Evaluation of Management Measures to Improve the Water Quality and Ecology of Normandale Lake

Prepared for
Nine Mile Creek Watershed District

October 2017

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Executive Summary

With nearly 100 percent surface coverage, aquatic plants are a dominant feature of Normandale Lake. Interpretation of monitoring data and modeling results demonstrate the importance of the aquatic plant population in the control of phosphorus concentrations in Normandale Lake and prevention of phytoplankton blooms by limiting light availability and competing for nutrients. However, the aquatic plant and filamentous algae population has become excessive (a maximum of approximately 2 million wet pounds in 2017) and is threatening attainment of Nine Mile Creek Watershed District water quality and aquatic community goals by causing very low dissolved oxygen (which is detrimental to fish and other aquatic life). The excessive aquatic plant and filamentous algae population is also hindering lake usage by creating unpleasant odors and physically inhibiting lake access due to plant density. The aquatic plant population included a large population of curlyleaf pondweed in 2017 and the overall population appears to be dominated by a few species.

The root cause of the abundant aquatic plant community is excessive nutrients. These nutrients come from external sources, which are currently being addressed with the ongoing implementation of upstream watershed management practices, and internal sources which can be controlled by inactivating phosphorus in the lake bottom sediment with the application of alum. The aquatic plant and filamentous algae community itself can also be directly managed. This may include mechanical harvesting to physically remove plants and reduce plant coverage, lake drawdown, and/or chemical treatment to control invasive species such as curlyleaf pondweed. The low oxygen concentrations in the lake can be addressed by constructing a system that directly injects oxygen in the water column of Normandale Lake. These management approaches are summarized in Section 1.0 of this report.

1.0 Introduction and Study Objectives

Normandale Lake is located in the northwestern part of Bloomington. The existence of the lake is the direct result of the Mount Normandale Lake flood control project implemented in the late-1970s, which included construction of a dam across Nine Mile Creek to the west of Normandale Boulevard, with a weir control structure and a low flow bypass structure. The lake has a water surface of approximately 112 acres, a maximum depth of approximately 10 feet, and a mean depth of 4.2 feet at normal water surface elevation of 808.0.

The Nine Mile Creek Watershed District has historically used a process referred to as Use Attainability Analyses (UAA) to assess the water quality condition of its lakes relative to the desired beneficial uses that can be reasonably achieved and maintained and identify management recommendations. The UAA process addresses a wide range of goals (e.g., water quantity, aquatic communities, recreational use, wildlife), with the primary focus being achievement of the water quality goals. As part of the 2017 *Nine Mile Creek Watershed District Water Management Plan*, the NMCWD has expanded its emphasis on the role of ecological indicators (aquatic plants, phytoplankton, fish, etc.) in overall lake health, as well as the feedback mechanisms between these indicators. The NMCWD has also adopted the Minnesota lake eutrophication standards as part of their 2017 Plan.

The Minnesota lake eutrophication standards include criteria for total phosphorus, chlorophyll *a*, and Secchi disc transparency for shallow and deep lakes. Historically (1990 to 2016) Normandale Lake has met the Minnesota shallow lake eutrophication standards for chlorophyll *a* and Secchi disc depth but not for total phosphorus. Summer average chlorophyll *a* has ranged from 4 to 19 µg/L and Secchi disc depth has been quite good ranging from 1.1 to 2.4 meters (Figure 1 and Figure 2, respectively). Summer average total phosphorus has ranged from 41 to 133 µg/L, with several years exceeding the MPCA's shallow lake criteria of 60 µg/L (Figure 3).

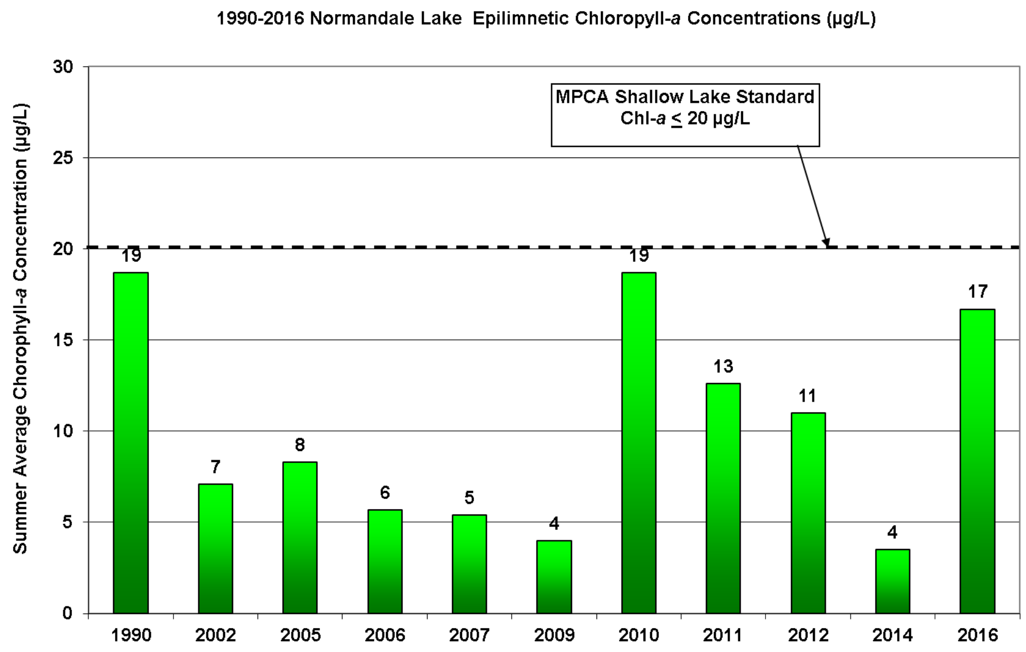

Figure 1 **Summary of historic chlorophyll-*a* concentrations in Normandale Lake**

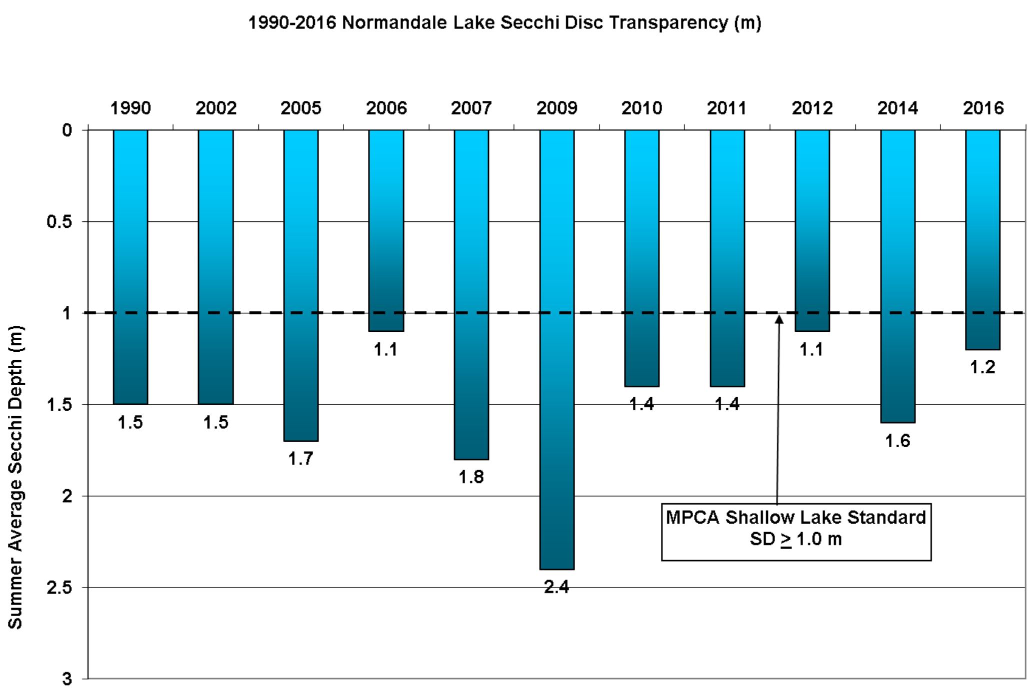

Figure 2 **Summary of historic Secchi depth transparency in Normandale Lake**

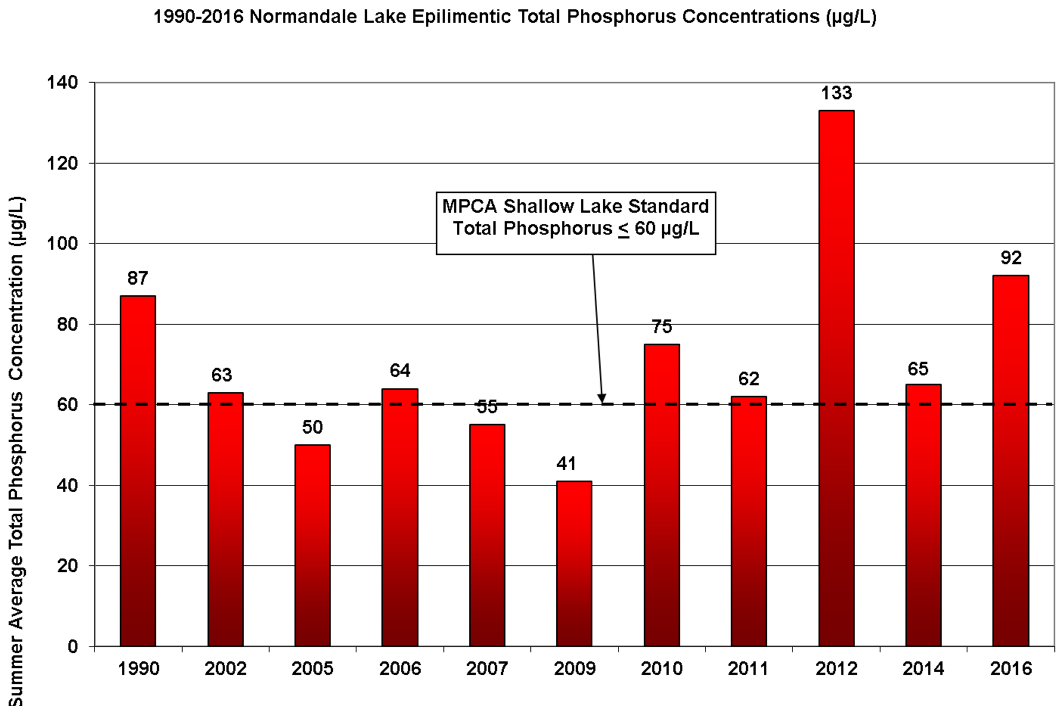

Figure 3 Summary of historic total phosphorus concentration in Normandale Lake

The water quality parameters included in the State's nutrient criteria (total phosphorus, chlorophyll *a*, and Secchi depth transparency) provide an indication of the overall water quality and trophic state of the lake, however, the ecology (aquatic communities) and use of the lake are strongly affected by the dense and widespread growth of aquatic plants and filamentous algae in the lake. For example, aquatic plants were found at 124 out of 125 points sampled during an August, 2017 point intercept survey. The total estimated wet mass of aquatic plants and filamentous algae in August 2017 was 1,754,831 pounds (795,974 kilograms). In addition to aquatic plants that are attached to the lake bottom, there is an abundant population of unattached floating species such as Wolfia, *Lemna minor* (common duckweed), and *Spirodela polyrhiza* (greater duckweed). Filamentous algae is also abundant and the aquatic plants coontail and curlyleaf pondweed also float on the lake surface. The result is that oxygen transfer is inhibited at the lake surface and the lake experiences very low oxygen during the summer months. The total average water column dissolved oxygen concentration in the summer in 2010 was 4.7 mg/L and in 2016 it was 2.3 mg/L. The State of Minnesota standard for dissolved oxygen is 5.0 mg/L.

The extensive coverage of aquatic plants has an effect on the general use of the lake and surrounding area inducing foul smells which are likely from hydrogen sulfide generated in the lake bottom sediments. Some management action is needed, however, the potential benefits of aquatic plant management have to be weighed against how management may affect in-lake phosphorus, clarity, and chlorophyll *a*. Management should not cause the lake to exceed the shallow lake nutrient criteria that are part of the Minnesota eutrophication standards. For example, in August 2017, the mass of phosphorus tied-up in aquatic plants and filamentous algae in Normandale Lake is estimated to be 579 pounds (this assumes water content of 90 percent and total phosphorus of 3,300 milligrams phosphorus per kilogram dry plant mass). Aquatic plants and filamentous algae are an important phosphorus control mechanism for the lake. Roughly half of the phosphorus that enters Normandale Lake is captured internally (e.g., removed by the lake). Modeling conducted as part of this study (discussed in detail below) suggest that aquatic plant growth accounts for approximately 15 to 19 percent of the phosphorus captured by the lake. Hence, it is important to recognize that any activity that may potentially reduce the aquatic plant population in the lake also has the potential to reduce phosphorus capture, resulting in an increase in phosphorus concentrations in the water column. Reductions of aquatic plants and filamentous algae may also lead to increases in phytoplankton.

Given the considerations discussed above, this study was designed to evaluate several lake management approaches applied separately or in concert to improve the overall lake health, with emphasis on achieving a healthy balance among aquatic communities.

A one dimensional hydrodynamic and ecological and water quality model (GOTM-FABM) was developed for Normandale Lake for several purposes, including:

- To better understand the overall ecological function of the lake.
- To quantify aquatic plant and filamentous algae growth and the effect of aquatic plants and filamentous algae on: (1) in-lake phosphorus concentrations in the lake, (2) phytoplankton growth, and (3) dissolved oxygen.
- Evaluate the effect of reducing internal phosphorus loads via whole lake alum treatment (designed to bind phosphorus and inhibit phosphorus release from lake-bottom sediments) on: (1) phosphorus concentrations in the water column of the lake, (2) phytoplankton growth (chlorophyll *a*) in Normandale Lake, and (3) aquatic plant growth in the lake
- Evaluate the effect of reducing external phosphorus loads (in this case, with the use of an inflow alum treatment system) on: (1) phosphorus concentrations in the water column of the lake, (2) phytoplankton growth (chlorophyll *a*) in the lake, and (3) aquatic plant growth in Normandale Lake.

Additional management approaches that were evaluated but could not be modeled included:

- Direct oxygen aeration of the lake water column.
- Aquatic plant and filamentous algae harvesting.
- Curlyleaf pondweed treatment.
- A lake drawdown to manage invasive aquatic plants and promote native aquatic plants.

2.0 Normandale Lake Water Quality and Biota

Recent monitoring data from Normandale Lake, both water quality and biological, are presented in this section to facilitate a better understanding of the current condition of the lake. Data presented are not exhaustive and are presented to facilitate discussion of this study's findings.

2.1 Normandale Lake and Nine Mile Creek Water Quality

This current study used the most recent two years of lake data (2010 and 2016), and associated tributary monitoring data. The primary tributary to Normandale Lake is Nine Mile Creek, and while there is a direct tributary watershed, the water quality of Nine Mile Creek can be considered characteristic of the stormwater inputs to Normandale Lake.

Table 1 Average Nine Mile Creek water quality for selected monitoring parameters

Year	Location	Parameter						
		Ortho-Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Total Phosphorus (mg/L)	TKN (mg/L)	Nitrate + Nitrite (mg/L)	Total Suspended Solids (mg/L)	Volatile Suspended Solids (mg/L)
2010[1]	Nine Mile Creek-N2	0.032	0.044	0.157	1.58	0.14	32.3	12.5
	Nine Mile Creek-N3	0.055	0.068	0.254	1.66	0.50	26.0	11.3
	Composite N2 and N3[3]	0.046	0.058	0.214	1.63	0.35	28.6	11.8
2016[2]	Nine Mile Creek-N2	0.039	0.050	0.104	1.01	0.15	14.2	5.00
	Nine Mile Creek-N3	0.047	0.064	0.335	1.97	0.46	152	34.0
	Composite N2 and N3	0.045	0.061	0.281	1.74	0.39	119	27.1

1. Water quality monitoring period from March 17 to October 14, 2010

2. Water quality monitoring period from March 8 to November 3, 2016

3. Average Nine Mile Creek total flow (station N2 + station N3) and direct tributary inflow in 2010 averaged 13.9 cfs and in 2016 it averaged 12.6 cfs during the water quality monitoring period.

High concentrations of phosphorus, nitrogen, and solids in Nine Mile Creek have the potential to cause eutrophication of Normandale Lake. The residence time of Normandale Lake is fairly short (18 days in 2010 during the open water season) and there is not much time for phosphorus removal by settling. However, it can be seen in the figures below (Figure 4) that the phosphorus concentration in the lake water column is quite low given the concentration of phosphorus in Nine Mile Creek, indicating that other mechanisms (e.g., aquatic plant and filamentous algae growth, discussed below) are contributing to phosphorus capture. It is also notable that there is a steady increase in phosphorus in Normandale Lake beginning in early June of each year (Figure 4), and this steady increase in phosphorus is characteristic of internal phosphorus loading. The build-up of phosphorus in the lake bottom sediments, which can be seen in Figure 5, is also a clear indication of internal phosphorus loading in the lake.

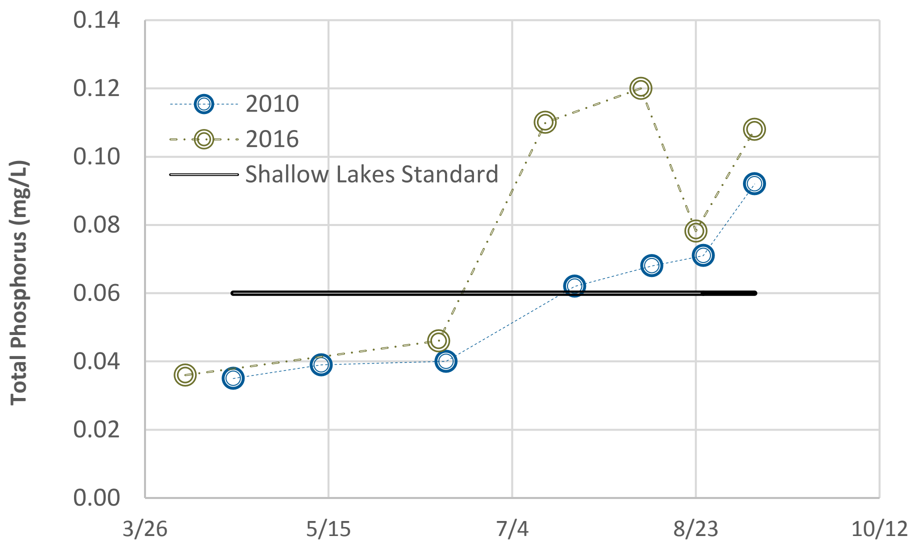

Figure 4 **Total phosphorus in the surface of Normandale Lake**

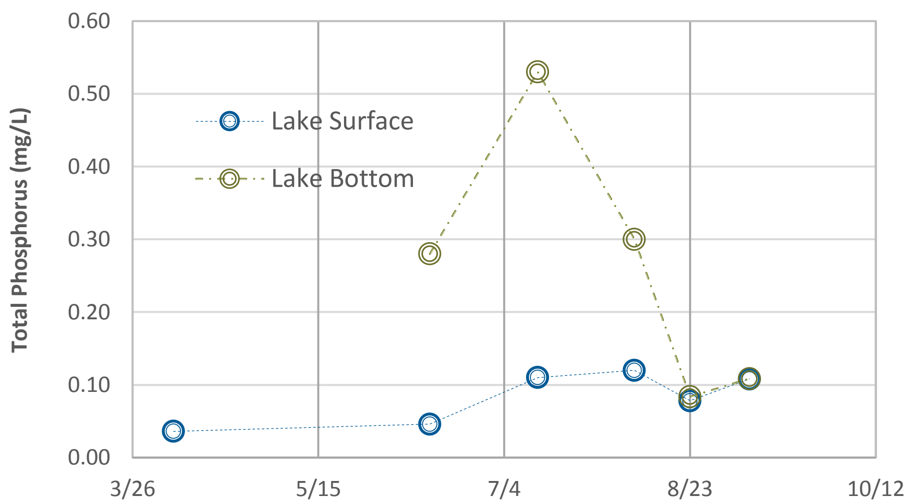

Figure 5 **Total phosphorus in the surface and bottom of Normandale Lake in 2016**

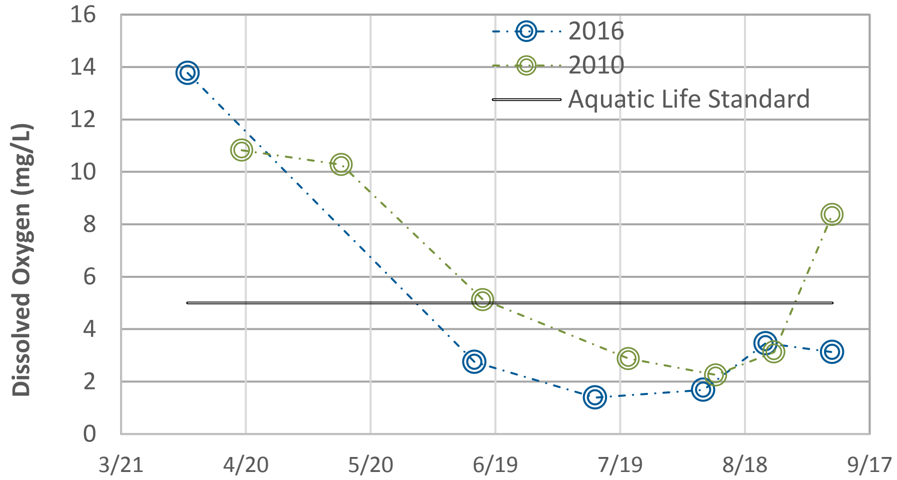

Figure 6 **Average total water column dissolved oxygen concentration in 2010 and 2016**

Increases in the lake's surface total phosphorus in both 2010 and 2016 corresponded with a significant decline in dissolved oxygen that began in June of each year (Figure 6). To a limited degree in 2016, phytoplankton populations (measured as chlorophyll *a*) increased with greater phosphorus in the water column, however, a similar response was not observed in 2010 (Figure 7).

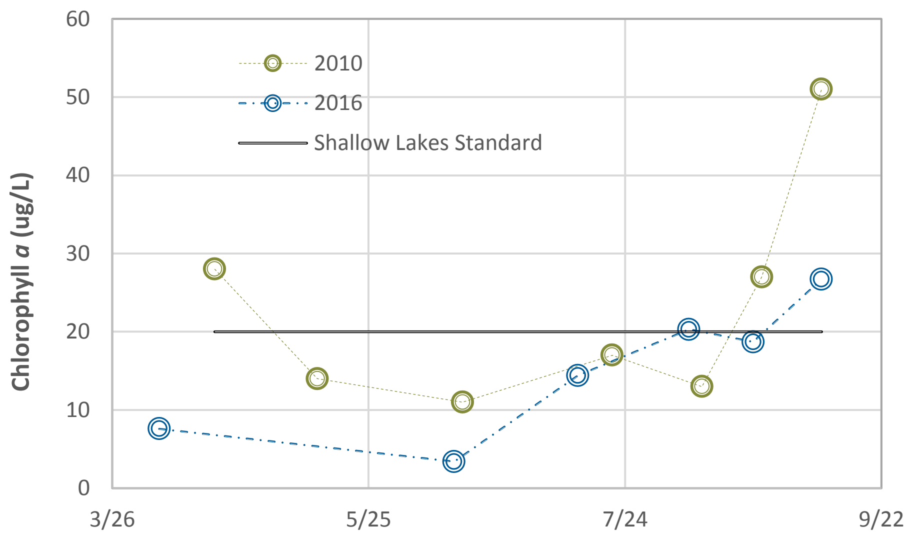

Figure 7 **Chlorophyll *a* concentrations in the surface of Normandale Lake**

2.2 Macrophytes and Filamentous Algae in Normandale Lake

Macrophytes, also called aquatic plants, are plants that grow in aquatic systems such as streams and lakes. There is a wide range of aquatic plants, some attached to the lake bottom, some unattached and floating, some submerged and some, like cattails, grow in but emerge from the water column. Macrophytes are an important part of a lake ecosystem and provide critical habitat for aquatic insects and fish.

Results of a point-intercept survey conducted in June and August 2017 indicate that the extent of macrophytes and filamentous algae coverage is significant. In June, aquatic plants were found in all of the 125 pre-defined sampling locations. In August, only one sampling location did not contain plants. Figure 8 below shows the dominate species in the lake, which include elodea (EC), curlyleaf pondweed (PC), coontail (CD), and filamentous algae (FA).

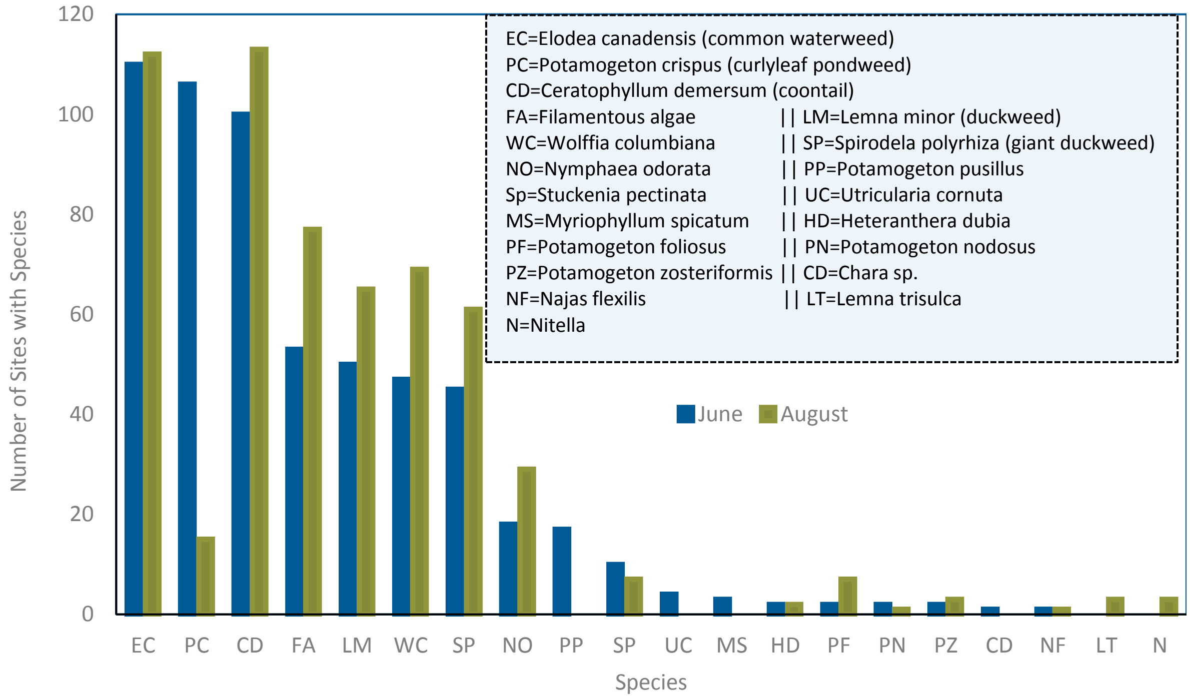

Figure 8 Relative abundance of aquatic plants in Normandale Lake in 2017

The curlyleaf pondweed population was extensive in 2017, comprising 29 percent of the lake's total aquatic plant and filamentous algae biomass in the lake in June. Increases in curlyleaf pondweed appear to have been a regional phenomenon, likely triggered by early ice-off and climate. By August, the curlyleaf pondweed population was significantly reduced, with the die-off and decomposition in June and July likely contributing to the low oxygen observed during these months. It is estimated that the total aquatic plant and filamentous algae wet biomass was 2,266,130 pounds (1,027,894 kilograms) in June and 1,754,831 pounds (795,974 kilograms) in August. With the curyleaf pondweed die-off, other species such as filamentous algae, and the non-attached floating species duckweed (*Lemna minor* and *Spirodela polyrhiza*) and wolfia filled the void left by curlyleaf pondweed.

The quality of aquatic plants in Normandale Lake has been steady since 2010 and has largely exceeded the Minnesota Department of Natural Resources Floristic Quality Index goal (see Figure 9). This suggests that there is a reasonably diverse population of native aquatic plants in the lake. However, the aquatic plant biomass survey conducted in 2017 demonstrates that most of the lake's biomass resides in coontail, elodea, curlyleaf pondweed, white water lily, and duckweed. For example, in August 2017 99.6 percent of the total lake mass could be accounted for by just four species. The relative percent mass of those four dominant species was: (1) coontail-38%, (2) elodea-41%, (3) white water lilly-17%, and (4) duckweed-3.6%. A more even distribution as well as diverse population aquatic plants would benefit Normandale Lake.

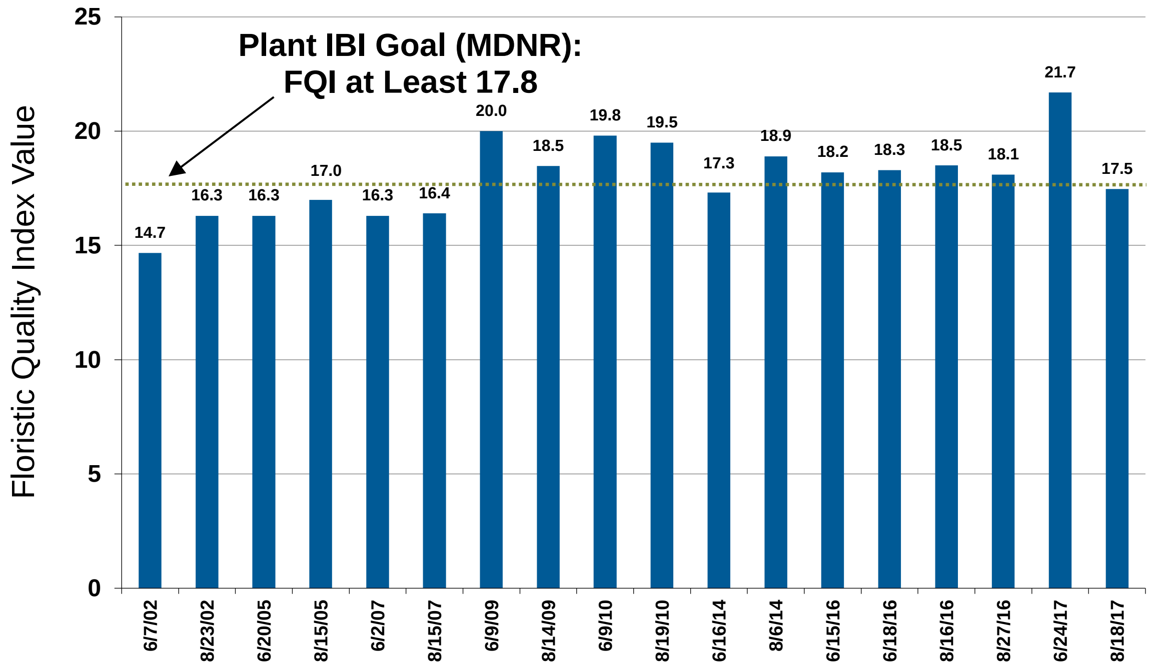

Figure 9 **Floristic Quality Index values for Normandale Lake since 2002**

Filamentous algae are also present in Normandale Lake with an average lake-wide rake fullness of 1 in August and 0.68 in June[1]. Biomass was not directly determined for filamentous algae but is included in the total biomass estimate for the lake. Three species of filamentous algae, *Pithophora (*horsehair algae), *Rhizoclonium hieroglyphicum* (filamentous green algae), and *Spirogyra* were collected and identified in 2017. These species are often visible to residents as they float on the water surface or are attached to aquatic plants during the summer months. Filamentous algae at the beginning of the open water season

[1] Aquatic plant surveys are conducted by throwing a rake into the lake and pulling it out to examine the plants that are pulled up with the rake. A rake fullness of 4 indicates that the rake is full of aquatic plants and 1 indicates that approximately 25 percent of the rake length contains aquatic plants (ranking of 2 and 3 imply 50 percent and 75 percent coverage). Zero is implicitly given to a condition when a rake has no plants. The total rake capture as well as each species is given a ranking from 1 to 4.

often begin growing on the bottom of lakes and move upward either with the growth of aquatic plants or by floating facilitated by gas bubble production. These species have similar nutrient requirements to aquatic plants and phytoplankton[2]. Hence, strategies to reduce aquatic plant and phytoplankton growth by nutrient reduction should also reduce filamentous algae growth.

[2] In Kohlman Lake (Ramsey Washington Metropolitan Watershed District) in 2015 the average concentration of phosphorus in dry filamentous algae was 2.5 grams per dry kilogram of material while aquatic plants had 3.3 grams of phosphorus per dry kilogram of plant material.

3.0 Water Quality Modeling of Management Options

3.1 Model Description

The GOTM-FABM model used for this study is a hydrodynamic and ecological (water quality) model, meaning it simulates lake temperature, stratification, water movement, nutrients, solids, phytoplankton growth, aquatic plant growth, dissolved oxygen, as well as several other chemical and biological parameters in lakes. It was developed by a consortium of European universities with staff at Arhus University in Denmark being lead developers.

This model was used to better understand and quantify several relationships, including:

- The effect of macrophytes on phytoplankton growth and overall population size (typically measured as chlorophyll *a*).
- The effect of phosphorus reduction (both external loads from stormwater and internal loads from lake-bottom sediment) on macrophyte and phytoplankton growth.
- The effect of phosphorus reduction (both external loads from stormwater and internal loads from lake-bottom sediment) on phosphorus concentrations in the water column of the lake.
- The relationship between light availability on macrophyte and phytoplankton growth.
- The deposition of phosphorus into lake-bottom sediments and the release of phosphorus from lake sediments.
- The cause of low oxygen in the lake.

3.2 Model Inputs and Set Up

Model inputs included climate (air temperature, relative humidity, percent cloud cover, wind speed), inflow and outflow rates, and inflow water chemistry (nutrients, solids, dissolved oxygen). The models were run for 2010 and 2016 starting at ice-off (approximately March 17, 2010, and March 8, 2016) and finishing at the end of October.

3.3 Calibration and Functional Observation

The process of model calibration involved changing a range of coefficients (e.g., "nobs") such that the model output is close to the measured data. For a model such as GOTM-FABM, the calibration parameters have to be based on reasonable literature-derived values in order for the mass balance of nutrients (in water, sediment, and in biota) and other key biological growth parameters to converge. Calibration is important such that predictions (e.g., for different management scenarios) are based upon a model with realistic calibration parameters. The results of the calibration process for select parameters are summarized in Table 2 below.

Table 2 **Comparison of average model predictions and average monitoring results for selected model parameters**

Year	Condition	Parameter (mg/L)		
		Dissolved Oxygen	Total Phosphorus	Chlorophyll *a*
2010[1]	Model	8.6	0.103	21.6
	Measured	5.8	0.120	18.5
2016[2]	Model	15.4	0.066	11.9
	Measured	4.4	0.083	15.2

1. Period of modeling results and monitoring data was from 4/19/2010 to 9/8/2010.
2. Period of modeling results and monitoring data was from 4/6/2016 to 9/8/2016.

Calibrated models should also be able to capture the seasonal changes in key parameters such as phosphorus. Capturing the seasonal change in total phosphorus (see calibration in Figure 9) indicates the model is correctly modeling the magnitude of internal phosphorus loading as well as the uptake and removal of phosphorus by biota such as phytoplankton and aquatic plants (see Figure 10).

A strength of the GOTM-FABM model is that it is capable of capturing the effect of other growth limiting factors such as light, in addition to nutrients (phosphorus as well as nitrogen limitation). The effect of shading by macrophytes, subsequent light limitation, as well as light inhibited phytoplankton growth can be seen in Figure 11, which shows the seasonal change in phytoplankton and macrophyte mass. The model results indicate that macrophyte growth (an increase in the population size) appears to inhibit phytoplankton growth (population size). Once the macrophytes stop growing (e.g., a stable population size), the phytoplankton begin growing. This demonstrates that the large macrophyte population in Normandale Lake is controlling phytoplankton and is likely preventing phytoplankton blooms during the summer months.

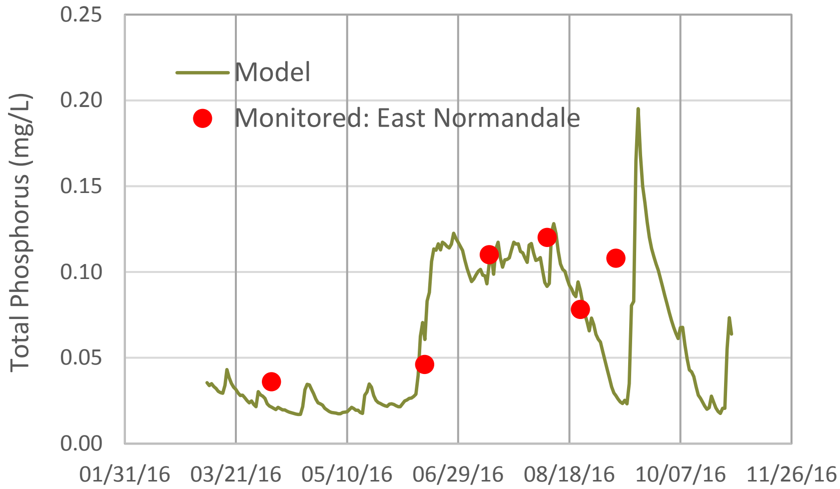

Figure 10 **Comparison of model predicted and measured total phosphorus in the surface water of Normandale Lake. Increase in phosphorus during late June through mid-August demonstrates the effect of internal loading on phosphorus concentrations in the water column of Normandale Lake (2016).**

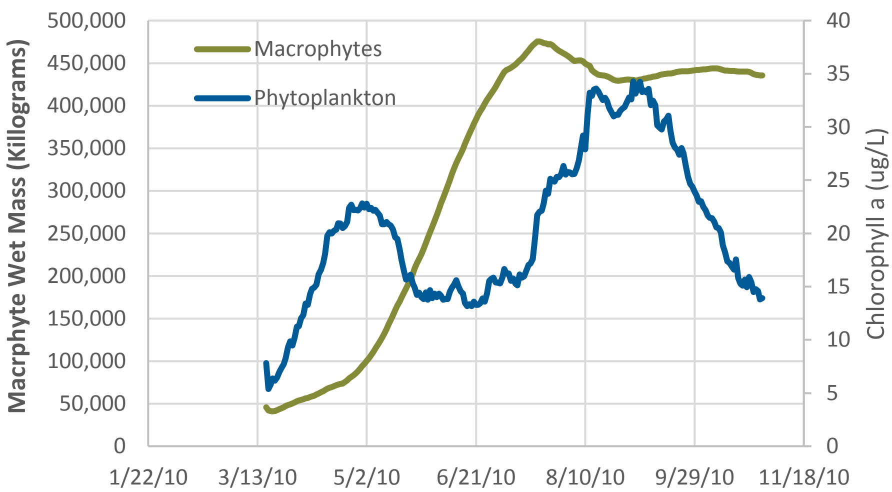

Figure 11 **Comparison of model predicted total wet mass of macrophytes in Normandale Lake and the concentration of phytoplankton (measured as chlorophyll a) in the surface waters of the lake (2010).**

3.4 Management Scenarios

Several modeling scenarios were conducted to better understand the effect of a range of phosphorus reduction strategies on: (1) phosphorus concentrations in the lake, (2) phytoplankton growth, and (3) macrophyte growth. Note that macrophytes in the model are representing any attached aquatic plant or filamentous algae or largely fixed plant that is not emergent. In essence, not phytoplankton. The modeled management scenarios included: (1) reduction of internal loading with a whole lake alum treatment, (2) reduction of external phosphorus loading (simulated as an inflow alum treatment facility that flocculates and removes phosphorus), and (3) a combination of internal and external loading control.

Reduction of internal loading by binding phosphorus in the lake sediments with alum (active component being aluminum) was simulated. The assumed alum dose was based upon the observed concentration of the phosphorus fraction in the lake sediment (e.g., the mobile phosphorus fraction), which is largely responsible for internal phosphorus loading. Alum dosing assumptions included: (1) a targeted aluminum to aluminum bound phosphorus ratio (Al:Al-P) of 75:1; (2) an 85 percent reduction in mobile phosphorus; (3) treatment of the upper 8 cm (3+ inches) of lake sediment with alum, i.e., aluminum; (4) total alum application of 23,024 gallons; and (5) total sodium aluminate application of 11,512 gallons. Sodium aluminate is similar to alum except it contains aluminum in a chemical with the formula $Na\mathbf{Al}(OH_4)$. Alum contains aluminum in the form $\mathbf{Al}_2(SO4)_3$. Aluminum is Al. Sodium aluminate is used in combination with alum to protect aquatic life from any potential pH effects of alum application.

The external load control scenario was simulated as an alum treatment facility located just upstream of Normandale Lake to treat Nine Mile Creek inflows. This modeling approach was taken due to strong interest expressed by local residents regarding the effects of an alum treatment facility on lake water quality. The simulation was based on an assumption that an alum treatment facility would remove 82 percent[3] of the total phosphorus that enters the treatment system. A range of treatment flows were simulated. Alum treatment systems are typically designed and sized to treat flows up to a targeted rate (see "Maximum Treated Flows" in Table 3). Flows above the targeted maximum flow rate are bypassed. Hence, there is greater overall efficiency from a capital cost standpoint when these systems are designed to treat lower maximum flows.

It should be noted that although the external load control scenario was simulated as an alum treatment facility, the phosphorus removals are largely analogous to implementation of stormwater Best Management Practices (BMPs) in the watershed, which will also lead to reduced phosphorus in Nine Mile Creek and ultimately reduced phosphorus loads to Normandale Lake. For example, the 5 cfs inflow alum treatment system that was simulated corresponds to a 25 percent reduction in total phosphorus from the watershed. The modeling results for the 5 cfs inflow alum system hence would be analogous to a 25 percent reduction in phosphorus with BMP implementation (based on 2010 data- see Table 3). Per the NMCWD's 2017 Water Management Plan, reductions in external loading will be achieved through stream bank stabilization, implementation of the NMCWD permitting program, and implementation of stormwater best management practices and lake management strategies in the upstream watershed.

[3] The inflow alum treatment facility currently in operation at the Ramsey Washington Metro Watershed District has a treatment efficiency of 82 percent total phosphorus removal.

Table 3 **Treatment volume and phosphorus removal with construction of an inflow alum treatment facility**

Maximum Treated Flows (cfs)	2010		2016	
	% of Total Stream Volume Treated	% Total Phosphorus Reduction	% of Total Stream Volume Treated	% Total Phosphorus Reduction
0	0%	0%	0%	0%
5	31%	25%	36%	29%
10	46%	38%	53%	43%
15	56%	46%	62%	51%
20	63%	52%	69%	56%

3.5 Results

The predicted outcomes of internal and external phosphorus load control on total phosphorus concentration, phytoplankton (measured as chlorophyll *a*), and the total wet mass of macrophytes in Normandale Lake are shown in Table 4 (for 2010) and Table 5 (for 2016). The challenge for Normandale Lake is that the lake already acts as a significant sink for phosphorus, meaning, phosphorus is removed by aquatic plants, phytoplankton growth and settling, and by solids settling (phosphorus is incorporated into the solids). Any disturbance of these phosphorus removal mechanisms can lead to higher phosphorus concentrations in the lake. Although reduced phosphorus loading does have the effect of reducing macrophyte growth (see Table 4 and Table 5), this also means less phosphorus removal by plants. The outcome is that phosphorus concentrations in the water column of Normandale Lake are reduced minimally or not at all with phosphorus load reduction.

Another somewhat counter intuitive outcome of external and internal phosphorus reduction in Normandale Lake is that phytoplankton growth increases with phosphorus reduction. This is largely a function of increased light availability with reduced shading by macrophytes. Hence, any activity that increases light availability in the lake may be accompanied by increased phytoplankton growth. Aquatic plant harvesting may be the exception to this as harvesting removes some of the plant mass, but the overall mass of phosphorus taken up by aquatic plants is not reduced as long as aquatic plant growth is not significantly hindered by harvesting. This is difficult to predict, however, and the benefit of harvesting would need to be determined by a limited harvesting test period (e.g., 1 to 3 years of harvesting conducted as a test).

Table 4 **2010 total phosphorus concentration, phytoplankton (measured as chlorophyll *a*), and the total wet mass of macrophytes in Normandale Lake with internal and external phosphorus load control.**

Phosphorus Management Approach	Phosphorus Management Target	Maximum Flows Treated	% of Total Flow Treated	*Management Outcome: In-Lake Condition: June 1 to September 30*		
				Average Total Phosphorus (mg/L)	Average Chlorophyll *a* (mg/L)	Maximum Macrophyte Wet Mass (kg) In Entire Lake
None	NA	NA	0%	0.107	24	421,618
Inflow Alum Treatment Facility	External P Loads	5 cfs	31%	0.095	27	404,693
		10 cfs	46%	0.098	33	375,351
		15 cfs	56%	0.103	39	347,803
		20 cfs	63%	0.106	44	325,264
Whole Lake Alum Treatment	Internal P Loads	Not Applicable	0%	0.110	25	391,623
Whole Lake and Inflow Alum Treatment	External and Internal P Loads	5 cfs	31%	0.102	30	356,047

Table 5 **2016 total phosphorus concentration, phytoplankton (measured as chlorophyll a), and the total wet mass of macrophytes in Normandale Lake with internal and external phosphorus load control.**

Phosphorus Management Approach	Phosphorus Management Target	Maximum Flows Treated	% of Total Flow Treated	*Management Outcome: In-Lake Condition from June 1 to September 30*		
				Average Total Phosphorus (mg/L)	Average Chlorophyll *a* (mg/L)	Maximum Macrophyte Wet Mass (kg) In Entire Lake
None	NA	NA	NA	0.089	12.9	631,150
Inflow Alum Treatment Facility	External P Loads	5 cfs	29%	0.072	14.7	629,585
		10 cfs	43%	0.066	15.8	609,778
		15 cfs	51%	0.062	16.3	597,087
		20 cfs	56%	0.059	16.7	587,013
Whole Lake Alum Treatment	Internal P Loads	NA	NA	0.074	13.6	511,213
Whole Lake and Inflow Alum Treatment	External and Internal P Loads	5 cfs	29%	0.060	16.2	432,352

4.0 Management Options, Schedule and Costs

Table 6 summarizes the issues in Normandale Lake, in relation to the NMCWD's holistic lake health assessment factors. The table also describes the cause(s) of the issues and potential management options for consideration to improve lake health.

Table 6 Summary of issues and potential management options

NMCWD Holistic Lake Health Assessment Factors	Issues	Causes	Potential Management Options
Water Quality	High phosphorus (>60 µg/L average summer)	External and internal phosphorus loading	Whole lake alum treatment, upstream watershed BMP and lake management implementation.
	Potentially high phytoplankton	External and internal phosphorus loading	
Aquatic Communities	Invasive aquatic plants	Curlyleaf pondweed growth	Lake drawdown and chemical treatment of curlyleaf pondweed with endothall
	Low dissolved oxygen	Coverage of the lake surface by aquatic plants, curlyleaf pondweed die-off	Aquatic plant harvesting, aeration (direct oxygen injection)
Recreational Use[1]	Smell—hydrogen sulfide	Coverage of the lake surface by aquatic plants, curlyleaf pondweed die-off	Aquatic plant harvesting, aeration (direct oxygen injection)
	Excessive aquatic plants and filamentous algae	External and internal phosphorus loading	Whole lake alum treatment, BMP implementation in upstream watershed.

[1] The NMCWD considers water quality, aquatic communities, and water quantity to be the three primary factors in assessing the ecological health of a lake. The NMCWD also considers how recreation and wildlife habitat affect and are affected by overall lake health.

As summarized in the NMCWD's 2017 Water Management Plan, reductions in external loading to Normandale Lake will be achieved through stream bank stabilization, implementation of the NMCWD permitting program, implementation of management strategies for upstream lakes, and construction of stormwater best management practices in the watershed tributary to Normandale Lake. Because existing external and internal phosphorus loads to Normandale Lake are currently very large, ongoing external phosphorus reduction efforts need to be combined with other measures to concurrently meet the NMCWD goals of improved water quality and health of the aquatic community.

To maintain a more moderate aquatic plant population it is recommended that a whole lake alum treatment be conducted in concert with aquatic plant harvesting. The whole lake alum treatment will reduce internal phosphorus loads and facilitate reduced aquatic plant and filamentous algae growth by limiting phosphorus availability. The aquatic plant harvesting will reduce the coverage of the aquatic plant population which will improve exchange of oxygen between the lake and the atmosphere. This improved exchange of oxygen should lead to increased oxygen in the water column and improved fisheries habitat.

A lake drawdown and whole lake treatment targeting curlyleaf pondweed (treatment would be conducted with endothall in the spring at a dose of 1 mg/L) is recommended to promote a more diverse and native aquatic plant community. The current outlet structure includes a low flow bypass consisting of a 4-inch diameter hole cut through an 18-inch sluice gate at elevation 802.25 feet. Because of the constant and periodically high flows into Normandale Lake from Nine Mile Creek and the discharge limitations of the low flow bypass, it can be expected that the drawdown will not cover the entire lake. As such, the curlyleaf pondweed treatment with endothall is recommended to control pondweed across the entire lake (including those areas of the lake that are and are not affected by the drawdown). The drawdown is also expected to consolidate and aerate sediments and provide an opportunity to remove carp and other rough fish and restock the lake with a more balanced fishery. Because there is an opportunity to remove carp and re-balance the fishery, a carp and fisheries survey is recommended to determine if the carp population is large enough to disturb the ecology of Normandale Lake.

Direct oxygen injection is also recommended to keep the lake aerated for several reasons: (1) to prevent the generation of foul smelling hydrogen sulfide, (2) to help keep the lake sediments aerated and prevent internal loading as new, incoming phosphorus is deposited onto the lake bottom, and (3) to provide oxygen to fish species that cannot survive at low oxygen concentrations (e.g., 2-3 mg/L) that persist in Normandale Lake during the summer and to prevent winter fish kill. This system would inject pure oxygen into the water column across approximately half of the lake. The bubbles that are generated are small and not readily visible by those viewing or recreating on the lake and hence from a lake use standpoint this approach has benefits over forced air injection.

Table 7 summarizes the recommended schedule, permitting, engineering and design tasks and considerations, and estimated costs for the management options discussed above. The costs included in Table 7 are planning-level opinions of probable costs, intended to provide assistance in evaluating and comparing options and should not be assumed as absolute values for given alternatives.

It is important to note that management of Normandale Lake must be in conformance with the Army Corp of Engineers Section 404 permit that was issued in 1979 for construction of the dam. The permit contains several special conditions, including restrictions on vegetation control or dredging in the western portion of the lake. For management options being considered that are not allowed under the current permit, the NMCWD and City of Bloomington may need to seek modification to the existing permit.

As discussed in Section 3.4, the modeling analysis included evaluation of an alum treatment facility located just upstream of Normandale Lake to treat Nine Mile Creek inflows, due to strong interest expressed by local residents. Modeling results showed only moderate reductions in in-lake phosphorus concentrations. Due to the moderate reductions, high estimated capital cost to construct and operate an alum treatment facility, and land requirements for a pond to capture alum floc (minimum size of 1-2 acres for the 5 cfs treatment system with proportionately larger ponds needed for the large systems), this management option is not recommended for Normandale Lake.

Table 7 Management options, potential timing for implementation, tasks that need to be completed in preparation for the management activity, and opinion of probable cost

Management Option	Potential Timing	Preparatory Tasks/ Considerations	Opinion of Cost
Upstream Watershed BMP and Lake Management Implementation	Ongoing	Ongoing implementation of NMCWD 2017 Water Management Plan (see Tables 6-2 and 6-3)	See NMCWD 2017 Water Management Plan (Tables 6-2 and 6-3)
Lake Drawdown	Conduct in fall 2018	Carp and fisheries survey (spring/summer 2018)	$12,000
		Design and permitting (fall 2017-summer 2018)	$20,000
		Outfall construction/drawdown	$100,000–$300,000
Curlyleaf Pondweed Treatment	Spring 2018	Curlyleaf pondweed treatment. Apply for DNR permit and request a variance to treat more than 15% of the littoral area.	$100,000
In-lake Alum Treatment	Conduct in 2019 immediately after drawdown is completed and lake refills	Design and permitting (summer 2018)	$140,000
Aeration (Direct Oxygen Injection)	After drawdown, with timing dependent upon: (1) outcome of design analysis in the Engineer's Report, and (2) DNR and Army Corps of Engineers approval to harvest more than 50% of the lake's littoral area.	Consider installing a dual system (aeration plus ferric chloride for maintenance of internal phosphorus loading control)	$230,000, $15,000/year operation
Limited Plant Harvesting (2-3 Year Test)	After drawdown, with timing dependent upon DNR and Army Corps of Engineers approval to harvest more than 50% of the lake's littoral area.	Apply for DNR permit to harvest more than 50% of the littoral area. Request for modification of Army Corps of Engineers permit.	$50,000/year