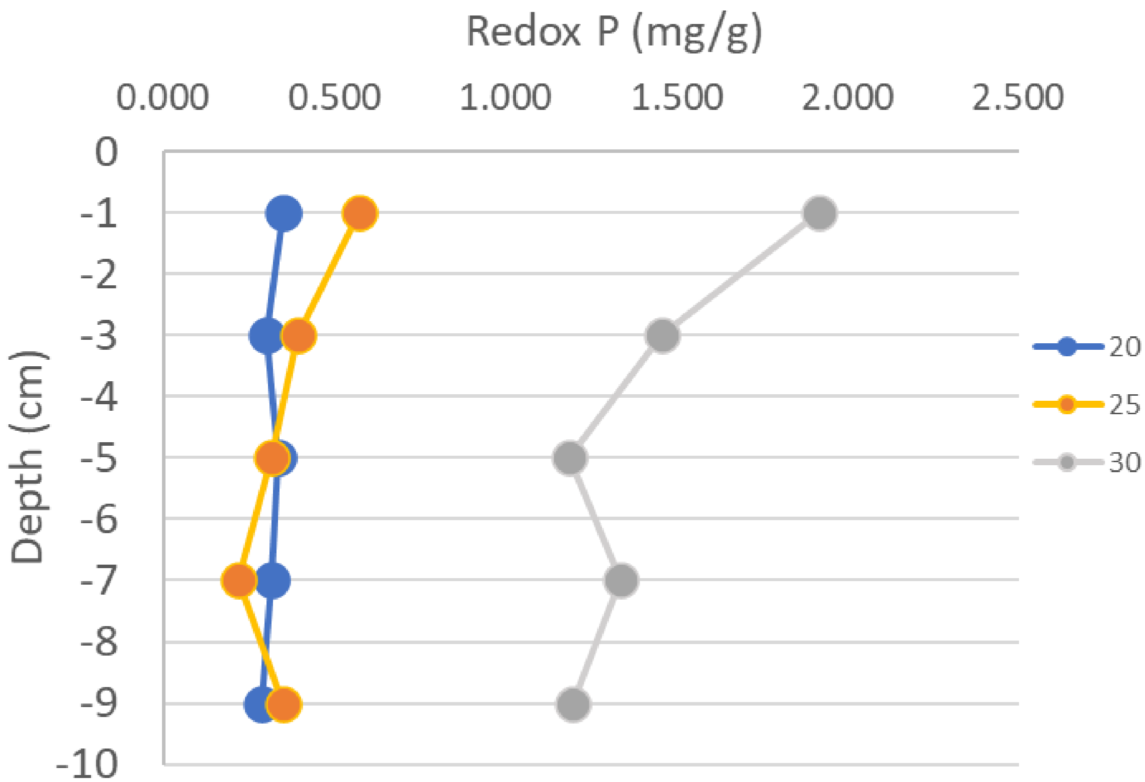

Figure 5. Blue Lake 2020 sediment redox P vertical profiles.

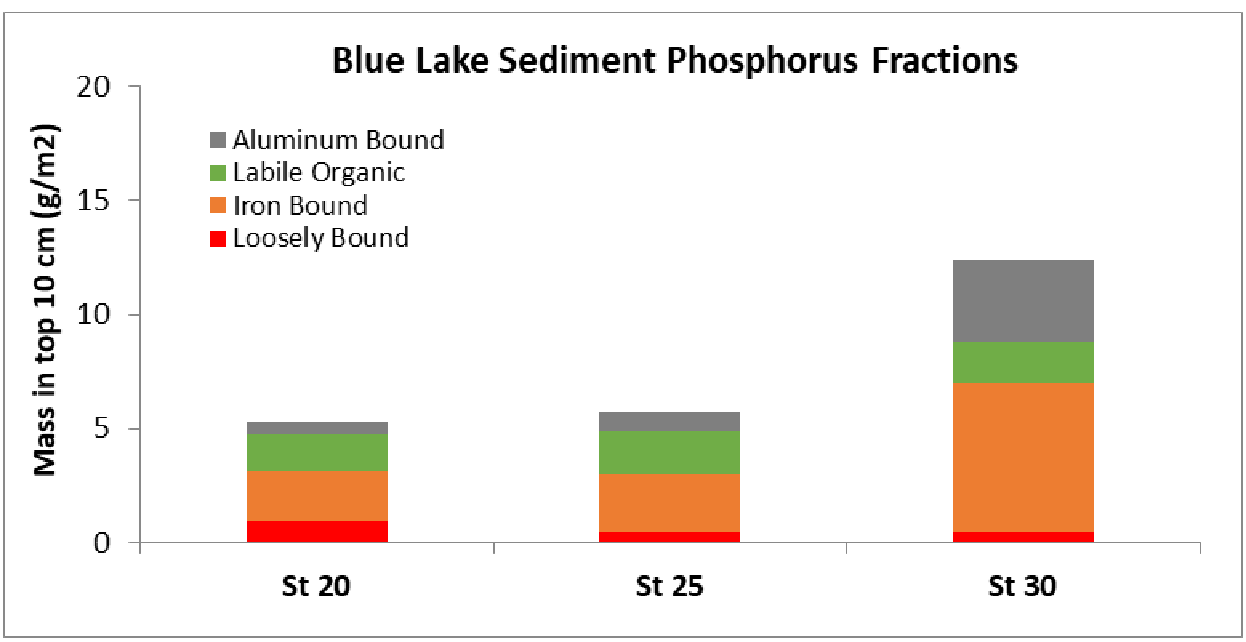

Figure 6. Total mass of each phosphorus fraction in the top 10 cm of sediment

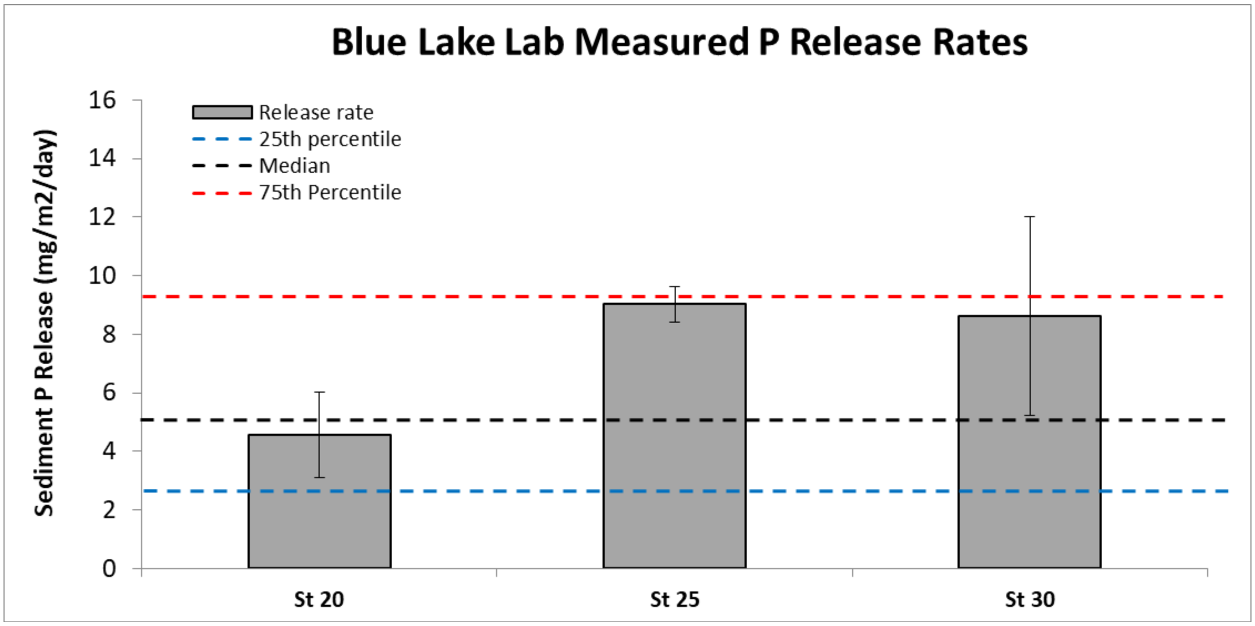

Figure 7. Blue Lake lab measured P release rates compared to other Minnesota lakes

Alum Treatment Design and Cost Benefit Analysis

Three main factors are considered when determining whether to treat a lake with alum: 1) the rate at which phosphorus is releasing from the sediment under anaerobic conditions; 2) the depth and area of lake experiencing anoxia; and 3) redox-P concentrations in the lake's sediments. The lab-measured sediment phosphorus release rates confirm anaerobic P release is elevated in Blue Lake (Figure 7). The DO data collected in 2013-2018 indicates that the 8-28 ft depth contour experiences varying degrees of low DO (anoxic) conditions (Figure 3). The sediment chemistry profiles (Figure 5) suggest all three sediment cores exhibited elevated redox-P concentrations in the top 6 cm. Based on this information, as well as, the results of the 2019 diagnostic study, it is recommended that an alum treatment be pursued to manage internal loading in Blue Lake.

Aluminum sulfate (alum) is one of the most common chemicals used for sediment-phosphorus inactivation as the absorption of phosphorus to aluminum is very stable under environmental conditions and provides a long-term sink of phosphorus in the lake. Alum is applied to lakes by injection of liquid alum just below the lake water surface. The alum quickly forms a solid precipitate (floc) and settles to the bottom of the lake, which converts highly mobile sediment phosphorus (redox-P) to an immobile phosphorus fraction (aluminum bound-P). This process reduces sediment phosphorus release rates, and ultimately reduces internal phosphorus loading in lakes. The mass of aluminum needed to convert redox-P to aluminum bound-P in each treatment zone was calculated using an empirically derived relationship between redox-P concentration and the ratio needed to inactivate the elevated redox-P (James et al, 2015).

The large amounts of alum applied during one application has the potential to drive pH below 6, causing aquatic toxicity concerns. Buffered alum applications (2:1 ratio of alum +sodium aluminate) help bolster the ambient alkalinity to reduce acidification and the associated risks. Additionally, splitting alum doses into a minimum of two applications of a buffered alum solution further minimizes this risk. A multiple dose approach also has the potential to 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 redox-P.

The DO profile data and the sediment core data allowed Wenck to develop a thorough cost/benefit analysis of three different scenarios in which alum is applied to the 15+ foot contours, the 20+ foot contours, and the 25+ foot contours (Figure 8). The diagnostic study stated a 360 lbs/yr reduction goal (all sources) in order for Blue Lake Lake to meet the 31 µg/L surface water quality target identified in the WRAPS report. In Figure 8, the cumulative P reduction (orange line) is plotted per depth contour. The cumulative phosphorus load reduction from the 2020 analysis peaks at approximately 700 lbs/yr at the 15 ft contour. However, the cost per pound removed is most advantageous, while still achieving the full 360 lbs/yr load reduction goal, at the 20+ foot contours (590 lbs/yr) and at the 25+ foot contours (381 lbs/yr).

The following assumptions were made for the cost/benefit scenarios highlighted in Figure 8:

- Alum would be applied at a rate to deactivate redox P (based on James et al, 2015) in the top 6 cm of the sediment over the course of two applications
- A buffered alum treatment (i.e. two parts alum to one part sodium-aluminate) would be conducted to reduce the potential for pH reductions below 6 which can be stressful or toxic for aquatic organisms
- Cost estimates were provided by HAB Aquatic Solutions, LLC which assumed:
    - COVID-19 is not significantly affecting alum and mobilization costs at this time
    - Cost estimates include both mobilization ($35,000) and alum product cost
- Cost estimates for the HAB's 2021 cost estimate include a 15% contingency to account for potential future changes in product and/or mobilization costs
- Follow-up sediment monitoring (details below) would be conducted between the first and 2nd dose to refine the 2nd dose treatment and maximize efficiency ($15,000)
- Final design and engineering (details below) were included in the cost estimates ($20,000)

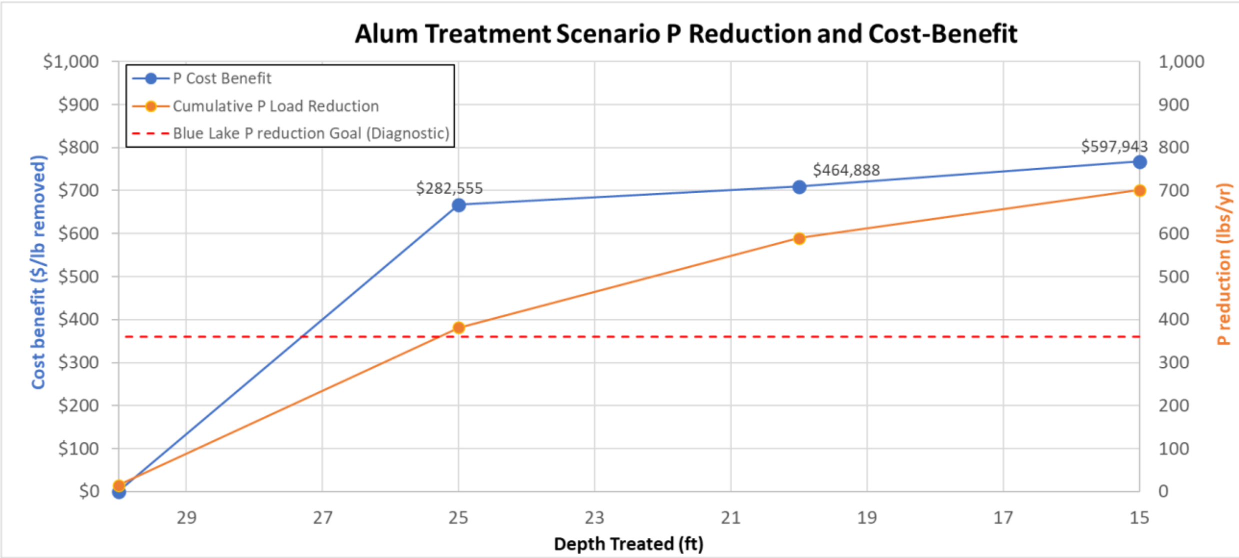

Figure 8. Blue Lake alum treatment cost-benefit analysis of three different scenarios
Figure Notes:

- The cumulative load reduction (orange line), cost-benefit (blue line), and total estimated treatment cost (data labels along blue line) are for both doses using assumptions stated above
- The cumulative load reduction and cost-benefit were developed using the 2020 data
- Total cost includes material cost ($2.00 Aluminum Sulfate and $5.00 Sodium Aluminate), Mobilization ($35,000), follow up monitoring ($15,000), engineering and contract management ($20,000), final design and engineering oversight ($20,000), and a 15% contingency

Alum Treatment Recommendations and Costs

The cost benefit analysis (Figure 8) highlights the cumulative cost per pound of P removed for each depth contour. Both the remediated internal load and the subsequent cost increase as the application area increases, thus the recommendation is based on balancing extending treatment area at increased cost.

As described above, Wenck recommends the buffered alum treatment be separated into two doses with follow up sediment and water quality monitoring. We recommend that the follow-up sediment cores be collected at least one year after the first dose application and cores be collected at similar locations to this study and include the following parameters: anaerobic phosphorus release, moisture content-bulk density, loss-on ignition organic matter, total aluminum, aluminum bound phosphorus, and redox-sensitive phosphorus. Wenck also recommends surface and hypolimnetic water quality monitoring in years following each treatment to confirm water quality improvements in Blue Lake and assess if future applications will need to expand to shallower regions of the lake.

Wenck presents two treatment options based on the cost benefit analysis, 1) treating 20+ foot contour; and 2) treating 25+ foot contour. Based on our analysis, both options 1 and 2 have very good cost-benefit and would achieve the total load reduction goal identified in the feasibility study. Although the 15+ foot contour scenario would achieve a significant load reduction, we considered this option less desirable at this time due to its higher cost-benefit and total cost. The cost estimates for options 1 and 2 are presented in Table 1 and are based on conversations with alum applicator HAB Aquatic Solutions and the assumptions listed above. The follow up sediment monitoring will be instrumental in determining a refined second dose that will optimize load reduction and the remaining grant funding. Wenck typically targets the first dose for the highest impact and then uses the follow up monitoring to further refine the application and expand the scope, if needed. The cost estimate also includes final design and engineering oversight which includes assisting local partners with bidding, permitting, specs, and application observation and monitoring.

Table 1. Alum application cost estimates for Options 1 and 2

	DEPTH (FT)	AREA (ACRE)	DOSE (AL g/m^2)	ALUMINUM SULFATE (GAL)	SODIUM ALUMINATE (GAL)	COST
Option 1	20-31	73	113	65,768	32,884	$ 299,250.00
Mobilization						$ 70,000.00
Sediment monitoring						$ 15,000.00
Final design & engineering						$ 20,000.00
15% Contingency						$ 60,638.00
					TOTAL	**$ 464,888**
Option 2	25-31	35	111	30,923	15,461	$ 140,700.00
Mobilization						$ 70,000.00
Sediment Monitoring						$ 15,000.00
Final design & engineering						$ 20,000.00
15% Contingency						$ 36,855.00
					TOTAL	**$ 282,555.00**

* Material costs are based on unit application price assumptions of $2.00/gal for $Al_2(SO_4)_3$ and $5.00/gal for $NaAlO_2$
** the 15% contingency includes the entire cost (material, mobilization, monitoring, and final design)
***Both Options 1 and 2 assume the alum treatment would be split across two applications with follow-up monitoring in-between each application. Thus, each individual dose would be approximately ~$224,944 (Option 1) and ~$133,778 (Option 2), plus $15,000 for sediment monitoring

Alum Treatment Longevity

Huser et. al. (2015) compiled and analyzed data for 114 lakes treated with alum to identify factors driving longevity of post-treatment water quality improvements. They identified three key factors that affected treatment longevity: 1) total alum dose; 2) lake morphometry (as measured by the Osgood Index); and 3) watershed to lake area ratio. Using multiple linear regression analysis, they constructed a partition model to estimate treatment longevity using the three factors identified above (Figure 9). Thus, this model can be used to estimate the longevity of the proposed alum treatment options for Blue Lake using the following inputs:

- Total alum dose = 113 g/m^2 (option 1) and 111 g/m^2 (option 2)
- Osgood Index = $Zm/(A)^{0.5}$ = 4.2; where
  - Zm = mean depth (meters) = 4.3

   - A = lake surface area (km^2) = 1.06
- Watershed to lake area ratio = 26

Results of the longevity partition model suggest that the estimated longevity of the proposed treatments for Blue Lake range from 5-10 years. It should be pointed out, however, that Blue Lake's Osgood index is below the 5.7 breakpoint in the partition model (Figure 9). An Osgood Index of 6 generally represents the point where lakes are stratified or polymictic, with lower ratios being polymictic (Osgood 1998). Blue Lake, despite an Osgood Index of 4.2, demonstrates strong stratification for much of the summer growing season based on the available temperature/DO data. Thus, it could be argued that Blue Lake is truly a stratified, dimictic lake and therefore alum longevity, according to the partition model, could be as high as 23 years.

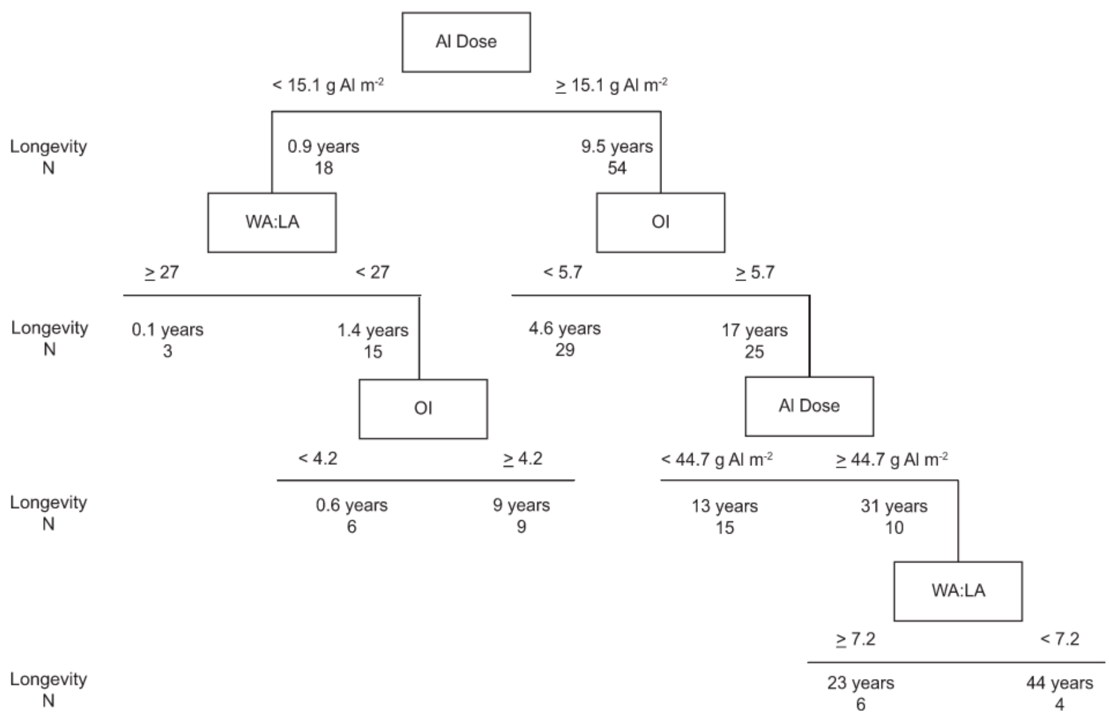

Figure 9. Partition model to estimate alum longevity (Huser et. al. 2016)

Due to the uncertainties in the alum longevity partition model presented above, an alternative analysis was performed to estimate how long it will take to bury the alum layer after the alum application. The important factor to consider for this analysis is how much P sedimentation is occurring and not just overall sedimentation. To do this, we focused on the estimated P sedimentation rate from the lake response model used in the Blue Lake Diagnostic Study (Wenck 2019). The Canfield-Bachmann sedimentation equation (Canfield et al, 1981) was used to estimate how long it would take to replace inactivated phosphorus in the top 5 cm of sediment. It is important to note that this analysis should not be interpreted as the exact life of an alum treatment, but rather to assess whether a treatment will be quickly buried based on phosphorus settling and if additional watershed load should be reduced prior to an alum treatment.

We ran two scenarios to assess alum burial for proposed alum treatment options 1 and 2. The first scenario assesses the alum burial based on current watershed loading conditions as presented in the Blue Lake Diagnostic Study. The second scenario assessed alum burial assuming watershed load reductions are reduced by 16% to an average inflow total phosphorus concentration of 100 µg/L (currently average is 119 µg/L). This exercise suggests that burial of the alum layer to 5 cm ranges from 13 years to 17 years depending on which alum treatment option is pursued and the degree of future watershed phosphorus load reductions (Table 2). In general, watershed load reductions of 16% would improve estimated burial time by approximately two years for option 1 and one year for option 2.

Table 2. Estimated alum burial (5 cm) for proposed treatment options

WATERSHED LOADING SCENARIO	ALUM TREATMENT OPTION	ALUM BURIAL (YEARS)
Current Watershed Load Rate	1	15
	2	13
100 µg/L Watershed Load Rate	1	17
	2	14

In-lake Response to Alum Treatment

Reducing internal loading in Blue Lake will achieve significant phosphorus load reductions which, in turn, should increase water clarity and light availability to the submerged vegetation community. The exact response of the vegetation community to improved water quality conditions is not certain and difficult to predict, however, increased plant biomass and coverage within the lake can be expected. The availability of propagules and seeds, the amount of herbivory and the influence of current and remnant populations will largely influence which species will occur and respond to the change in light conditions. The preparation for and planning of a vegetation response to the alum treatment will be an important step as a conflict with recreational users may occur where vegetation reaches the water surface and impedes swimming and boating activities.

Aquatic vegetation surveys have been completed periodically on Blue Lake. Eurasian watermilfoil (EWM) has never been detected in Blue Lake, however curly-leaf pondweed (CLP) is present and has been actively managed by the LID. Blue Lake exhibits fair diversity in native aquatic vegetation (currently meeting state thresholds) and it is expected that native species will likely become more abundant as clarity improves. The lake is 51% littoral, and it is strongly recommended that lake residents and other users be provided education materials regarding potential vegetation response to alum treatments and improved water clarity. Historic DNR fish surveys have noted very low levels of common carp, and therefore it is unlikely that sediment disturbance by common carp would decrease the longevity of the alum treatments or reestablishment of native vegetation.

It is recommended that the local partners, in cooperation with the DNR, develop a vegetation management plan for Blue Lake that will be used to guide vegetation management decisions for the first few years following the alum treatment. This plan should include a monitoring plan and a decision framework for if/how management should proceed depending on monitored response of the vegetation community. Prior to the fist alum dose, it is highly recommended that the DNR or local partners conduct at least one pair of comprehensive early- and late-season vegetation surveys to serve as pre-treatment “baseline” conditions for the vegetation management plan.

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