Keller Lake In-Lake Treatment Feasibility Study

Prepared for
Black Dog Watershed Management Organization (BDWMO)

August, 2018

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Certifications

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the state of Minnesota.

8-15-2018

Gregory John Wilson
PE #: MN 25782

Date

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1.0 Project Background and Purpose

On behalf of the Black Dog Watershed Management Organization (BDWMO), Barr Engineering Company (Barr) completed this study to evaluate the feasibility of performing an aluminum sulfate (alum) treatment of Keller Lake to improve lake water quality. This feasibility study includes sediment core collection/analysis, determination of an alum dosage plan, and compilation/consolidation of supporting information for a BWSR Clean Water Fund grant application to complete in-lake management practices.

Figure 1-1 shows the watershed divides and drainage patterns for Keller Lake, including subcatchments. Table 1-1 shows the lake morphology/depth and other watershed/water body characteristics for the lake (as published in the TMDL report).

Table 1-1 Lake Morphology and Watershed Characteristics

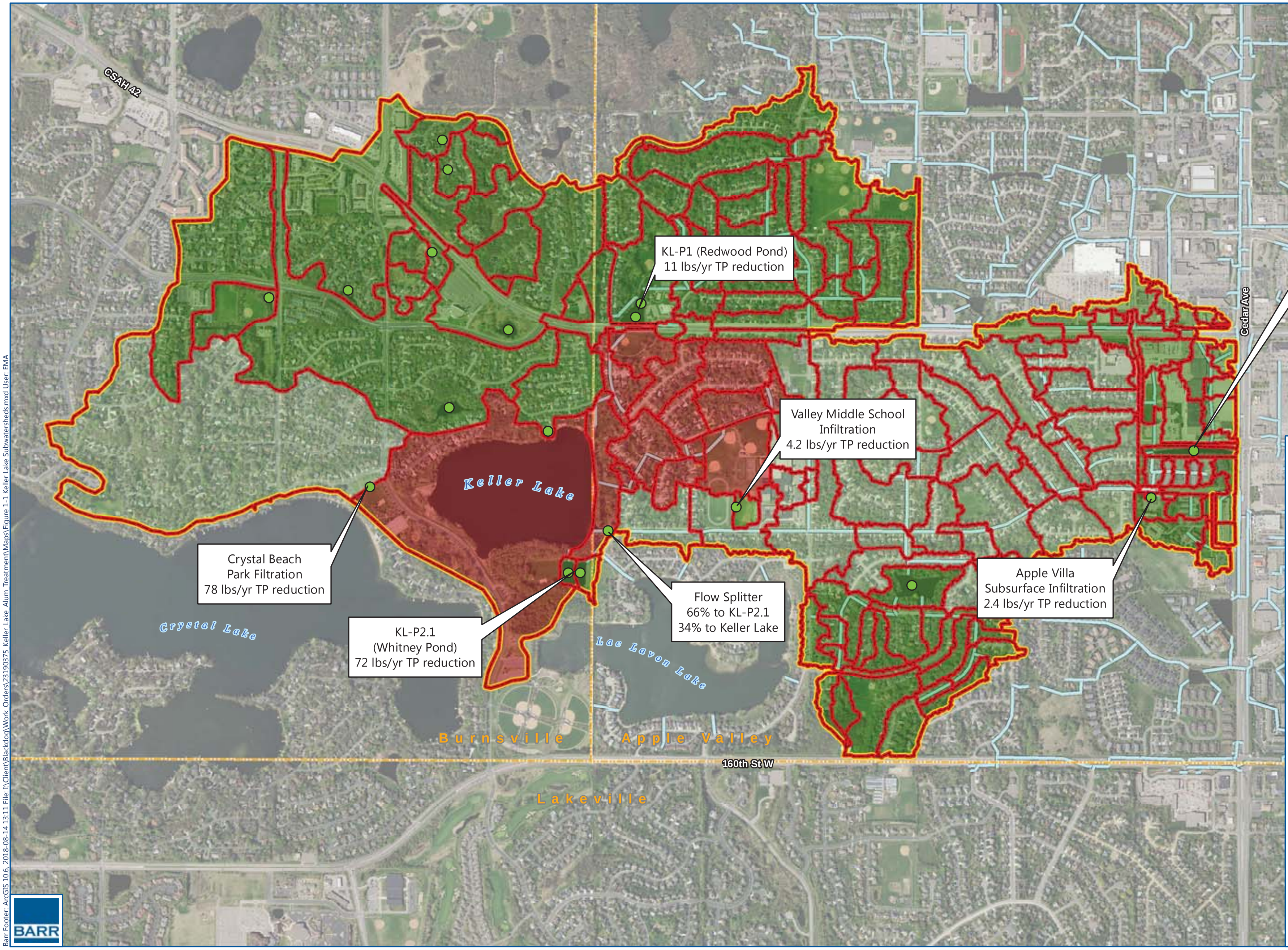
Parameter	Keller Lake
Surface Area (acres)	52
Average Depth (feet)	4.8
Maximum Depth (feet)	8
Residence Time (years)	0.3
Direct Drainage Area (acres)	1,447

1.1 Summary of Lake TMDLs and Past Studies

In preparing this study, Barr systematically reviewed reports and data collected on Keller Lake, including the total maximum daily load (TMDL) report and implementation plan, sustainable lake management plans, storm sewer and treatment practice plans, proposed redevelopment plans, fish and aquatic plant survey reports, bathymetric surveys and internal loading analyses.

The TMDL report (Barr, 2011) estimated that internal load accounted for 40% of the annual phosphorus load during an average year and called for the following total phosphorus load reductions for Keller Lake:

- 52% reduction in the external load (wasteload allocation, or WLA) from the tributary area to Keller Lake
- The load allocation (LA) represents a 77% reduction in the existing portion of the phosphorus load (that is almost entirely made up of internal load)



● BMP

🟨 Keller Lake Watershed

🟥 Subwatershed

Storm Pipe

Municipal Boundary

Subwatershed Treatment

Partially-Treated

Treated

Untreated

Note: Intensive street sweeping 2.1 lbs/yr TP reduction

N

0 550 1,100
Feet
1 inch = 1,100 feet

KELLER LAKE
DRAINAGE AREAS
Keller Lake Alum Treatment
Black Dog WMO

FIGURE 1-1

BARR

Anoxic sediment phosphorus release rates were previously estimated in the TMDL. The release rate estimates were based on phosphorus fractionations (or the fractions of phosphorus attached to individual constituents in the sediment) and a relationship developed by Pilgrim et al. (2007). The release rates were then used to calibrate the internal loading for the lake water quality modeling in the TMDL study.

The results of lake and watershed modeling from the TMDL study and implementation planning were used for this feasibility analysis.

1.2 Summary of Recent Water Quality Monitoring

Figures 1-2, 1-3 and 1-4 show how average summer total phosphorus, chlorophyll-a and Secchi disc transparency, respectively, have varied for Keller Lake. The monitoring data shows that the lake occasionally met each one of the criteria while the ferric chloride treatment system was in operation, but has not been consistently meeting any of the three shallow lake criteria during the past ten years.

Figure 1-2 Summer Average (June-Sept.) Total Phosphorus Concentrations (µg/L)

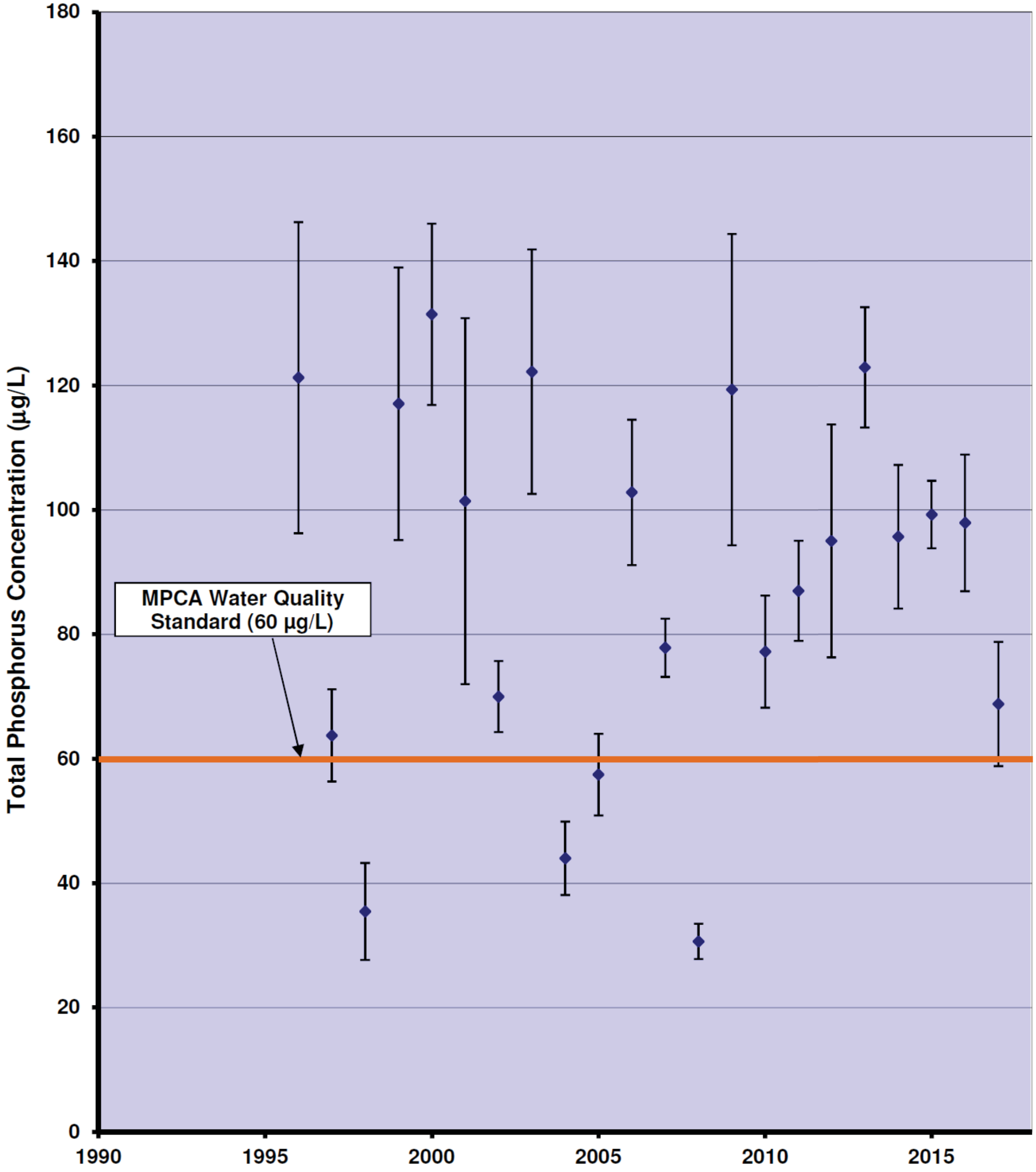


Figure 1-3 Summer Average (June-Sept.) Chlorophyll-a Concentrations (µg/L)

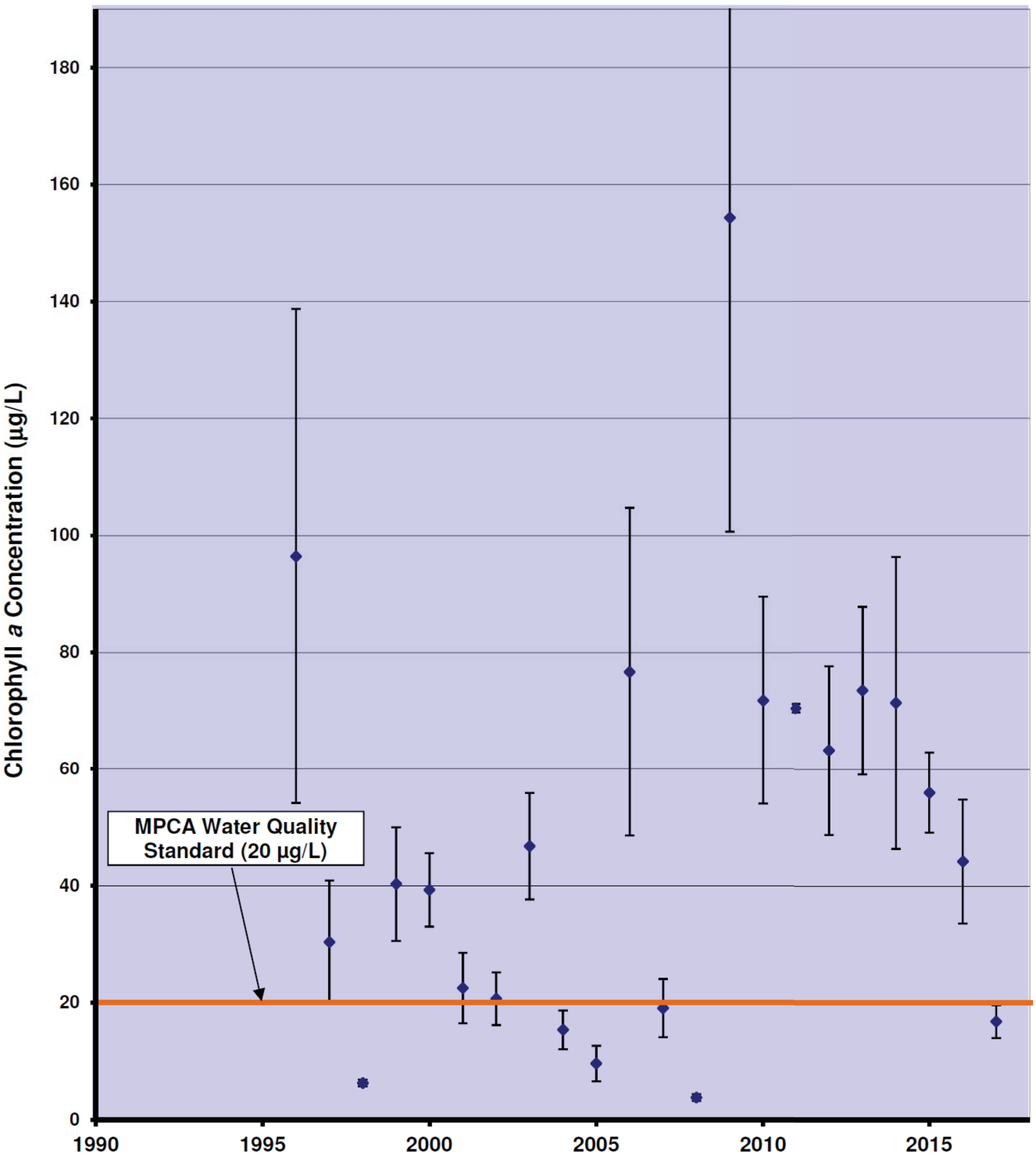
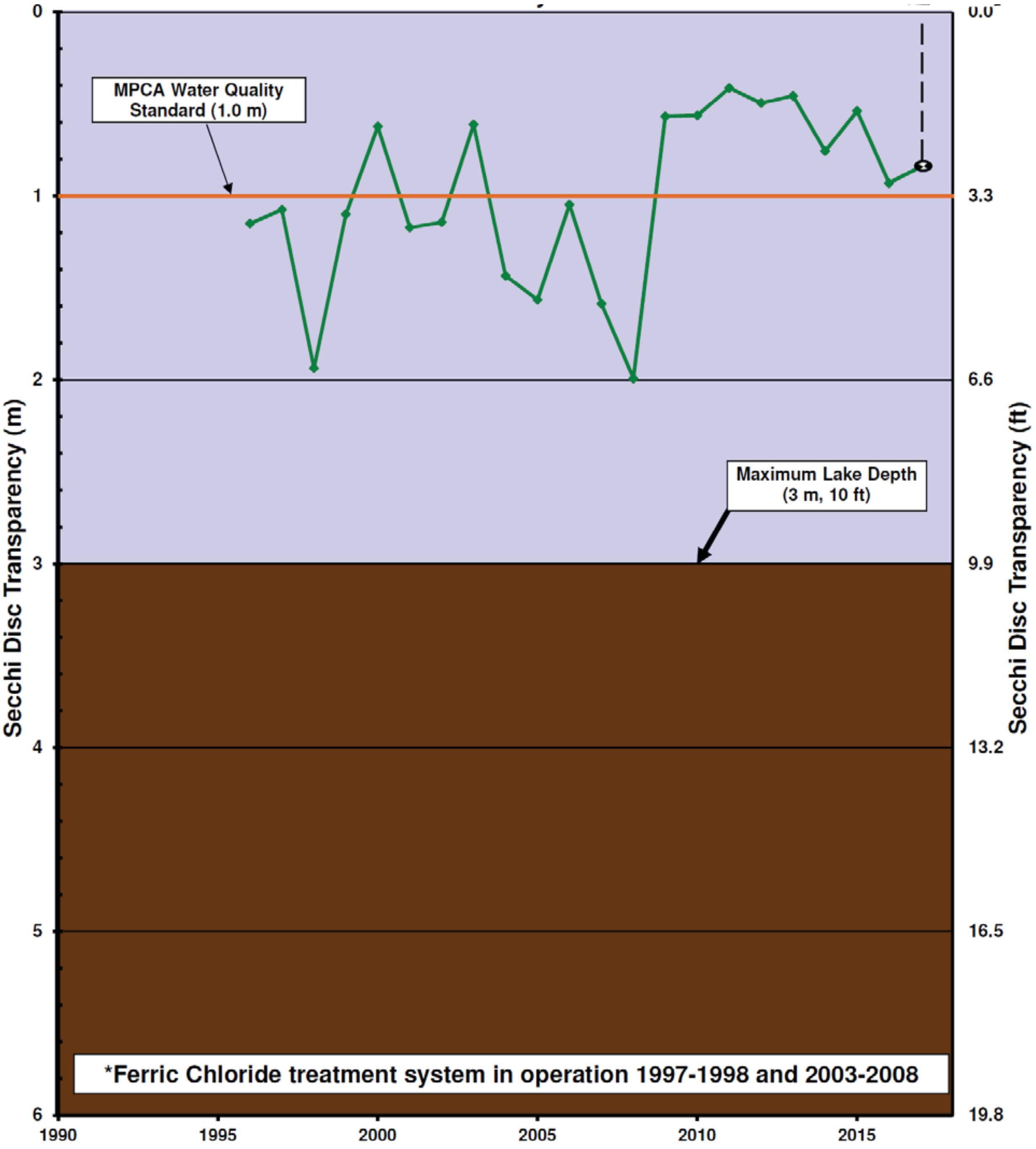


Figure 1-4 Summer Average (June-Sept.) Secchi Disc Transparency (meters)



1.3 Current Analysis of Lake Sediment Cores

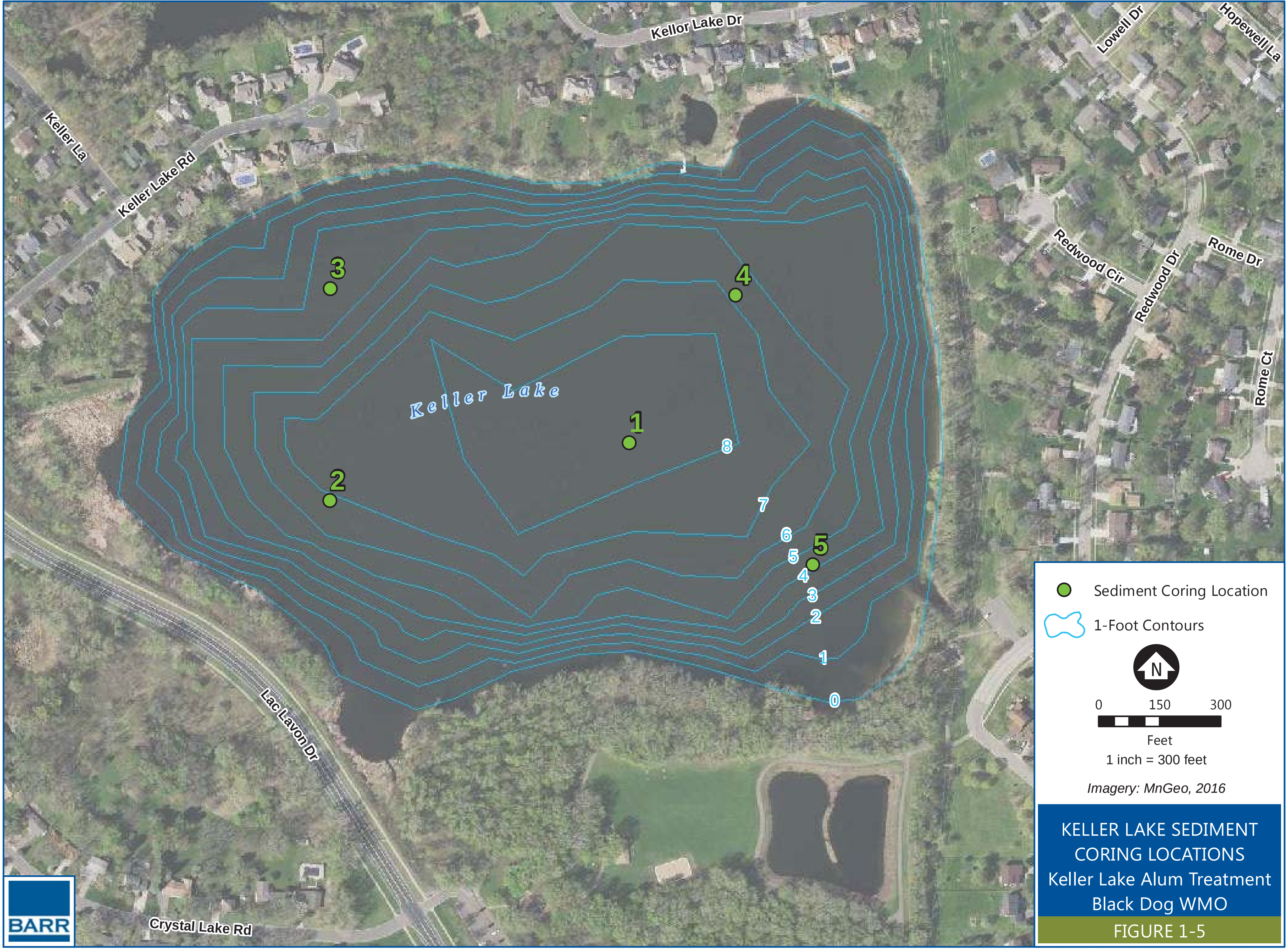
Phosphorus from stormwater over time accumulates in the bottom sediments of lakes. During the spring and fall, this phosphorus is largely tied-up in the sediments, but during the warm summer months the phosphorus can be released from bottom sediments and move upward into the water column. This can lead to summer and sometimes early fall algal blooms. Not all of the phosphorus that is incorporated into bottom sediments releases into the water column. Phosphorus in sediment is typically attached to something and can be found in the following forms (often referred to as "fractions"): calcium-bound phosphorus (Ca-P), aluminum-bound phosphorus (Al-P), iron-bound phosphorus (Fe-P), and organically-bound phosphorus (Org-P). Ca-P and Al-P are largely inert and are immobilized in the bottom sediment. Org-P decays over time and releases phosphorus into the water column over the course of several years. Fe-P is the phosphorus form that readily releases into the water column during warm summer months as oxygen is depleted in the sediment.

The primary purposes of collecting sediment cores is to quantify the amount of Fe-P and Org-P in sediment. The more Fe-P and Org-P in sediment, the more alum will need to be applied to immobilize these phosphorus fractions. In general, aluminum treatment (either as alum or sodium aluminate, for example), forces the Fe-P to bind to aluminum and form Al-P (the inert form of aluminum). In most cases, alum treatments are designed to also provide excess aluminum in sediment, which can then bind phosphorus years after the treatment. When aluminum in the form of alum or other solutions is added to a lake, it forms an aluminum hydroxide floc that settles to the lake bottom. The aluminum floc will mix into the top few to several inches of sediment over time and becomes diluted. The sediment phosphorus data collected at different depths was used to help determine the expected sediment mixing depth for each core location.

The total mass of Fe-P and Org-P in the actively mixed layers (upper few inches) of sediment were determined for each lake. Alum doses were then calculated for each lake by determining an appropriate Al:Al-P ratio, following techniques designed by Pilgrim et al. (2007).

Five sediment cores were collected on May 10, 2018 in Keller Lake (see Figure 1-5). Each sediment core was sliced into 2-cm sediment samples down to a depth of 10 cm, and 4 cm intervals were collected down to 18 cm or deeper. Sediment samples were returned to the Barr Engineering laboratory and analyzed for the phosphorus fractions identified previously. In general, Fe-P concentrations in the sediment of Keller Lake were low, while organic-P was high. Phosphorus concentrations and physical characteristics were relatively similar among all five cores of Keller Lake (see Figure 1-6).

Barr Footer: ArcGIS 10.6, 2018-08-15 07:48 File: I:\Client\Blackdog\Work_Orders\23190375_Keller_Lake_Alum_Treatment\Maps\Figure 1-5 2018 Sediment Coring Locations.mxd User: gjw



● Sediment Coring Location

1-Foot Contours

N

0 150 300

Feet

1 inch = 300 feet

Imagery: MnGeo, 2016

KELLER LAKE SEDIMENT CORING LOCATIONS

Keller Lake Alum Treatment

Black Dog WMO

FIGURE 1-5

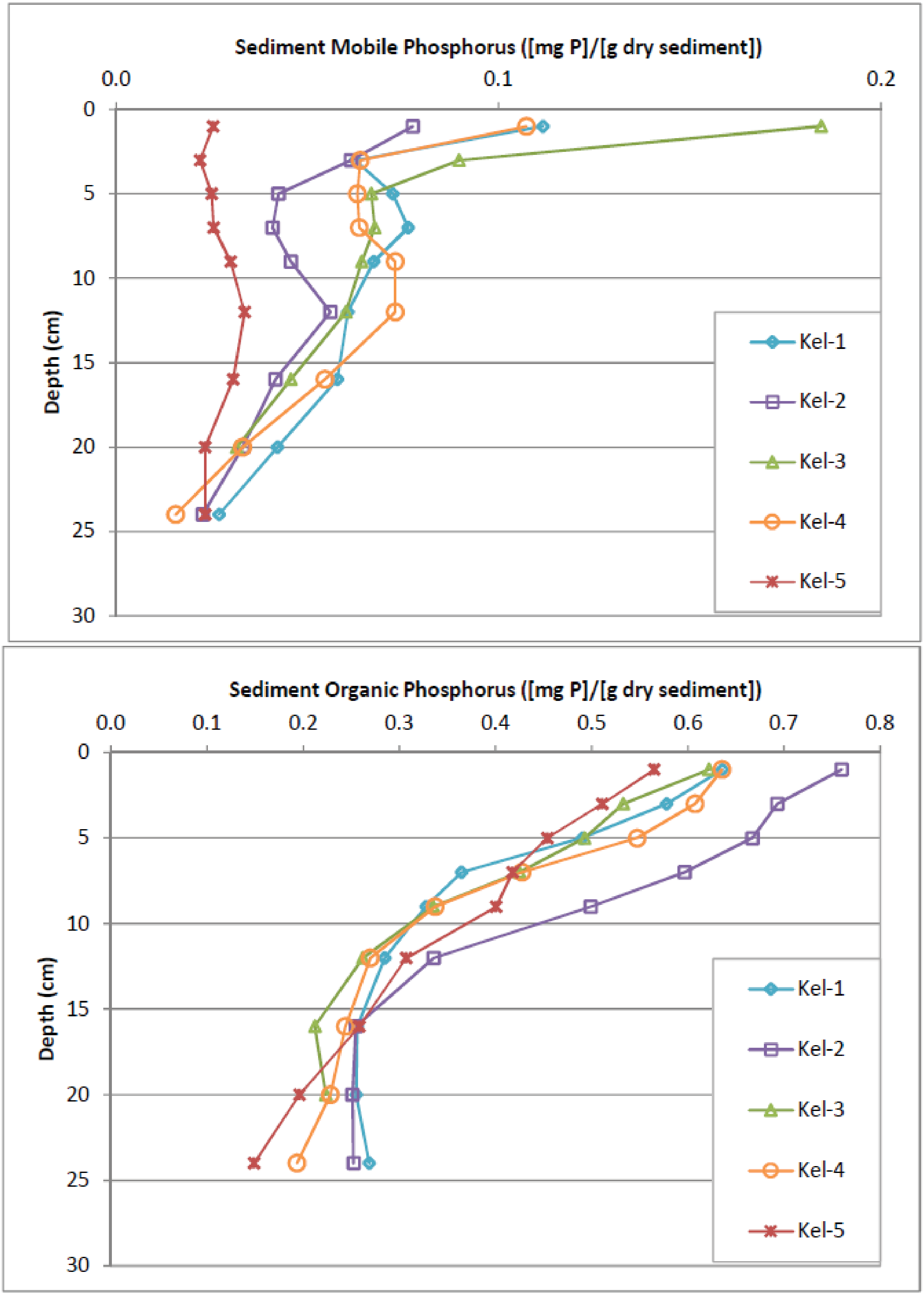


Figure 1-6 **Results of Keller Lake Sediment Phosphorus Fractionations**

2.0 Phosphorus Loading and BMP Analysis

A key component to performing diagnoses is selecting a rigorous approach to evaluating potential water quality benefits. The simplified lake and watershed modeling approach used in the 2011 TMDL project did not account for intra-annual variations in lake water quality as it lumps parameters at an annual time scale and would not have distinguished internal phosphorus loading sources from watershed sources during the critical (summer) conditions for water quality impairment. Therefore, it is expected that load reductions associated with in-lake management practices will result in greater water quality improvements than those implied by the TMDL allocations for external and internal phosphorus loads.

2.1 Existing Management Practices

2.1.1 Watershed Best Management Practices (BMPs)

Figure 1-1 shows the locations in the Keller Lake watershed where the cities have previously implemented BMPs for stormwater treatment with structural measures. Also highlighted on Figure 1-1 are areas of the watershed receiving full, partial, or no water quality treatment prior to discharging to Keller Lake. Based on an evaluation of the GIS mapping (see Figure 1-1), it is estimated that 84% of the watershed is currently receiving stormwater treatment of the runoff phosphorus loading on an annual basis.

Table 2-1 summarizes the BMPs implemented since the completion of the Keller Lake TMDL and the estimated annual phosphorus removals. The estimated total phosphorus removals achieved by projects implemented since the completion of the TMDL is approximately 159 pounds per year. To achieve the total phosphorus reduction required by the TMDL, the city of Apple Valley (and Dakota County) needs to further reduce the phosphorus loading to Keller Lake by 57 pounds per year, based on updated P8 modeling (Barr, 2017). Following the implementation of the Crystal Beach Park filtration project, the City of Burnsville is currently meeting its portion of the TMDL WLA.

Table 2-1 Expected Performance of BMPs Implemented Since Completion of Keller Lake TMDL

BMP	Estimated Annual TP Removal (lbs/yr)[1]
Infiltration Basin at Southview Elementary/Valley Middle School	4.2
Subsurface Infiltration System at Apple Villa Apartments (pending)	2.4
KL-P2.1 (Whitney Pond)	72.4
Intensive Street Sweeping (in Apple Valley)	2.1
Crystal Beach Park Filtration	78
Total TP Removal (Since Completion of TMDL)	**159.1**

[1]—Based on critical water year (2006) modeling from Keller Lake TMDL

2.1.2 Past In-Lake Treatment Measures and Aquatic Invasive Species Control

Other in-lake treatment measures completed within the past 15 years included herbicide treatments in the spring of 2017 and 2018 to control curlyleaf pondweed and mechanical harvesting each year since 2004.

3.0 Social Implications of In-Lake Management

The goal of past stakeholder engagement efforts was to involve the public, regulatory agencies and BDWMO/city staff in the process of identifying and vetting management solutions for each lake. The City of Burnsville met with Keller Lake residents three times since the completion of the TMDL study, most recently on February 28, 2017. The group acknowledged concerns about the presence of curlyleaf pondweed and understands that improving water quality could result in more aquatic plant growth. However, Keller Lake is shallow enough that plants already can grow over the entire lake bed.

In addition to the recent discussions with the stakeholders, questions/comments were also raised about the following in-lake management topics addressed as a part of the TMDL study public notice:

- Effectiveness of alum treatment in the presence of benthivorous (bottom-dwelling) fish communities (e.g., carp)
- The relationship between water clarity and macrophyte (aquatic plant) growth

Based on follow-up discussions with staff from State agencies and BDWMO staff, it is recommended that the BDWMO work with the Minnesota Department of Natural Resources to complete a Lake Vegetation Management Plan (LVMP) and implement in-lake management practices (see Section 4). Public outreach efforts regarding in-lake management will continue into the fall of 2018.

4.0 Summary

4.1 Water Quality Improvement Options

As discussed in Section 2.1, and shown in Figure 1-1, there are several existing BMPs in the watershed. As previously discussed, the City of Burnsville is currently meeting its portion of the TMDL WLA. An evaluation of the Apple Valley subwatersheds (Barr, 2017) revealed that there is one high-priority watershed location where a watershed BMP was prioritized for implementation and is slated to utilize watershed-based BWSR funding for construction in 2020.

Table 4-1 provides rough estimates of planning level construction costs for the watershed BMP at the recommended location. It is expected that wider-scale implementation of other watershed BMPs will occur as a part of retrofit opportunities over time (not shown in Table 4-1), but would likely need to be implemented as a part of street reconstruction projects to realize significant cost savings. It is also expected that the total alum treatment costs for Option 2 will be closer to the values shown, as it reflects the current collection and analysis of additional sediment cores across the lake surface for phosphorus fractionations and dose determinations. Table 4-1 confirms that in-lake alum treatment is significantly more cost-effective than the planned watershed BMP.

Table 4-1 Summary of Water Quality Improvement Options

Water Quality Improvement Option	Estimated Annual TP Reduction (lbs/yr)	Opinion of Potential Costs	Annual Cost per Pound TP Removed ($/lb)
Option 1—Expand Redwood Pond and Modify Outlet for Improved Stormwater Treatment	11	$280,000	$25,450
Option 2—Alum Treatment of Keller Lake	186	$220,000[1]	$1,180

[1]—Includes the total combined cost of two phases of in-lake aluminum applications.

4.2 Recommendations

4.2.1 Alum Treatment for Keller Lake

The application of aluminum has two expected mechanisms: (1) aluminum binds with iron-bound phosphorus in the sediment, thereby forming Al-P, and (2) a residual amount of unbound aluminum remains in the sediment and is available to bind phosphorus that is released from the decay of Org-P. For most lake systems alum dosing is designed to provide some amount of “excess” aluminum to bind phosphorus released from decayed Org-P. However, the aluminum added to the sediment will age over time and be less effective at capturing more phosphorus. Due to the high amount of Org-P in the Keller Lake sediment, it is recommended that the alum treatment be split into two applications separated by two or more years in order to capture more of the Org-P in the sediment as it decays over time.

Two forms of aluminum are typically applied to lakes: alum and sodium aluminate. When alum is added to a lake, it will lower the pH (make it more acidic), while sodium aluminate will raise the pH (more basic).

Therefore, these two chemicals are often added in combination to neutralize the pH effects during treatment. At lower doses, alum-only applications can be conducted without adversely affecting the pH (i.e. pH stays above 6). Alum is typically less expensive and easier to work with than sodium aluminate, and an alum-only treatment may be preferable when it will not cause an unacceptable change in pH. Existing alkalinity and pH data were used to evaluate Keller Lake's susceptibility to a pH change from the addition of alum. A chemical model called PHREEQC was used to model the pH change from the prescribed alum dose to Keller Lake; model inputs included the measured pH and alkalinity, and the prescribed alum dose. The model demonstrated that the pH would remain above 6.0 with an alum treatment only for the individual aluminum applications prescribed in Table 4-2. A minimal pH target of 6.0 will minimize the risk of adversely affecting aquatic life and ensure that aluminum hydroxide floc ($Al[OH]_3$) will form readily and settle quickly.

Table 4-2 Recommended Alum Dosing for Split Applications

Lake	First Application		Second Application		Total	
	gallons alum	gallons sodium aluminate	gallons alum	gallons sodium aluminate	gallons alum	gallons sodium aluminate
Keller	13,888	6,944	13,888	6,944	27,776	13,888

It is recommended that the combined alum and sodium aluminate treatment applications be utilized for Keller Lake for the aluminum doses described in Table 4-2. The second application would occur two or more years after the first application, which would be scheduled for the spring of 2019. In no case would the second application be expected to extend beyond 2021. Each alum application would be applied at a low enough dose, and would be buffered by sodium aluminate, such that the lake's pH would not be expected to drop below the threshold of 6.0. The pH in the waterbody must be closely monitored during alum applications, and if the pH reaches the critical value of 6.0, the treatment should be stopped until the pH can recover. If pH and alkalinity conditions are different at the time of treatment and show a greater potential to lower pH below 6.0 during treatment, the treatment plan could be altered to replace a portion of the alum with sodium aluminate in order to buffer the pH.

Splitting the alum treatment into multiple applications would also allow for adjustments to the final alum dose, based on observations of water quality and/or sediment chemistry following the first application. The total estimated costs (including contractor mobilization, engineering and treatment oversight) for the recommended split application of alum to each lake are shown in Table 4-1. Typically, in-lake alum treatments are effective for 15 to 20 years, with shallow lakes experiencing shorter durations of effectiveness, depending on the extent of watershed treatment. However, it is expected that the split applications of alum, combined with the extent of stormwater treatment in the Keller Lake watershed, will ensure that the effective life of the Keller Lake alum treatment is greater than ten years and would likely approach 15 years. The BDWMO will be responsible for any future maintenance that will be needed to achieve the effective life of the project.

4.2.2 Lake Vegetation Management Plan (LVMP)

A lake vegetation management plan (LVMP) is a document the Minnesota Department of Natural Resources (DNR) develops with public input to address aquatic plant issues on a lake. The LVMP is intended to balance riparian property owner’s interest in the use of shoreland and access to the lake with preservation of aquatic plants, which is important to the lake’s ecological health. It is recommended that the BDWMO work with the DNR and the public to develop a LVMP for Keller Lake that will prescribe the permitted aquatic plant management actions (mechanical and/or herbicides) for a five-year period, including controls for invasive plants and restoration of lake shore habitat. The BDWMO should also pass along recent plant surveys and inquire with the DNR about whether the survey information can be used as the control for future plant management actions.

5.0 References

Barr Engineering Company. 2011. Crystal, Keller, and Lee Lakes Nutrient Impairment Total Maximum Daily Load Report and Earley Lake Water Quality Assessment. Prepared for Black Dog Watershed Management Commission (BDWMO) and the Minnesota Pollution Control Agency (MPCA).

Barr Engineering Company. 2017. Keller Lake Subwatershed Assessment. Prepared for the City of Apple Vall.ey

Pilgrim, Keith M., Brian J. Huser, and Patrick L. Brezonik. 2007. A method for comparative evaluation of whole-lake and inflow alum treatment. Water Research. 41 (2007) 1215 – 1224.