Comparative Analysis of Minnesota Lakes Treated with Alum to Inform Spring Lake Treatment

Prepared for the
Prior Lake – Spring Lake Watershed District (PLSLWD)

April 23, 2013

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1.0 Introduction

1.1 Background

The Prior Lake – Spring Lake Watershed District (PLSLWD) requested a comparative analysis of the available information on alum treatments that have been conducted on lakes with similar ecoregion and bathymetric characteristics to Spring Lake, which is being considered for an in-lake alum treatment. The results of this analysis are intended to provide an explanation of why these other whole-lake alum treatments have succeeded or failed and how this information can be used to inform the projected lifespan and success of the proposed treatment for Spring Lake.

Spring Lake is a 642 acre lake, with a maximum depth of 35 feet, and an average depth of 16 feet. The littoral area of the lake is 301 acres – 47% of the total lake area. The watershed of Spring Lake is 12,670 acres, and consists mostly of agricultural land use. According to the TMDL report for Spring Lake, the average residence time of Spring Lake is 2.5 years. The Spring Lake mean summer total phosphorus concentration (TP) reported in the TMDL for the period of 1996-2006 is 0.114 mg/L. The MPCA water quality criteria for Spring Lake require a mean summer total phosphorus concentration of less than 0.040 mg/L.

In September 2012, Barr prepared a report for the PLSPWD that prescribed an alum dose to control internal loading of phosphorus in Spring Lake. The prescribed alum dose was based on an analysis of the various phosphorus fractions (mobile-P and organic-P) in sediment cores collected in 2012. Due to variations in sediment phosphorus concentrations in the lake, two separate alum doses were prescribed for different zones of the lake: 103 grams aluminum per square meter (g Al/m^2) for the 194-acre Zone 1, and 56 g Al/m^2 for the 215-acre Zone 2. The average overall dose would be 78 g Al/m^2 for the combined 409-acre treatment area. Additionally, the report (Barr Engineering Company, 2012) recommended the alum application be split into three separate applications to be spread out over approximately 7 or more years.

For this comparative analysis, lake/watershed characteristics and water quality data were obtained for eleven other Minnesota lakes that have undergone alum treatments to reduce internal loading of phosphorus. Although more than eleven Minnesota lakes or ponds have been treated with alum than are discussed in this report, many of the other lakes that have been treated are shallower and do not possess similar lake mixing characteristics. This report focuses on Minnesota lakes that are similar to Spring Lake (i.e., larger lake with a significant portion of the area deeper than 15 feet).

1.2 Literature Summary

There have been many lake treatments with alum in the past 40 plus years. Welch and Cooke (1999) evaluated alum treatment effectiveness and longevity for twelve lakes that received treatments between 1970 and 1986. At the time of the evaluation, internal phosphorus loading from the lakes with adequate information on sediment phosphorus release had experienced good control of phosphorus release for an average of 13 years after treatment, with a range of between 4 and 21 years. Seven of the treated lakes with adequate data showed a long-term average of two-thirds reduction in internal loading following treatment, and the initial rate dropped by 80% or more in six of these lakes (Welch and Cooke, 1999). These lakes also experienced substantial improvement in trophic state with reductions in surface-water phosphorus and chlorophyll-a concentrations, as well as algae bloom magnitude and frequency and improved conditions for dissolved oxygen and water transparency. Cooke et al. (2005) identified the following problems that limit the long-term effectiveness of an alum treatment:

- Low doses
- Focusing of the alum floc layer by wind mixing
- Interference with macrophytes
- Sinking of high-density floc
- Bioturbation of the floc
- Insufficient reduction of external nutrient loading or coverage by new sediment

2.0 Analysis of Comparable Alum Treated Lakes

2.1 Lake Alum Treatments Considered for Comparative Analysis

Lake characteristics and in-lake surface-water (epilimnetic) phosphorus concentrations were obtained for eleven Minnesota lakes that have undergone alum treatments and possess similar bathymetry or lake mixing characteristics as Spring Lake. The lakes, their associated characteristics, and details of the alum treatments are listed in Table 1. The lakes range in size from 59 acres (Long Lake, Washington County) to 649 acres (Clear Lake, Waseca County). Lake Harriet has the greatest maximum depth (87 feet), and Lake Susan has the shallowest maximum depth (17 feet). Alum doses in Table 1 are expressed in units of grams of aluminum per square meter of lake treatment area. The same lake characteristic data and proposed alum treatment rates for Spring Lake are included in Table 1 to allow for comparison with the other lakes that have had alum applications.

Table 2 summarizes the in-lake summer-average total phosphorus concentrations, including the 10-yr period prior to each lake's respective alum treatment date. Summer averages for various time periods following the alum treatment are also listed in Table 2: 1-year period following alum treatment, 1 to 3-year period following alum treatment, 4 to 6-year period following alum treatment, 7 to 10-year period following alum treatment, and the period that is more than 11 years following the alum treatment. For several of these Minnesota lakes, alum treatments have occurred too recently to determine the longer term post-treatment averages. Additionally, for several lakes, total phosphorus data were either not collected every year, or data were not readily available since the alum treatment.

All of the lakes presented in Table 2 demonstrated reductions in total phosphorus concentrations following an alum treatment when compared to the 10-year period immediately prior to the treatment. The immediate and 1 to 3-year post-alum treatment phosphorus reductions varied from 27% to 84% compared to the 10-year pretreatment average for each lake. For the 4 to 6-year period following treatment, reductions in summer average TP of 28% to 77% were observed compared to the 10-yr pretreatment period. For lakes that have more than seven years of data following an alum treatment, the average for the 7 to 10-year period and the period more than ten years following an alum treatment was reduced by 17% to 74% when compared to the 10-year pretreatment average TP.

Table 1. Lake Morphometry and Alum Treatment Details

Lake	ID	County	Lake Surface Area (acres)	Littoral Area (acres)	Maximum Depth (ft)	Average Depth (ft)	Watershed Area (acres)	Watershed to Lake Surface Area Ratio	Date of Alum Application	Treatment Area Dose (g Al/m2)	Treatment Target Area (as % of total lake area)	Total Volume Alum (gallons)	Alum Dose Normalized to Total Lake Area (g Al/m2)
Bryant	27006700	Hennepin	178	64	45	15	3,250	18	Oct-08	37	100	121,000	37
Calhoun	27003100	Hennepin	419	123	82	35	2,990	7.1	Oct-01	42	96	252,000	33
Cedar	27003900	Hennepin	169	63	51	20	1,970	12	Fall 1996	27	87	72,103	23
Clear	81001400	Waseca	649	448	34	13.5	3,751	5.8	Fall 1988	33	51	185,757	15
Harriet	27001600	Hennepin	341	85	87	32	8,328	24	May-01	32	29	68,624	11
Langdon	27018200	Hennepin	144	83	38	8.3	1,055	7.3	Mar-98	70	--	101,000	38
Long-Henn.	27016000	Hennepin	285	131	33	14	8,215	29	Jun-96	25.6	70	125,500	24
Long-Wash.	82011800	Washington	58.5	26.5	34	11	3,126	53	Nov '08, Nov '09	109	--	85,264	79
McCarrons	62005400	Ramsey	81	25	57	25	1,070	13	Oct-04	60	100	90,500	60
Rebecca	27019200	Hennepin	263	138	30				Nov-11	81	--	285,135	59
Susan	10001300	Carver	88	75	17	10	2,402	27	Apr-98	30	--	40,000	25
Spring Lake	70005400	Scott	642	301	35	16	12,670	20	--	103 / 56	30 / 33	369,000 / 215,000	49

Table 2. In-Lake Total Phosphorus (TP) Concentrations Pre-Alum and Post-Alum Treatments.

Lake	10-yr Ave Pre-Alum Treatment TP	1-yr Post-Alum Treatment TP		1-yr to 3-yr Post-Alum Treatment TP		4-yr to 6-yr Post-Alum Treatment TP		7-yr to 10-yr Post-Alum Treatment TP		≥ 11-yr Post-Alum Treatment TP	
	(mg/L)	(mg/L)	% Δ	(mg/L)	% Δ	(mg/L)	% Δ	(mg/L)	% Δ	(mg/L)	% Δ
Bryant	0.046	0.027	*-43%*	0.028	*-39%*	0.029	*-39%*				
Calhoun	0.027	0.014	*-47%*	0.015	*-44%*	0.014	*-47%*	0.018	*-35%*		
Cedar	0.038	0.023	*-40%*	0.020	*-46%*	0.023	*-38%*	0.024	*-36%*	0.025	*-34%*
Clear	0.128	0.021	*-84%*	0.037	*-71%*						
Harriet	0.026	0.019	*-27%*	0.018	*-29%*	0.019	*-28%*	0.022	*-15%*		
Langdon	0.340	0.086	*-75%*	0.086	*-75%*	0.077	*-77%*	0.158	*-53%*	0.090	*-74%*
Long-Henn.	0.145	0.042	*-71%*	0.053	*-63%*	0.061	*-58%*	0.065	*-55%*	0.062	*-57%*
Long-Wash.	0.032	0.012	*-63%*	0.018	*-43%*						
McCarrons	0.039	0.015	*-62%*	0.015	*-62%*	0.013	*-67%*	0.018	*-55%*		
Rebecca	0.093	0.028	*-70%*	0.029	*-69%*						
Susan	0.099	0.037	*-63%*	0.041	*-58%*			0.074	*-26%*	0.082	*-17%*
Spring Lake	0.114										

Notes

% Δ - Percent reduction in average total phosphorus compared to 10-yr pretreatment average.

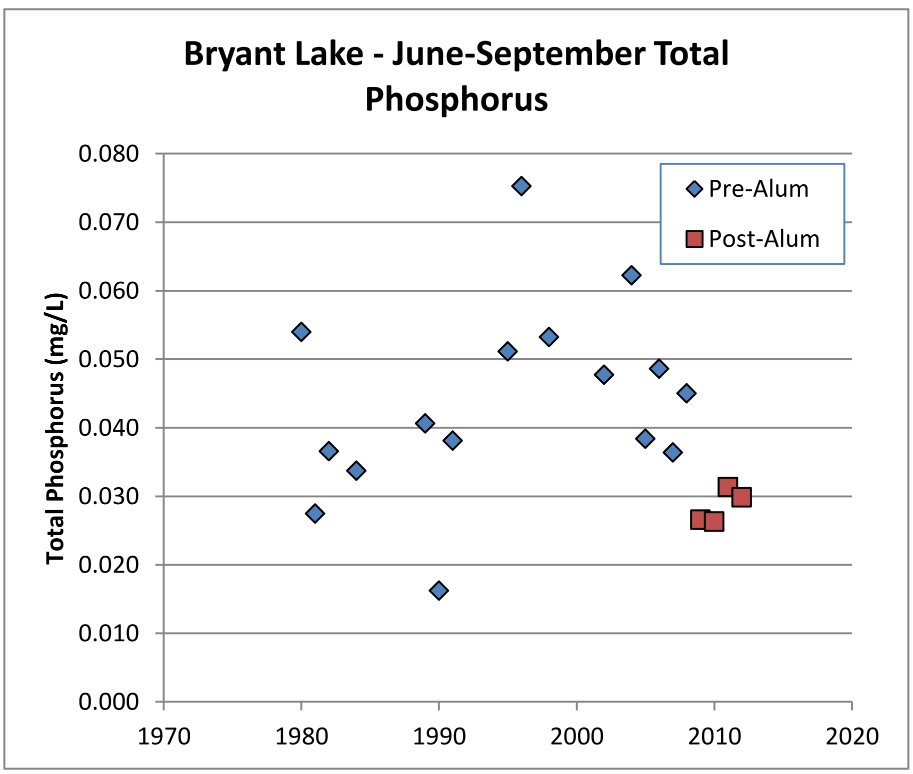
2.2 Details of Individual Lake Alum Treatments

The alum treatments for individual lakes are discussed in more detail below. The historic record of summer-average total phosphorus concentrations is also included for each lake.

2.2.1 Bryant Lake

Bryant Lake is a 178-acre lake in Hennepin County. An alum treatment was conducted in October, 2008. The treatment was designed to be 50% of the total prescribed dose, with a second application to be applied 5 years later (currently under consideration for Fall, 2013). Prior to the treatment, the 10-year average of total phosphorus was 0.046 mg/L. For all four seasons following the treatment, the summer-average total phosphorus concentration has been 0.031 mg/L or less, which is less than the water quality goal of 0.040 mg/L. The alum treatment is achieving the desired results for Bryant Lake; however, only four seasons have passed subsequent to the alum treatment, so long-term effectiveness cannot be adequately assessed at this time.

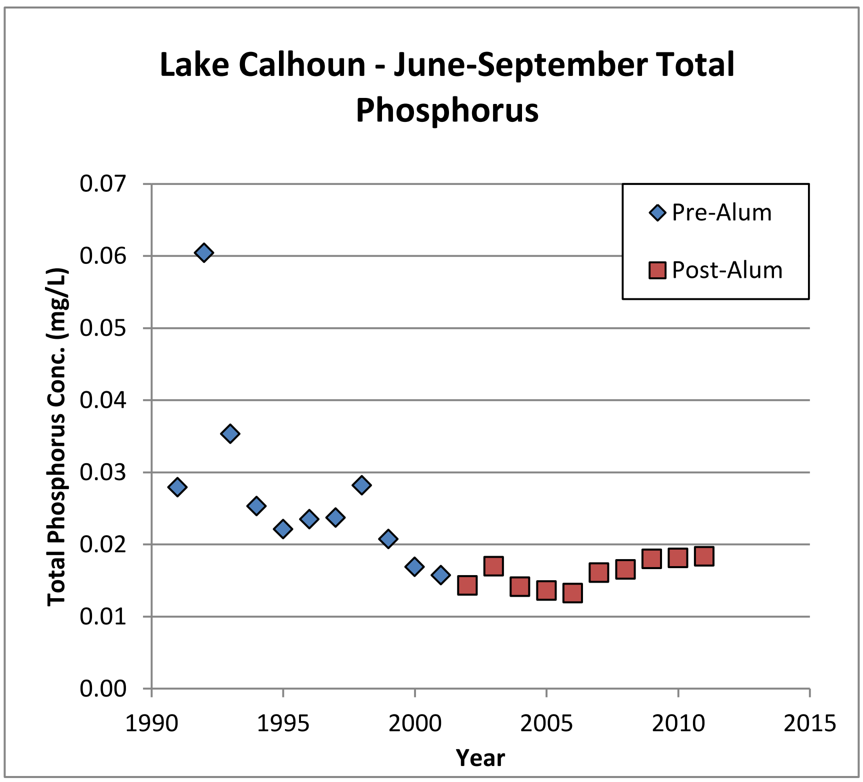
Year	June-Sept Ave. TP (mg/L)	n
1980	0.054	3
1981	0.028	4
1982	0.037	10
1984	0.034	4
1989	0.041	8
1990	0.016	8
1991	0.038	8
1995	0.051	7
1996	0.075	7
1998	0.053	8
2002	0.048	8
2004	0.062	8
2005	0.038	5
2006	0.049	8
2007	0.036	5
2008	0.045	15
2009	0.027	14
2010	0.026	9
2011	0.031	9
2012	0.030	8



2.2.2 Lake Calhoun

Calhoun Lake is a 419-acre lake that is part of the Minneapolis Chain of Lakes. Of the lakes considered in this report, only Lake Harriet has a greater maximum depth. An alum treatment was conducted in October 2001. The goal of the treatment was to reduce internal P loading by 50%. Only 2/3 of the suggested alum dose was used in Lake Calhoun because of budgetary constraints (Huser et al., 2011). The in-lake water quality goal for Lake Calhoun is 0.025 mg/L P, which the lake has achieved for 10 straight years (2002-2011) following the alum treatment. Lake Calhoun is downstream of Cedar Lake and Lake of the Isles, both of which also received in-lake alum applications. In addition, watershed projects have been implemented to further reduce the external loading of phosphorus to the lake in advance of the alum treatment. The results of the Cedar Lake alum treatment are further described in Section 2.2.3, while Lake of the Isles is a shallow lake that was not considered for this analysis. The alum treatment of Lake Calhoun has been successful to-date.

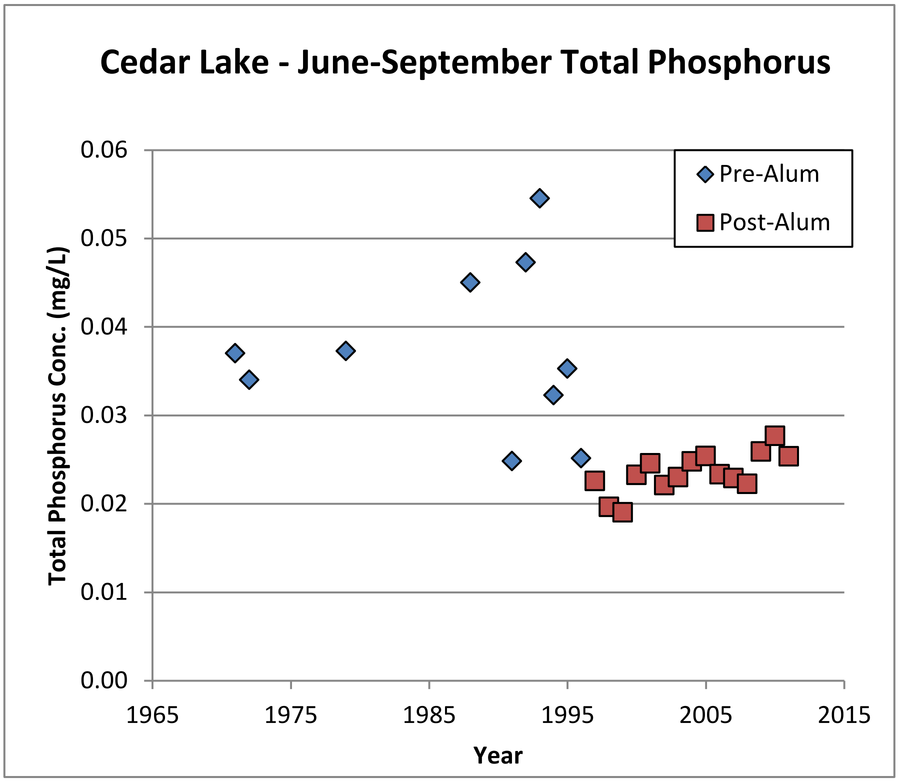
Year	June-Sept Ave. TP (mg/L)	n
1991	0.028	17
1992	0.060	7
1993	0.035	6
1994	0.025	9
1995	0.022	8
1996	0.024	8
1997	0.024	10
1998	0.028	10
1999	0.021	8
2000	0.017	8
2001	0.016	12
2002	0.014	10
2003	0.017	8
2004	0.014	8
2005	0.014	8
2006	0.013	8
2007	0.016	10
2008	0.017	9
2009	0.018	8
2010	0.018	9
2011	0.018	9



2.2.3 Cedar Lake

Cedar Lake is a 169-acre lake that is part of the Minneapolis Chain of Lakes. An alum treatment was conducted in the fall of 1996. In addition, watershed projects have been implemented to further reduce the external loading of phosphorus to the lake in advance of the alum treatment. The water quality goal of Cedar Lake is 0.025 mg/L TP concentration. The 7-yr to 10-yr average post-treatment phosphorus concentration was 0.024 mg/L, a 36% reduction compared to the 10-yr pretreatment period average. The summer-average P concentration was 0.025 mg/L or less each year for the 10-yr period of 1997-2006. The alum treatment of Cedar Lake has been successful to-date.

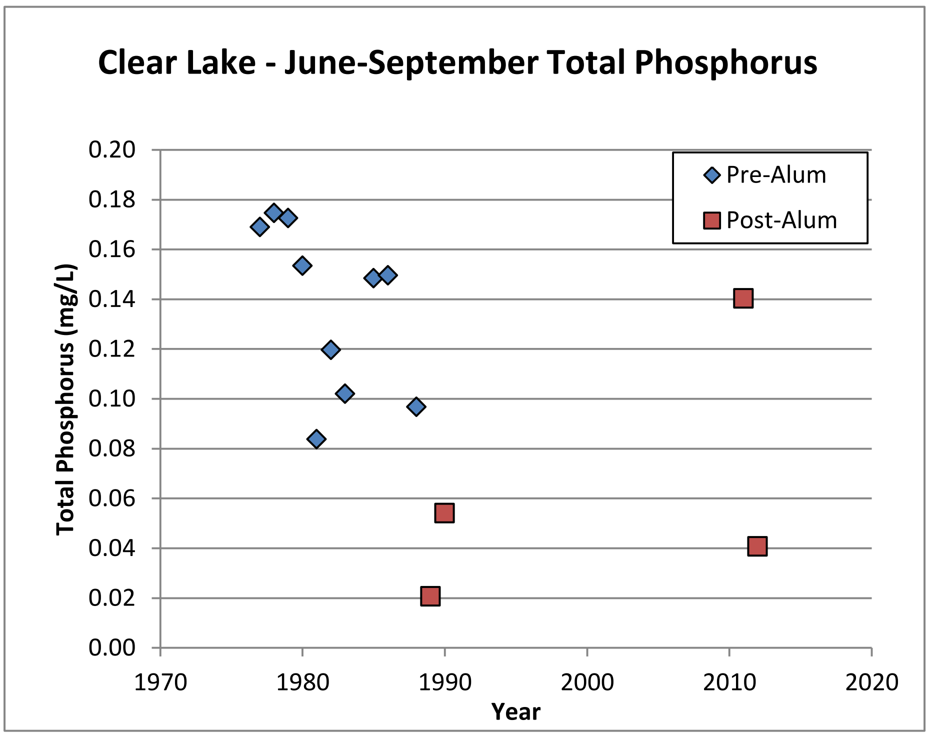
Year	June-Sept Ave. TP (mg/L)	n
1971	0.037	6
1972	0.034	7
1979	0.037	12
1988	0.045	4
1991	0.025	16
1992	0.047	7
1993	0.055	6
1994	0.032	8
1995	0.035	8
1996	0.025	8
1997	0.023	9
1998	0.020	8
1999	0.019	8
2000	0.023	8
2001	0.025	11
2002	0.022	11
2003	0.023	8
2004	0.025	8
2005	0.025	8
2006	0.023	9
2007	0.023	8
2008	0.022	8
2009	0.026	8
2010	0.028	9
2011	0.025	9



2.2.4 Clear Lake

Clear Lake is a 649-acre lake located in Waseca County. It has the largest surface area of the lakes considered in this memorandum. An alum treatment was conducted in the fall of 1988, and targeted areas of the lake with water depths greater than 15 feet. A large carp population was reported prior to a fisheries restoration project. In large numbers, bottom feeding carp can have a significant negative impact on water quality. A rotenone treatment occurred in October, 1987 to kill the fish in Clear Lake, and the lake was subsequently restocked with gamefish. In the first year following the alum treatment, the total phosphorus concentration had decreased to 0.021 mg/L, compared to the 10-year pretreatment average of 0.128 mg/L. A limited amount of data were available for the period of 1991-2010, so the determination of alum treatment success is inconclusive at this time due to insufficient data and the confounding effect of the fisheries restoration project.

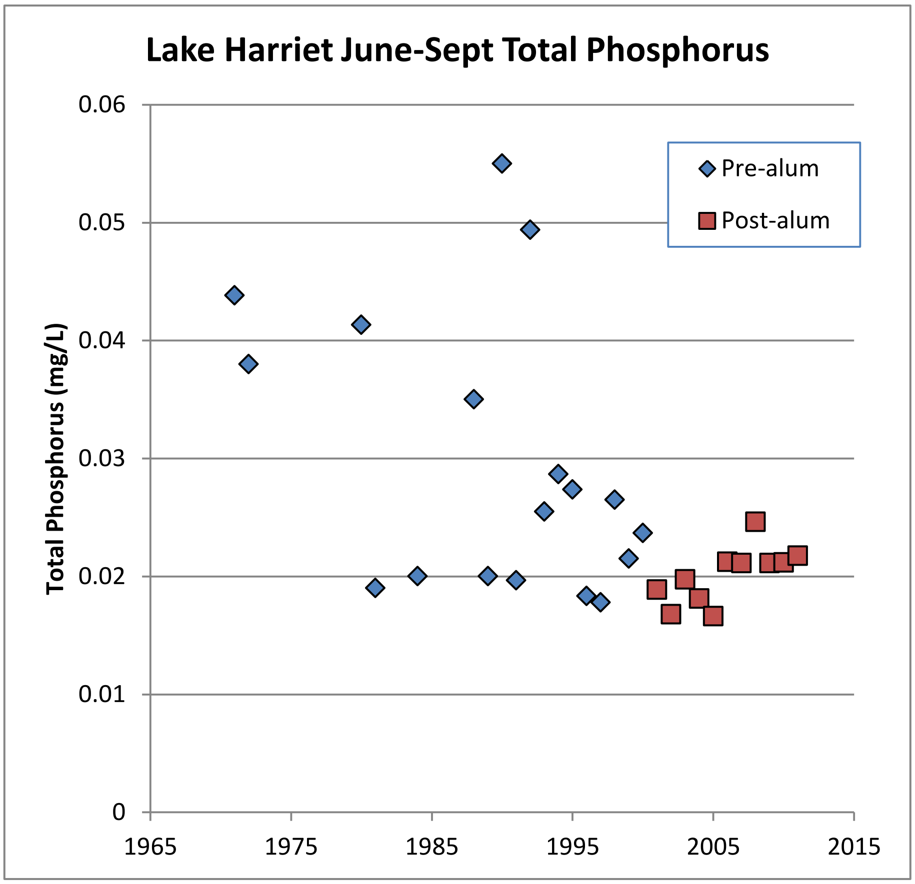
Year	June-Sept Ave. TP (mg/L)	n
1977	0.169	3
1978	0.175	3
1979	0.173	4
1980	0.153	5
1981	0.084	4
1982	0.120	5
1983	0.102	4
1984	0.068	1
1985	0.148	5
1986	0.150	4
1988	0.097	7
1989	0.021	7
1990	0.054	6
2011	0.140	4
2012	0.041	4



2.2.5 Lake Harriet

Lake Harriet is a 341-acre lake that is part of the Minneapolis Chain of Lakes. It is the deepest of the lakes considered in this report. The alum application that occurred on Lake Harriet in May, 2001 was an experimental application, and was not designed to reduce internal phosphorus loading from anoxic phosphorus release. The application was designed to decrease algal growth by limiting the amount of P available in the sediment to cyanobacteria (blue-green algae) that are able to use this P and then become buoyant and accumulate within aquatic plants of the littoral region of the lake. The alum was applied only within the littoral areas, or about 30% of the lake surface area (Huser et al., 2011).

Year	June-Sept Ave. TP (mg/L)	n
1971	0.044	6
1972	0.038	7
1980	0.041	3
1981	0.019	3
1984	0.020	4
1988	0.035	2
1989	0.020	2
1990	0.055	2
1991	0.012	9
1992	0.049	8
1993	0.026	6
1994	0.029	9
1995	0.027	8
1996	0.018	9
1997	0.018	10
1998	0.027	6
1999	0.022	8
2000	0.024	9
2001	0.019	8
2002	0.017	9
2003	0.020	8
2004	0.018	8
2005	0.017	8
2006	0.021	9
2007	0.021	8
2008	0.025	8
2009	0.021	8
2010	0.021	8
2011	0.022	8

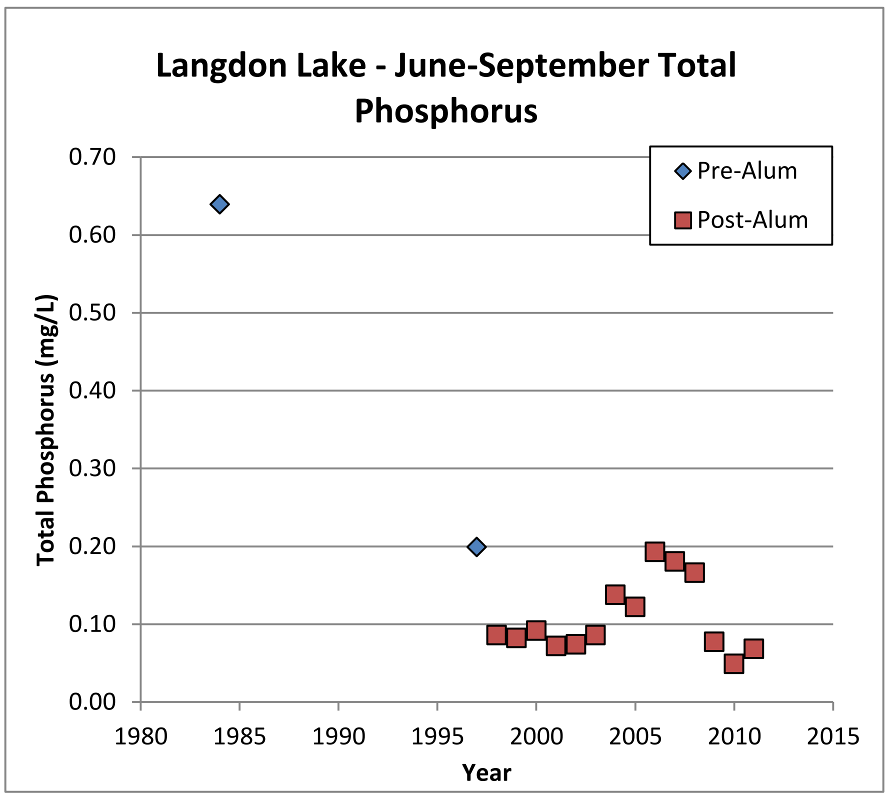


If the alum dose applied to Lake Harriet is averaged over the entire surface area, it is the lowest dose of alum per lake surface area of the lakes considered in this report. Although the alum was only applied in the littoral areas of Lake Harriet, sediment investigations in subsequent years indicated a significant amount of the alum had migrated to the deeper center of the lake (Huser et al., 2011). Short term benefits to in-lake phosphorus concentrations were observed for several years subsequent to the alum application. Lake Harriet is downstream of Lake Calhoun, and therefore would have benefited from the Lake Calhoun alum treatment and resulting improvement of Lake Calhoun water quality (as further described in Section 2.2.2).

2.2.6 Langdon Lake

Langdon Lake is a 140-acre lake located in Hennepin County. Eighty three acres, or 58%, of the lake is less than 15 feet deep. Historically, the Mounds Wastewater Treatment Plant discharged to wetlands upstream of Langdon Lake, contributing to a severe phosphorus problem in the lake and its upstream watershed. An alum treatment was conducted in March of 1998. Summer-average total phosphorus concentrations remained high (0.072 – 0.092 mg/L) in the five year period following the alum treatment. However, this appears to be a substantial reduction compared to the period before the alum treatment. Although the alum treatment was not successful in improving the water quality of Langdon Lake enough to meet MPCA's nutrient criteria, the data indicates that it did improve water quality substantially for the six-year period following the alum treatment and the last three years represent the best water quality on record.

Year	June-Sept Ave. TP (mg/L)	n
1983	0.940	1
1984	0.639	5
1985	0.620	1
1987	0.450	1
1988	0.380	1
1989	0.500	1
1990	0.530	1
1991	0.390	1
1993	0.300	1
1995	0.230	1
1996	0.190	1
1997	0.199	9
1998	0.086	7
1999	0.082	9
2000	0.092	8
2001	0.072	8
2002	0.074	8
2003	0.086	9
2004	0.138	7
2005	0.122	8
2006	0.193	7
2007	0.181	2
2008	0.166	8
2009	0.077	9
2010	0.049	9
2011	0.068	9

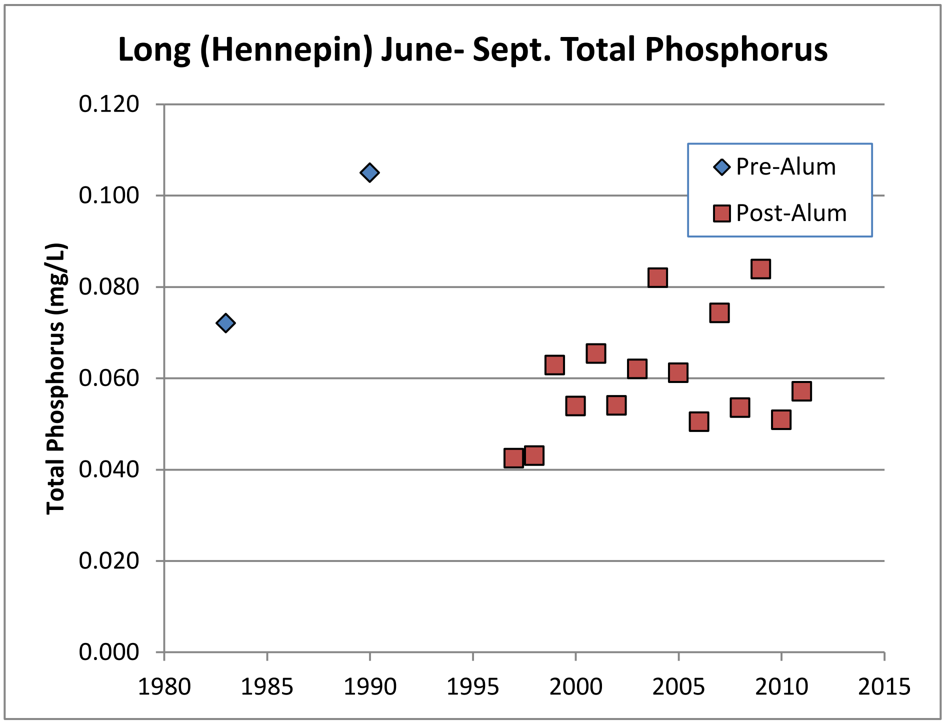


Years with only one data point not graphed.

2.2.7 Long Lake (Hennepin County)

Long Lake is a 285-acre lake located in Hennepin County. The littoral area is 131 acres, and the maximum depth is 33 feet. The lake was treated with alum in June of 1996, with a whole-lake average dose of 24 g Al/m^2. In recent years, the majority of alum applications are conducted in spring or fall, in part because summer algae blooms and aquatic vegetation can interfere with the settling of the alum floc. The alum floc can attach to buoyant algae, and be blown by the wind to near shore areas, or be concentrated in certain areas rather than settling and blanketing the lake sediment in a uniform fashion.

Year	June-Sept Ave. TP (mg/L)	n
1981	0.080	1
1982	0.080	1
1983	0.072	5
1984	0.050	1
1985	0.040	1
1986	0.040	1
1987	0.060	1
1988	0.580	1
1989	0.060	1
1990	0.105	16
1991	0.090	1
1995	0.080	1
1997	0.042	9
1998	0.043	6
1999	0.063	8
2000	0.054	8
2001	0.065	10
2002	0.054	8
2003	0.062	9
2004	0.082	8
2005	0.061	19
2006	0.050	7
2007	0.074	7
2008	0.054	9
2009	0.084	10
2010	0.051	10
2011	0.057	9



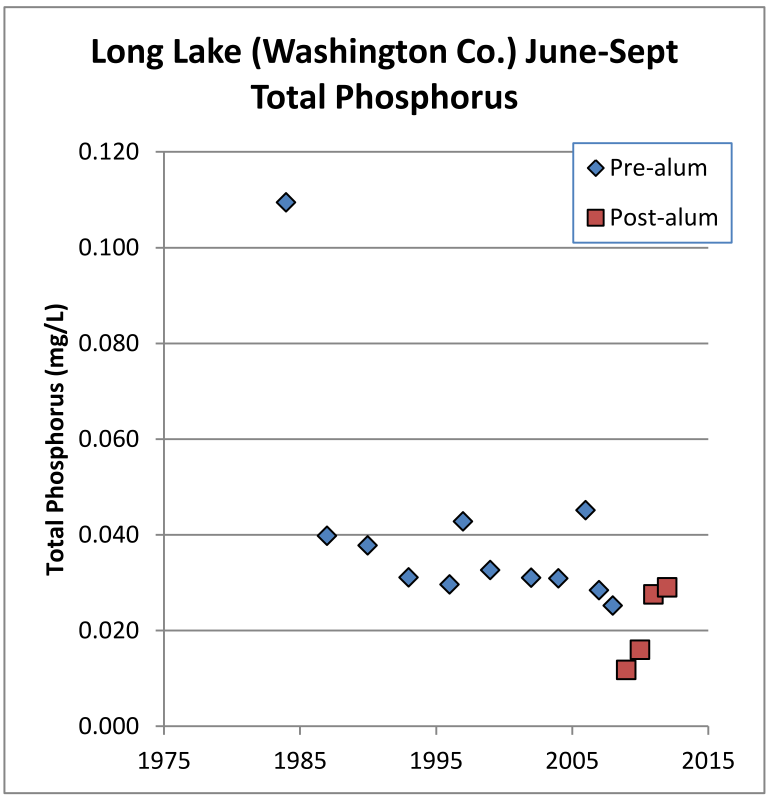
Years with only one data point not graphed.
Alum treatment June 1996.

Limited water quality data were available for the period before the alum treatment, with most pre-treatment years having only a single total phosphorus concentration during the June-September period, making a comparison of pre-treatment and post-treatment water quality difficult. Summer-average TP concentrations ranged from 0.042 to 0.084 mg/L for the period of 1997-2011, indicating the alum treatment was not successful in improving Long Lake water quality enough to meet the MPCA lake nutrient criterion of 0.040 mg/L TP.

2.2.8 Long Lake (Washington County)

Long Lake is a 58.5-acre lake in Washington County. The littoral area is 26.5 acres, and the maximum depth is 34 feet. It is the smallest lake included in this report. An alum treatment was split into two separate applications that occurred in November, 2008 and November, 2009. The lake has high densities of Eurasian watermilfoil, an invasive, non-native aquatic plant. An herbicide treatment was also conducted in Spring, 2011 to reduce the Eurasian watermilfoil in the lake. For the four year period following the alum treatment, Long Lake has met the MPCA water quality criteria of 0.040 mg/L TP. In the short term, the Long Lake alum treatment has been a success, but the long term response in this lake will need to be measured under a range of climatic conditions as it possesses the largest watershed to lake surface ratio of the projects included in this analysis.

Year	June-Sept Ave. TP (mg/L)	n
1971	0.024	1
1975	0.071	1
1979	0.040	1
1984	0.109	5
1987	0.040	4
1990	0.038	4
1993	0.031	9
1996	0.030	5
1997	0.043	5
1999	0.033	8
2002	0.031	5
2004	0.031	9
2006	0.045	8
2007	0.028	13
2008	0.025	9
2009	0.012	13
2010	0.016	4
2011	0.028	15
2012	0.029	8

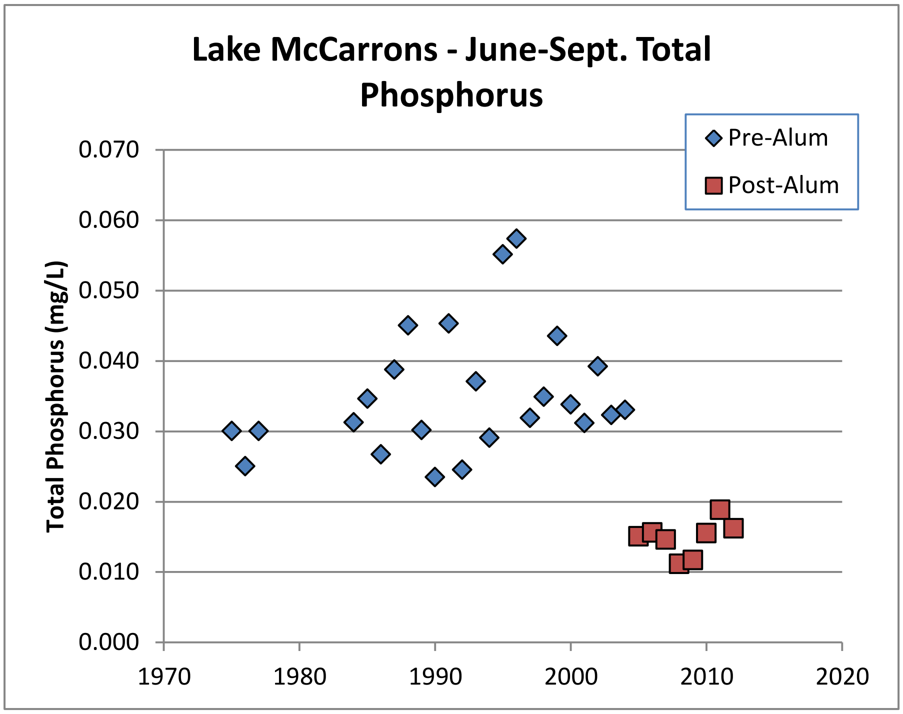


Years with only one data point not graphed.

2.2.9 Lake McCarrons

Lake McCarrons is an 81-acre lake located in Ramsey County. An alum treatment was conducted in October, 2004. Total phosphorus concentrations were reduced substantially (65%) by the alum treatment. In 2012, the eighth year following the alum treatment, the summer-average total phosphorus was 0.016 mg/L, which is a 60% reduction from the 10-year pre-treatment average of 0.039 mg/L. The Lake McCarrons alum treatment has been successful, and the lake is still experiencing substantial reduced TP eight years after treatment, despite the fact that the Villa Park wetland treatment system implemented in the lake watershed has not performed as expected.

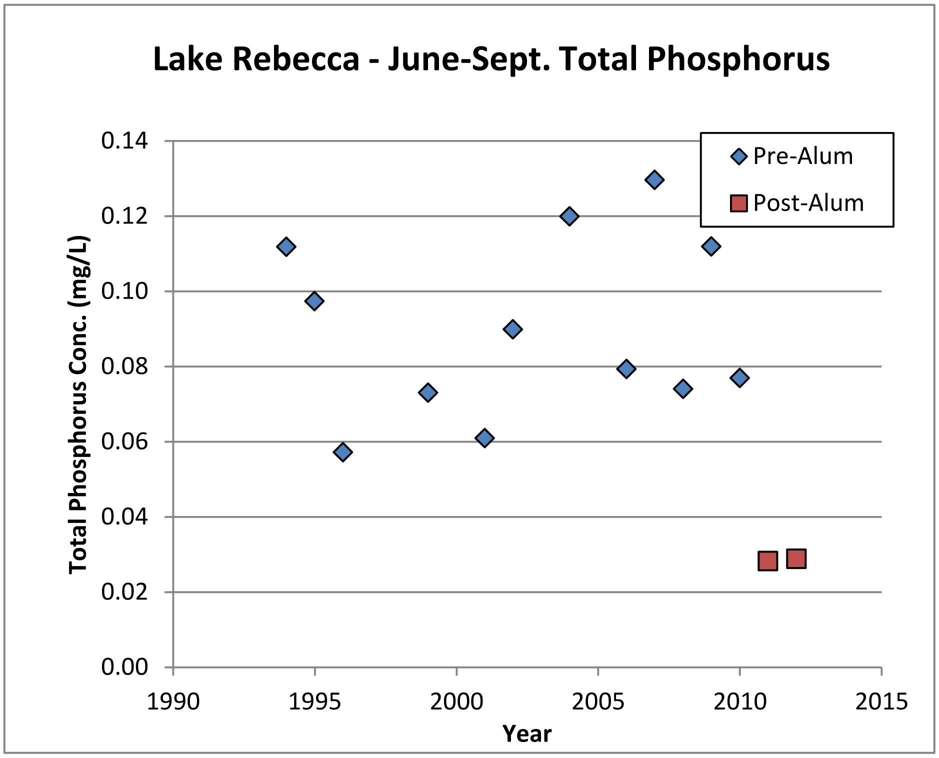
Year	June-Sept Ave. TP (mg/L)	n
1975	0.030	2
1976	0.025	2
1977	0.030	2
1984	0.031	8
1985	0.035	13
1986	0.027	9
1987	0.039	8
1988	0.045	12
1989	0.030	12
1990	0.023	13
1991	0.045	11
1992	0.025	6
1993	0.037	14
1994	0.029	15
1995	0.055	16
1996	0.057	14
1997	0.032	7
1998	0.035	8
1999	0.044	15
2000	0.034	15
2001	0.031	15
2002	0.039	14
2003	0.032	7
2004	0.033	14
2005	0.015	19
2006	0.016	6
2007	0.015	7
2008	0.011	7
2009	0.012	6
2010	0.016	6
2011	0.019	6
2012	0.016	6



2.2.10 Lake Rebecca

Lake Rebecca is a 263-acre lake located in Hennepin County. An alum treatment was conducted in November, 2010, with a total lake area average dose of 59 g Al/m^2. A substantial reduction in the in-lake phosphorus concentration has been observed in the two years following the alum treatment, with summer-average TP less than 0.030 mg/L. The alum treatment has been successful in the short term, but long term benefits will be dependent on continued controls of phosphorus.

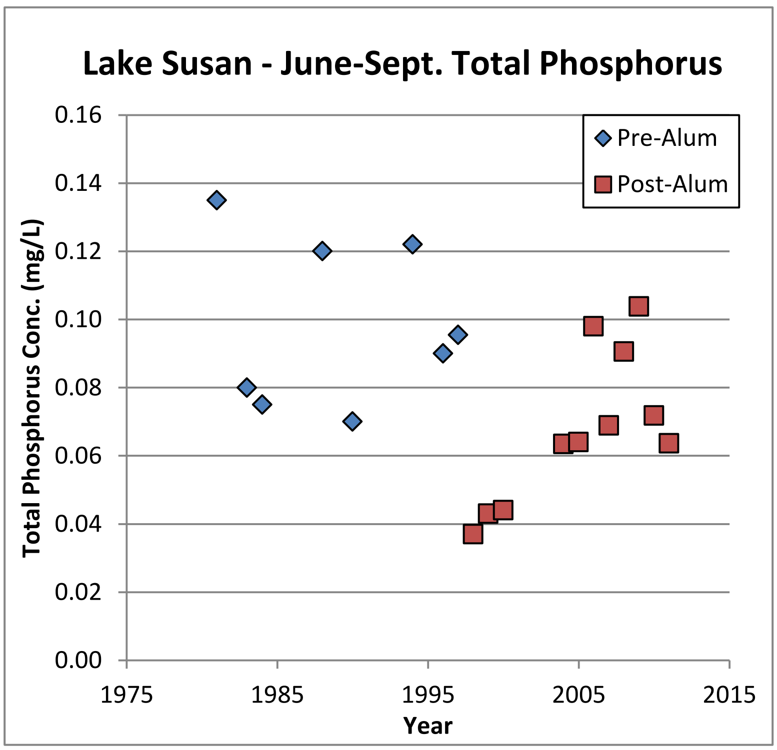
Year	June-Sept Ave. TP (mg/L)	n
1994	0.112	11
1995	0.097	12
1996	0.057	11
1999	0.073	8
2001	0.061	7
2002	0.090	6
2004	0.120	8
2006	0.079	8
2007	0.130	9
2008	0.074	9
2009	0.112	9
2010	0.077	9
2011	0.028	9
2012	0.029	8



2.2.11 Lake Susan

Lake Susan is an 88-acre lake in Carver County. With a littoral area of 75 acres and a maximum depth of 17 feet, it is the shallowest lake included in this report. An alum treatment was conducted on Lake Susan in April of 1998, with a total lake area average dose of 25 g Al/m^2. In addition to the alum treatment, a significant removal of rough fish was conducted in the Spring of 1998—11.7 tons of bullhead and 9.4 tons of carp were captured and removed. Carp and bullheads are bottom feeding fish that, when present in large numbers, can have a significant negative impact on water quality. It is difficult to differentiate the effects of the alum treatment from the rough fish removal, but Lake Susan experienced significantly better water quality in the short term for the three years following the alum treatment. Long term success was not achieved, as the in-lake TP increased to 0.098 mg/L by 2006, nine years after the alum treatment. It is noted that the alum treatment dose for Lake Susan is one of the lowest of the eleven lakes included in this analysis.

Year	June-Sept Ave. TP (mg/L)	n
1981	0.135	--
1983	0.080	--
1984	0.075	--
1988	0.120	--
1990	0.070	--
1994	0.122	4
1996	0.090	--
1997	0.095	7
1998	0.037	7
1999	0.043	5
2000	0.044	5
2004	0.064	6
2005	0.064	8
2006	0.098	3
2007	0.069	8
2008	0.091	13
2009	0.104	13
2010	0.072	12
2011	0.064	9



Note: Years 1983, 1984, 1988, 1990, & 1996 were estimated from figure in "Lake Susan Evaluation for 2000"

3.0 Summary/Implications for Spring Lake Treatment

Of the alum treatments considered in this report, Lake McCarrons and Lake Calhoun would be rated two of the most effective alum treatments. Substantial reductions of in-lake TP were observed in both lakes, with both lakes achieving water quality goals for a substantial period of time (8-10 years) following the alum treatment. Cedar Lake also demonstrated long term reductions in TP, and met its water quality goals for the 10 year period following alum treatment. Long Lake (Washington County), Lake Rebecca, and Bryant Lake have demonstrated substantial reductions in the short term that resulted in those lakes meeting their respective water quality goals following alum treatment, but their alum treatments are too recent to assess long term benefits.

The results of this analysis indicate that the alum treatments conducted for Clear Lake, Lake Susan and Long Lake in Hennepin County may not have met the respective water quality improvement goals. It should be noted that the alum treatment doses for these three lakes are among the lowest of the eleven lakes included in this analysis. Long Lake in Hennepin County was the only lake in this analysis that was treated during the summer when algae bloom conditions and/or aquatic vegetation could interfere with the coagulation and subsequent settling of the alum floc. Also, another contributor to diminished expectations for water quality improvement in Clear Lake may result from the fact that that a storm water alum treatment facility included in the overall restoration plan has not been operated in recent years. Finally, there may have been a confounding effect of fisheries restoration efforts in both Lake Susan and Clear Lake, as efforts have been made to control rough fish populations in both lakes, but it is unclear how successful those efforts have been to-date and to what extent the recent water quality has been affected by these and other efforts to control TP loading.

The implications of this literature summary and comparative analysis for the proposed Spring Lake alum treatment include the following:

- The proposed alum dose for Spring Lake is sufficient to immobilize the releasable phosphorus contained in the lake sediments subject to anoxia each summer, especially when compared to the other successful long-term lake treatments that have occurred in Minnesota
- Focusing of the alum floc layer by wind mixing and interference with macrophytes or algae blooms can be avoided in Spring Lake by applying the alum in early spring or late fall under fully mixed conditions with calm winds

- Sinking of high-density floc is not expected to present a problem in Spring Lake because the substrate is fairly dense, based on the sediment core data
- Bioturbation of the floc is not expected to be a significant threat to water quality improvement as the alum floc layer will be present in the deeper water of Spring Lake where it won't be as susceptible to resuspension or release following the chemical inactivation with alum because the bound phosphorus will resettle in the hypolimnetic sediment; in addition, rough fish removal and control efforts are expected to continue in Spring Lake which should further limit the potential for bioturbation
- Insufficient reduction of external nutrient loading or coverage by new sediment likely represents the primary potential limitation to the long-term effectiveness of the alum treatment for Spring Lake. The September, 2012 report (Barr Engineering Company, 2012) that prescribed an alum dose to control internal loading of phosphorus in Spring Lake recommended the alum application be split into three separate applications to be spread out over approximately 7 or more years. This recommendation serves the following purposes:
    - Improves the overall treatment efficiency of each application of alum to the lake sediments
    - Allows for further monitoring or study (and subsequent prioritization) of watershed sources of phosphorus under varying climatic conditions
    - Allows for further implementation of watershed controls for external phosphorus loading
    - Allows for further implementation of rough fish controls for internal phosphorus loading to Spring Lake.

References

Barr Engineering Company. 2012. Spring Lake Sediment Core Analysis, Alum Dose Determination and Application Plan. Prepared for Prior Lake-Spring Lake Watershed District (PLSLWD).

Cooke, Dennis G., Eugene B. Welch, Spencer A. Peterson, Stanley A. Nichols. 2005. Restoration and Management of Lakes and Reservoirs.

Huser, Brian J., Brezonik, Patrick, and Newman, Raymond. 2011. Effects of alum treatment on water quality and sediment in the Minneapolis Chain of Lakes, Minnesota, USA. Lake and Reservoir Management, 27: 220-228.

Huser, Brian J. Water Research, 2012. Variability in phosphorus binding by aluminum in alum treated lakes explained by lake morphology and aluminum dose.

Welch, Eugene B. and Dennis G. Cooke. 1999. Effectiveness and longevity of phosphorus inactivation with alum. Lake and Reservoir Management, 15: 5-27.