DRAFT

Lake Cornelia and Lake Edina Water Quality Study

Use Attainability Analyses for Lake Cornelia (updated from 2010) and Lake Edina (first version)

Prepared for
Nine Mile Creek Watershed District

May 2019

BARR
4300 MarketPointe Dr • Suite 200
Minneapolis, MN 55435
952.832.2600 • www.barr.com

Lake Cornelia and Lake Edina Water Quality Study

Use Attainability Analyses for Lake Cornelia (updated from 2010) and Lake Edina (First version)

May 2019

Contents

List of Tables

List of Figures

List of Appendices, Attachments, or Exhibits

Acronyms

Acronym	Description
AACE	Association for the Advancement of Cost Engineering
AIS	Aquatic Invasive Species
BMP	Best Management Practice
Chl *a*	Chlorophyll *a*
EWM	Eurasian watermilfoil
FiN	Fishing in the Neighborhood
FQI	Floristic Quality Index
HSG	Hydrologic Soil Groups
MDNR	Minnesota Department of Natural Resources
MnLEAP	Minnesota Lake Eutrophication Analysis Procedure
MPCA	Minnesota Pollution Control Agency
NCHF	North Central Hardwood Forests
NMCWD	Nine Mile Creek Watershed District
RPBCWD	Riley Purgatory Bluff Creek Watershed District
SSURGO	Soil Survey Geographical Database
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSS	Total Suspended Solids
UAA	Use Attainability Analysis
USGS	U.S. Geological Survey
WHO	World Health Organization
WiLMS	Wisconsin Lake Modeling Suite

1.0 Introduction

This report describes the results of the Use Attainability Analysis (UAA) for Lake Cornelia and Lake Edina in Edina, Minnesota. Both lakes are summarized in this report due to the significant influence of Lake Cornelia on Lake Edina's water quality. An UAA provides the scientific foundation for a lake-specific best management plan that will permit maintenance of, or attainment of, the intended beneficial uses of a waterbody. The UAA is a scientific assessment of a water body's physical, chemical, and biological condition. This study includes both a water quality assessment and prescription of protective and/or remedial measures for Lake Cornelia and Lake Edina and their tributary watersheds. The work presented in this report follows analyses that were previously completed for an UAA developed for North Cornelia in 2010.

The conclusions and recommendations presented in this report are based on historical water quality data, a fisheries survey conducted in 2018, several years of aquatic plant surveys, and the results of intensive lake water quality monitoring in 2015, 2016, and 2017. Lake models were developed and calibrated to the 2015, 2016, and 2017 data sets to gain a better understanding of the influence of various phosphorus sources on lake water quality. The models were also used to quantify the expected outcome of different management actions on lake water quality. Water quality goals for the lakes were identified based on the lakes' designated beneficial uses (e.g., runoff management, curly-leaf pondweed control). In addition, best management practices (BMPs), including both external and internal phosphorus controls, were evaluated to compare their relative effect on total phosphorus concentrations in the lakes. Management scenarios were then assessed to determine attainment or non-attainment of the lake goals.

1.1 Purpose and Process of the UAA

The Nine Mile Creek Watershed District (NMCWD) has historically used a process referred to as Use Attainability Analysis (UAA) to assess the water quality condition of its lakes relative to the desired beneficial uses that can be reasonably achieved and maintained with implementation of management recommendations. The UAA process addresses a wide range of goals (e.g., water quantity, aquatic communities, recreational use, and wildlife), with the primary focus being achievement of water quality goals. As part of the *Nine Mile Creek Watershed District Water Management Plan* (Plan) adopted in 2017 and amended in 2018 and 2019 (NMCWD, 2017, amended 2019), 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. A properly functioning ecosystem supports the attainment of good water quality. The NMCWD has also adopted the Minnesota eutrophication standards as part of their 2017 Plan.

The UAA employs a watershed runoff model and an in-lake water quality model to quantify the benefits of management efforts. The in-lake water quality model predicts changes in lake water quality based on the results of the watershed runoff model (external inputs) as well as internal processes such as sediment phosphorus release due to anoxia and bioturbation (carp/goldfish), curly-leaf pondweed death and decay, and enhanced phosphorus settling rates due to phytoplankton bloom treatments. Using these models, various watershed and lake management strategies can be evaluated to determine their likely effects on lake water quality. The resulting lake water quality can then be compared with the water quality goals to see if the management strategies are able to produce the desired changes in the lake. Using the tools of the UAA, the cost-effectiveness of the management strategies can also be evaluated.

1.2 Scope of UAA Study

This UAA evaluates current and various proposed conditions for Lake Cornelia and Lake Edina. Several steps are necessary for the evaluation of the watersheds, lakes, and management initiatives. Those steps, briefly summarized below, are described in detail in the following sections.

Identification of Goals and Expectations- To evaluate lake management strategies, it is first necessary to establish the criteria against which outcomes can be measured.

Assessment of Current Conditions- The conditions of Lake Cornelia's and Lake Edina's watershed, biological communities, water quality, and in-lake response to nutrient (phosphorus) inputs were evaluated for this study. Sources of phosphorus to Lake Cornelia and Lake Edina were identified and quantified through modeling analyses.

Evaluation of Management Strategies- A variety of watershed (external) loading and internal loading reduction scenarios were evaluated. The in-lake model was used to predict the lakes' responses to these changes. Costs of the management strategies were estimated so that those costs could be compared to the in-lake benefits that the management initiatives are expected to provide.

2.0 Shallow Lake Characteristics and Water Quality

Lake Cornelia and Lake Edina can both be classified as shallow lake ecosystems. Shallow lakes are lakes that generally have well mixed water columns throughout most of the year and have depths that allow for light penetration to reach the entire sediment surface (i.e., potential for macrophyte growth over the entire lake). Shallow lakes classically exist in two states: (1) clear water with submerged and emergent macrophytes; and (2) turbid water with phytoplankton. The concentration of nutrients entering the shallow water system, the biovolumes of benthivorous fish per unit lake area, and the presence or absence of invasive species such as curly-leaf pondweed are primary drivers that determine the state of shallow lakes.

There are a number of concepts and terminology that are necessary to describe and evaluate a lake's water quality. This section is a brief discussion of those concepts.

2.1 Eutrophication

Eutrophication, or lake degradation, is the accumulation of sediments and nutrients in lakes. As a lake naturally becomes more fertile, biological production enhances and sediment inflow accumulates filling the lake's basin. Over a period of hundreds to thousands of years, a lake can successively become a pond, a marsh and, ultimately, a terrestrial site. This process of eutrophication is natural and results from the normal environmental forces that influence a lake. Cultural eutrophication, however, is an acceleration of the natural processes and is caused by human activities. Nutrient and sediment inputs from wastewater treatment plants, septic tanks, agriculture, and stormwater runoff can far exceed the natural inputs to the lake. Nutrient enrichment in lakes often intensifies primary production resulting in the manifestation of algal blooms. Enhanced sediment loadings can attenuate light and reduce lake transparency, which can limit macrophyte growth. Since macrophytes assist in creating a stable water state, especially in shallow lakes, high suspended sediment and enhanced nutrients can often lead to impaired water quality.

2.2 Nutrients

Biological production in an aquatic ecosystem is limited by the concentrations of essential nutrients. The "limiting nutrient" concept is a widely applied principle in ecology and in the study of eutrophication. It is based on the idea that phytoplankton and plants require many nutrients to grow, but the nutrient with the lowest availability, relative to the amount needed by the phytoplankton or plant, will limit growth. It follows then, that identifying the limiting nutrient will point the way to controlling aquatic plant and algal growth. Nitrogen (N) and phosphorus (P) are generally the two growth-limiting macronutrients in most natural waters. Thus, efforts to improve water quality typically focus on reducing the growth-limiting nutrient concentration in the waterbody; however, it is often difficult to identify and control all of the nutrient loadings to a specific waterbody.

Two primary sources, external and internal loads, are responsible for elevated nutrient concentrations in lakes. Nutrients that enter lakes through watershed runoff, groundwater inputs, or atmospheric deposition are considered external loads. As urbanization has occurred, more areas of impermeable surfaces have been developed causing increased stormwater runoff and pollutant transport during storm and spring thaw events. In urbanized areas, stormwater runoff typically flows through storm sewer systems to the downstream waterbody, which generally results in faster velocities than natural channel flow and can result in higher suspended loadings. Implementation of the NMCWD's stormwater management rules for new development and redevelopment and efforts to install retrofit best management practices (BMPs) are helping to reduce external loads to nearby waterbodies. However, for many shallow lakes, internal load reduction measures (e.g., alum treatment, aquatic plant management, fish management) are also required to meet water quality goals.

Once external nutrient loads enter a lake, over time, the nutrients accumulate in the sediment through the settling of particulates and through organism decay. Natural lake processes such as sediment resuspension, chemical dissolution, or microbial reduction can reintroduce these nutrients to the overlying water body resulting in internal loading. This is specifically common for phosphorus, which can be found bound to the sediment under oxidized conditions. The binding of phosphorus to iron in sediments allows the sediment to act as a sink or source depending on the lake's physical and chemical conditions. Therefore, understanding the chemical and physical conditions and the timing of these conditions will be important considerations when developing an internal loading management plan.

2.2.1 Stratification impacts on internal loading

Lake stratification, the separating of an upper, well mixed warm layer (epilimnion) from a cool, bottom layer (hypolimnion) (Figure 2-1), can lead to low oxygen concentrations in lake bottom waters and trigger internal phosphorus loading. For shallow lakes like Lake Cornelia and Lake Edina, stratification is typically irregular and can happen on a daily, weekly, or longer timescale. Mixing likely occurs regularly in Lake Cornelia and phosphorus released from sediments is then made available to phytoplankton during these frequent mixing events. Because Lake Edina is very shallow, mixing likely occurs daily and this may help to prevent internal loading.

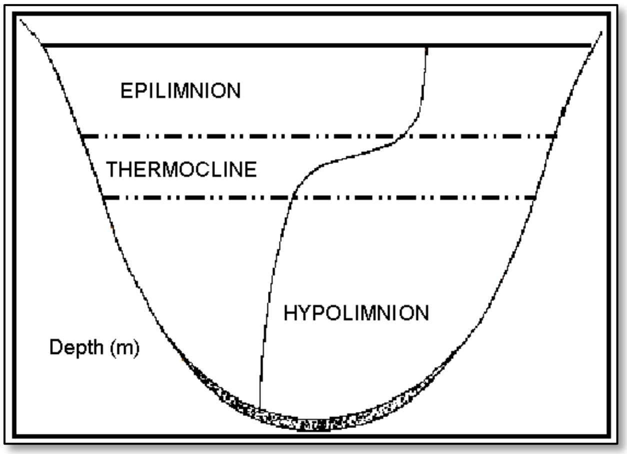


Figure 2-1 Generalized thermal lake stratification diagram

2.2.2 pH impacts on internal loading

The pH of the water column can also play a vital role in affecting the phosphorus release rate under conditions when oxygen is present in the water column (oxic conditions). Photosynthesis by macrophytes and algae during the day tend to raise the pH in the water column, which can enhance the phosphorus release rate from the oxic sediment. Enhancement of phosphorus release at elevated pH (pH > 7.5) is thought to occur through replacement of the phosphate ion (PO_4^{-3}) with the excess hydroxyl ion (OH^-) on the oxidized iron compound (James, et al., 2001). Large increases in pH are often the consequence of phytoplankton blooms.

2.2.3 Organism impacts on internal loading

Benthivorous fish, such as carp, bullhead and goldfish, can have a direct influence on the phosphorus concentration in a lake (LaMarra, 1975). These fish typically feed on decaying plant and animal matter and other organic particulates found at the sediment surface. The fish digest the organic matter, and excrete soluble nutrients, thereby transforming sediment phosphorus into soluble phosphorus available for uptake by algae at the lake surface. Benthivorous fish can also cause resuspension of sediments in shallow ponds and lakes, transporting phosphorus from sediment into the water column, causing reduced water clarity and poor aquatic plant growth, as well as high phosphorus concentrations (Cooke, Welch, Peterson, & Newroth, 1993). In some cases, the water quality impairment caused by benthivorous fish can negate the positive effects of BMPs and lake restoration.

The critical difference between biological (e.g., benthivorous fish feeding) and physical (e.g., wind and waves) sediment resuspension is the area and the frequency to which these components can induce impacts. The volume of sediment impacted by physical resuspension is largely influenced by the geometry of the lake (e.g., size, fetch, bathymetry) and wind events (e.g., direction, velocity). For example, a wind event may develop wave induced sediment resuspension along a portion of the shoreline. However, biological resuspension from feeding or mating activities can occur over a much larger area and is impacted by the number of organisms in the aquatic ecosystem. Additionally, while physical resuspension occurs in a periodic, episodic-based fashion, benthivorous fish resuspension can be more continuous.

2.2.4 Curly-leaf pondweed impacts on internal loading

Another potential source of internal phosphorus loading is the die-off of curly-leaf pondweed. Curly-leaf pondweed is an invasive (i.e., non-native) aquatic plant that is common in many of the lakes in the Twin Cities metropolitan area. Curly-leaf pondweed grows under the ice during the winter and gets an early start in the spring, crowding out native species. It releases a small reproductive pod that resembles a small pine cone in late-June, and then begins its die-back in late-June and early-July. The biomass sinks to the bottom of the lake and begins to decay, releasing phosphorus into the water column and causing oxygen depletion, exacerbating the internal sediment release of phosphorus. This cycle typically results in an increase in phosphorus concentrations in the lake in late-June of early-July.

2.3 Climate Change Considerations

Considerable studies have been devoted to predicting the impacts of a warming climate on the hydrologic cycle. Of particular concern are the changes to atmospheric moisture content, evaporation, precipitation intensity, and the possibility of increased risk for drought and flooding extremes (Trenberth, 1999; Trenberth, Smith, Qian, Dai, & Fasullo, 2003; Giorgi, et al., 2011; Trenberth, 2011).

Alterations to the hydrologic cycle will consequently impact freshwater ecosystems. Observational records and climate model projections show evidence of freshwater vulnerability to a warming climate (Dokulil & Teubner, Eutrophication and climate change: Present situation and future scenarios, 2011). Freshwater characteristics such as lake stratification and mixing, ice coverage, and river flow could see discernable changes by the end of the 21st century (Dokulil & Teubner, 2011; Dokulil, 2013). Increases in nutrient loadings and water temperatures, changes to water levels, and amplified eutrophication could impact aquatic organisms and influence biodiversity.

2.3.1 Projected Changes to the Hydrologic Cycle

Larger concentrations of greenhouse gases in the atmosphere, such as carbon dioxide and methane, create an increased downwelling of longwave radiation to the earth's surface (Trenberth, 1999). This enhanced downwelling not only escalates surface temperature warming, but also induces changes to the atmospheric moisture content and evaporation. Higher atmospheric temperatures allow for an expanded water holding-capacity of the atmosphere and enhanced radiation causes elevated rates of evaporation. This results in increases to the atmospheric moisture content, which, consequently, will impact precipitation (Trenberth, 1999; Trenberth, Smith, Qian, Dai, & Fasullo, 2003; Kharin, Zwiers, Zhang, & Wehner, 2013).

While changes to precipitation amounts and intensity are expected on a global scale, the changes will be geographically disproportionate. Shifts in the natural modes of atmospheric circulation have been documented. The increase in evaporation and atmospheric moisture content causes more moisture to be transported from divergence regions (i.e., subtropics) to convergence zones (i.e., tropics and mid-latitudes). This causes wet areas to become wetter and dry areas to become drier (Trenberth, 1999). In recent decades annual average precipitation has risen in the Northeast, Great Plains, Pacific Northwest, and Alaska, while decreases have been observed for parts of the Southwest United States and in Hawaii (Cayan, 2013; Walsh, 2014; Dettinger, Udall, & Georgakakos, 2015).

According to the National Oceanic and Atmospheric Administration's (NOAA's) 2013 assessment of climate trends for the Midwest (NOAA, 2013), upward trends in annual and summer precipitation amounts have been observed. The frequency of higher intensity storms have also been noted. Specifically in Minnesota, climatologists have identified four significant climate trends (MDNR, 2017):

- Increasing annual precipitation
- Increasing frequency and size of extreme rainfall events
- Increasing temperatures, with winter temperatures warming the fastest
- Decline in severity and frequency of extreme cold weather

Overall, the changes to precipitation induced by atmospheric warming pose difficult challenges. The shift to more frequent, high intensity precipitation events in Minnesota indicates a risk for extreme flood events. Higher intensity precipitation events typically produce more runoff than lower intensity events with similar amounts of precipitation because higher intensity rainfall can overwhelm the capacity of the land surface to infiltrate and attenuate runoff.

Not only do these hydrologic changes pose challenges for agriculture, infrastructure, and human safety; but also has the potential to induce changes to aquatic environments. The subsequent section describes the anticipated impacts to aquatic ecosystems if atmospheric warming trends continue.

2.3.2 Projected Changes to Waterbodies (Physical and Chemical)

In freshwater lakes, one of the most important atmospheric variables influencing the lake's physical and chemical parameters is temperature. Due to enhanced air temperatures and the projected increasing trends, lake water temperature and the number of ice free days are projected to change in most inland waters globally. Increases in lake temperature will affect mixing regimes, the length and depth of summer stratification in deep lakes, and the oxygen concentration in the hypolimnion (Dokulil, 2013; Dokulil, 2014; Dokulil, 2016). As water temperature rises, lake stability enhances, which results in longer thermal stratification and shorter mixing periods (Dokulil, 2013). Resistance to mixing between the nutrient rich hypolimnion and nutrient poor epilimnion across the thermocline increases considerably at temperature gradients of only a few degrees Fahrenheit (Sahoo, et al., 2016).

Prolonged lake stability and a lower thermocline enhances the risk of oxygen depletion in the hypolimnion (Jeppesen, et al., 2009; Sahoo, et al., 2016). Anoxic conditions in the hypolimnion can cause nutrient release from the sediments raising the potential for algal blooms. Additionally, overall oxygen concentrations in the lake will be reduced as solubility decreases when the water temperature warms (Dokulil & Teubner, 2011).

In the tropics and mid-latitudes where precipitation is likely to increase, with the heighted chance for extreme events, other concerns are warranted. Intense rainfalls resulting in flooding could raise the loading of suspended sediments associated with larger areas experiencing soil erosion (Dokulil & Teubner, 2011; Dokulil, 2016). The combination of longer dry periods and extreme precipitation events could create episodic and intense pulse flows affecting aquatic habitats, bank stability, and species (Dokulil, 2016). Additionally, the increase in the number of extreme, high intensity rain events is likely to increase the runoff driven phosphorus transfers from the land to the water (Jeppesen, et al., 2009).

2.3.3 Projected Changes to Eutrophication

The potential for increased erosion and nutrient inputs from large runoff rates combined with higher water temperatures and prolonged lake stratification in summer could lead to widespread, climate-related eutrophication based on the results of existing studies (Dokulil & Teubner, 2011; Dokulil, 2013). Nutrient enrichment, whether through external or internal loading, stimulates the development of phytoplankton biomass. This resulting surface biomass absorbs light, can shade out benthic algae or macrophytes, and can produce negative lake aesthetics (Dokulil & Teubner, 2011). Unfortunately, not only has previous research projected larger biomasses of phytoplankton in a warmer climate, but research also predicts that a higher proportion of these phytoplankton biomasses will consist of potentially toxic cyanobacteria assemblages (Jeppesen, et al., 2009; Dokulil & Teubner, 2011; Jeppesen, et al., 2014; Dokulil, 2016). Multiple regression analyses on data from 250 Danish lakes sampled during the month of August indicated higher dominance of cyanobacteria with a warming climate. Studies during heat waves in the northern hemisphere also showed that higher percentages of cyanobacteria correlated with rises in temperature (Huisman, Matthijs, & Visser, 2005).

Changes in the seasonal pattern and dynamics of freshwater productivity could also be a consequence of a changing climate. With the earlier onset of warmer air temperatures in the spring, the timing of the phytoplankton peak is likely to shift forward. If the phytoplankton blooms contain a larger percentage of cyanobacteria species or if the timing of algal production falls out of synchrony with the food demands of zooplankton and fish, then upper levels of the food chain could be negatively impacted (Dokulil, 2016). Enhanced phytoplankton biomasses can also induce thermal feedback mechanisms for lakes. The thermal structure of lakes can be influenced by phytoplankton via light attenuation. The area of biomass at the surface of a lake affects vertical short-wave radiation. Thus, a large area of phytoplankton biomass can result in greater surface temperatures and stronger stratification by influencing the temperature gradient with depth (Dokulil, 2013). Additionally, increased light attenuation at the surface will reduce light availability at the lake bottom influencing macrophyte growth (Jeppesen, et al., 2014).

This UAA study did not directly assess potential impacts to lake responses due to a changing climate. However, any current and/or future management efforts for waterbodies will be affected by changing climate conditions. Continued monitoring of lake conditions will be important as management efforts are implemented and as changing climate conditions progress. Long-term studies of waterbodies will be essential in order to create the most effective plans to overcome climate-induced impacts.

3.0 Identification of Goals and Expectations

3.1 NMCWD Goals for Lake Management

The NMCWD's approach to assessing and improving lake health is illustrated in Figure 3-1. The primary factors identified as affecting lake ecological health include chemical water quality (e.g., nutrient concentrations), aquatic communities, and water quantity (groundwater and surface water). The effects of recreation and wildlife habitat on overall lake health are also considered.

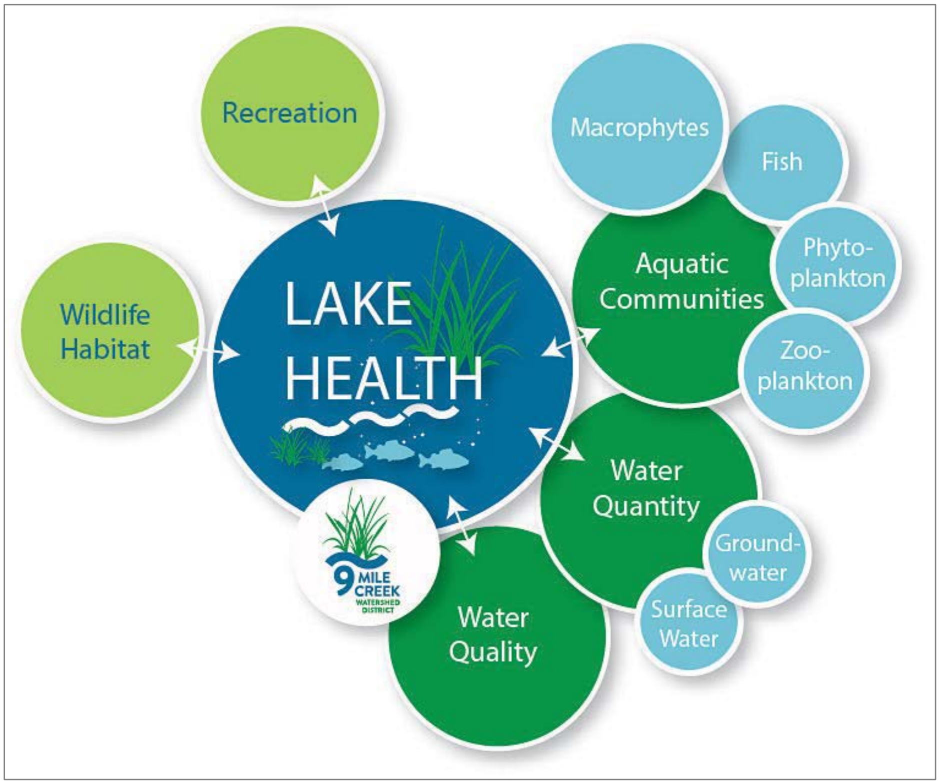


Figure 3-1 NMCWD Holistic Lake Health Assessment Factors (NMCWD, 2017, amended 2019)

3.1.1 Water Quality Goals

One of the primary goals of the District is to "ensure the water quality of the lakes and streams of the NMCWD is protected and enhanced." In 1996, the NMCWD established lake water quality management goals based on designated uses for a waterbody (i.e., full-contact recreational activities such as swimming; non-full body contact recreational activities such as boating, canoeing, or water skiing; fishing and aesthetic viewing; runoff management). In 2008, the MPCA adopted eutrophication water quality standards for Minnesota lakes, which vary by ecoregion and include criteria for both shallow and deep lakes. The MPCA defines "shallow" lakes as having a maximum depth of 15 feet or less or having at least 80% of the lake area shallow enough to support aquatic plants (referred to as "littoral area").

In their 2017 Plan, the NMCWD adopted the state's lake eutrophication standards as their lake water quality goals, as well as the state water quality standards for Escherichia coli and chloride. The water quality goals for shallow lakes (including Lake Cornelia and Lake Edina) are presented in Table 3-1.

Table 3-1 NMCWD Water Quality Goals for Shallow Lakes

Water Quality Parameter	Water Quality Standard for Shallow Lakes[1, 2]
Total Phosphorus (summer average, µg/L)	60
Chlorophyll *a* (summer average, µg/L)	20
Secchi Disc Transparency (summer average, m)	1.0
Total Suspended Solids (mg/L)	NA
Daily Dissolved Oxygen Flux (mg/L)	NA
Biological Oxygen Demand (5 day) (mg/L)	NA
Escherichia coli (# per 100 mL)	126 [3]
Chloride (mg/L)	230

[1] NMCWD goals are based on MPCA standards included in MN Rules 7050. Revisions to MN Rules 7050 will supersede NMCWD standards. Note that MN Rule 7050.0220 includes standards for additional parameters that are enforced by the MPCA.
[2] Shallow lakes have a maximum depth less than 15 feet or littoral area greater than 80% of the total lake surface area.
[3] 126 organisms per 100 mL as a geometric mean of not less than five samples within any month, nor shall more than 10% of all samples within a month exceed 1,260 organisms per 100 mL.

3.1.2 Other Lake Health Goals

In addition to the water quality goals presented in Table 3-1, the NMCWD's 2017 Plan expresses the desire to establish holistic lake health targets for District-managed lakes. The holistic lake health targets consider a wide range of factors, with an increased emphasis on the role of ecological factors in overall lake health and the interrelated nature of these factors.

Table 3-2 lists the evaluation factors used by the NMCWD to holistically assess lake health. Numerical goals exist for some of the factors presented in this table (e.g., MPCA water quality standards), while other holistic health factors are assessed qualitatively by comparing to narrative criteria. The NMCWD collaborates with stakeholders and regulatory agencies (MPCA, MDNR) to develop lake-specific numerical goals for ecological indicators where appropriate.

Table 3-2 NMCWD Holistic Lake Health Assessment Evaluation Factors

Lake Health Assessment Factors	Evaluation Factors
Chemical Water Quality	• Nutrients • Sediment • Clarity • Chlorophyll *a* • Chloride
Aquatic Communities	• Aquatic Plant IBI[1]- species richness and floristic quality • Invasive Species Presence • Phytoplankton Populations • Blue-green Algae Presence • Zooplankton Populations
Water Quantity	• Water Levels • Water Level Bounce • Groundwater Levels
Recreation	• Shore Access • Navigation Potential • Aesthetics • Use Metrics
Wildlife	• Upland biodiversity • Buffer extent/width

[1] Lake plant eutrophication Index of Biotic Integrity (IBI) methodology developed by the MDNR and MPCA

3.2 Lower Minnesota River Watershed TMDL Report—Draft

Both Lake Cornelia and Lake Edina were first listed on the 303(d) Impaired Waters list in 2008 for impaired aquatic recreational use due to excess nutrients. For all water bodes listed on the 303(d) Impaired Waters list, the MPCA is required to conduct a Total Maximum Daily Load (TMDL) study for each pollutant that causes the water body to not meet the state water quality standards. A TMDL study for the Lower Minnesota River Watershed, which included Lake Cornelia and Lake Edina, was completed in 2017-2018. The draft TMDL report was submitted to the MPCA in June 2018 (Barr Engineering Co. & MPCA, 2018).

The Lower Minnesota River Watershed TMDL report was developed as part of a larger effort to address impaired waters in the northern urban portion of the watershed in the Twin Cities Metropolitan area (Barr Engineering Co. & MPCA, 2018). The areas investigated in the report include portions of Carver and Hennepin Counties, specifically the Riley Purgatory Bluff Creek Watershed District (RPBCWD) and Nine Mile Creek Watershed District (NMCWD). The report provides TMDLs for 13 lakes impaired for nutrients (which include North Cornelia, South Cornelia, and Lake Edina), two streams impaired for bacteria, and one stream impaired for total suspended solids (TSS) and impaired biota.

The modeling efforts for the Lower Minnesota River Watershed TMDL report indicate that the percent reductions in total phosphorus loadings for North Cornelia, South Cornelia, and Lake Edina needed to reach the MPCA's water quality total phosphorus standard of 60 µg/L are 59%, 61%, and 34%, respectively, during the growing season. These total phosphorus load reductions were also divided among watershed, upstream lakes, and internal loads. Table 3-3 summarizes the estimated load reductions required for each lake to reach water quality goals. The TMDL analysis for North Cornelia indicates that total phosphorus reductions should be focused on external as well as internal management efforts. The results for South Cornelia indicate that management efforts in upstream lakes (North Cornelia) will have a large impact on reducing lake total phosphorus concentrations. Internal management efforts were also recommended. For Lake Edina, the TMDL analysis suggests that upstream management efforts in North and South Cornelia will assist in reducing in-lake total phosphorus concentrations in Lake Edina. External management efforts in the direct Lake Edina watershed are also recommended for load reductions. Refer to the Draft Lower Minnesota River Watershed TMDL for further details.

Table 3-3 Growing Season Total Phosphorus Load Reductions Summary from the Draft Lower Minnesota River Watershed TMDL Report

Water Body	Watershed Load Reductions		Internal Load Reductions		Upstream Lake Reductions		Total Load Reductions	
	lbs/growing season	% of Total	lbs/growing season	% of Total	lbs/growing season	% of Total	lbs/growing season	% of Existing
North Cornelia	110	51%	104	49%	-	-	214	59%
South Cornelia	0	0%	150	60%	100	40%	250	61%
Lake Edina	38	42%	0	0%	52	58%	90	34%

3.3 Natural or Background Water Quality Conditions

There were three major baseline water quality prediction methods that were used to assess natural, background water quality in Lake Cornelia in the past and these methods have been referenced in previous UAAs. The first baseline water quality prediction method is the Minnesota Lake Eutrophication Analysis Procedure (MnLEAP), which is intended to be used as a screening tool for estimating lake conditions and for identifying "problem" lakes (Heiskary & Wilson, 1990). Results of the MnLEAP modeling completed for Lake Cornelia in the 2010 UAA identified the lake as one that could achieve "better" water quality than is currently observed by showing estimated natural total phosphorus concentrations ranging from 55-97 µg/L.

The second baseline water quality prediction method is based on the Vighi and Chiaudani (MEI) model (1985). The Vighi and Chiaudani MEI model provides reasonable estimates of pre-European settlement total phosphorus concentrations for lakes, based on current alkalinity or conductivity water quality measurements. The modeling results completed for the Lake Cornelia 2010 UAA indicated that pre-European settlement (natural background) total phosphorus concentrations ranged from 27-66 µg/L.

The third baseline water quality prediction method is the Wisconsin Lake Modeling Suite (WiLMS) model (WI-DNR, Wisconsin Lake Modeling Suite (WILMS), 2004). The WiLMS model (Lake Total Phosphorus Prediction Module) uses an annual time step and predicts spring overturn, growing season mean, and annual average total phosphorus concentrations in lakes. Natural, background total phosphorus concentrations found during the Lake Cornelia 2010 UAA were estimated at 53-133 µg/L.

For additional information on these baseline water quality prediction methods, please refer to the Lake Cornelia UAA developed in 2010. These methods were not revised for this UAA update as the previous estimates were adequate. These baseline water quality prediction methods were also not estimated for Lake Edina for this UAA effort.

3.4 NMCWD Adaptive Management Approach

The NMCWD implements an adaptive management approach to improve lake health based on water quality and assessment of the other holistic lake health factors. While striving to achieve the state standards for shallow lakes, the NMCWD recognizes that achieving the water quality goals may not be feasible for some lakes or may require a timeframe that extends several decades. For these situations, the NMCWD's objective it to make reasonable and measureable progress towards meeting the water quality goals and other holistic lake health targets.

The NMCWD reviews lake monitoring data annually to assess progress toward lake management goals. For lakes that are meeting the goals, the NMCWD continues periodic monitoring to track variations in water quality and potential trends. If water quality declines or if water quality does not meet NMCWD goals, a lake-specific Use Attainability Analysis is developed or updated to identify additional protection and improvement measures, as is being completed in this report for Lake Cornelia and Lake Edina.

4.0 Lake Basin and Watershed Characteristics

The following sections describe the unique characteristics of the Lake Cornelia and Lake Edina basins. General features of the land use in the lakes' watersheds are discussed. The network of water storage and treatment ponds is also described, as well as the flows in and out of the lake.

4.1 Lake Cornelia Basin Characteristics

Lake Cornelia is located in the central portion of the City of Edina. The lake was a natural marsh area prior to the 1960s when a control structure was installed by the City of Edina. Lake Cornelia is comprised of North (North Cornelia) and South (South Cornelia) basins, connected by a 12-inch culvert under 66^{th} Street (with an invert elevation of 859.0 feet MSL) on the south side of the North Cornelia, and a secondary 12-inch pipe located on the southeast side of North Cornelia (with an invert elevation of 860.2 feet MSL). Ultimately water levels in North Cornelia are controlled by the outlet structure at South Cornelia. The outflow from South Cornelia discharges directly over a 14-foot long weir structure with a control elevation of 859.1 feet MSL. Discharge from South Cornelia are conveyed to Lake Edina through an extensive storm sewer network. Due to limited storm sewer capacity downstream of Lake Cornelia, stormwater runoff from portions of Cornelia Drive and Dunberry Lane backs up into the lake during large storm events, which provides temporary storage of the flood volumes.

4.1.1 North Cornelia

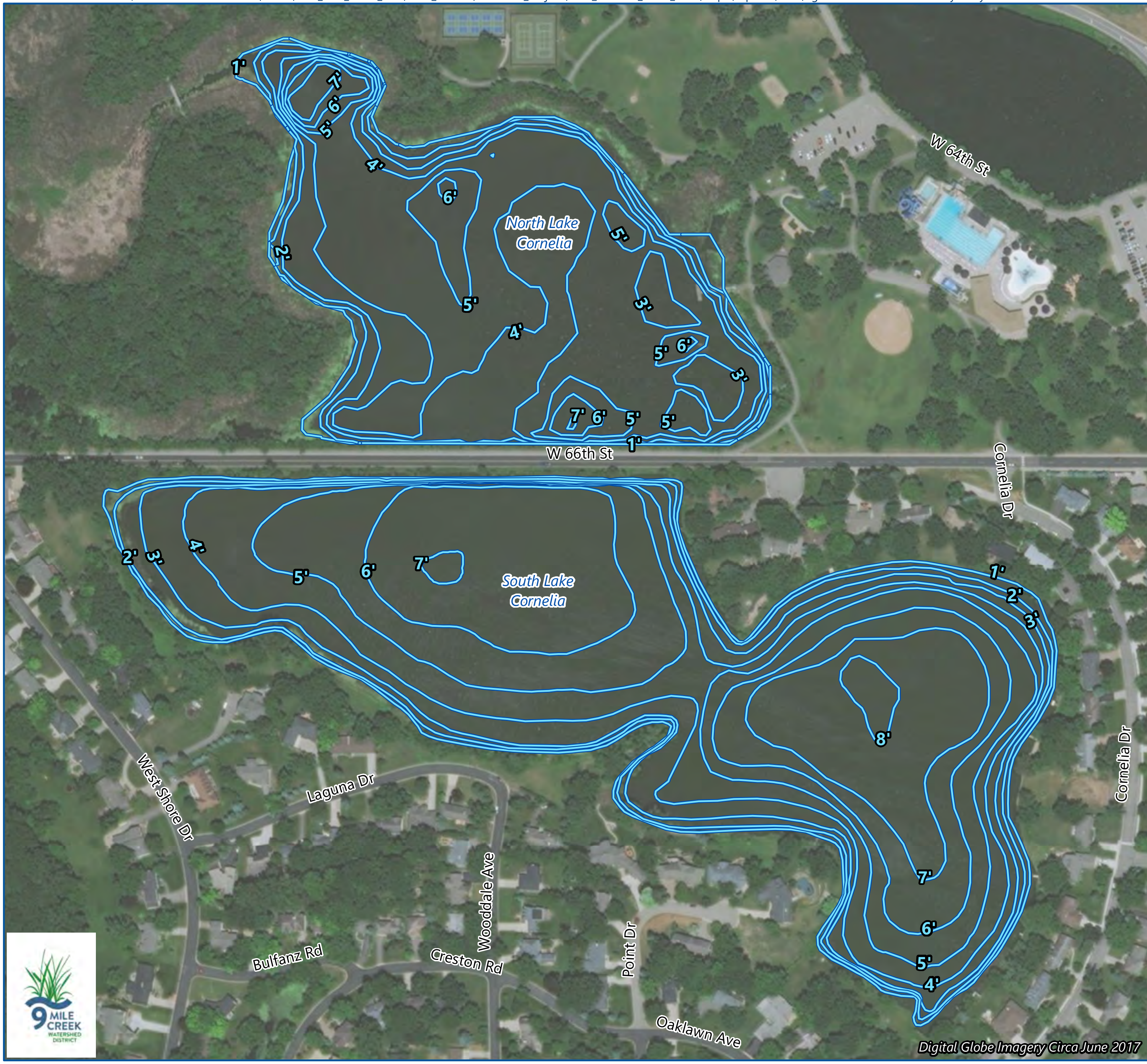
North Cornelia has a water surface area of approximately 19 acres, a maximum depth of 7 feet, and a mean depth of approximately 3 feet at a normal water surface elevation of 859.1. At this elevation the lake volume is approximately 75 acre-feet. The water level in the lake is controlled mainly by weather conditions (snowmelt, rainfall, and evaporation), by the outlet capacity of the pipe on North Cornelia, and by the elevation and capacity of the outlet structure located on South Cornelia. The stage-storage-discharge relationship that was used in this study for North Cornelia is shown in Table 4-1. The bathymetric information used to inform this stage-storage-discharge relationship is shown on Figure 4-1 and is based on surveys completed by the City of Edina in 2017.

4.1.2 South Cornelia

South Cornelia has a water surface area of approximately 33 acres, a maximum depth of 8 feet, and a mean depth of 4.2 feet at a normal surface elevation of 859.1. At this elevation the lake volume is approximately 166 acre-feet. The water level in the lake is controlled by the elevation of the weir structure at the south side of the lake. The stage-storage-discharge relationship that was used in this study for Lake Cornelia is shown in Table 4-1. The bathymetric information used to inform this stage-storage-discharge relationship is shown on Figure 4-1 (City of Edina, 2017).

Table 4-1 Stage-Storage-Discharge relationships for Lake Cornelia

Elevation	Area (acres)	Cumulative Storage (ac-ft)	Discharge (cfs)	Comment
North Cornelia				
852.00	0.2	0.0	0.0	Wet Detention Storage Volume
853.00	0.7	0.4	0.0	
854.00	2.3	1.9	0.0	
855.00	10.5	8.3	0.0	
856.00	15.6	21.3	0.0	
857.00	16.7	37.5	0.0	
858.00	17.6	54.7	0.0	
859.00	18.7	72.8	0.0	Invert of outlet pipe
859.1	18.9	74.7	0.0	Normal Water Level
859.25	19.3	77.6	0.1	Available Live Storage for Flood Control
859.50	19.8	82.5	0.5	
860.00	20.9	92.6	1.5	
860.50	31.1	105.6	2.5	
862.00	32.7	153.5	4.3	
863.00	36.3	188.0	15.0	
South Cornelia				
851.00	0.4	0.0	0.0	Wet Detention Storage Volume
852.00	4.2	2.3	0.0	
853.00	11.5	10.1	0.0	
854.00	17.9	24.8	0.0	
855.00	23.4	45.5	0.0	
856.00	27.7	71.0	0.0	
857.00	29.9	99.8	0.0	
858.00	31.3	130.4	0.0	
859.00	33.2	162.7	0.0	
859.10	33.2	166.1	0.3	Normal Water Level
859.25	33.3	171.0	2.2	Available Live Storage for Flood Control
859.50	33.5	179.4	6.5	
859.75	33.6	187.8	10.0	
860.00	33.8	196.2	10.8	
861.00	34.7	230.4	23.5	
861.10	35.0	233.9	23.9	
862.10	36.7	269.8	27.8	
863.10	39.0	307.7	31.7	
864.00	40.2	343.3	35.2	
865.80	41.2	416.5	60.4	
868.00	49.5	516.3	92.1	



1-ft Bathymetric Contours*

* Source: City of Edina, 2017

N

0 150 300

Feet

LAKE CORNELIA BATHYMETRY

FIGURE 4-1

Since Lake Cornelia's two basins are shallow, the lake is prone to frequent wind-driven mixing of the lake's shallow waters during the summer. Therefore, one would expect Lake Cornelia to be *polymictic* (mixing many times per year) as opposed to lakes with deep, steep-sided basins that are usually *dimictic* (mixing only twice per year). Daily monitoring of the lake would be necessary to precisely characterize the mixing dynamics of a lake, but the limited data gathered from Lake Cornelia strongly suggests that the lake is polymictic.

4.2 Lake Edina Basin Characteristics

Lake Edina is located south of Lake Cornelia in the City of Edina. The lake is a natural marsh area. North Cornelia and South Cornelia are located upstream of Lake Edina and discharges from South Cornelia are conveyed to Lake Edina through an extensive storm sewer network. The control structure from Lake Edina is a 12-foot weir structure, with a control elevation of 822.0 feet MSL. Outflow from Lake Edina discharges to the North Fork of Nine Mile Creek via a 36-inch storm sewer under Trunk Highway (TH) 100.

Lake Edina has a water surface area of approximately 25 acres, a maximum depth of 5 feet, and a mean depth of approximately 3 feet at a normal water surface elevation of 822.0 feet MSL. At this elevation the lake volume is approximately 68 acre-feet. The water level in the lake is controlled mainly by weather conditions (snowmelt, rainfall, and evaporation), by the outlet capacity of the pipe, by the volume of flow received from South Cornelia, and through groundwater interactions with Nine Mile Creek. The stage-storage-discharge relationship that was used in this study for Lake Edina is shown in Table 4-2.

Table 4-2 Stage-Storage-Discharge relationship for Lake Edina

Elevation	Area (acres)	Cumulative Storage (ac-ft)	Discharge (cfs)	Comment
Lake Edina				
817.00	0.0	0.0	0.0	Wet Detention Storage Volume
818.00	0.1	0.1	0.0	
819.00	11.5	5.9	0.0	
820.00	20.6	21.9	0.0	
821.00	23.6	44.0	0.0	
822.00	24.6	68.1	0.0	Normal Water Level
822.20	24.8	73.0	1.6	Available Live Storage for Flood Control
822.50	25.1	80.5	4.3	
823.00	25.6	93.2	9.3	
824.00	27.1	119.5	21.8	
826.00	34.6	181.3	57.0	
827.00	37.3	217.2	100.0	
828.50	410.3	552.9	115.0	

The bathymetric information used to inform this stage-storage-discharge relationship is shown on Figure 4-2 (City of Edina, 2017).

Since Lake Edina is shallow, the lake is prone to frequent wind-driven mixing of the lake's shallow waters during the summer. One would therefore expect Lake Edina to be *polymictic* (mixing many times per year) as opposed to lakes with deep, steep-sided basins that are usually *dimictic* (mixing only twice per year). Daily monitoring of the lake would be necessary to precisely characterize the mixing dynamics of a lake, but the limited data gathered from Lake Edina strongly suggests that the lake is polymictic.

Barr Footer: ArcGIS 10.6.1, 2019-04-30 14:33 File: I:\Client\Nine_Mile_Creek_WD\Work_Orders\23270634_Project\2018_Cornelia_Edina_UAA\Maps\Reports\UAA\Figure 4-2 Lake Edina Bathymetry.mxd User: RCS2

LAKE EDINA BATHYMETRY

FIGURE 4-2

4.3 Watershed Characteristics

Land use practices within a lake's watershed impact the lake and its water quality by altering the volume of stormwater runoff, sediment load, and nutrient load (namely phosphorus) that reaches the lake from the lake's watershed. Each land use contributes a different amount of runoff and phosphorus to the lake, thereby impacting the lake's water quality differently. As land use changes over time, changes can be expected in downstream water bodies as a result.

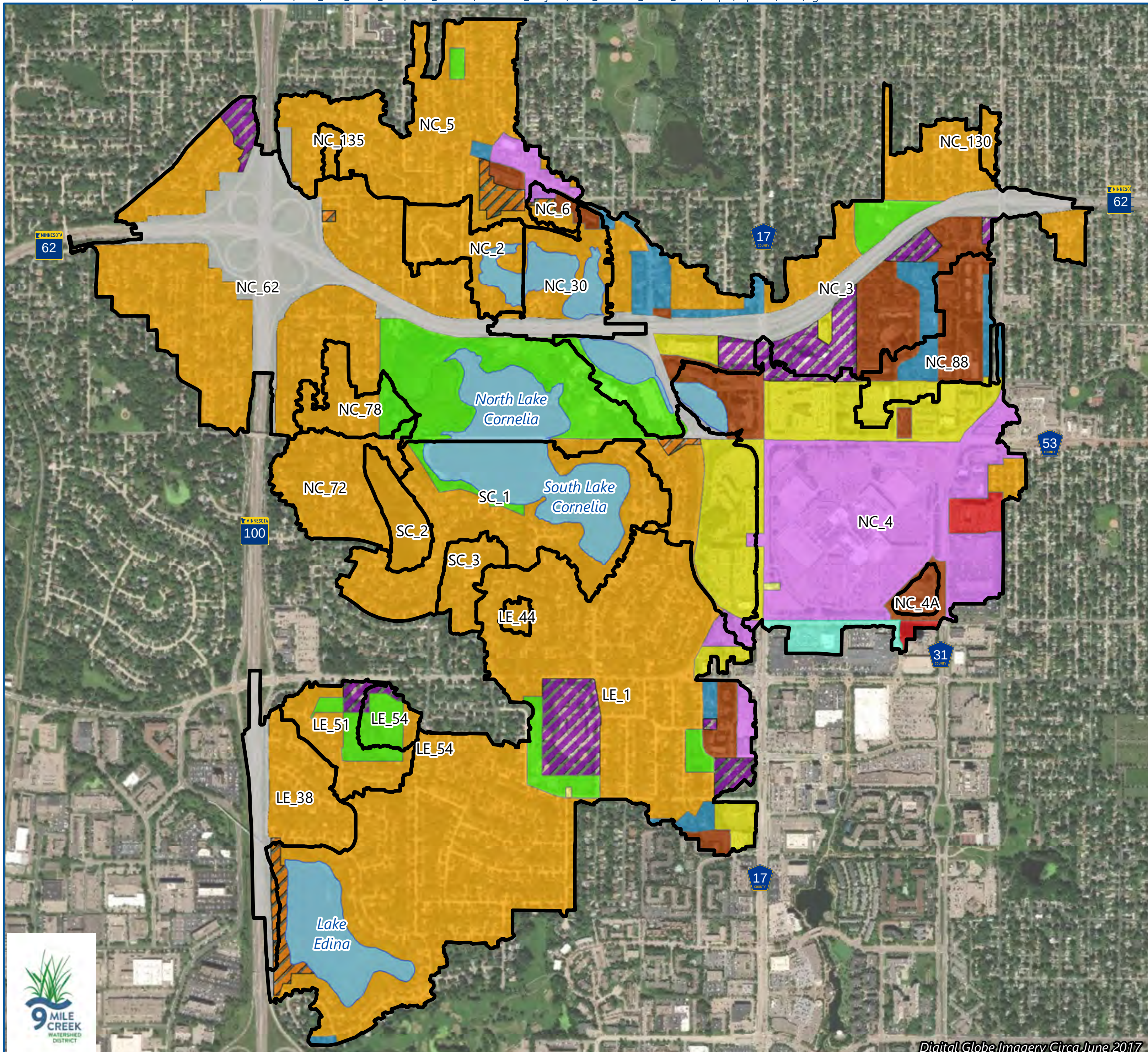
Historically, the Lake Cornelia and Lake Edina watersheds were primarily comprised of basswood, sugar maple, and oak forests. There were also numerous wetlands located throughout the watersheds. The terrain varies from relatively flat to rolling.

Lake Cornelia's watershed is 986 acres, including the surface area of the lake (~52 acres). Runoff from the watershed enters both North and South Cornelia through overland flow and from several storm sewer outfalls at various points along the lakeshore, although the majority of the watershed flows through North Cornelia before entering South Cornelia. Lake Edina's watershed is 1,380 acres, including the 986-acre watershed of Lake Cornelia and the surface area of the lake (~25 acres). Runoff from the watershed enters Lake Edina through overland flow and from several storm sewer outfalls along the lakeshore.

Based on the 2016 Generalized Land Use Inventory Dataset developed by the Metropolitan Council (Metropolitan Council, 2016) and analysis of aerial imagery, the watersheds of Lake Cornelia and Lake Edina are near fully-developed. Table 4-3 provides a summary of the land use classifications within each watershed. The major land use classification in each watershed is low-density residential (single family detached). The watershed also includes some proportions of commercial, highway, and open water. To a lesser extent, the land use consists of high density residential, developed park, high impervious institutional, open space, and office space. Figure 4-3 shows a map of the land use classifications within each watershed.

Table 4-3 Land Use Classifications in the Lake Cornelia and Lake Edina Watersheds

Land Use Classification	North Cornelia	South Cornelia	Lake Edina
Institutional	3%	0%	6%
Major Highway	12%	0%	3%
Mixed Use Commercial	1%	0%	0%
Mixed Use Residential	1%	0%	0%
Multi-Family	7%	0%	2%
Office	8%	0%	2%
Open Water	5%	29%	6%
Park/Recreational	7%	3%	5%
Retail/Commercial	13%	0%	1%
Single Family Attached	3%	0%	1%
Single Family Detached	39%	68%	72%
Undeveloped/Open Space	1%	0%	2%
Total Watershed Area (ac)	873.7	112.6	393.1



Subwatersheds

Land Use (Met Council, 2016)

- Industrial and Utility
- Institutional
- Major Highway
- Mixed Use Commercial
- Mixed Use Residential
- Multifamily
- Office
- Open Water
- Park, Recreational, or Preserve
- Retail and Other Commercial
- Single Family Attached
- Single Family Detached
- Undeveloped

N

0 500 1,000 1,500

Feet

LAND USE
LAKE CORNELIA AND
LAKE EDINA WATERSHEDS

FIGURE 4-3

4.4 Lake Inflows and Drainage Areas

Watershed modeling depends on the evaluation of the watershed conditions as they relate to stormwater runoff. Therefore, the hydrology of the Lake Cornelia and Lake Edina watersheds is discussed in the following sections.

4.4.1 Natural Conveyance Systems

Under existing conditions, Lake Cornelia and Lake Edina receives natural surface water inflows only from their direct watersheds.

4.4.2 Stormwater Conveyance Systems

The stormwater conveyance system in the Lake Cornelia watershed is comprised of a network of storm sewers, ditches, ponds, and wetlands. The ponds, and wetlands help to provide water quality treatment of the runoff prior to discharge to Lake Cornelia. Storm sewers and ditches convey stormwater runoff to and from the ponds and wetlands, and ultimately convey the runoff from the watershed to Lake Cornelia. The locations of the major stormwater conveyance features are shown on Figure 4-4.

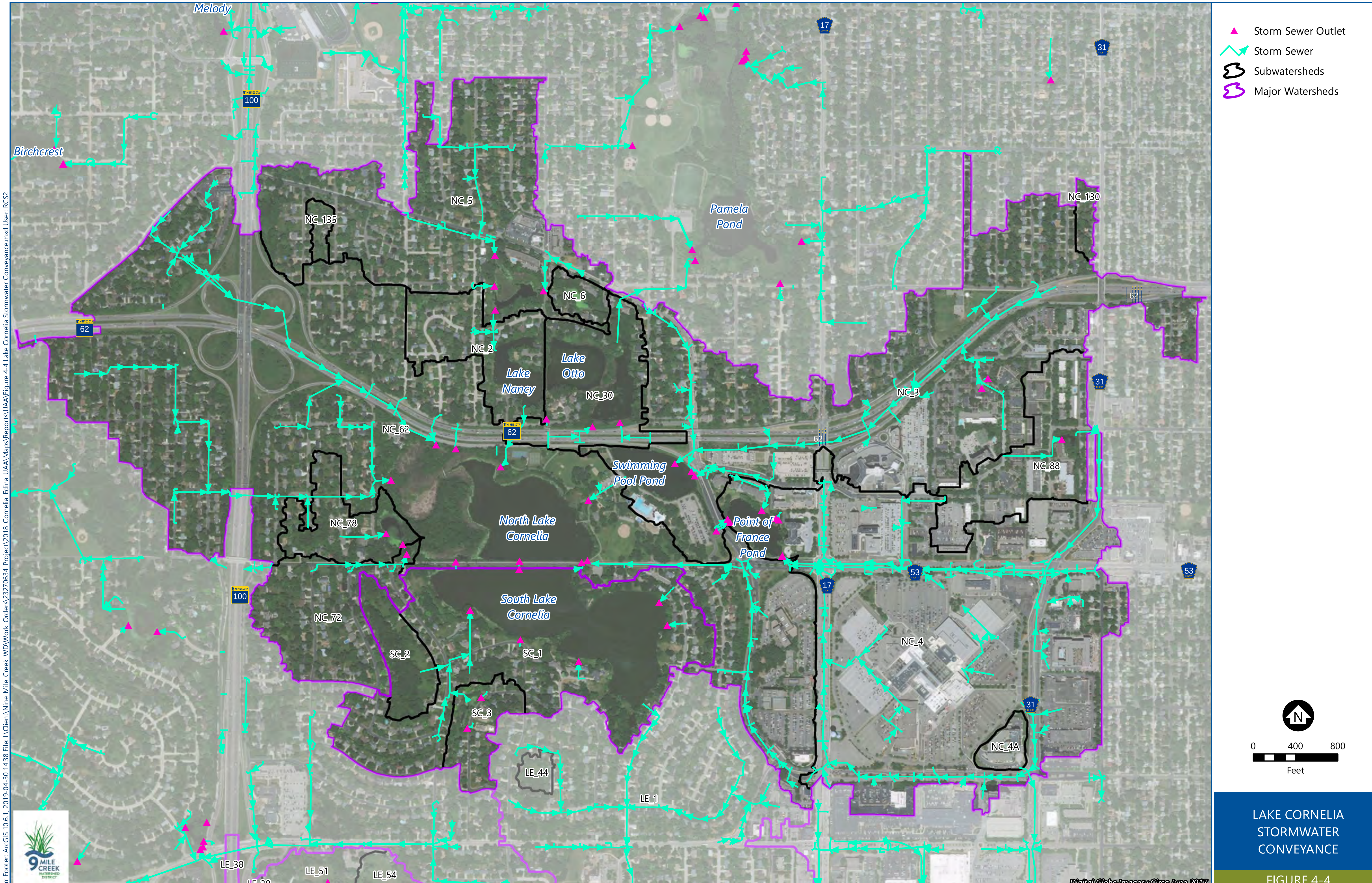
There are about 15 ponding areas (wet and dry detention ponds, infiltration basins, and wetlands) in the Lake Cornelia watershed. There are also two constructed underground storage areas. A detailed listing of existing pond information is located in Appendix A.

Similar to Lake Cornelia's conveyance features, Lake Edina's conveyance system is comprised of a network of storm sewers, dry detention ponds, and wetlands within the tributary watershed. The locations of the major stormwater conveyance features Figure 4-5.

There are four ponding areas (dry detention ponds, infiltration basins, and wetlands) in the Lake Edina watershed. A detailed listing of existing pond information is located in Appendix A.

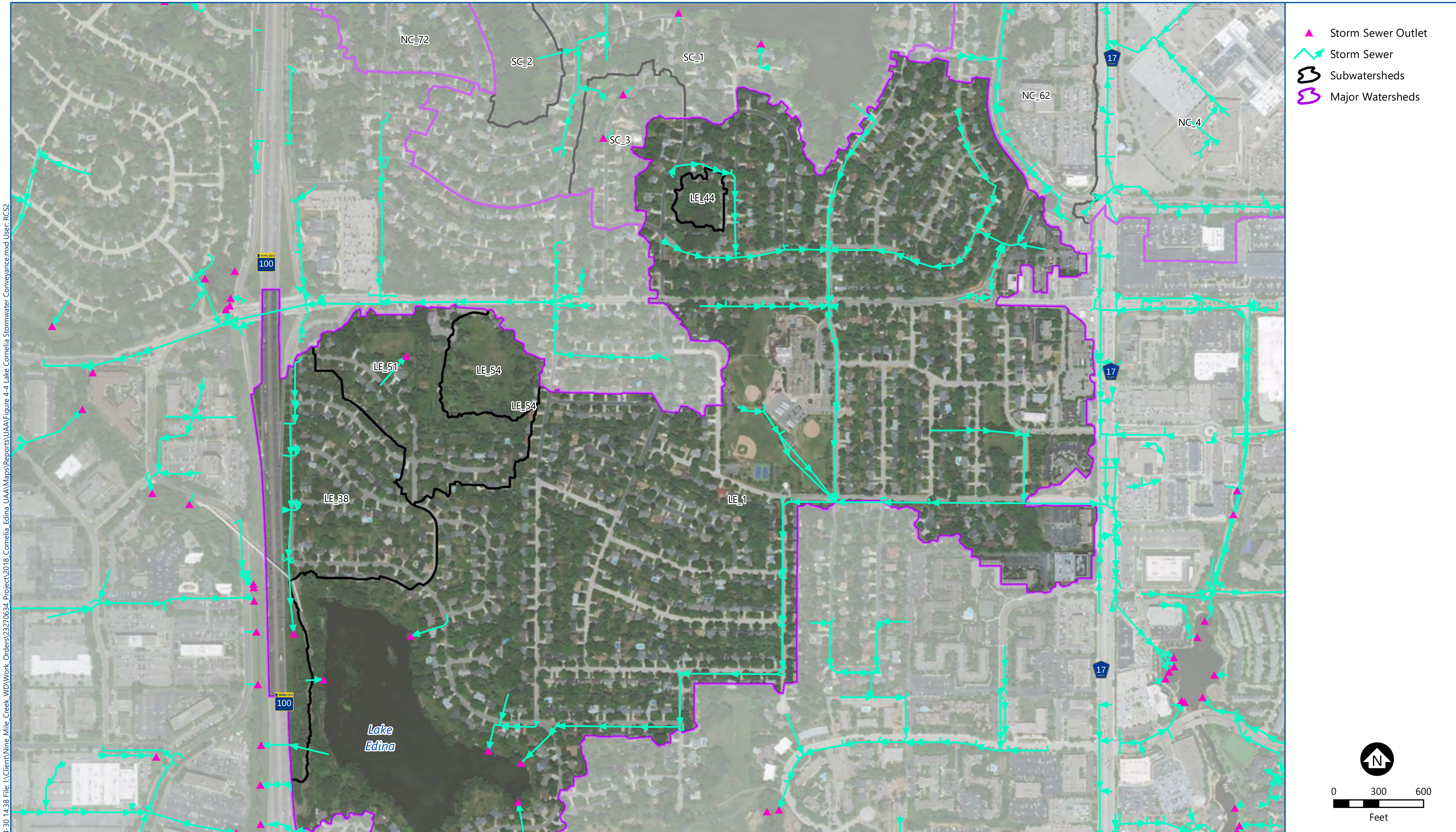
4.4.3 Southdale Center Cooling System Discharge

Prior to 2011, the Southdale Shopping Center pumped groundwater through their heating and cooling system and discharged the wastewater into Point of France Pond, which is upstream of North Cornelia. Based on historic records, the Southdale cooling water discharge resulted in approximately 30 to 40 million gallons of water per year entering the North Cornelia watershed (ranging from 1.0 million to 6.8 million gallons per month). In 2011, the Minnesota Department of Natural Resources (MDNR) did not renew the Southdale groundwater appropriation permit, which required Southdale to abandon the use of groundwater in their heating and cooling system and eliminated the discharge of cooling water to Lake Cornelia and downstream Lake Edina.



LAKE CORNELIA STORMWATER CONVEYANCE

FIGURE 4-4



LAKE EDINA STORMWATER CONVEYANCE

FIGURE 4-5

Barr Footer: ArcGIS 10.6.1, 2019-04-30 14:38 File: I:\Client\Nine_Mile_Creek_WD\Work_Orders\23270634_Project\2018_Cornelia_Edina_UAA\Maps\Reports\UAA\Figure 4-4 Lake Cornelia Stormwater Conveyance.mxd User: RCS2

5.0 Existing Water Quality

5.1 Water Quality

The NMCWD conducted intensive water quality monitoring in North and South Cornelia in 2015, 2016, and 2017 in support of this UAA. The NMCWD also collected data in 2004 and 2008. Intensive monitoring was conducted for Lake Edina in 2008, 2012, 2015 and 2017. Monitoring data was also collected through the Metropolitan Council Citizen Assisted Monitoring Program (CAMP) from North Cornelia in 2003, 2005, 2006, 2007, and 2008 and from Lake Edina in 2004 and 2005.

5.1.1 Phosphorus, Chlorophyll *a*, and Clarity

The NMCWD intensive monitoring included the lake eutrophication parameters of total phosphorus (TP), chlorophyll *a*, and Secchi disc depth to assess water clarity. Data are presented using box plots. The box plots show averages (red cross), median values (straight horizontal line), maximum and minimum values (blue dots), as well as the region where 50 percent of the data lie (the area within the boxes). Box plots show on Figure 5-1 and Figure 5-2 display the summer average TP and chlorophyll *a* concentrations for North and South Lake Cornelia from 2003 through 2017. Figure 5-3 shows the summer average Secchi disc transparency depths for North and South Cornelia from 2003 through 2017. Figure 5-4 shows box plots of historic summer average TP and chlorophyll *a* concentrations from 2004 through 2017 for Lake Edina. The historic summer average Secchi disc transparency depths for Lake Edina are shown on Figure 5-5.

5.1.1.1 Lake Cornelia (North and South Basins)

There is significant variability in total phosphorus and chlorophyll *a* concentrations in North and South Cornelia from year to year, as well as within a given year. The significant variability can be a reflection of numerous factors, including climatic variability, changing aquatic plant populations, curly-leaf pondweed treatments, copper sulfate treatments to control phytoplankton blooms, and likely periodic winter fish kills. There does not seem to be a clear or consistent trend in TP and chlorophyll *a* concentrations in the lake over the monitoring period presented (both North and South Cornelia). The TP and chlorophyll *a* concentrations in North and South Cornelia are well above the 0.06 mg/L (60 µg/L) and 20 µg/L shallow lake criteria, respectively.

5.1.1.2 Lake Edina

It can be seen that for Lake Edina there is significant variation in total phosphorus and chlorophyll *a* concentrations from year to year, as well as within a given year (i.e., the individual points and the size of the box are an indication of change or data variability). Summer average TP and chlorophyll *a* concentrations in Lake Edina were generally higher than the shallow lake criteria of 0.06 mg/L (60 µg/L) and 20 µg/L, respectively.

It appears that TP and chlorophyll *a* concentrations in Lake Edina have declined in recent years; however, there is an insufficient amount of data to determine if it is a statistically-significant trend. In the spring of 2015, the water level dropped to the point that the lakebed was dry for an extended period. This may have had an effect on internal phosphorus release from lake sediments or the biota may have been altered in some way that has altered the phosphorus and phytoplankton (measured as chlorophyll *a*) growth dynamics. The 2017 summer average TP and chlorophyll *a* concentrations were the lowest measured since 2004 (for data collected by the District and Metropolitan Council Environmental Services). A comparison of aquatic plant surveys conducted in 2012 and 2017 indicate that the aquatic plant coverage was notably greater in 2017; this increased abundance may be responsible for the lower TP and chlorophyll *a* concentrations in 2017.

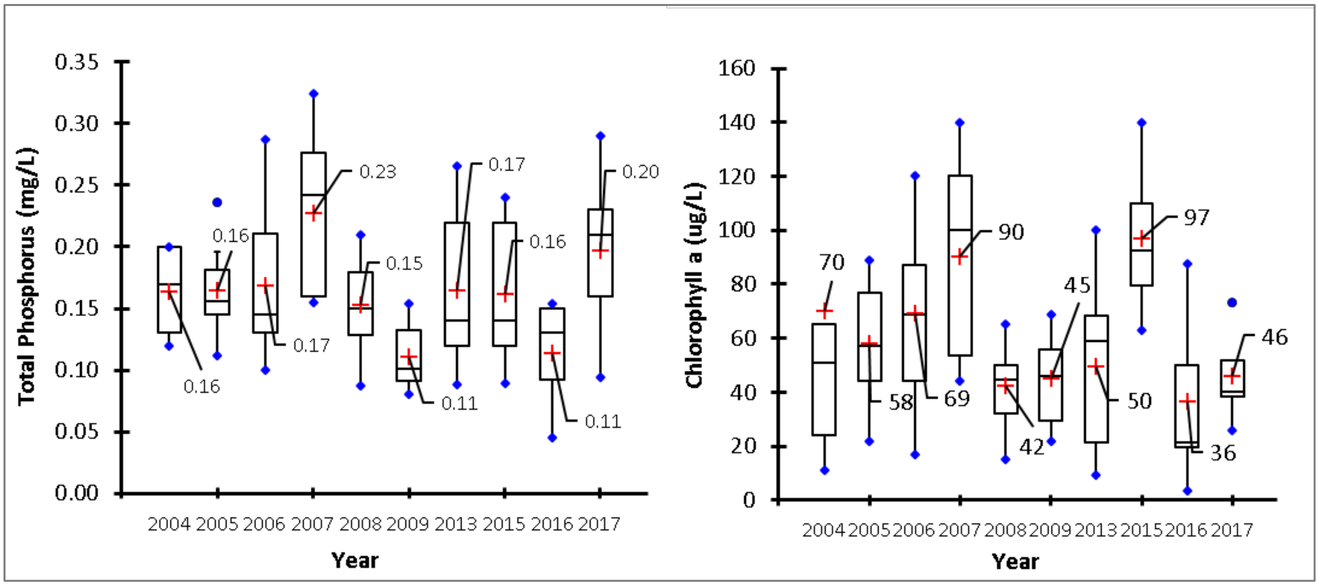


Figure 5-1 Summer total phosphorus and chlorophyll *a* concentrations in North Cornelia from 2004 through 2017. The red crosses indicate the average summer (June through September) concentrations.

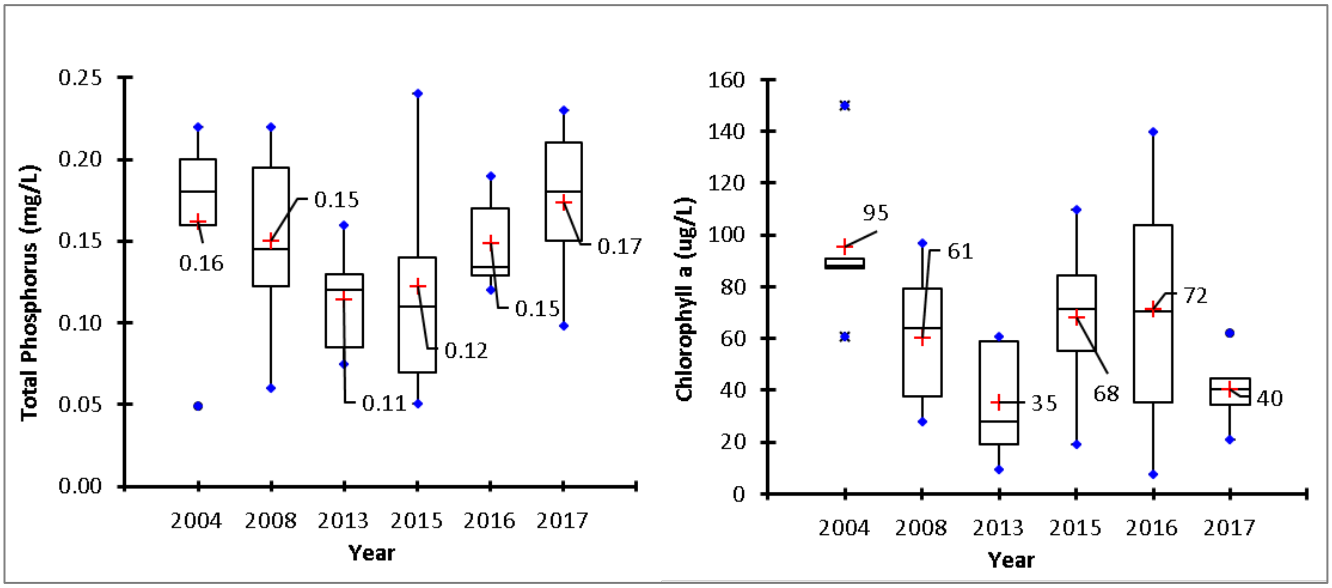


Figure 5-2 Summer total phosphorus and chlorophyll *a* concentrations in South Cornelia from 2004 through 2017. The red crosses indicates the average summer (June through September) concentrations.

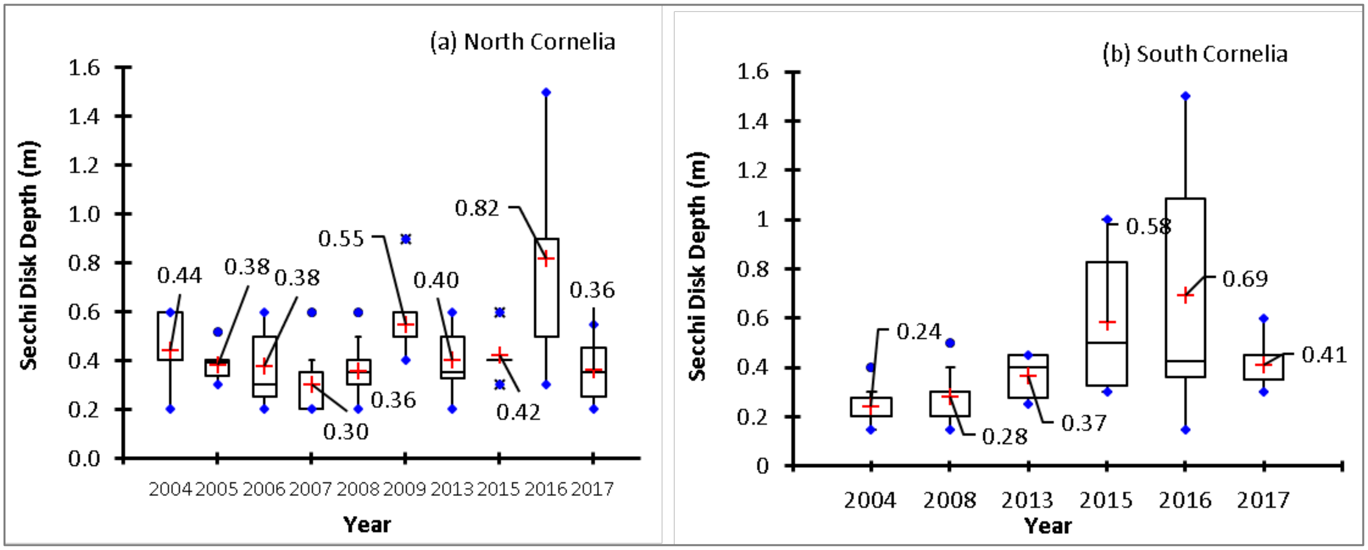


Figure 5-3 Summer average Secchi disc depth readings in (a) North and (b) South Cornelia from 2004 through 2017. The red crosses indicate the average of summer (June through September) readings.

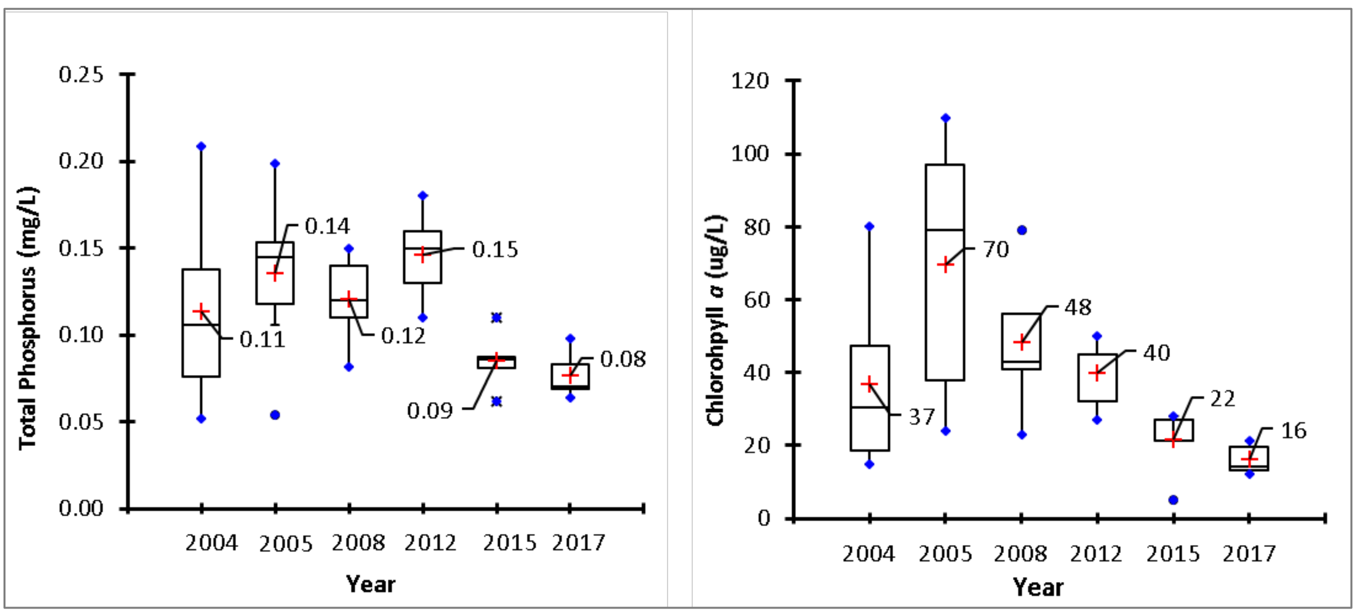


Figure 5-4 Summer total phosphorus and chlorophyll *a* concentrations in Lake Edina from 2004 through 2017. The red crosses indicate the average summer (June through September) concentrations.

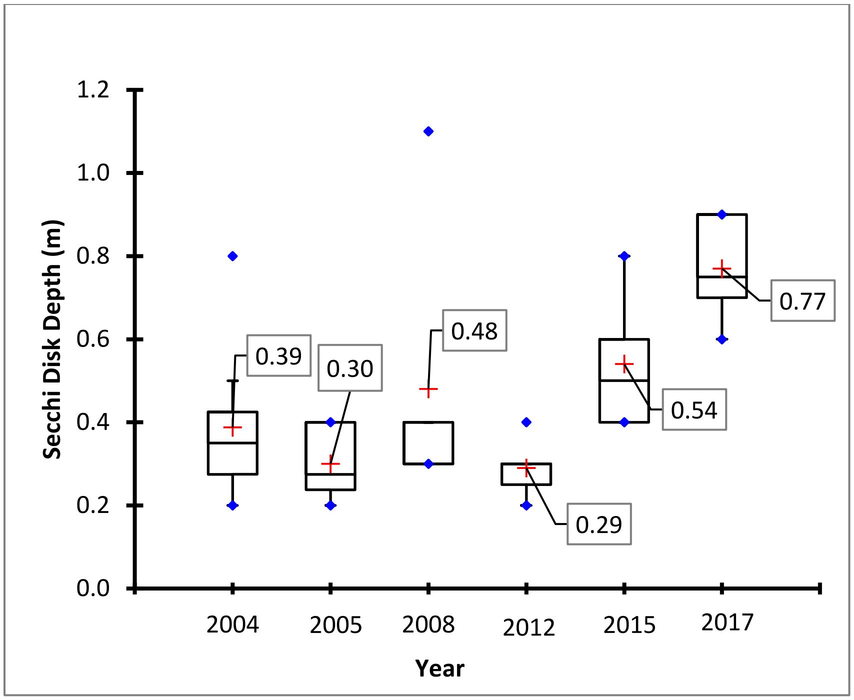


Figure 5-5 Summer average Secchi disc depth readings in Lake Edina from 2004 through 2017. The red crosses indicate the average of summer (June through September) readings.

5.1.2 Chlorides

Because high concentrations of chloride can harm fish and plant life, MPCA has established a chronic exposure chloride standard of 230 mg/L or less, and considers two or more exceedances of the chronic standard in 3 years to be an impairment. In April of 2015 and 2016, chloride concentrations in North Cornelia exceeded the MPCA standard of 230 mg/L (254 mg/L on April 14, 2015) and June 12 (314 mg/L on April 6, 2016). Although North Cornelia has not been listed by the MPCA as impaired for chlorides, the data indicate the lake meets the MPCA criterion for impairment. Following the high concentrations recorded in April of 2015 and 2016, chloride concentrations in North Cornelia decreased to below the standard throughout the summer months. Spring chloride concentrations were not recorded in 2017.

South Cornelia and Lake Edina also showed patterns of high chloride concentrations in the spring, with concentrations lowering throughout the late-spring and summer months. However, the chloride concentrations in these lakes did not exceed the MPCA standard of 230 mg/L.

5.2 Sediment Quality

5.2.1 Lake Cornelia (North and South Basin)

Phosphorus in lake bottom sediments is often bound to a range of different elements such as iron and manganese (often referred to as mobile phosphorus), aluminum, or calcium. Phosphorus can also be found incorporated into organic matter (organically-bound phosphorus). It is the mobile phosphorus fraction that releases from sediment during low oxygen conditions (this is often called internal loading). Organically-bound phosphorus also releases phosphorus from lake sediment but at a slow rate.

Phosphorus composition data from cores taken from lake-bottom sediments in 2008 were used to estimate the maximum potential phosphorus release rate (internal loading) in North and South Lake Cornelia and to estimate doses and costs for an alum treatment. Mobile phosphorus in the top 10 centimeters of cores taken in North Lake Cornelia was 55 $\mu g/cm^3$ while in South Cornelia it was 17 $\mu g/cm^3$. Hence, it can expected that internal loading will be greater in North Lake Cornelia. Table 5-1 provides the maximum potential internal loading rates for North and South Lake Cornelia and a comparison with other lakes in the metro area. It can be seen that the maximum potential release rate for North and South Cornelia are similar to other metro lakes that are eutrophic and experience mid-summer phytoplankton (algae) blooms.

5.2.2 Lake Edina

Sediment cores were collected at four locations in Lake Edina in 2018 and analyzed for mobile phosphorus, aluminum-bound phosphorus, calcium-bound phosphorus, and organically-bound phosphorus. The average mobile phosphorus in the top 10 centimeters of the four cores taken in Lake Edina was 3.6 $\mu g/cm^3$. This is significantly lower than the mobile phosphorus concentrations in North and South Lake Cornelia. This mobile phosphorus concentration is essentially "background" and it can be expected that there is essentially no release of the mobile phosphorus fraction in the bottom sediments of Lake Edina during the summer months or any other season. There were typical concentrations of organically-bound phosphorus in the Lake Edina sediments. Organically-bound phosphorus has a slow rate of decay and release from lake bottom sediments and as a result has the potential to be a minor source of phosphorus. However, UAA in-lake modeling efforts indicate phosphorus release from lake bottom sediments is limited (see Section 6.3). Overall, it can be concluded that there is no need to treat Lake Edina sediments for phosphorus internal loading.

Table 5-1 Maximum potential internal loading rate for North and South Cornelia and Lake Edina compared to other Twin Cities Metro Area Lakes.

Lake	Maximum Potential Internal P Load (mg/m²/d)
Kohlman[1]	17.0
Isles (pre-alum, deep hole)[2]	14.1
Harriett (pre-alum, deep hole) [2]	11.1
Calhoun/Bde Maka Ska (pre-alum, deep) [2]	10.8
Fish E[3]	10.5
Cedar (pre-alum) [2]	9.3
Fish W[3]	8.1
Como[3]	7.6
North Cornelia	**7.6**
Calhoun/Bde Maka Ska (pre-alum, shallow) [3]	5.6
Keller[1]	3.5
Parkers[3]	3.5
Phalen[3]	2.3
McCarrons[3]	2.0
Bryant[3]	1.5
South Cornelia	**1.3**
Nokomis[3]	1.0
Minnewashta[3]	0.2
Edina	0.0
Christmas[3]	0.0

Sources:
[1] (Barr Engineering Co., 2007)
[2] (Huser & Pilgrim, 2014)
[3] (Pilgrim, Huser, & Brezonik, 2007)

5.3 Aquatic Communities

The fish, zooplankton, phytoplankton, and aquatic plants residing in Lake Cornelia and Lake Edina are all linked and the composition and abundance of biota observed in the lakes provide indications of their impaired conditions and how biological management could improve water quality. The biota in Lake Edina are also reflective of the shallow lake ecology that results in low lake levels during dry conditions as well as influences from Lake Cornelia such as nutrient loading and biological inputs.

5.3.1 Lake Cornelia

5.3.1.1 Aquatic Plants

Macrophytes, also called aquatic plants, grow in aquatic systems such as streams and lakes. There is a wide range of macrophytes including species attached to the lake bottom, species unattached and floating, submerged species, and emergent species (e.g., cattails). Macrophytes are an important part of a shallow lake ecosystem and provide critical habitat for aquatic insects and fish. A healthy native plant community contributes to the overall health of the lake. However, a dense non-native plant community can create problems, including recreational use impairment, fluctuating water quality, and a less than ideal fisheries habitat, which has adverse impacts on the fish community. The dense growth makes it difficult for invertebrates and other organisms that fish eat to survive. So, with less to eat and less open water, fish populations decrease (MPCA, Eurasian Water Milfoil, 2019). The dense growth makes it hard for fish to catch food. When fish are less effective at controlling prey species, an unbalanced fishery results (Indiana Department of Natural Resources, 2019)

The Minnesota Department of Natural Resources (MDNR) developed the Lake Plant Eutrophication IBI in recent years to assist the MPCA in assessing lake impairment based on the plant community. The Lake Plant Eutrophication IBI includes two metrics to assess the viability of aquatic life. The first metric is species richness—the estimated number of species in a lake. The second metric is floristic quality index (FQI), which distinguishes the quality of the plant community and can be a reflection of the quantity of nutrients in the lake.

The MDNR's Lake Plant Eutrophication IBI was used to assess the health of the North and South Lake Cornelia plant communities. Aquatic plant data collected by NMCWD from 2004 through 2017 was used to determine species richness and FQI scores. The scores were then compared with MDNR Lake Plant Eutrophication IBI impairment thresholds (a minimum of 11 species and an FQI score of at least 17.8) to determine whether the Lake Cornelia plant community would be considered impaired.

The Lake Cornelia plant community has generally failed to meet the MDNR Lake Plant Eutrophication IBI criteria since 2004, a reflection of the lake's poor water quality. The number of species observed in North Cornelia ranged from 2 to 7 which is less than the plant IBI impairment threshold of at least 11 species (Figure 5-6). The FQI values from the north basin ranged from 6.4 to 12.7 which is less than the plant IBI impairment threshold for FQI of at least 17.8 (Figure 5-7). The number of species observed in South Cornelia ranged from 3 to 12 (Figure 5-8). This metric met the MDNR plant IBI impairment threshold during August 2015 and June 2016, but was less than the plant IBI impairment threshold of at least 11 species during all other surveys. The FQI values from South Cornelia ranged from 6.9 to 18.1. FQI met the MDNR plant IBI during August 2015, but was less than the plant IBI threshold for FQI of at least 17.8 during all other surveys (Figure 5-9). The plant IBI has not yet been used by the MPCA/MDNR to determine impairment. However, it is expected to eventually be used as an assessment tool to determine biological impairment.

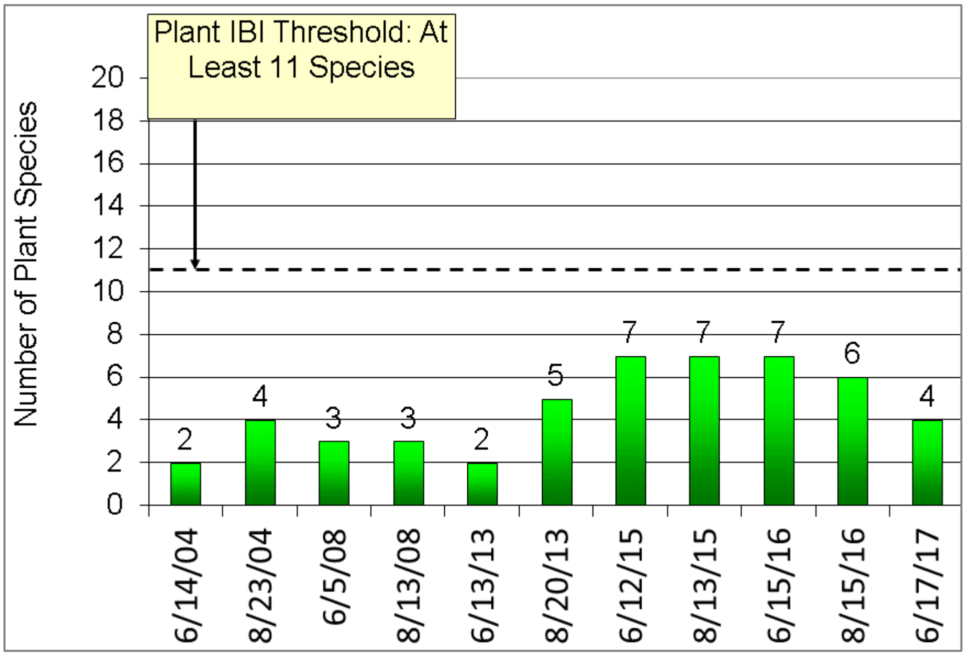


Figure 5-6 **North Cornelia Macrophyte Species Richness Compared with Plant IBI Threshold for Species Richness**

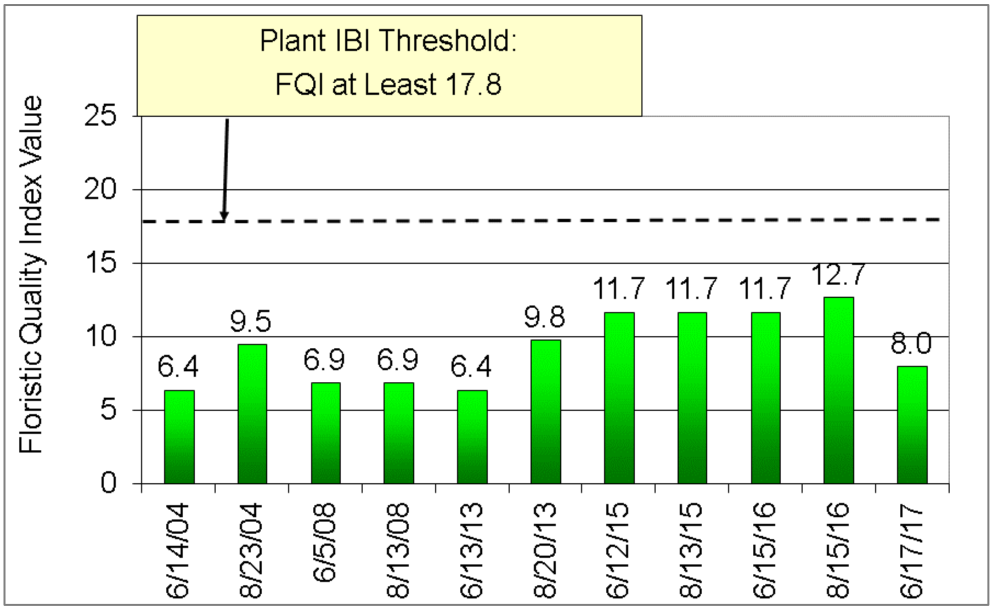


Figure 5-7 **North Cornelia Floristic Quality Index (FQI) Compared with Plant IBI Threshold for FQI**

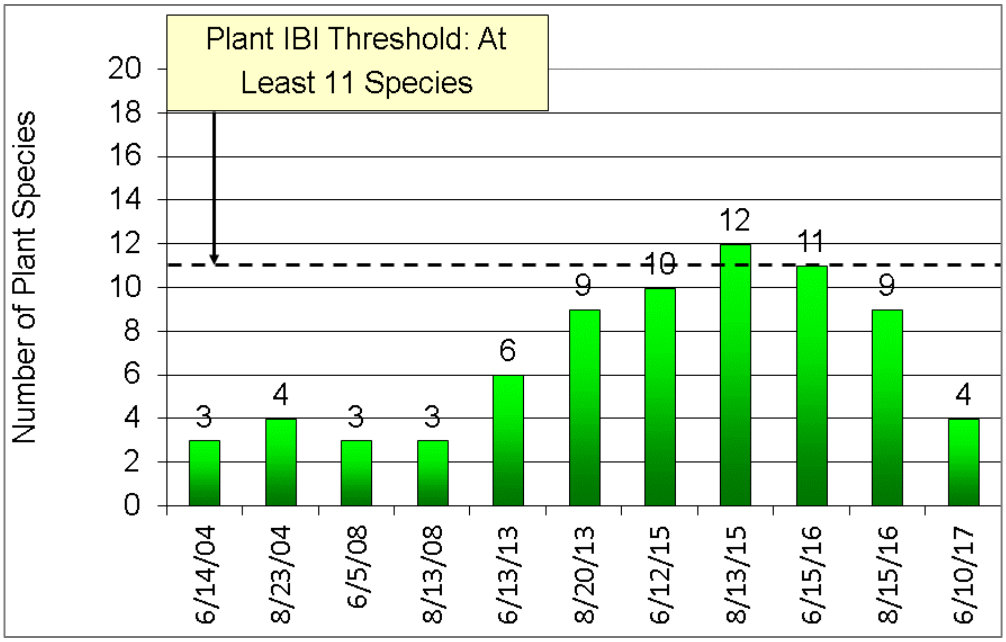


Figure 5-8 **South Cornelia Macrophyte Species Richness Compared with Plant IBI Threshold for Species Richness**

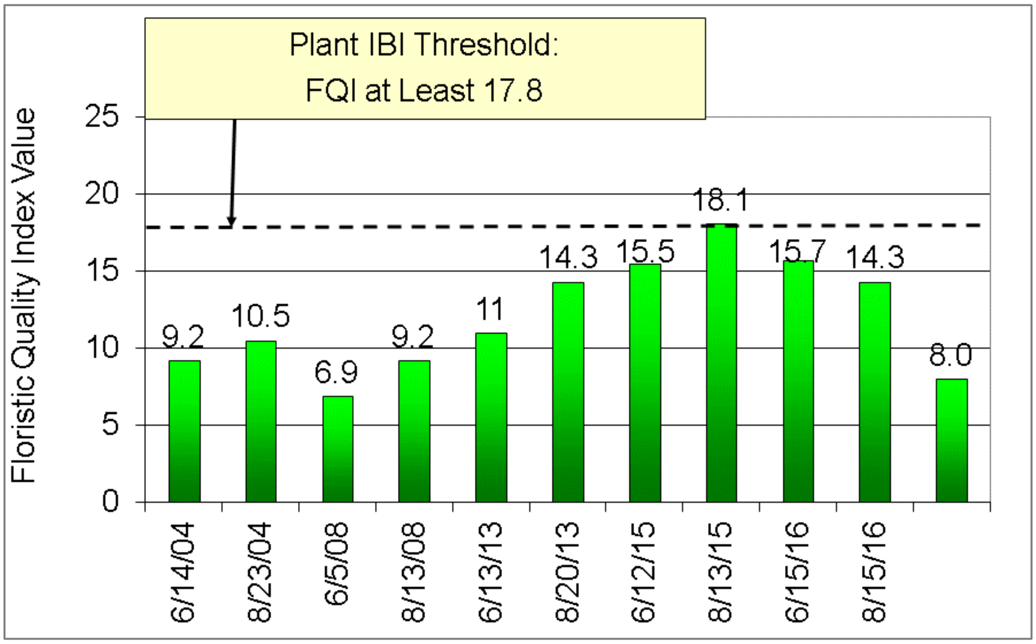


Figure 5-9 **South Cornelia Floristic Quality Index (FQI) Compared with Plant IBI Threshold for FQI**

Three non-native aquatic invasive species (AIS) are present in Lake Cornelia: hybrid cattail, purple loosestrife, and curly-leaf pondweed.

In 2017, hybrid cattail was prevalent in North Cornelia. The hybrid cattail spreads aggressively through underground roots and can become very dense, crowding out native species (Wisconsin Wetlands Association, 2017).

Purple loosestrife has been observed in North and South Cornelia since 2004. Purple loosestrife was observed along the northwest shoreline of North Cornelia during 2004, 2008, and in June of 2015. In August of 2015, purple loosestrife was again present along the northwest shoreline of North Cornelia, but was also observed along the southeast shoreline. Purple loosestrife has also been observed in South Cornelia since 2004. During the 2004, 2008, and 2015 surveys, purple loosestrife was found sporadically along the entire shoreline. In 2017, purple loosestrife was common in both North and South Cornelia and moderately dense around much of the undeveloped lakeshore.

Curly-leaf pondweed was not observed in North or South Cornelia during the 2004 survey; however, curly-leaf pondweed was present in North and South Cornelia in a few small patches in 2008 and 2013. In 2015, curly-leaf pondweed was problematic throughout North and South Cornelia. In June 2015, the density was light in the center of North Cornelia, but denser along the northern, eastern, and southern shores. Curly-leaf pondweed was also found throughout North Lake Cornelia in August 2015. Although less dense than in June, a moderate to heavy density was observed near shore and a light density at the center indicating a late die-off of the species in 2015. Additionally, curly-leaf pondweed was observed throughout South Lake Cornelia in both June and August, 2015.

In 2016, the density of curly-leaf pondweed surveyed in Lake Cornelia was significantly more than what was observed in previous years. The June plant survey documented dense curly-leaf pondweed growth throughout the entire lake. It is hypothesized that the increased phosphorus pulse from senescence of the dense curly-leaf pondweed community increased the severity of late-summer blue-green algal blooms. Curly-leaf pondweed normally dies near the end of June and then decays, adding a pulse of phosphorus to the lake. When the 2016 dense growth of curly-leaf pondweed in the Lake Cornelia senesced, the lake's phosphorus concentrations rapidly increased, which may have fueled the severe blue-green algal blooms that occurred that year.

On April 23, 2017, a point-intercept plant survey was completed by the City of Edina. The survey found curly-leaf pondweed forming a solid mat over the entire lake with the exception of a few meters (about 6 feet) buffer near the immediate shoreline (Figure 5-10). The City completed an herbicide (endothall) treatment in May 2017 to manage the curly-leaf pondweed. A post-treatment survey was completed in early-June 2017 and curly-leaf pondweed was not observed in North Cornelia and was only observed at one location in South Cornelia. Thus, the herbicide treatment effectively managed the lake's curly-leaf pondweed infestation.

Figure 5-10 Curly-leaf pondweed growth observed in Lake Cornelia in 2017.

In 2017, the number of plant species observed in North (4 species) and South Cornelia (4 species) were lower than the number of species observed during 2013 through 2016 (Figure 5-6 and Figure 5-8). Similarly, FQI was lower in 2017 than 2013 through 2016 for North (8.0) and South Cornelia (8.0) (Figure 5-7 and Figure 5-9). In June 2017, 5 species were absent from North Cornelia that had been observed in June 2016. Similarly, in the June 2017 survey, nine species were absent in South Cornelia that had been observed in June 2016. The species that were not observed between June 2016 and June 2017 in North and South Cornelia include curly-leaf pondweed, targeted by the herbicide treatment, three native pondweed species (*Potamogeton foliosus*, *Potamogeton nodosus*, and *Stuckenia pectinata*), four native bulrush species (*Bulboschoenus fluviatilis*, *Schoenoplectus acutus, Schoenoplectus tabernaemontani, and Schoenoplectus sp*.), muskgrass (*Chara sp*.), and coontail (*Ceratophyllum demersum*). It is possible that the later treatment of curly-leaf pondweed that occurred in May 2017 effected the native plant species of North and South Cornelia. For future curly-leaf pondweed herbicide treatments, it is recommended that the herbicide be applied before the lake's average water column temperature reaches 60°F, prior to the native plant growing season. Completing the herbicide application prior to the start of the native plant growing season should protect the native plants.

5.3.1.2 Phytoplankton

Blue-green algae numbers were lower during 2004 through 2013 than 2015 through 2016. Changes in the Lake Cornelia phytoplankton community since 2004 are hypothesized to have been influenced to some extent by the curly-leaf pondweed within the lake. Curly-leaf pondweed was not observed in 2004, was first observed in 2008, and remained at low levels during 2008 through 2013. A rapid increase in curly-leaf pondweed extent during 2015 may have resulted in a rapid increase in phytoplankton growth, especially blue-green algae. In 2016, the lake's curly-leaf pondweed infestation was more severe than 2015 and the resultant blue-green algal bloom in 2016 was more severe than the lake's 2015 blue-green algal bloom.

The Lake Cornelia phytoplankton community during 2013 through 2018 was impacted by algaecide treatments. The City of Edina started treating Lake Cornelia with copper sulfate to control algal populations in 2013. Table 5-2 shows the approximate dates of the algal treatment efforts based on past records since 2013.

Table 5-2 Lake Cornelia algal copper sulfate treatments

Algal Copper Sulfate Treatments
July 19, 2013
August 21, 2013
June 18, 2014
July 25, 2014
August 18, 2015
August 3, 2016
August 9, 2017
September 7, 2017
July 11, 2018

The changes to the phytoplankton species composition and abundance from 2004 through 2017 can be seen in Figure 5-11 for North Cornelia and Figure 5-12 for South Cornelia.

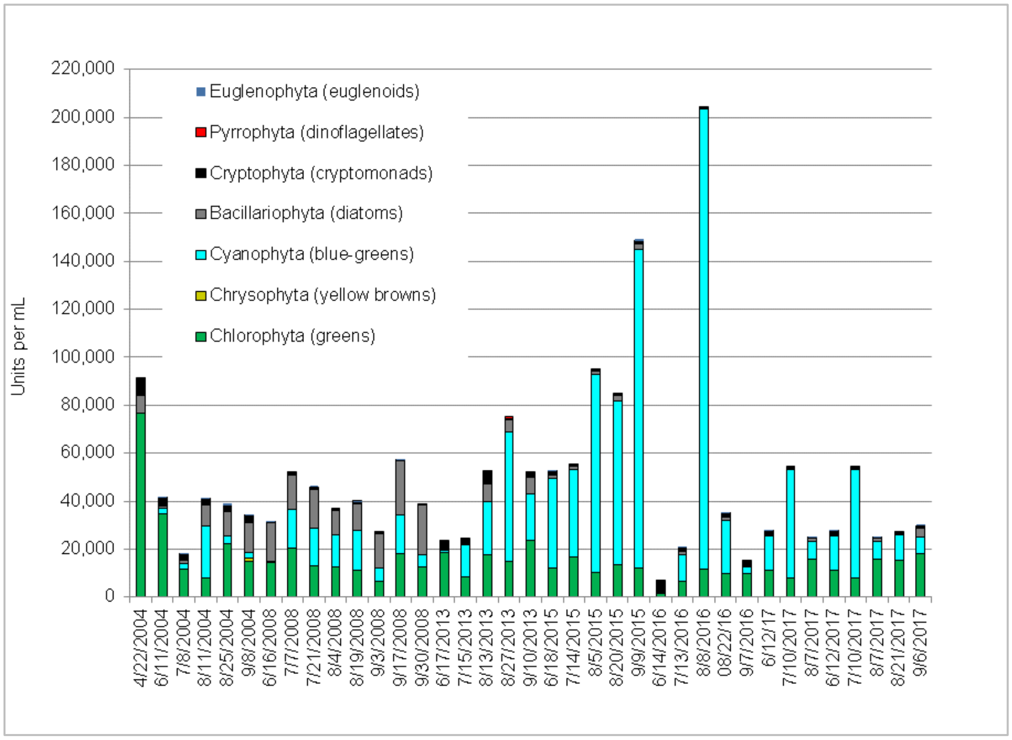


Figure 5-11 North Cornelia Phytoplankton Data Summary (2004-2017)

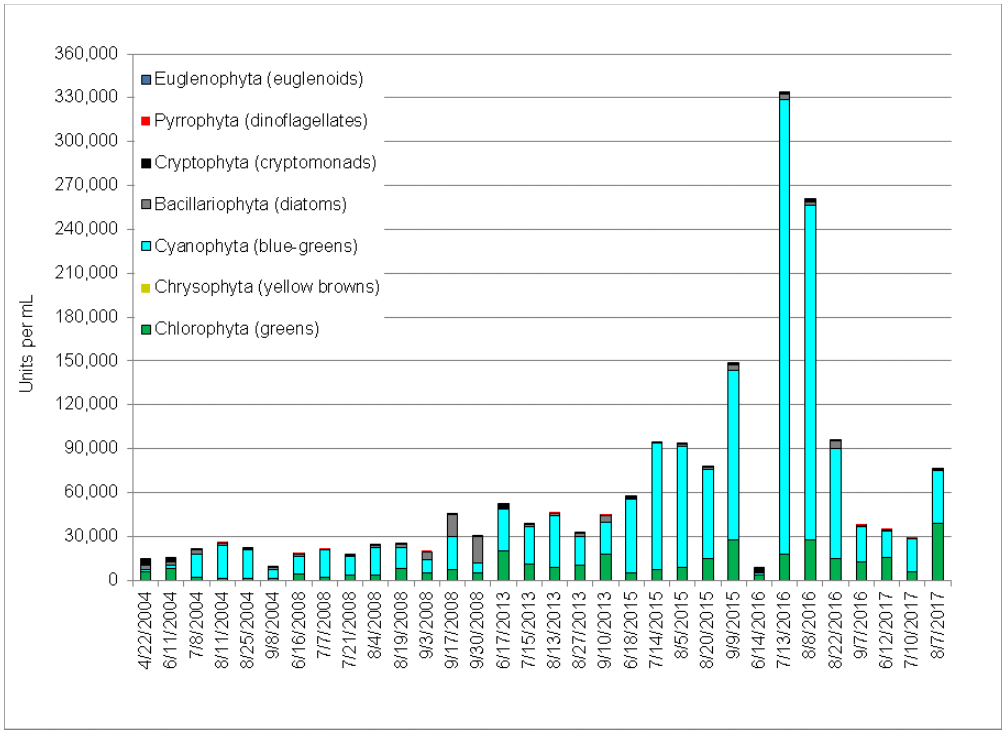


Figure 5-12 South Cornelia Phytoplankton Data Summary (2004-2017)

Blue-green algae are associated with water quality problems and can be a source of health concerns. The World Health Organization (WHO) has established the following guidelines for assessing the risk posed to lake users by exposure to blue-green algae (World Health Organization, 2003):

- ***No Risk:*** Lakes with blue-green algae densities less than 20,000 cells per milliliter pose no risk to the health of humans or pets.
- ***Low Risk:*** Exposure to lakes with blue-green algae density levels between 20,000 and 100,000 cells per milliliter poses a low risk of adverse health impacts (i.e., skin irritation or allergenic effects such as watery eyes).
- ***Moderate Risk:*** Exposure to lakes with blue-green algae densities greater than 100,000 cells per milliliter poses a moderate health risk (i.e., long-term illness from algal toxins is possible).

The WHO guidelines were applied to the data observed in North and South Cornelia. During the late summer periods of 2015 and 2016 when higher numbers of blue-green algae were present, comparison with the WHO guidelines indicated a moderate risk of adverse health effects from exposure to blue-green algae in North and South Lake Cornelia (Figure 5-13 and Figure 5-14). Low risk of adverse health effects from exposure to blue green algae was also present earlier in the growing season for 2013, 2015, and 2017 in both North and South Cornelia when lower numbers of blue-green algae were observed

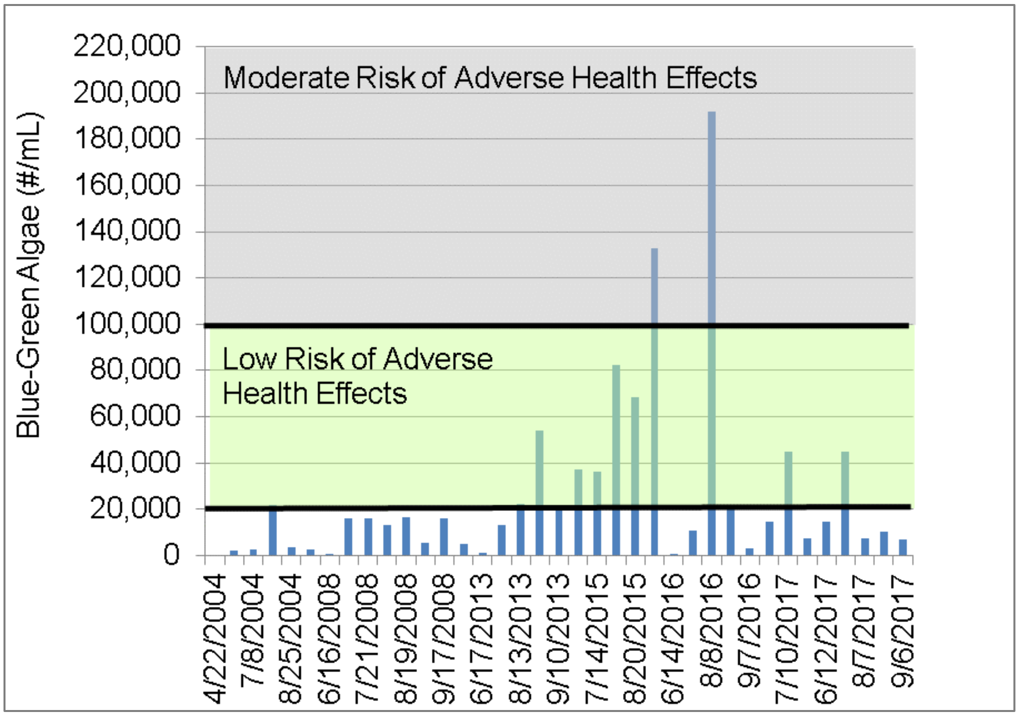


Figure 5-13 **North Cornelia blue-green algae data compared with the World Health Organization's Risk of Adverse Health Effects Guidelines**

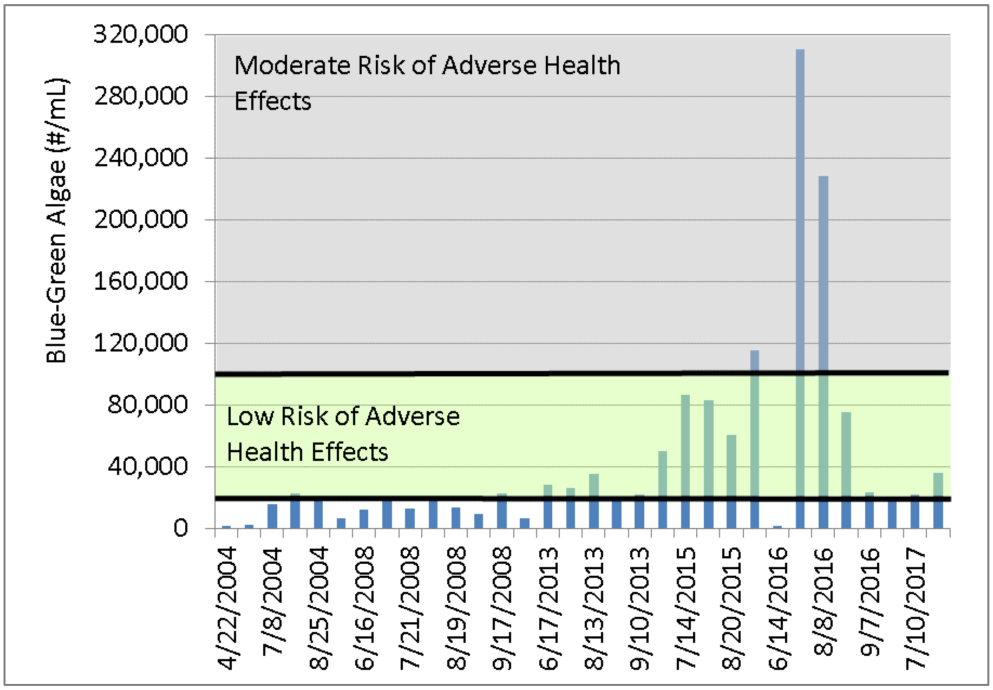


Figure 5-14 **South Cornelia blue-green algae data compared with the World Health Organization's Risk of Adverse Health Effects Guidelines**

The City of Edina performed an algaecide chemical treatment of Lake Cornelia on August 3, 2016 to manage the lake's algal bloom. Although the numbers of blue-green algae were reduced by the treatment, the District and City were concerned that algal toxins could still be present in the lake and pose health risks to lake users. The District collected algal toxin samples on September 7 and September 21, 2016 and verified the presence of high levels of algal toxin (Microcystin) that exceeded the public health advisory level.

In August 2017, blue-green algal scum was observed in both North and South Cornelia and was sampled/tested for three algal toxins. The tests verified high levels of two algal toxins, microcystins and anatoxin-a, both exceeding public health advisory levels.

5.3.1.3 Zooplankton

Zooplankton are microscopic animals that are a source of food for fish (e.g., bluegills, crappies). They were sampled 8 times in 2008 and five times during 2013, 2015, and 2016. During 2008 through 2016, all three groups of zooplankton (rotifers, copepods, and cladocerans) were generally present in Lake Cornelia. The relative abundance of each group during each sampling period can be viewed in Figure 5-15 for North Cornelia and Figure 5-16 for South Cornelia. Small rotifers and copepods and smaller cladocerans dominated the community; because they do not graze as heavily on algae as the larger cladocerans, they generally have limited impact on the lake's water quality.

The data suggest that changes in the Lake Cornelia zooplankton community in 2015 may have been influenced by the rapid increase in blue-green algae. Blue-green algae are a poor food source for zooplankton. In addition, smaller-bodied zooplankton species are unable to consume the larger-sized blue-green algae. The total number of zooplankton sampled in 2015 were much lower than 2008 and 2013. Cladocerans were consistently present throughout 2008 and 2013, but were absent during June and July of 2015 and present at very low numbers during August and September. A few large-bodied Cladocerans were present in 2008 and 2013, but only small-bodied cladocerans were present in 2015. It is difficult to discern between the impact of fish predation and the impact of changes in food source on the lake's zooplankton. It is likely that the changes in the 2015 zooplankton community were influenced by increased blue-green algae species.

In 2016, rapid increases in zooplankton, especially cladocerans, occurred following treatment of Lake Cornelia with algaecide in early August. The algaecide reduced blue-green algae in the lake. The data suggest the reduction in blue-greens was followed by rapid increases in zooplankton numbers. Cladoceran numbers increased more than copepods and rotifers.

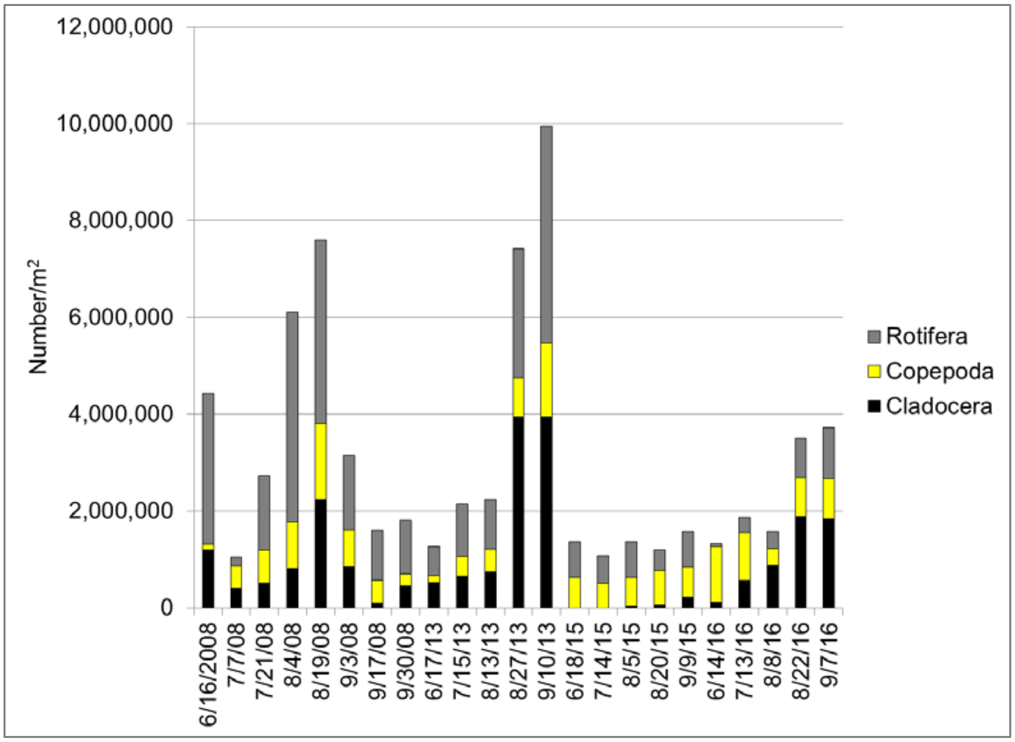


Figure 5-15 North Cornelia Zooplankton Data Summary (2008-2015)

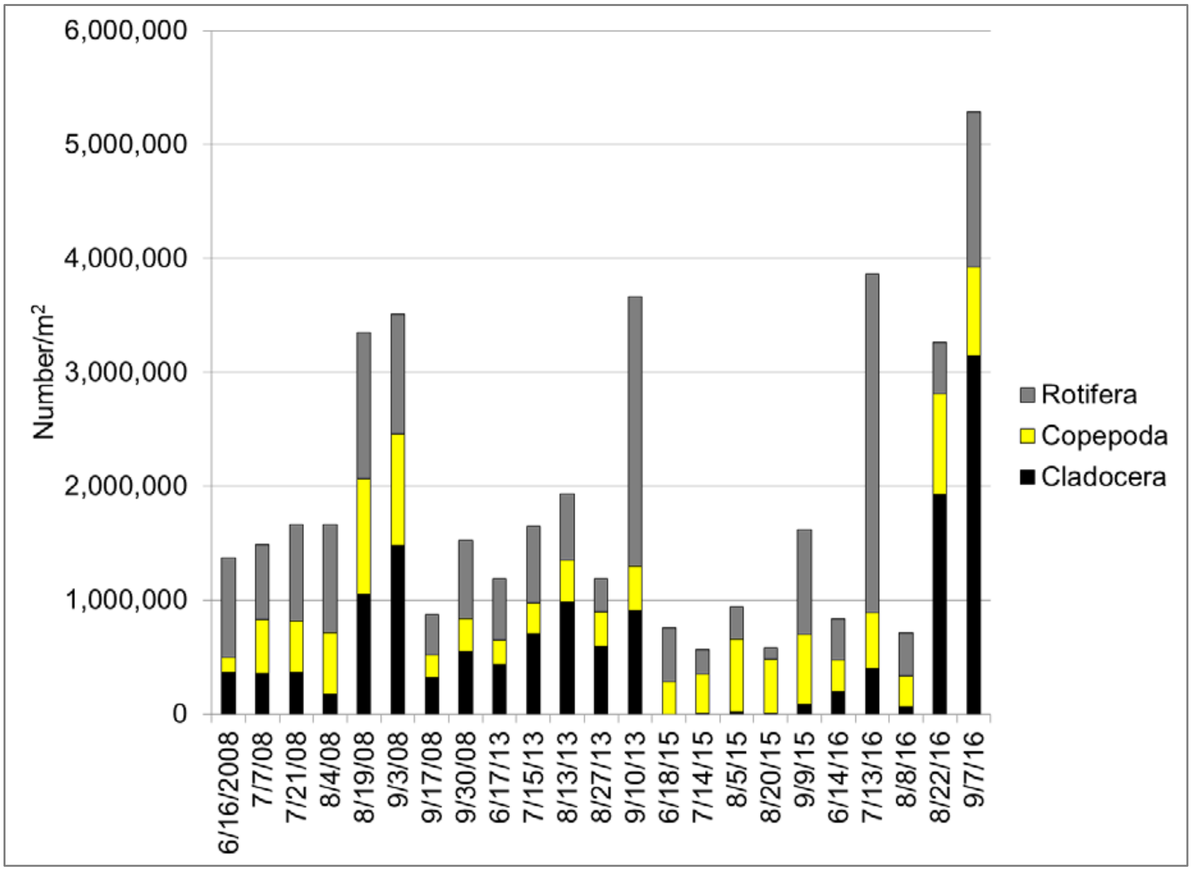


Figure 5-16 South Cornelia Zooplankton Data Summary (2008-2015)

5.3.1.4 Fish

To gain a more complete understanding of the ecology of Lake Cornelia, the District commissioned a fish survey in 2018 with the primary intent to quantify the common carp population (Maxwell (RPBCWD), 2018). The full survey report is included as Appendix B.

Fish caught in fyke nets set in North and South Lake Cornelia were generally small pan fish with black bullhead being very abundant. Nearly all of the fish (see Table 5-3 and Table 5-4) were less than 8 inches suggesting that periodic winter kill is preventing fish from maturing to larger size classes. These fish are planktivores (they eat zooplankton) and benthivorous (bottom, sediment feeders), the black bullhead in particular. The zooplankton data collected in 2015 suggest that the Cladocera population may have been heavily grazed upon by these small fish. It is likely that the fish population in Lake Cornelia is having an adverse effect on water quality. Zooplankton eat phytoplankton, and if the zooplankton population is reduced they will be less able to reduce the phytoplankton population, which in turn affects lake clarity. The black bullhead are benthivorous and in the process of feeding the large population of bullheads could cause increased sediment resuspension, turbidity, and the transport of phosphorus from lake bottom sediments into the lake.

Very few common carp were found in Lake Cornelia with electrofishing, which is the preferred approach to quantify carp populations. Conversely, a significant number of goldfish were caught while electrofishing in Lake Cornelia and in upstream detention ponds. Goldfish are omnivores and are not strictly benthivorous, and hence they may not have the same effect on water quality as common carp. However, they could be significant zooplankton grazers. Electrofishing was also conducted in Swimming Pool Pond, Point of France Pond, and the waterbodies north of Highway 62 known as Lake Otto and Lake Nancy. A significant number of goldfish were identified in Swimming Pool Pond and connected waterbodies north of Trunk Highway (TH) 62. Point of France Pond had a high number of common carp with an estimated biomass of 196 pound per acre. To manage the goldfish and common carp, it will be important to better understand the movement of the fish between these ponds and Lake Cornelia.

Overall the fish sampled in the Lake Cornelia system were small in size and species richness was limited. This is most likely a result of the 2017-2018 winterkill and past winterkills that have occurred. The low number of bluegill and other sunfish species captured from the surveys reflect a limited population that may not be able to control common carp and goldfish recruitment effectively. The frequency of winterkills and the availability of connected shallow waterbodies that winterkill which act as nurseries, are most likely preventing bluegills from effectively controlling carp and goldfish within the system.

It should also be noted that the MDNR, as part of its Fishing in the Neighborhood (FiN) program, has been stocking Lake Cornelia on a near annual basis (stocking records provided on LakeFinder up to the year 2014) with bluegill, black crappie, hybrid sunfish, and pumpkinseed sunfish.

Table 5-3 South Cornelia fyke net results showing the number of fish caught by size

Species	Number of Fish Caught in Each Size Category (inches body length)									
	0-5	6-8	9-11	12-14	15-19	20-24	25-29	30+	Total	Fish/Net
Black bullhead	75	82	1						159	53
Bluegill sunfish	1	2							3	1
Goldfish	16								16	5.3
Golden shiner	16	1							17	5.7

Table 5-4 North Cornelia fyke net results showing the number of fish caught by size

Species	Number of Fish Caught in Each Size Category (inches body length)									
	0-5	6-8	9-11	12-14	15-19	20-24	25-29	30+	Total	Fish/Net
Black bullhead	148	161	1						676	225
Back crappie		2							2	0.67
Bluegill sunfish	31								31	10
Common carp	1								1	0.33
Goldfish	9								9	3
Golden shiner	63	23							90	30
Green sunfish	20								20	
Hybrid sunfish	12								12	
Pumpkinseed	12								12	

5.3.2 Lake Edina

5.3.2.1 Aquatic Plants

As mentioned for Lake Cornelia, macrophytes (aquatic plants) are an important part of a shallow lake ecosystem and provide critical habitat for aquatic insects and fish. The MDNR developed a Lake Plant Eutrophication IBI to assist the MPCA with determining lake impairment based on the plant community. Lake Edina plant survey data from 2004 through 2017 were assessed to determine species richness (the number of species) and FQI scores. The scores were compared with MDNR Lake Plant Eutrophication IBI impairment thresholds (a minimum of 11 species and an FQI score of at least 17.8) to determine whether the Lake Edina plant community would be considered impaired.

As shown in Figure 5-17 and Figure 5-18, the Lake Edina plant community has generally failed to meet the MDNR Lake Plant Eutrophication IBI criteria since 2004, a reflection of the lake's poor water quality. The 2017 plant community in Lake Edina was poor, but had improved from previous years. The number of plant species observed in 2017 was higher than the number of species observed during 2008 through 2015—6 to 8 in 2017 compared with 3 to 4 in previous years. Similarly, Figure 5-18 shows that FQI was higher (better) in 2017 than 2008 through 2015. The plant IBI has not yet been used by the MPCA/MDNR to determine impairment. However, it is expected to eventually be used as an assessment tool to determine biological impairment.

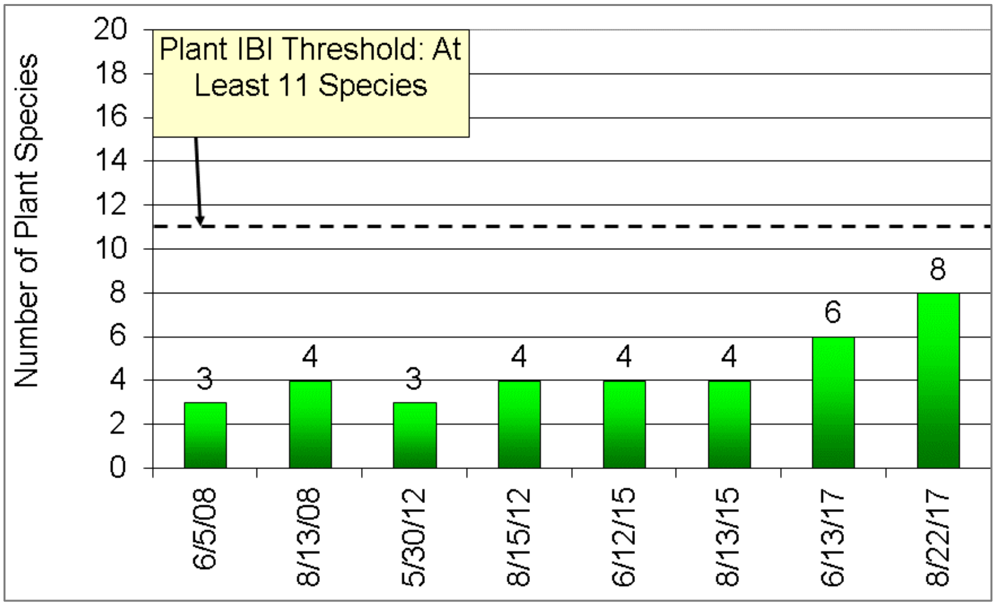


Figure 5-17 Lake Edina Species Richness Compared with Plant IBI Threshold for Species Richness

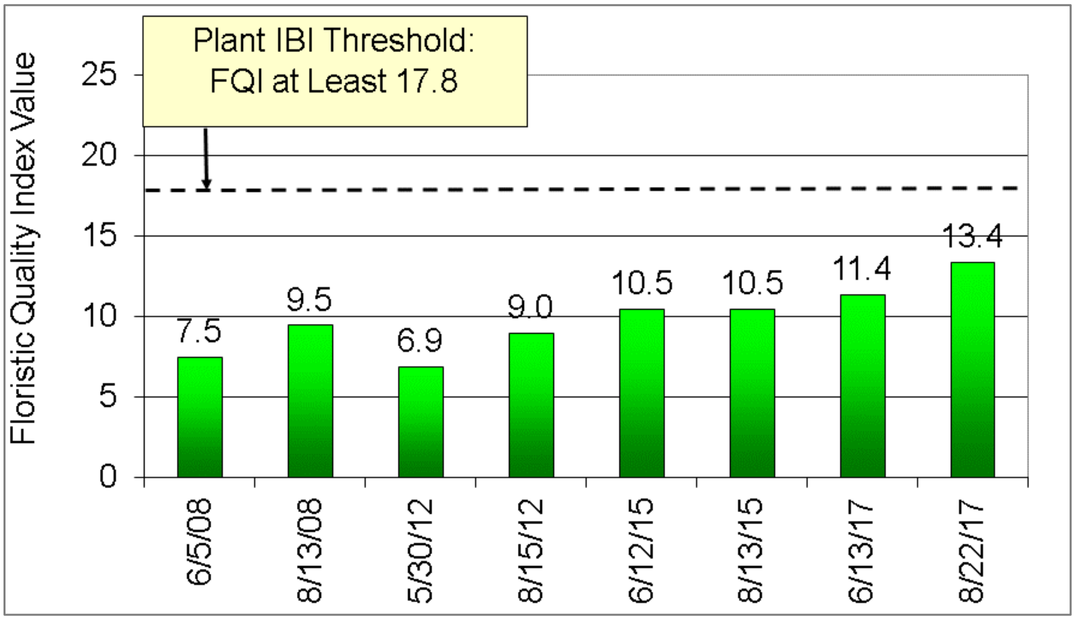


Figure 5-18 Lake Edina Floristic Quality Index (FQI) Compared with Plant IBI Threshold for FQI

Three non-native aquatic invasive species (AIS) are present in Lake Edina: purple loosestrife, curly-leaf pondweed, and Eurasian watermilfoil.

Purple loosestrife was observed along the perimeter of the lake during the 2008, 2012, 2015, and 2017 sampling periods.

Curly-leaf pondweed has been observed at low levels in Lake Edina since 2008. In 2008, curly-leaf pondweed was found at a single location in the southeast area of the lake. In 2012 and 2015, curly-leaf pondweed was observed at a single location in the central western area of the lake. In June of 2017, the species was observed at two locations, both in the western area of the lake. In August, it was observed at a single location in the central western area of the lake.

Although Eurasian watermilfoil was first observed in Lake Edina during 2017, it was widespread and increased in extent between June and August. Unlike many other plants, Eurasian watermilfoil does not rely on seed for reproduction. Its seeds germinate poorly under natural conditions and it generally reproduces by fragmentation—each fragment can grow into a new plant. The plant produces fragments after fruiting at least once or twice during the summer. These fragments can be carried downstream by water currents or spread by waves or boaters throughout a waterbody (WI-DNR, Eurasian Watermilfoil - Beaver Dam Lake, 2012). Eurasian watermilfoil fragments in Lake Edina could be carried downstream to Normandale Lake.

Once established in an aquatic community, Eurasian watermilfoil reproduces from fragments and stolons (runners that creep along the lake bed). Stolons, lower stems, and roots persist over winter and store the carbohydrates that help Eurasian watermilfoil claim the water column early in spring, photosynthesize, divide, and form a dense leaf canopy that shades out native aquatic plants. Eurasian watermilfoil's fast growth rate (up to 2 inches per day in spring and summer), its ability to spread rapidly by fragmentation, and its ability to effectively block out sunlight needed for native plant growth often results in monotypic stands. Monotypic stands of Eurasian watermilfoil provide only a single habitat, and threaten the integrity of aquatic communities in a number of ways. For example, dense stands disrupt predator-prey relationships by fencing out larger fish, and reducing the number of nutrient-rich native plants available for waterfowl. Eurasian watermilfoil spreads rapidly and can grow to dominance in as little as 2 years (WI-DNR, Eurasian Watermilfoil - Beaver Dam Lake, 2012; WI-DNR, Aquatic Plant Eurasian Watermilfoil, 2012).

5.3.2.2 Phytoplankton

The Lake Edina phytoplankton community has generally reflected the lake's poor water quality. During 2008 through 2015, average phytoplankton numbers increased annually and blue-greens dominated the phytoplankton community (Figure 5-19). In 2017, phytoplankton numbers declined and the lake's average 2017 phytoplankton number was the lowest on record. The composition of the 2017 phytoplankton community was different from previous years. Green algae dominated the phytoplankton community and numbers of blue-greens were very low.

The change in numbers of phytoplankton observed in 2017 reflects a change from planktonic algae within the water column to mats of filamentous algae residing on the lake's surface. Algal mats were observed during both the June 13, 2017 plant survey and the August 21, 2017 water quality monitoring event. Surface algal mats outcompeted planktonic algae that reside in the water column by consuming nutrients and creating shade which limited light beneath the lake's surface. Samples from the algal mats were collected and analyzed in the laboratory to determine whether they were harmful blue-greens or harmless greens. The algal species comprising the mats in the lake were green algal species—*Rhizoclonium* in June and *Spirogrya* in both June and August.

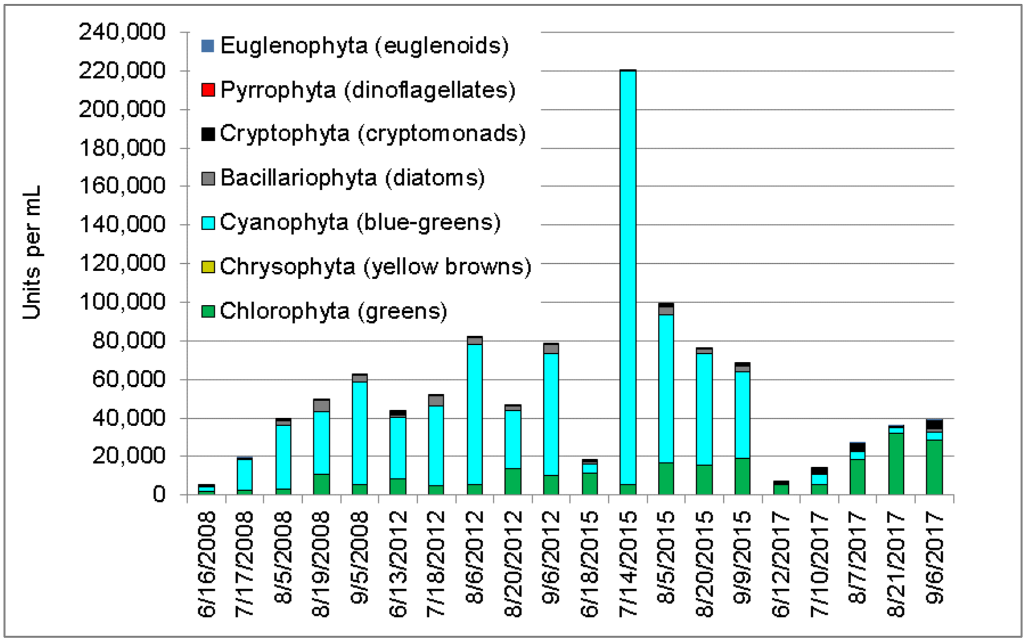


Figure 5-19 Lake Edina Phytoplankton Data Summary (2008-2017)

It is hypothesized that the changes to the Lake Edina phytoplankton community since 2008 are partially due to treatment efforts. The City of Edina started treating Lake Edina with copper sulfate to control algal populations in 2013. Table 5-5 shows the approximate dates of the algal treatments based on past records since 2013.

Table 5-5 Lake Edina algal copper sulfate treatments

Algal Copper Sulfate Treatments
August 6, 2013
August 21, 2013
August 18, 2014
July 16, 2015
August 18, 2015
August 3, 2016
July 25, 2017
August 23, 2017
June 8, 2018

Blue-green algae are associated with water quality problems and can be a source of health concerns. The World Health Organization (WHO) has established guidelines for assessing the risk posed by exposure to blue-green algae (World Health Organization, 2003). Blue-green algae numbers observed in Lake Edina were compared with WHO guidelines to assess risk of adverse health impacts from the blue-greens (Figure 5-20). During mid-July 2015, comparison with the WHO guidelines indicated a moderate risk of adverse health effects from exposure to the blue-green algae species in Lake Edina based on the number of blue-green algae observed. Algaecide treatments were then applied in July and August to reduce the numbers of blue-green algae and the associated health risks. Users also had a low risk of adverse health effects from exposure to blue-green algae species in Lake Edina in 2008, 2012, and 2015. The blue-green algal numbers were low throughout 2017 and, according to WHO criteria, posed no risk to lake users during this year.

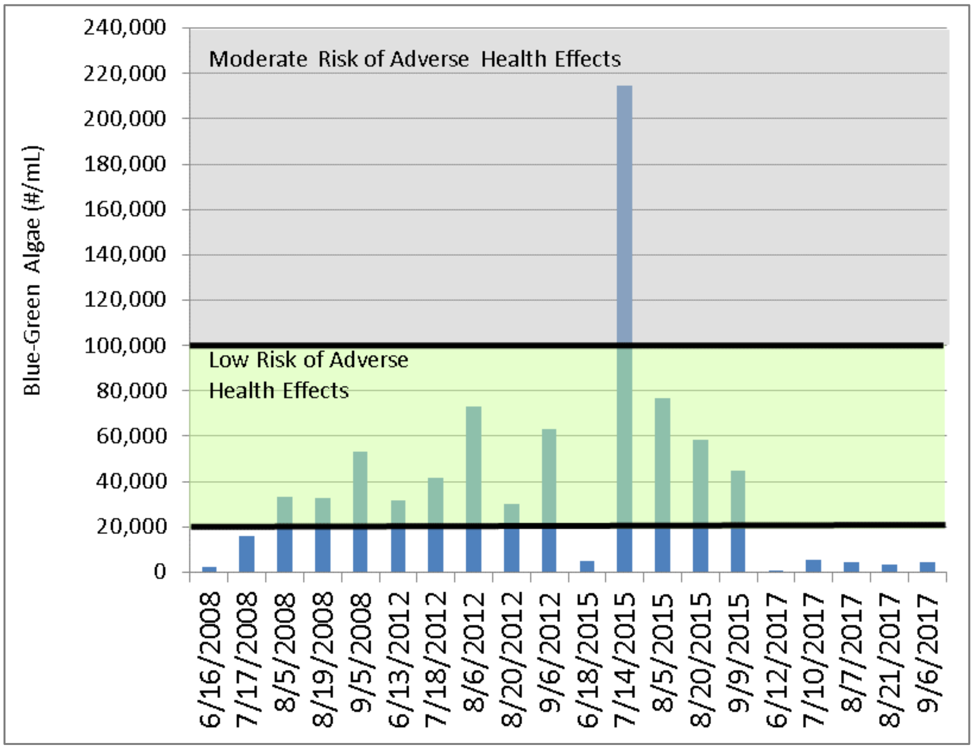


Figure 5-20 Lake Edina Blue-green Algae Data Comparison with World Health Organization Risks Guidelines

5.3.2.3 Zooplankton

Zooplankton are microscopic animals that are a source of food for fish (e.g., bluegills, crappies). During 2008 through 2017, all three groups of zooplankton (rotifers, copepods, and cladocerans) were generally present in Lake Edina (Figure 5-21). Small rotifers and copepods and smaller cladocerans dominated the community; because they do not graze as heavily on algae as the larger cladocerans, they generally have limited impact on the lake's water quality.

The data suggest that changes in the Lake Edina zooplankton community in 2015 and 2017 may have been influenced by changes in numbers of blue-green algae (Figure 5-22). The increase in blue-green algae during 2015 (from 47,757 units/ mL in 2012 to 79,914 units/mL in 2015) was associated with a decline in cladocerans (from 92,105 per m^2 in 2012 to 3,678 per m^2 in 2015). A few large-bodied Cladocerans were present in 2008 and 2012, but only small bodied cladocerans were present in 2015. Blue-green algae are a poor food source for zooplankton. In addition, smaller-bodied zooplankters are unable to consume the larger sized blue-greens.

The decline in blue-green algae in 2017 (from 79,914 units/mL in 2015 to 3,515 units/mL in 2017) was associated with an increase in cladocerans (from 3,678 per m^2 in 2015 to 198,864 per m^2 in 2017). In addition, some large-bodied cladocerans were again observed in the lake during 2017. The phytoplankton community in 2017 was dominated by green algae, a good food source for cladocerans. We are unable to discern between the impact of fish predation and the impact of changes in food source on the lake's zooplankton. If we assume the fish community remained stable, the changes in the 2015 and 2017 cladoceran numbers would likely be due to changes in numbers of blue-green algae within the lake.

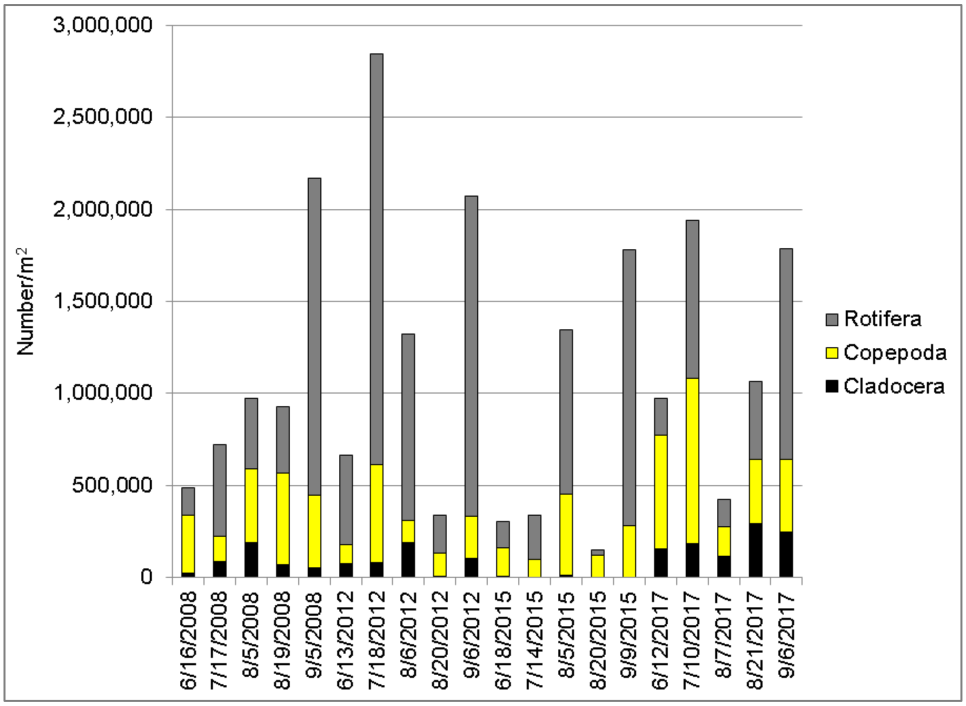


Figure 5-21 Lake Edina Zooplankton Data Summary (2008-2017)

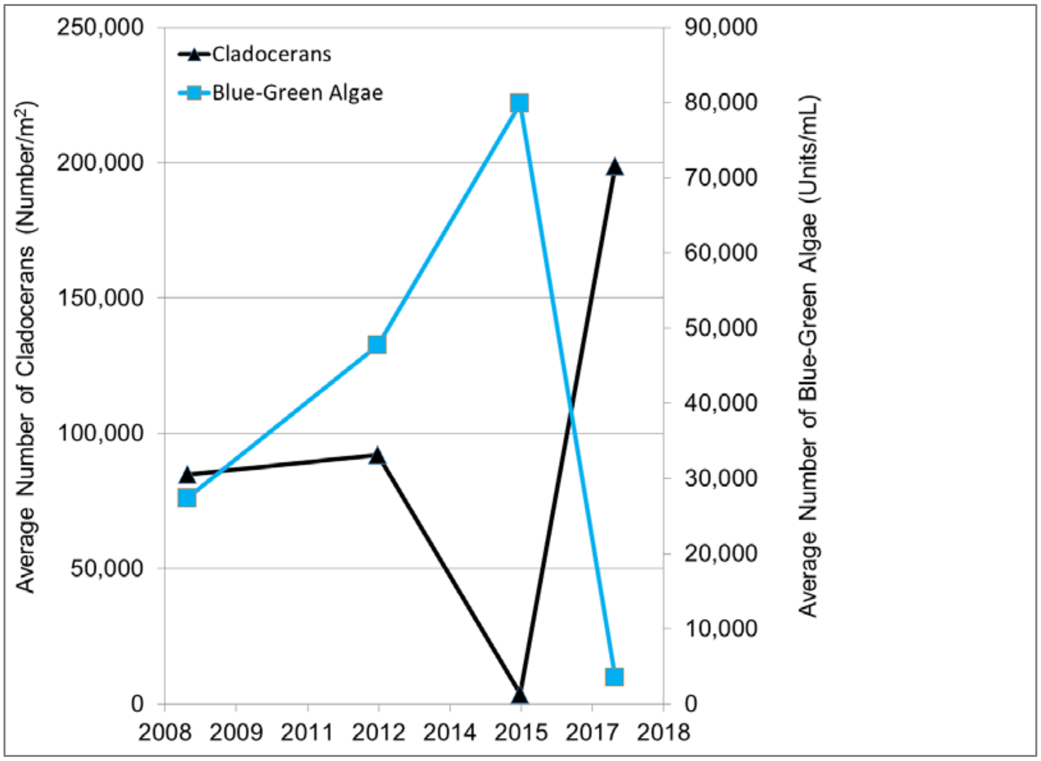


Figure 5-22 **Lake Edina average annual cladoceran and blue-green algae numbers comparison**

5.3.2.4 Fish

Fisheries information was not available for Lake Edina.

6.0 Water Quality Modeling for the UAA

Phosphorus levels in Lake Cornelia and Lake Edina are high, and will continue to be greatly affected by the amount of phosphorus loading received. For this UAA study, water and phosphorus loading to Lake Cornelia and Edina were evaluated for a 3-year period (2015, 2016, and 2017). Modeling was used to link water and phosphorus loading to Lake Cornelia and Lake Edina to observed phosphorus concentrations in the water column of these lakes. Somewhat unique to this study was the inclusion of internal lake processes such as phosphorus release from lake sediments (internal loads), curly-leaf die-off, copper sulfate treatments, and potential rough fish effects (included as part of internal loading). Model years 2015, 2016, and 2017 were typical of the variability that these lakes may experience from a watershed loading, in-lake management, and biological variability perspective.

6.1 P8 Model Runoff and Phosphorus Loading

Central to a lake water quality analysis is the use of a water quality model that has the capacity to predict the amount of runoff and pollutants that reach a lake via stormwater runoff (external loading). The P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds) modeling software was used to estimate watershed loads to the lakes (I.E.P, Inc., 1990). The P8 model incorporates hourly precipitation and daily temperature data; long-term climatic data can be used so that watersheds and BMPs can be evaluated for varying hydrologic conditions. The P8 model was used to calculate the daily water volume and phosphorus loads introduced from each tributary subwatershed in the Lake Cornelia and Lake Edina watersheds. P8 model inputs included:

- **Climate Data:** hourly precipitation and daily temperature.
    - Source: Minneapolis-St. Paul International Airport (MSP)
- **Watershed:** storm sewer network, tributary land areas (both pervious and impervious)
- **Best management practices:** ponds, including the water storage and solids and phosphorus settling functionalities

The P8 model was run for the Lake Cornelia and Lake Edina watersheds for water years 2015, 2016, and 2017.

Since no data has been collected regarding the inflow water quantity or quality for Lake Cornelia or Lake Edina on a subwatershed scale, detailed calibration of the P8 model was not feasible. The P8 model outputs, used as inputs for the in-lake models (described below) is thought to be best-suited for considering relative changes in loading under varying watershed conditions.

6.2 Water Balance Calibration

6.2.1 Precipitation and Runoff

The annual water and watershed phosphorus loadings to Lake Cornelia and Lake Edina under existing land use conditions were estimated for three different water years, each having distinctly different in-lake phosphorus concentrations, water clarity, and biota (e.g., type of phytoplankton, zooplankton, and aquatic plants). The precipitation totals during the three modeled water years are summarized in Table 6-1. Of the three modeled water years, 2016 had the greatest amount of precipitation for the entire water year and for the growing season (May 1 through September 30). Water year 2015 had the lowest amount of precipitation when looking at the entire water year. Water year 2015 was also a year with lower-than-average snowpack, which yielded less snowmelt runoff than typical years and resulted in significant reductions of water levels in upstream stormwater ponds and within the lakes. Water levels were so low on Lake Edina in spring 2015 that portions of the lake essentially became a mudded, open area (Figure 6-1). By mid-June the water levels in Lake Edina rebounded due to heavier precipitation events that occurred throughout May and June. Water year 2017 had the lowest amount of precipitation throughout the growing season of the 3 years analyzed in this study (approximately 3 inches less than 2015 and 5.4 inches less than 2016).

Annually and seasonally varying climatic conditions affect watershed runoff and subsequently lake volume and hydraulic residence time (lake volume divided by flow through the lake). In some cases where phosphorus in stormwater is greater than phosphorus in the receiving lake, a shorter hydraulic residence time is associated with higher in-lake phosphorus. Hence, loading and flushing (e.g., hydraulic residence time) can have an effect on annual and seasonal phosphorus concentrations in the lake.

Table 6-1 Precipitation amounts for 2015, 2016, and 2017

Model Year	Water Year (Oct 1 through Sept 30) Precipitation (inches)	Growing Season (May 1 through Sept 30) Precipitation (inches)
2015	30.2	22.9
2016	41.2	25.3
2017	35.2	19.9

Figure 6-1 Photo taken of Lake Edina low water levels in April 2015

6.2.2 Stormwater Volume Calibration (Water Balance)

The changes in water volumes of the lakes over time were calibrated by matching the modeled surface elevations of North and South Cornelia and Lake Edina to monitored data during the period of October 2014 through September 2017. To translate the water loadings into water surface elevations, a water balance model was utilized. The model uses estimated daily watershed runoff inflows (predicted by the P8 model), daily precipitation, daily evaporation, daily discharge (estimated with outlet rating curves), estimated groundwater inflow or outflow, and observed lake levels to estimate changes in the water levels of the lakes. The South Cornelia water balance model also included the daily discharge predicted by the North Cornelia water balance model. Similarly, the Lake Edina water balance model included the daily discharge predicted by the South Cornelia water balance model.

Figure 6-2 shows an example of the water balance calibration that was completed for North Cornelia for model year 2015. Appendix C displays the water balance calibrations for North and South Cornelia and Lake Edina for each modeled year. The predicted water levels, shown by the green line on the plots, were calibrated to match as closely as possible to the observed monthly water levels, indicated by the blue diamonds. Groundwater outflow (red line) was used to calibrate the modeled water surface elevations to the observed data. Groundwater outflow was used as a calibration parameter in the fall, winter, and early spring periods of the 2015 and 2016 North and South Cornelia water balance models. The water balance modeling for 2015, 2016, and 2017 included ground water interactions in Lake Edina. Previous studies have indicated that the water levels in Lake Edina are impacted by groundwater interactions with downstream Nine Mile Creek (Barr Engineering Co., 2015).

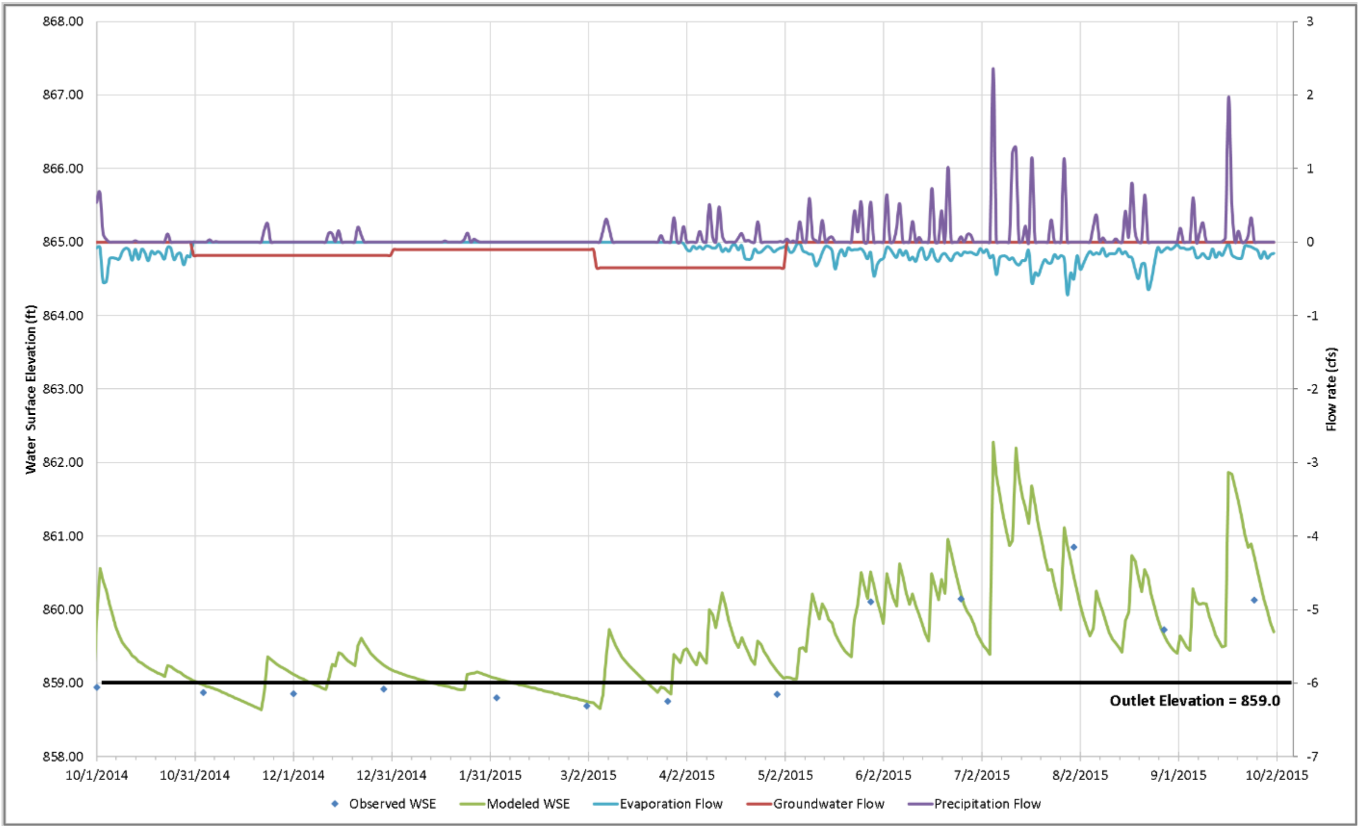


Figure 6-2 North Cornelia (2015) Water Balance

In 2017, continuous observed water level data was available for Lake Edina from May 28, 2017 through October 1, 2017. From this continuous dataset, average daily water levels were calculated in order to compare the monitored data to the predicted daily water levels from the in-lake model. The daily data developed from the continuous monitored dataset are represented by an orange line in the Lake Edina 2017 plot (Appendix C). As shown on the figure, the modeled water levels of Lake Edina in 2017 match fairly well with the continuous observed dataset. The timing of the peaks and the slopes of the water level declines correlate well.

Overall, the water balance calibrations for all three water bodies and for each modeled year correlate well with the observed monitored data. Table 6-2 provides a summary of the modeled surface runoff water loads that were simulated for North Cornelia, South Cornelia, and Lake Edina for each modeled year. The table also provides the modeled lake discharges. Comparing South Cornelia's direct watershed runoff load to the water volume discharging from North Cornelia into South Cornelia, one can see that a large portion of South Cornelia's water volume is determined by the outflow from North Cornelia. Similarly, comparing Lake Edina's direct watershed runoff load to the load entering from South Cornelia, one can see that the outflow from South Cornelia comprises a large portion of the Lake Edina water volume.

Table 6-2 Water Balance Summary of Watershed Runoff Inflows and Outlet Discharges

Water Body	Modeled Parameter	Model Year 2015 (acre-feet)	Model Year 2016 (acre-feet)	Model Year 2017 (acre-feet)
North Cornelia	Watershed Runoff	750	1,050	925
	Outlet Discharge	640	1,041	953
South Cornelia	Watershed Runoff	38	54	48
	Outlet Discharge	600	1,122	1,019
Lake Edina	Watershed Runoff	187	262	230
	Outlet Discharge	570	1,186	1,189

6.3 In-Lake Phosphorus Modeling

The focus of the in-lake phosphorus modeling effort was to assess phosphorus inputs and outputs and estimate the in-lake concentration changes of phosphorus in North and South Lake Cornelia and Lake Edina over time. Once the in-lake phosphorus dynamics under existing conditions are understood and quantified, the effectiveness of phosphorus reduction approaches can be evaluated using the model. From a very simplistic basis, the concentration of phosphorus in a lake is the mass of phosphorus in the lake divided by the lake volume. However, the mass of phosphorus in the lake and the volume of the lake are consistently changing over time. The water balance modeling allowed for tracking water volume changes of the lakes. An in-lake phosphorus mass balance model tracks the movement of phosphorus into and out of the lake over time.

There are several processes that dynamically increase or reduce the concentration of phosphorus in the lake water column, including (the "-" or "+" indicates that the mechanism either reduces or increases phosphorus):

- **Atmospheric Deposition (+):** Phosphorus deposits into the water body from the atmosphere
- **Settling (-)**: Phosphorus in phytoplankton and attached to particles settles out of the lake water column to the sediments.
- **Flushing (-)**: Phosphorus that leaves through a lake outlet.
- **Internal Sediment Loading (+)**: Phosphorus from lake bottom sediments may release into the water column during low oxygen conditions.
- **Copper sulfate treatment (- and +):** In the short term, phytoplankton die and begin to settle and the phosphorus in the phytoplankton cells also settles. However, the dead phytoplankton cells decay over time and release phosphorus. When the phytoplankton decay they can also consume oxygen which then leads to increased internal loading from the sediment.
- **Benthivorous fish (+):** Although not modeled as a separate internal load, benthivorous fish are presumed to cause additional internal phosphorus loading during certain modeling periods due to stirring of the bottom sediments
- **Curly-leaf pondweed die-off and decay (+)**: Phosphorus in the plant tissue is released into the water column when curly-leaf pondweed dies and decays.

The model integrates these phosphorus loads and losses as part of a daily time-step used in a finite difference approach. Each of these processes occur during different periods and hence they are quantified (e.g., calibrated) by matching the in-lake phosphorus concentration with the field-measured phosphorus concentration. Additional detail is provided below for several of these processes.

6.3.1 Atmospheric Deposition

An atmospheric wet and dry deposition rate of 0.42 kg/ha/year was applied to the surface area of the lake to determine annual phosphorus loading. An annual total phosphorus load from atmospheric deposition of approximately 4-5 pounds was estimated for North Cornelia for each modeling year. For South Cornelia, the annual total phosphorus load from atmospheric deposition was approximately 6 pounds. The estimated annual total phosphorus load from atmospheric deposition in Lake Edina was approximately 4-5 pounds.

6.3.2 Settling and Copper Sulfate

Phosphorus attached to particles or incorporated into phytoplankton were given a constant settling rate expressed in meters per day. For periods when documented application of copper sulfate occurred, this settling rate was increased to account for a period of enhanced phytoplankton death and settling. Following the copper sulfate settling period, the settling rate was returned to the constant settling rate used under "normal" conditions. For both Lake Cornelia and Lake Edina, the settling rate was used to assist with model calibration (e.g., match the model-predicted and observed phosphorus concentrations).

6.3.3 Internal Sediment Loading and Benthivorous Fish

In shallow lakes it is challenging to identify the extent of internal loading by just evaluating the in-lake monitoring data. Internal phosphorus loading from the sediments can occur when oxygen is depleted during microbial decomposition. When oxygen is depleted and can no longer be used by microbes as an electron acceptor, microbes will start to use other compounds as electron acceptors. Specific species of microbes can use iron in the sediments as electron acceptors and in doing so, will release the phosphate bound to the iron. This process is complex and is affected by numerous factors including the species of microbes (over space and time), lake stratification, water temperature, sediment composition, and the amount and type of organic matter, just to name a few. It is difficult to measure all of the factors that are involved in internal phosphorus release from the sediments. Therefore, the available monitored data, along with model equations were used to estimate the internal loading potentials of the lakes in this UAA process.

. Internal phosphorus release for Lake Cornelia was estimated based upon the maximum potential phosphorus release rate computed from lake sediment cores. The rate of phosphorus release was then modified depending upon the oxygen concentration in the water column. This was accomplished by using a Michaelis-Menten equation to modify the phosphorus release rate, V_0, (i.e., the internal loading rate) in accordance with the oxygen concentration in the lake water column. The equation is as follows:

$$V_0 = V_{max} \frac{1 - [D0]}{K_M + [DO]}$$

where V_{max} is the maximum potential phosphorus release rate, [DO] is the measured concentration of dissolved oxygen, and K_M is the Michaelis-Menten constant. K_M indicates the dissolved oxygen concentration when the total phosphorus release rate is equal to one half the maximum potential phosphorus release rate. V_{max} was estimated for each lake based on sediment core data. For the majority of the modeled periods, measured DO concentrations were used in the Michealis-Menten equation; however, for certain periods (mostly during late-summer and early-fall), adjustments were made to the DO concentrations to calibrate the model to observed in-lake phosphorus concentrations. DO concentrations were measured in the lakes on approximately a monthly basis and all measurements occurred during the day. Since microbial activity and phytoplankton respiration, which influence the rate of oxygen consumption and production, can change dramatically over time and space, monthly measurements in one location in the lake can only provide a glimpse into a lake's internal loading potential. Continuous monitoring of DO concentrations in multiple locations of a lake would be needed to better quantify the internal loading potential. However, the costs and logistics of completing this effort may be significant.

Section 5.2 discusses the internal loading potential of North and South Cornelia and Lake Edina based on sediment core analyses. As mentioned previously, of the three lakes, North Cornelia has the greatest internal loading potential with a maximum internal loading rate equal to 7.6 mg of phosphorus per meter-squared per day. South Cornelia was found to have a maximum internal phosphorus loading rate equal to 1.5 mg $P/m^2/d$. The concentration of mobile phosphorus in Lake Edina sediment was at background levels and based upon an equation developed by Pilgrim et. al. (2007), it is expected that the internal release rate is near zero.

The effect of benthivorous fish was not explicitly included in the models, however, it was implicitly included in the internal loading rate, as well as the settling rate. More benthic disturbance equates to a reduced overall settling rate and enhanced internal sediment loading through an increased maximum potential phosphorus release rate (V_{max}). The effect of benthivorous fish was included in the in-lake modeling process for South Cornelia for water years 2016 and 2017 by modifying the maximum internal loading rate during specific periods in the model to calibrate to observed in-lake total phosphorus concentrations. This is discussed further in Section 6.3.5.

6.3.4 Curlyleaf Pondweed Die Off and Decay (Lake Cornelia Only)

The concentration of phosphorus in curly-leaf pondweed is on average 4.3 grams per kilogram of dry plant material (measured based on samples from Kohlman Lake in Maplewood, Minnesota). When curly-leaf dies and decomposes, phosphorus is released from the plant tissue, adding phosphorus to the water column over time. Curly-leaf pondweed typically begins to die-off in June. Like most biological populations, die-off of the entire curly-leaf pondweed population does not happen all at once but rather occurs over time. Model calibration using curly-leaf pondweed die-off and decay was necessary to match observed and modeled data in the summer. The mortality rate was estimated to be 10 to 15 percent of the population per day. As the remaining population gets smaller, so too does the mass of plant tissue that dies until there is only a very small population remaining. A total of 10 to 15 percent of the dead pondweed population was assumed to decompose each day. This approach was used to calibrate the

North Cornelia in-lake models for 2015 and 2017 and for South Cornelia in-lake models for 2015, 2016, and 2017.

6.3.5 In-Lake Water Quality (Phosphorus) Model Calibration

Calibration is a process in which model parameters and coefficients are reasonably adjusted such that the model predictions are similar to in-lake measurements. Results of the in-lake phosphorus model calibrations for North Cornelia are provided in Figure 6-3, Figure 6-4, and Figure 6-5 for modeled years 2015, 2016, and 2017, respectively. The results of the model calibrations for South Cornelia are presented in Figure 6-6, Figure 6-7, and Figure 6-8 for 2015, 2016, and 2017, respectively. Lake Edina was calibrated for the 2 years with available monitoring data (2015 and 2017) and the results of those model calibrations are presented in Figure 6-9 and Figure 6-11, respectively.

An in-lake model was also developed for Lake Edina for 2016 after completion of the two calibration models. The Lake Edina calibration models showed that approximately 99% of the in-lake phosphorus concentrations are influenced from upstream discharges from Lake Cornelia, direct watershed runoff contributions, and atmospheric deposition. Less than 1% of the in-lake phosphorus contributions were due to internal loading. Since the North and South Cornelia models were calibrated for 2016 and there was enough data to model Lake Edina watershed runoff in 2016, an in-lake model was also developed to represent Lake Edina existing in-lake conditions for 2016. Those results are presented in Figure 6-10.

For all plots, the blue line represents the modeled in-lake phosphorus concentrations of the water bodies. The pink squares represent the monitored phosphorus concentrations. On the secondary axes, the relative phosphorus loads from the watershed, internal sediment load, and curly-leaf pond weed death/decay are shown.

Calibration was challenging for North and South Cornelia with several highly-variable and sometimes human-induced loadings or losses such as variable internal sediment loading and curly-leaf die-off and decay (where start times of decay were influenced by herbicide treatments depending on the modeled year), copper sulfate treatments, and benthivorous fish feeding influences. However, calibration was conducted using measured data (e.g., phosphorus concentration in sediments, in-lake water column phosphorus concentrations, in-lake dissolved oxygen, and temperature) and consistent modeling approaches and coefficients throughout the modeling period and between the different model years.

An important calibration parameter to note is that curly-leaf pondweed loading was not included for North Cornelia for 2016. While macrophyte surveys did show curly-leaf pond weed growth in North Cornelia in 2016, observed in-lake phosphorus concentrations did not indicate a lake response to curly-leaf death and decay, as was evident in other modeled years. One explanation is that there were a few large storm events in 2016 at the typical time for curly-leaf pondweed die-off. Larger flows could have carried some of the curly-leaf pondweed plants downstream to South Cornelia. However, the exact cause for the missing in-lake response to curly-leaf pondweed die-off and decay for 2016 in North Cornelia is unknown.

Furthermore, it is important to note that a calibration parameter was introduced for South Cornelia for modeling years 2016 and 2017 that was not introduced for the other lakes or modeling periods. From mid-August through the end of September, a bioturbation factor was included for South Cornelia. The monitored phosphorus concentrations of South Cornelia during these periods showed high phosphorus loadings which could not be explained by internal loading from lake sediment, curly-leaf pondweed-, or external loading. As mentioned previously, the effect of benthivorous fish was not explicitly included in the model, however, it was implicitly included in the internal loading rate. More benthic disturbance equates to enhanced internal sediment loading through an increased maximum potential phosphorus release rate (V_{max}). During discussions with Dr. Prezemyslaw Bajer from the Department of Fisheries, Wildlife, and Conservation Biology at University of Minnesota, it was discovered that enhanced internal loading from benthivorous fish disturbances in August and September have been noted in other water bodies. Bajer's experience with carp baiting experiments suggest that carp forage quite actively in August through September when [the male fish] re-grow their reproductive organs for the next year. Additionally, Bajer mentioned that there is evidence in literature that carp's digging in the bottom sediments can increase during periods when the availability of benthic invertebrates decreases; however, the exact seasonal cycles of benthic invertebrate availability is unknown for South Cornelia. Furthermore, Bajer noted that some carp migrate out of lakes from May through June and migrate back in late summer. The migration patterns of carp and other fish species in Lake Cornelia are unclear. As mentioned in Section 5.3.1, fish surveys of North and South Cornelia and upstream detention ponds were taken in summer 2018. While the fish surveys provided a summary of the fish species located within the monitored areas, the surveys did not address fish migration patterns and how migration patterns can effect lake water quality over time. To manage the Lake Cornelia fisheries, it will be important to better understand the movement of the fish between the upstream ponds and North and South Cornelia.

The in-lake model calibration for Lake Edina was less complicated compared to Lake Cornelia. The major phosphorus inputs included discharge from Lake Cornelia, runoff from the direct Lake Edina watershed, and atmospheric deposition. The primary calibration parameter was the rate of phosphorus settling. The settling rate for 2015 and 2017 (the two calibration years) was the same for both Lake Edina calibration models except for periods when algal copper sulfate treatments were applied to the lake and a notable change in settling rate was apparent from the observed in-lake phosphorus concentrations. Two copper sulfate treatments were applied in 2015 (July and August) and two copper sulfate treatments were applied in 2017 (July and August). Modeled settling rates were increased around these periods such that the model-predicted and in-lake measured phosphorus concentrations matched. While no observed in-lake phosphorus concentrations were available for 2016, the in-lake model included a period of increased settling during the known period of algal copper sulfate treatments from the treatment record. The copper sulfate treatment settling rate used for 2016 was an average of the 2015 and 2017 modeled copper sulfate settling rates.

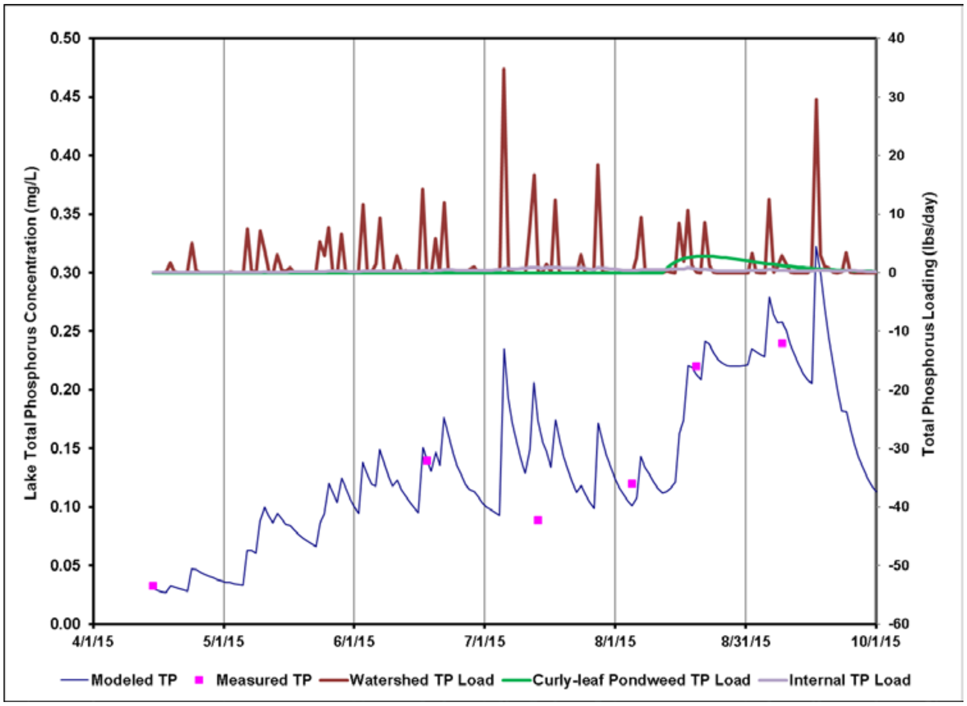


Figure 6-3 North Cornelia In-Lake Calibration Model for 2015

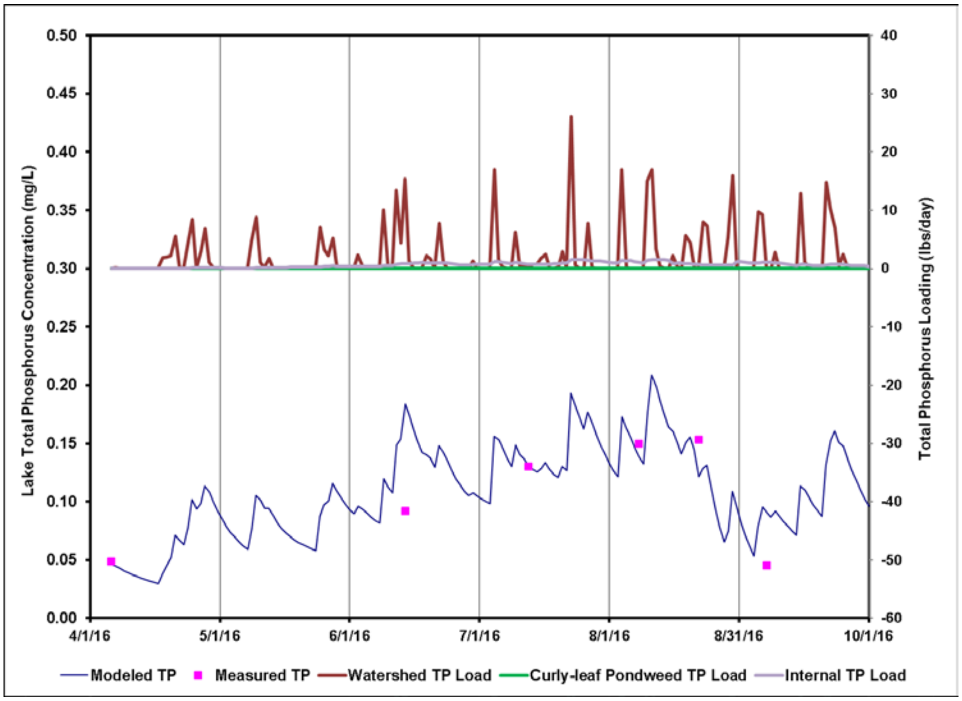


Figure 6-4 North Cornelia In-Lake Calibration Model for 2016

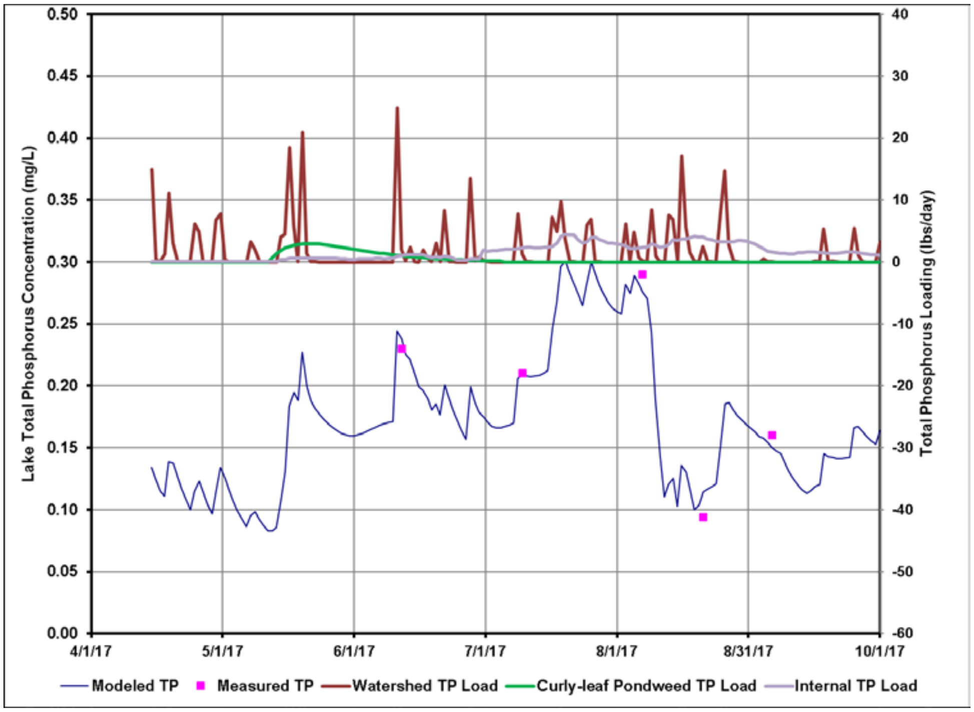


Figure 6-5 North Cornelia In-Lake Calibration Model for 2017

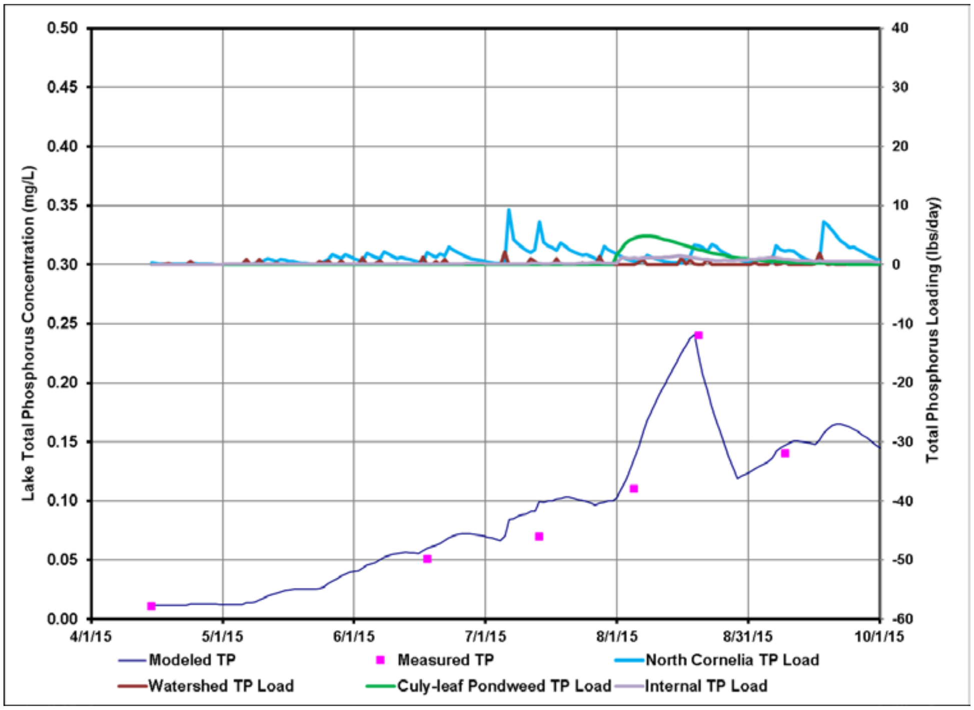


Figure 6-6 South Cornelia In-Lake Calibration Model for 2015

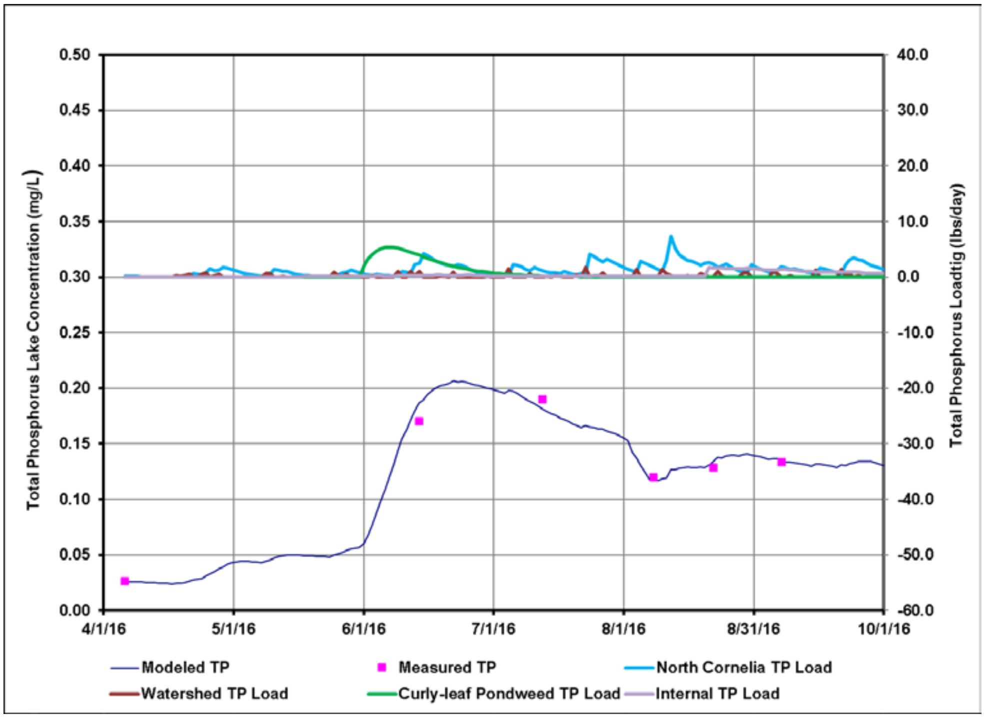


Figure 6-7 South Cornelia In-Lake Calibration Model 2016

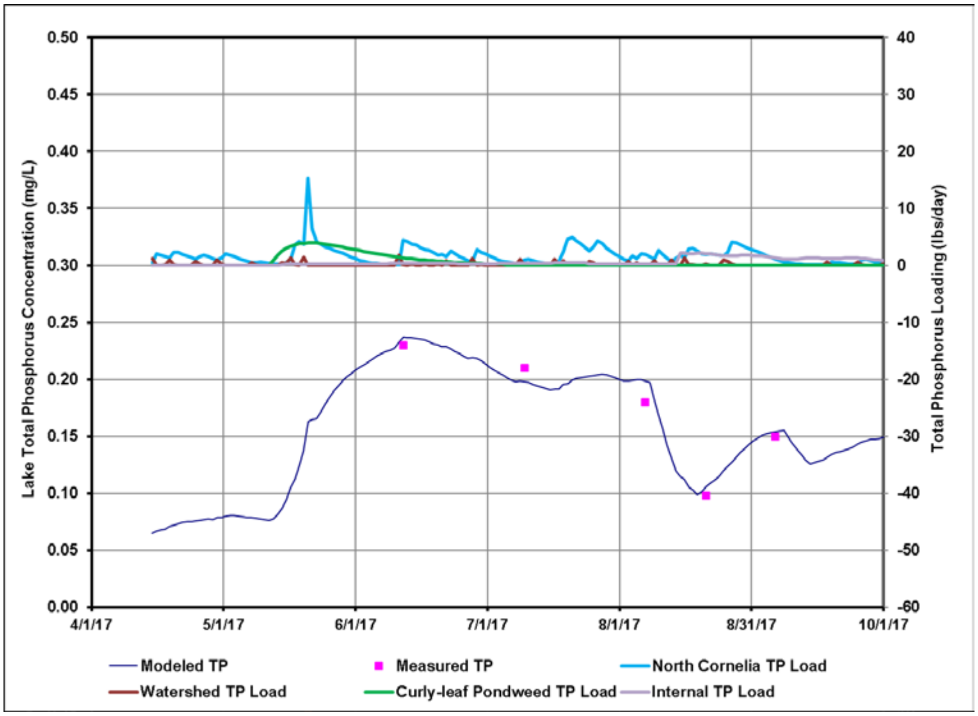


Figure 6-8 South Cornelia In-Lake Calibration Model 2017

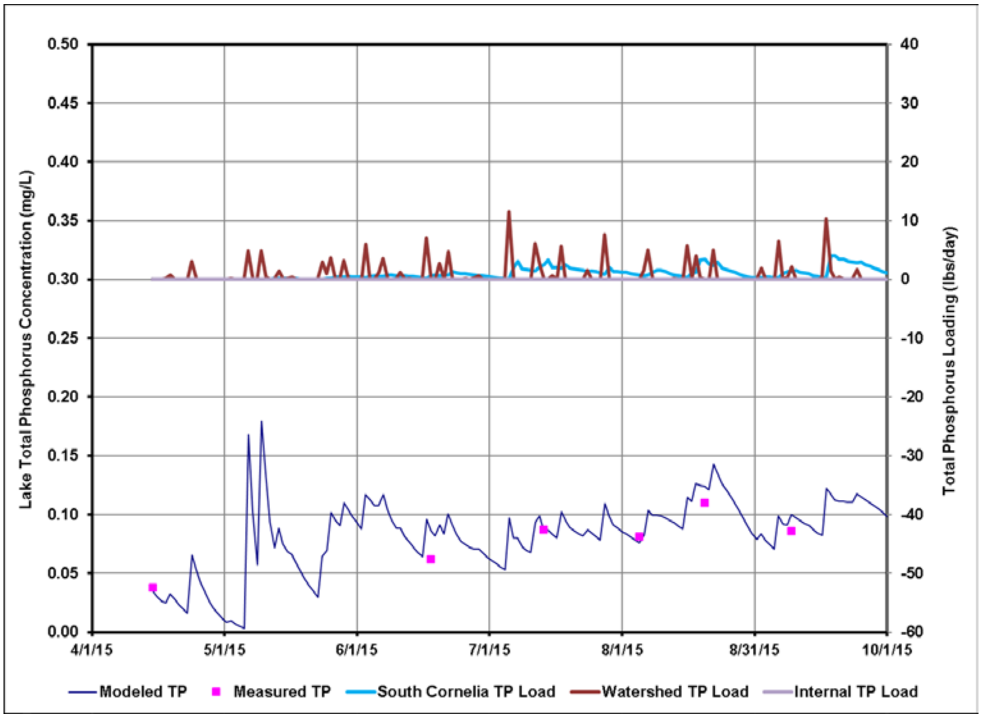


Figure 6-9 Lake Edina In-Lake Calibration Model 2015

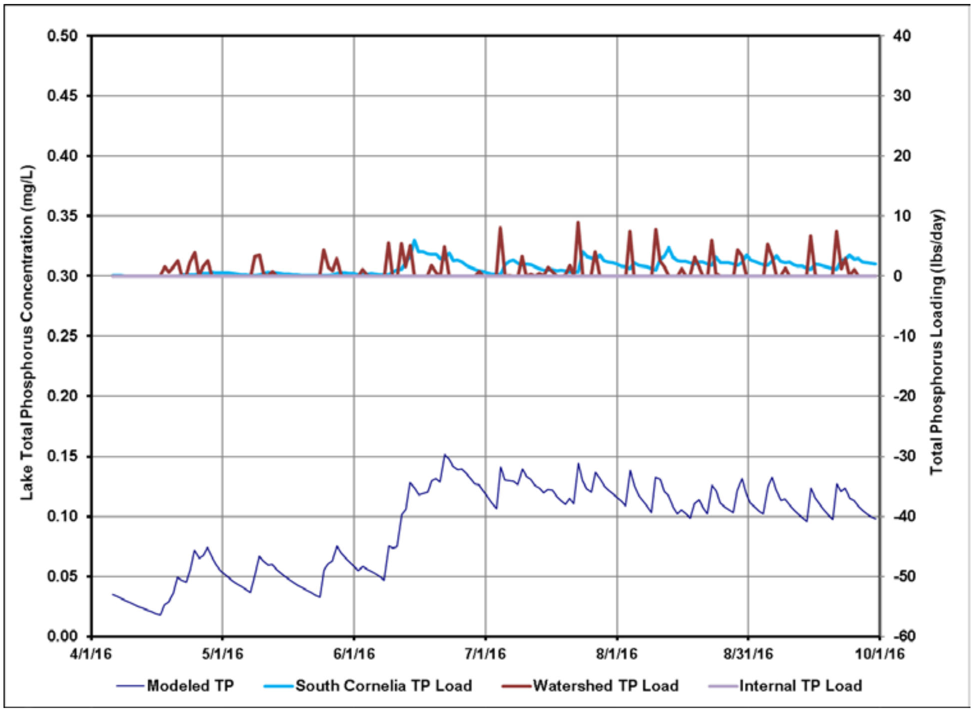


Figure 6-10 Lake Edina In-Lake Model 2016

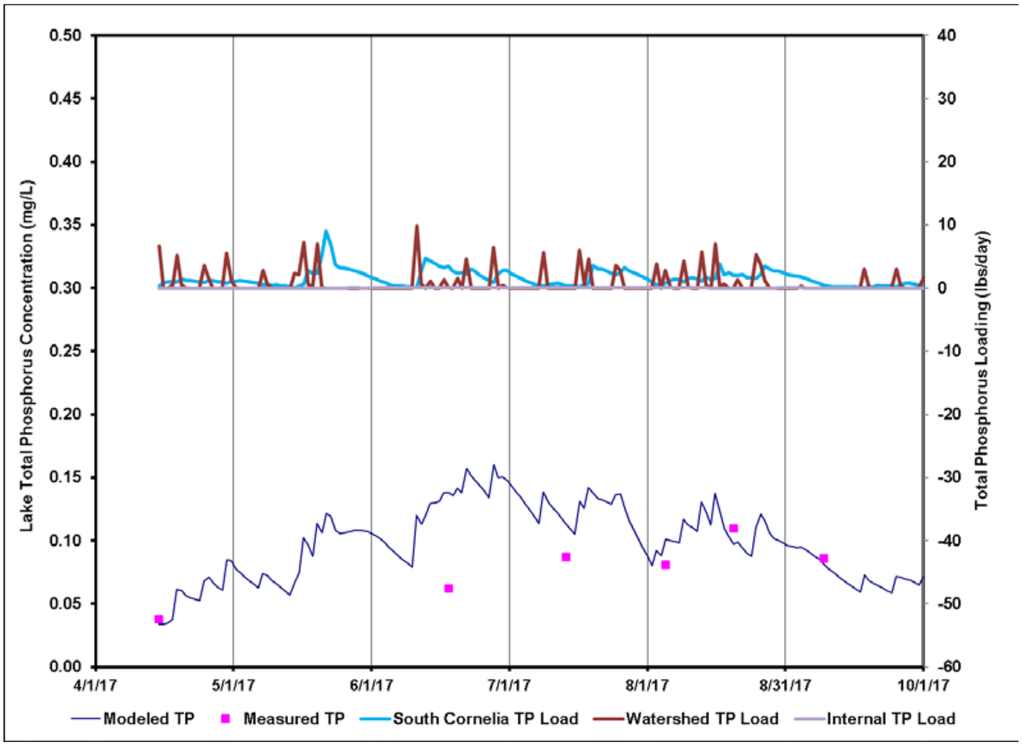


Figure 6-11 Lake Edina In-Lake Calibration Model 2017

6.3.6 In-Lake Water Quality (Phosphorus) Model Calibration Loading Summaries

After the in-lake water quality model calibrations were finalized for each calibration year, loading summaries were developed. Pie-charts were developed to show the relative loading contributions for each lake and for each modeled year. While each lake has some variability in the phosphorus loading contributions from year to year, general trends can be noted for the lakes.

Figure 6-12 shows the phosphorus loading summaries for North Cornelia. External watershed loading is a major contributor of phosphorus to North Cornelia (48% to 76%). In 2017, a lower proportion of the phosphorus loading came from watershed contributions, which can largely be explained by the reduced precipitation that fell during the growing season (May 1 through September 30). In 2017, an estimated precipitation depth of 19.9" fell during the growing season. Comparatively, approximately 22.9" and 25.3" of precipitation fell during the 2015 and 2016 growing seasons, respectively. Internal sediment loading and curly-leaf pondweed die-off/decay are also major contributors of phosphorus to North Cornelia. As mentioned previously, the exact reason for the absence of an in-lake response to curly-leaf pond weed in 2016 is unknown. However, having variations in relative loads will provide a conservative estimate of management success on lake water quality changes. Water bodies are dynamic over space and time, so having a range of management outcomes will provide a more realistic outlook on probable lake responses.

Figure 6-13 shows the phosphorus loading summaries for South Cornelia. All three calibration model years show similar results, with the main contribution of phosphorus to South Cornelia from North Cornelia (54% to 56% of the total phosphorus load). The second major contribution of phosphorus to South Cornelia is due to the die-off and decay of curly-leaf pondweed (19% to 23%) and the third is sediment internal loading (14% to 19%). As noted in Section 6.3.3, the internal sediment loading was enhanced in 2016 and 2017 due to bioturbation of the sediments from biota activity. The inclusion of bioturbation in the 2016 and 2017 in-lake models resulted in increased proportions of internal loading compared to what was observed in 2015. For South Cornelia, direct watershed loading still plays a role in phosphorus additions to South Cornelia, but to a much smaller extent than the other parameters. The direct watershed to South Cornelia (omitting open water areas) is approximately 13% the size of the direct watershed to North Cornelia.

Figure 6-14 shows the phosphorus loading summaries for Lake Edina. The two main sources of the phosphorus loading to Lake Edina are the upstream lakes (North and South Cornelia) and the direct watershed runoff. Internal phosphorus loading from sediments is minimal in Lake Edina. Therefore, any management efforts focused on North and South Cornelia (whether internal or external) will have an impact on the water quality of Lake Edina.

The loading summaries developed from the calibrated in-lake models provided direction for proposed management efforts. Section 7.0 describes the management efforts modeled for each lake and Section 8.0 describes the projected in-lake responses.

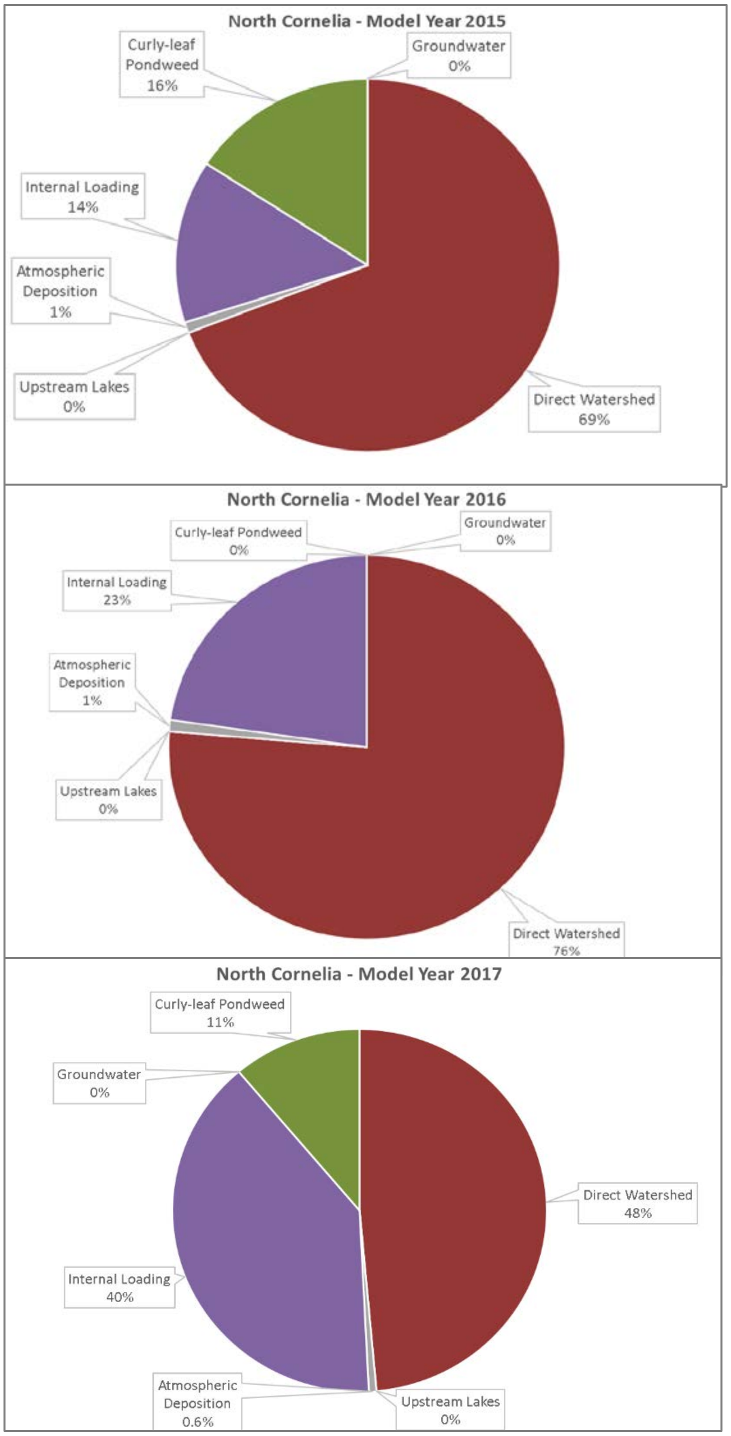


Figure 6-12 North Cornelia In-Lake Calibration Models' Loading Summaries

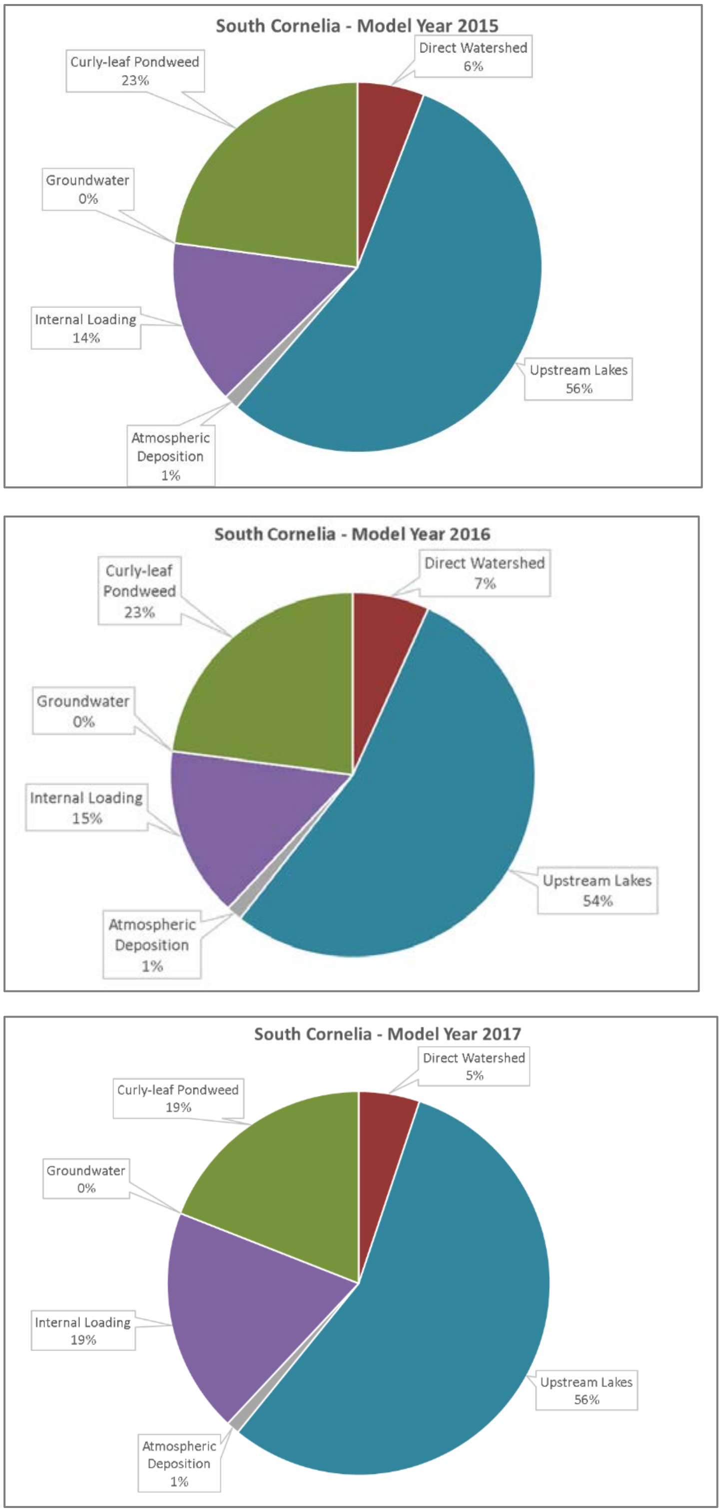


Figure 6-13 South Cornelia In-Lake Calibration Models' Loading Summaries

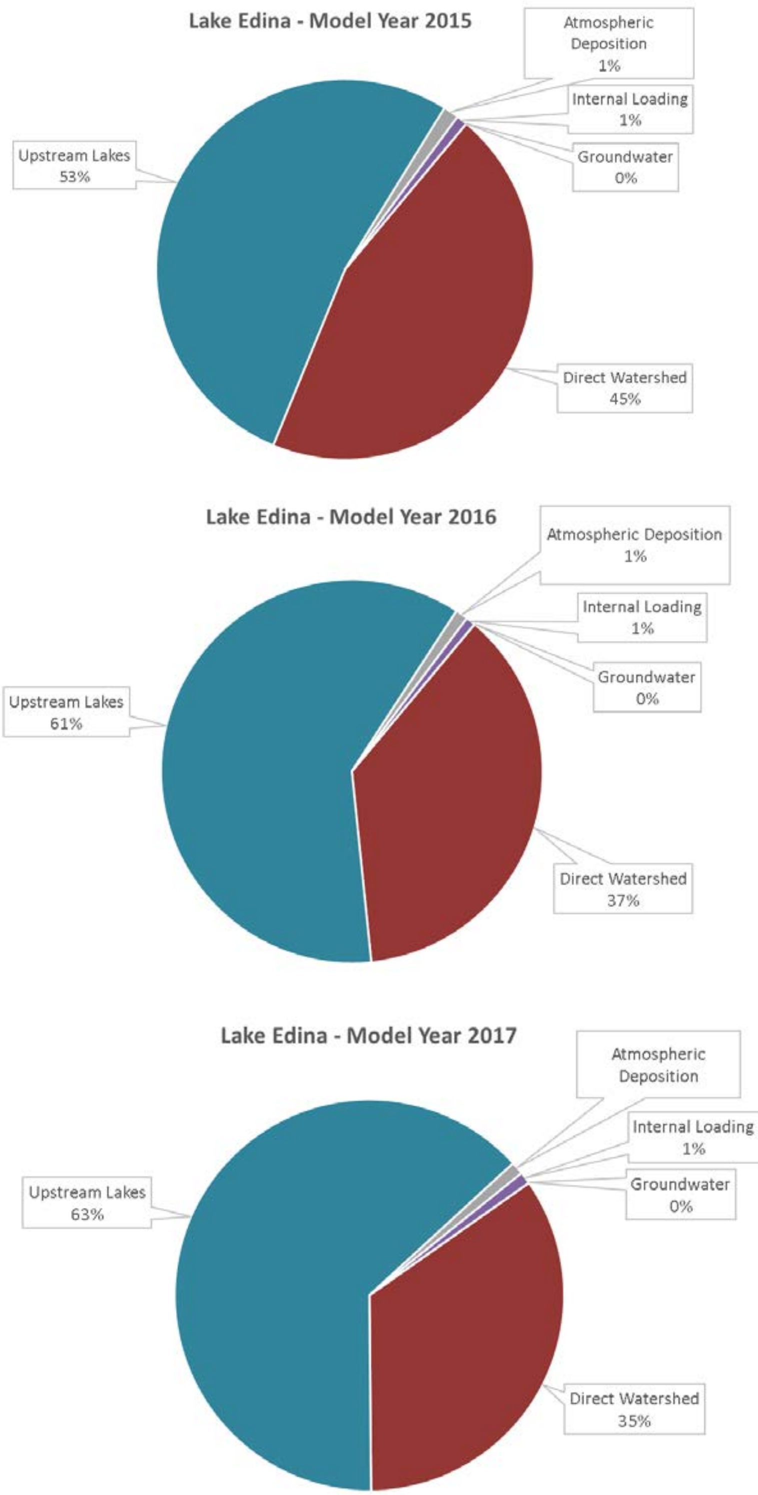


Figure 6-14 Lake Edina In-Lake Calibration Models' Loading Summaries

6.4 Modeling Chlorophyll *a* and Secchi Disc Transparency

The P8 model used for the analysis predicts watershed phosphorus loads to North and South Cornelia and Lake Edina, and the in-lake model is used to determine water quality in the lake itself. However, the in-lake model only estimates phosphorus concentrations. To estimate the likely chlorophyll *a* concentrations and Secchi disc transparencies lake-specific regression relationships were developed.

Eleven years of water quality data were available to develop relationships between total phosphorus concentration (TP), chlorophyll *a* concentration (Chl *a*), and Secchi disc transparency (SD) for North Cornelia. Figure 6-15 depicts the numerical water quality models used to estimate the relationships. For North Cornelia, the equations are:

$$[Chl - a] = 0.4003\,[TP] - 6.3171 \qquad R^2 = 0.4348$$
$$[SD] = 8.6531[TP]^{-0.614} \qquad R^2 = 0.4154$$

where the chlorophyll *a* and total phosphorus concentrations are in µg/L and Secchi disc depth is in meters.

Six years of water quality data were available to develop relationships between total phosphorus concentration (TP), chlorophyll *a* concentration (Chl *a*), and Secchi disc transparency (SD) for South Cornelia. Figure 6-16 depicts the numerical water quality models used to estimate the relationships. For South Cornelia, the equations are:

$$[Chl - a] = 0.3589\,[TP] + 7.8432 \qquad R^2 = 0.3503$$
$$[SD] = 4.5722[TP]^{-0.55} \qquad R^2 = 0.5043$$

where the chlorophyll *a* and total phosphorus concentrations are in µg/L and Secchi disc depth is in meters.

Six years of water quality data were available to develop relationships between total phosphorus concentration (TP), chlorophyll *a* concentration (Chl *a*), and Secchi disc transparency (SD) for Lake Edina. Figure 6-17 depicts the numerical water quality models used to estimate the relationships. For Lake Edina, the equations are:

$$[Chl - a] = 0.3605\,[TP] - 0.2411 \qquad R^2 = 0.3323$$
$$[SD] = 25.552[TP]^{-0.899} \qquad R^2 = 0.5841$$

where the chlorophyll *a* and total phosphorus concentrations are in µg/L and Secchi disc depth is in meters.

These equations were subsequently used to give indications of what may be expected with respect to Chl a and transparency, given the P8/in-lake model results for TP. It should be noted that the response of Chl a and Secchi depth to TP is highly variable. Due to the high variability, the regression equations can be expected only to allow a general indication of the lake response to changing TP concentrations, and the predicted Chl a and Secchi depth values should not be construed as absolute.

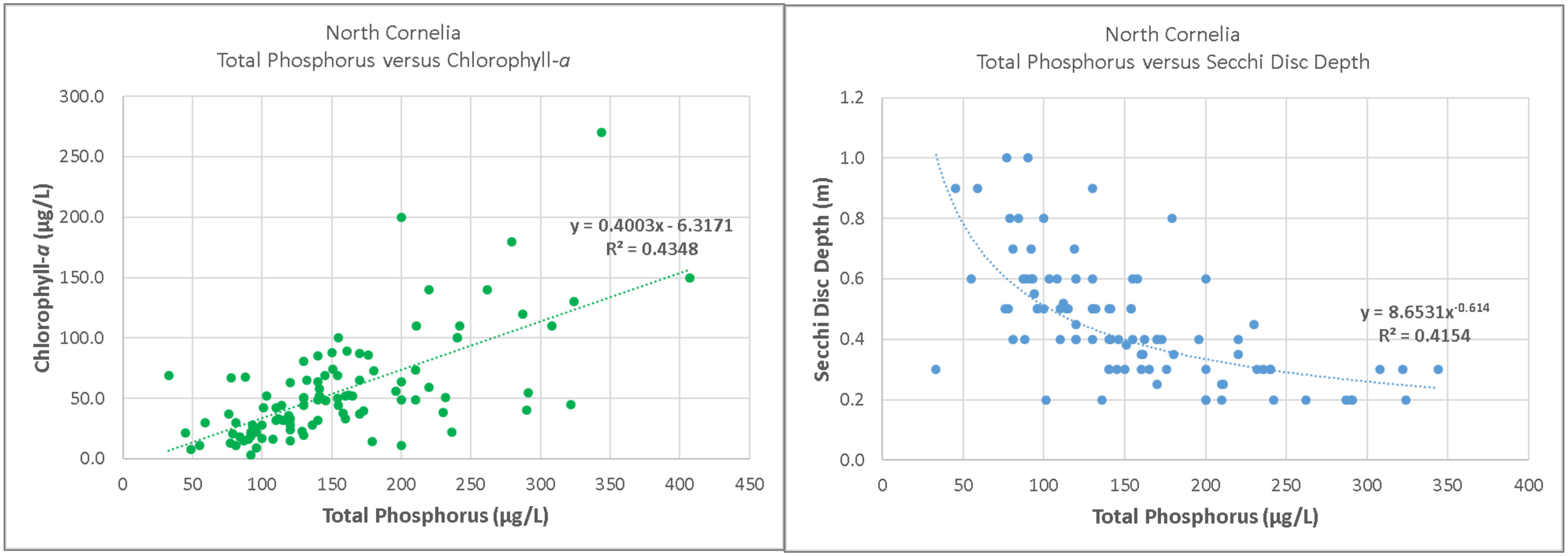


Figure 6-15 North Cornelia relationships between total phosphorus, chlorophyll *a*, and Secchi Disc Transparency

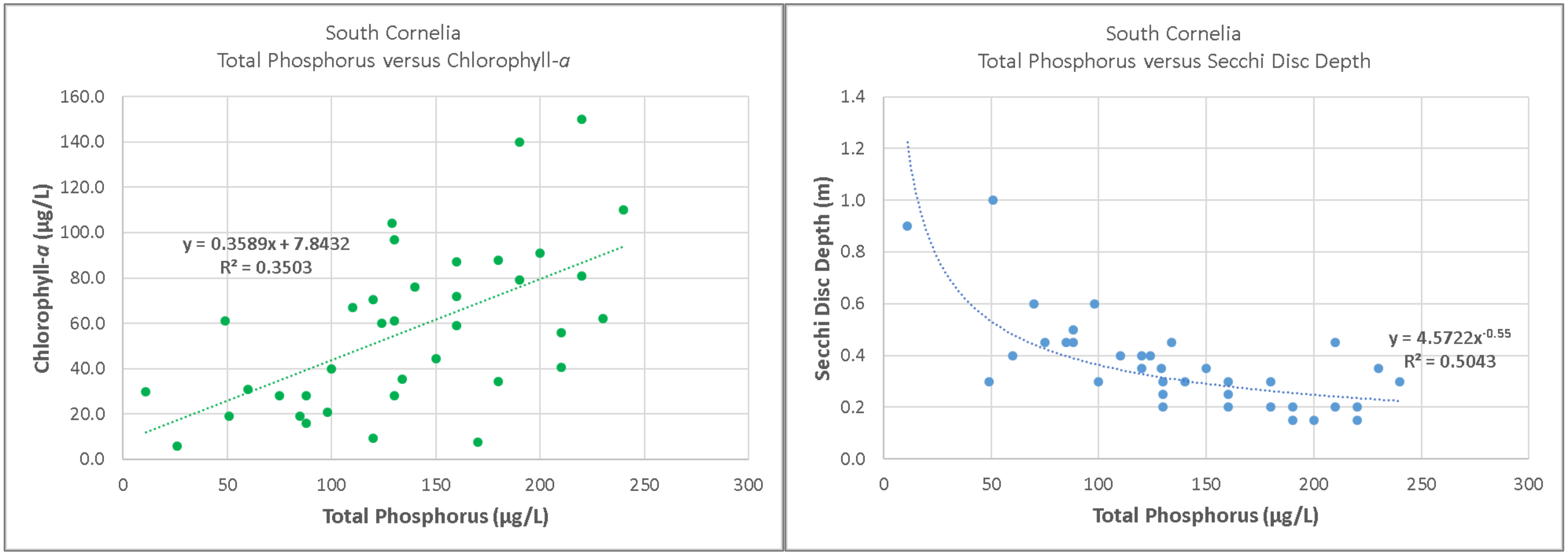


Figure 6-16 South Cornelia relationships between total phosphorus, chlorophyll *a*, and Secchi Disc Transparency

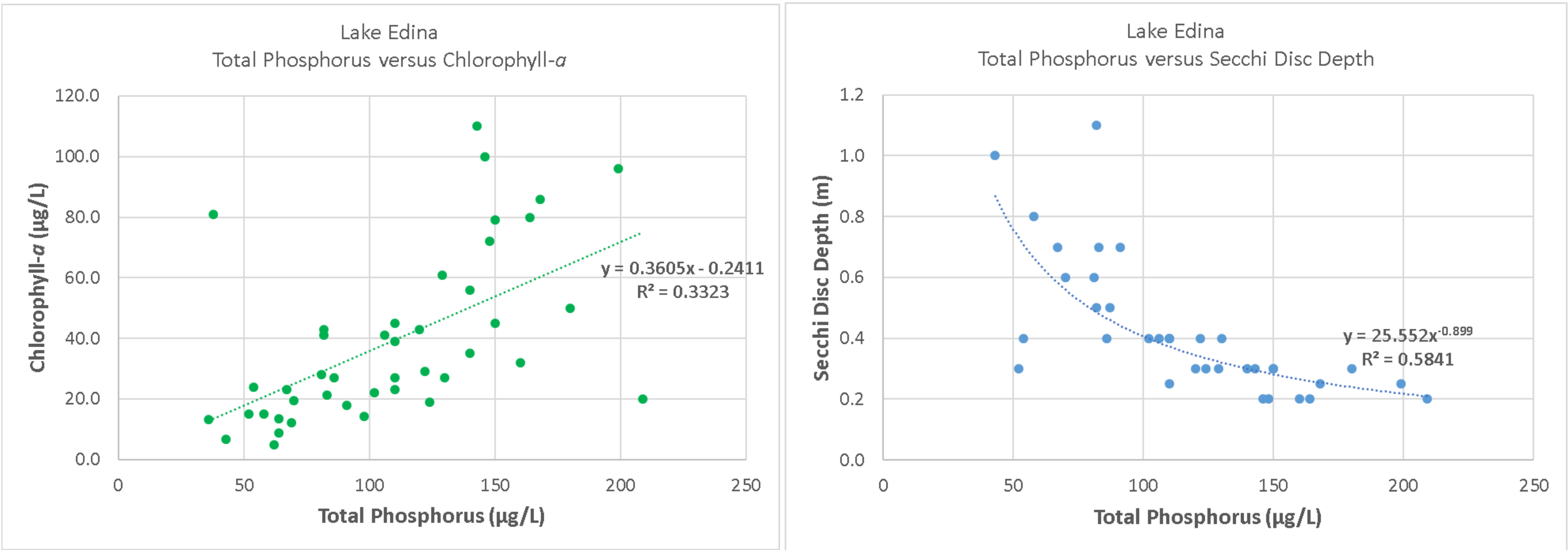


Figure 6-17 Lake Edina relationships between total phosphorus, chlorophyll *a*, and Secchi Disc Transparency

7.0 Evaluation of Management Strategies

Numerous in-lake and watershed management strategies were considered to evaluate the potential improvements in lake water quality and assess the extent to which lake water quality goals will be met (or progress made) through implementation of the management strategies. Watershed management strategies are designed to reduce external phosphorus loading to the lakes, whereas in-lake strategies are designed to reduce internal phosphorus loads and/or improve the health of the aquatic communities. The P8 watershed models and calibrated in-lake models were used to predict the effectiveness of the individual in-lake and watershed management strategies, and combinations thereof, in reducing phosphorus concentrations in Lake Cornelia and Lake Edina, and in turn, improving water quality. Although not quantified through modeling, the progress toward the goals of a healthy native plant population and fishery resulting from the evaluated in-lake and watershed management strategies was also considered.

Based on the observed and modeled water quality of North and South Lake Cornelia and information on the health of the aquatic communities, the following management strategies were considered:

- External load reductions (e.g., infiltration/filtration BMPs through retrofit or redevelopment, enhancement of existing BMPs, street sweeping, community efforts (leaf removal, reduced fertilizers, shoreline restoration))
- Curly-leaf pondweed treatments
- Alum treatment for lake sediments
- Winter aeration using direct oxygen injection
- Carp and goldfish tracking and benthivorous fish management

Based on the observed and modeled water quality of Lake Edina and information on the health of the aquatic communities, the following management strategies were considered:

- External load reductions (e.g., infiltration/filtration BMPs through retrofit or redevelopment, enhancement of existing BMPs, street sweeping, community efforts (leaf removal, reduced fertilizers, shoreline restoration))
- Management efforts in upstream lakes (North and South Cornelia)

A description of the evaluated watershed and in-lake management strategies is provided below. A summary of the predicted effectiveness of the strategies, and combinations thereof, in improving lake water quality is included in Section 8.0.

7.1 Watershed Management Strategies/Scenarios

A range of watershed management scenarios were considered to reduce external phosphorus loading to Lake Cornelia and Lake Edina, and in turn, improve water quality. The watershed (external) management scenarios evaluated were selected with the following targets in mind:

- **Maximize benefits to chain of lakes.** Runoff from the North Cornelia watershed flows through South Cornelia and Lake Edina prior to discharging to Nine Mile Creek. Because the North Cornelia watershed is the largest and most densely developed, runoff from this area also has the greatest impact on water quality throughout the chain of lakes. To maximize the water quality improvement benefits throughout the chain of lakes, several management scenarios were focused on the Lake Cornelia watershed.

- **Increase dissolved phosphorus removal.** Runoff from most of the commercial, high-impervious area tributary to Lake Cornelia is already conveyed through a series of ponds, such that much of the particulate phosphorus (phosphorus attached to sediment particles) in the runoff from this area has already settled out before reaching Lake Cornelia. Given the existing treatment, there was a desire to target dissolved phosphorus that is not typically removed by ponds.

- **Improve or "build on" effectiveness of existing treatment systems.** As mentioned above, runoff from much of the area tributary to Lake Cornelia already receives treatment from existing ponds or other BMPs. Opportunities to modify or add on to the existing management systems to improve effectiveness and/or expand the treatment spectrum were desired.

- **Include mix of structural and non-structural BMPs.** An optimal stormwater management program includes a mix of structure and non-structural BMPs. Structural BMPs remove a fraction of the pollutants and sediment loads contained in stormwater runoff prior to discharge into downstream water bodies, whereas, non-structural BMPs eliminate pollutants and sediment loads at the source and prevent them from entering stormwater flows. Examples of structural BMPs include ponds, bioretention/infiltration basins, filtration systems, or vegetated filter strips/buffers. Examples of non-structural BMPs include street sweeping, programmatic controls (i.e., rules/ordinances), reducing impervious surface, and other better-site-design techniques.

- **Provide reliable pollutant removal performance.** The watershed management scenarios should be designed to provide consistent and reliable pollutant removal throughout the growing season and over the long-term.

- **Be reasonably cost effective.**

- **Land availability.**

Based on these selection criteria, the following four external management scenarios were modeled:

1. Infiltration BMPs on commercial property
2. Filtration BMPs on commercial property
3. A spent lime/ CC17 treatment chamber as treatment train for flows from existing Swimming Pool Pond
4. Weekly street sweeping of all public city roads and all private commercial lots.

These targeted BMP scenarios are described in further detail below.

Based on results of the previous studies for these lakes, it was understood that substantial reductions in watershed phosphorus loading will likely be necessary to see significant improvements in lake water quality. As such, the watershed management scenarios that were evaluated encompass fairly large-scale efforts. Actual implementation of these watershed management scenarios could be scaled back or implemented over a long timeframe.

7.1.1 Infiltration BMPs on Commercial Properties

Infiltration BMPs were selected as a scenario for external management due to their numerous benefits. Infiltration BMPs, such as bioretention (rainwater gardens), infiltration basins, or underground infiltration systems, are effective in significantly reducing pollutant loading from developed sites. Stormwater runoff is captured and infiltrated, reducing the amount of stormwater volume and pollutants leaving the site, including both particulate and dissolved phosphorus. Infiltration basins remove solids and particulate nutrients (such as phosphorus) through settling and can reduce dissolved nutrient concentrations through adsorption, filtration, ion exchange, and decomposition as the water moves through the soil and infiltrates into the groundwater. Not only do infiltration-based BMPs reduce the amount of stormwater volume and pollutants leaving a site, they also can reduce downstream flooding by holding back water, assist with groundwater recharge and reduce peak runoff rates.

Under existing conditions, there are several redevelopment sites within the North Cornelia watershed that have implemented infiltration-based BMPs on their sites, including portions of the Southdale Shopping Center. These BMPs were installed in conformance with the NMCWD stormwater rule to achieve the onsite retention requirement (currently 1.1 inches of runoff from impervious surfaces), as well as sediment and phosphorus removal and peak flow reduction from the sites.

For this external management scenario, it was assumed that all commercial properties within the Lake Cornelia and Lake Edina watersheds that have soils conducive to infiltration would implement infiltration-based BMPs to capture and retain 1.1 inches of runoff from the impervious surface areas of the parcels. Approximately 194 acres of commercial parcel area was treated under this scenario (~99% of commercial parcel area) and the infiltration BMPs were sized to treat 147.5 acres of impervious surfaces. This scenario represents a condition where all commercial parcels are redeveloped in conformance with NMCWD's current stormwater rule. While this scenario represents extensive changes in the watershed that would likely occur over a long period of time, it was evaluated as a benchmark or "stretch goal" for external management efforts.

This scenario aligns well with the following target criteria:

- **Maximize benefits to chain of lakes.** Most of the commercial land area is within the North Cornelia watershed, so all three lakes within the chain would benefit from the reduction in phosphorus loading.

- **Increase dissolved phosphorus removal.** Infiltration-based BMPs would increase the amount of dissolved phosphorus removed from the watershed runoff.

- **Include mix of structural and non-structural BMPs.** The infiltration-based BMPs are considered structural BMPs, however, installation of the BMPs would be implemented as a result of the NMCWD regulatory program (non-structural/programmatic).

- **Provide reliable pollutant removal performance.** Infiltration-based BMPs would provide consistent and reliable pollutant removal throughout the growing season (and potentially throughout the winter during rainfall or snowmelt events). Assuming proper maintenance, it is expected that the infiltration-based BMPs would continue to provide consistent and reliable treatment, especially given the sandy soils within this area.

- **Be reasonably cost effective.** The infiltration-based BMPs would be constructed, funded, and maintained by the development community, thus minimizing direct costs to the City of Edina or NMCWD.

- **Land availability.** BMPs would be installed as part of conformance with the NCMWD stormwater rule as land within the watershed redevelops. Additional land acquisition would not be required.

To model this external management scenario, commercial parcels with soils classified as Hydrologic Soil Groups (HSG) A (high infiltration rate) and B (moderate infiltration rate) were identified within the lakes' subwatersheds. Soil conditions were estimated based on online data resources, including information from the Soil Survey Geographic Database (SSURGO), historical USGS quad maps, MDNR Public Waters Inventory, and anecdotal information compiled from historic project data. Impervious areas were estimated for these commercial parcel areas and infiltration-based BMPs were sized to capture 1.1-inches of runoff from the commercial impervious surface areas (for consistency with the NMCWD stormwater rule). The infiltration basins were added to the existing conditions P8 models to assess the impact of the commercial infiltration BMPs on the phosphorus loading from the watershed. The results from the P8 model were input into the in-lake model to evaluate the changes in phosphorus concentrations in the downstream lakes. Table 7-1 provides a summary of the infiltration basins modeled under this scenario.

Table 7-1 Infiltration BMP Treatment Volumes and Infiltration Rates

Lake	Watershed	Total Treatment Volume (ac-ft)[1]	Infiltration Rate (in/hour)[2]
Lake Edina	LE-1	0.84	0.8
North Cornelia	NC-3	1.37	0.8
	NC-4	9.66	0.8
	NC-5	0.32	0.45
	NC-6	0.07	0.45
	NC-62	1.71	0.6
	NC-88	0.39	0.8

[1] Treatment volume based on treating 1.1" of runoff from commercial impervious surfaces

[2] Infiltration rate based on HSG soil classifications

7.1.2 Filtration BMPs on Commercial Properties

For this external management scenario, it was assumed that commercial properties within the Lake Cornelia and Lake Edina watersheds that have soils conducive to infiltration would implement filtration-based BMPs to capture and filter 1.1 inches of runoff from the impervious surface areas of the parcels. Approximately 194 acres of commercial parcel area was treated under this scenario (~99% of commercial parcel area) and the filtration BMPs were sized to treat 147.5 acres of impervious surfaces. Filtration basins were considered for treatment due to their numerous benefits. Filtration basins allow for the removal of solids and particulate nutrients through settling and can reduce dissolved nutrient concentrations through adsorption, ion exchange, and decomposition as water moves through the initial soil matrix before being discharged through an underlying draintile system. Filtration basins can assist with peak flow reductions, but will have a minimal impact on the total volume of water that reaches downstream areas during precipitation events. This scenario was selected to analyze a condition that would reduce phosphorus loadings, but not impact water loadings. The same basins that were developed for the commercial infiltration scenario were used for this scenario, but modified in the P8 model to function as filtration basins.

This scenario aligns well with the same BMP target criteria as the Infiltration BMPs scenario, with exception that the filtration BMPs remove a lower percentage of dissolved phosphorus loads.

Similar to the Infiltration BMPs on Commercial Properties scenario, this scenario represents a condition where all commercial parcels are redeveloped in conformance with NMCWD's current stormwater rule. While this scenario represents extensive changes in the watershed that would likely occur over a long period of time, it was evaluated as a benchmark or "stretch goal" for external management efforts.

7.1.3 Spent Lime/CC17 Treatment Chamber

A third watershed management scenario evaluated to reduce external phosphorus loading was construction of a double-chamber spent lime/CC17 filter at the downstream discharge point of Swimming Pool Pond. Swimming Pool Pond has a tributary watershed of 410 acres, which is approximately 47% of the total North Lake Cornelia tributary watershed. Based on the P8 modeling analyses, the waterbody is effective in settling out sediment and associated particulate phosphorus; however, little to no dissolved phosphorus is removed as runoff flows through this waterbody into Lake Cornelia. The proposed spent lime/CC17 treatment chamber would serve as a "polishing" step, diverting a portion of the discharge from Swimming Pool Pond through the spent lime filtration chamber to remove dissolved phosphorus before discharge to Lake Cornelia.

The methods to remove dissolved phosphorus from stormwater are limited. To remove dissolved phosphorus (or phosphate) from runoff, phosphate must be either incorporated into recalcitrant organic material or be bound to cations (Ca^{2+}, Mg^{2+}, Fe^{2+}) or unreducible trace metals (Al^{2+}). Calcium carbonate is the primary component of spent lime. A spent lime treatment chamber uses chemical substitution to exchange phosphate for carbonate. As runoff filters through spent lime, calcium will preferentially bind to phosphate over carbonate and calcium phosphate will form. This type of "filtration" differs from other methods of dissolved phosphorus removal in that spent lime is not precipitating or flocculating phosphate (as an iron-enhanced sand filter or alum treatment do).

Using spent lime to treat stormwater is a relatively new and innovative approach that Barr has been experimenting with at a few locations throughout the Twin Cities metro area in recent years. Benefits of spent lime treatment to treat stormwater runoff include:

- Spent lime is considered a "waste material" from water treatment plants and thus, a green material with low material costs
- Rapid chemical substitution reactions between phosphate and carbonate lead to a high treatment capacity
- Spent lime material has high hydraulic conductivity, therefore allowing for large volumes of treatment over a relatively small footprint
- Spent lime treatment can remove both particulate and dissolved phosphorus
- Additional water quality benefits are attained through the removal of aluminum, calcium, iron, zinc, and lead
- Relatively easy maintenance with annual mixing of the lime material to maintain porosity, maintain hydraulic conductivity, and expose new spent lime surfaces to stormwater

While there are many benefits to spent lime, one drawback is that the material has limited capacity for prolonged inundation. Therefore, for the proposed treatment chamber located on the downstream end of Swimming Pool Pond it is recommended that the bottom layer of material be supplemented with CC17 due to the potential for periodic high water levels in North Cornelia. CC17 is a crushed limestone material that is more soluble that most limestone aggregates and thus, provides calcium that can bind phosphate and create calcium phosphate. Unlike spent lime, CC17's lifespan will not be reduced by prolonged inundation.

To model the effectiveness of this external management BMP, the spent lime/CC17 chamber was sized to filter 2 cubic feet per second (cfs) of discharge from Swimming Pool Pond prior to discharge into North Cornelia. A conceptual diagram of the double-chamber spent lime/CC17 treatment cell is depicted in Figure 7-1. Pilot studies conducted with spent lime and CC17 filters have demonstrated effective removal of total phosphorus and dissolved phosphorus fractions. For this UAA study, a total phosphorus removal efficiency of 62% was assumed for the modeling, which was the average removal efficiency for a spent lime filter located near Wakefield Lake, Maplewood, MN for the sampling period of 2012-2016. Treatment tests with CC17 have shown that the material is a good filter for particulates and that the material does not appear to clog as readily as sand. Additionally, recent testing completed on a CC17 treatment cell in Ramsey-Washington Metro Watershed District showed that the CC17 material had nearly the same or more treatment capacity to remove phosphorus than spent lime alone. This indicates that a combined treatment cell with CC17 and spent lime has the capacity to effectively treat discharges from Swimming Pool Pond.

This scenario aligns well with the following target criteria:

- **Maximize benefits to chain of lakes.** The proposed spent lime/CC17 chamber is directly upstream of North Cornelia, so all three lakes within the chain would benefit from the reduction in phosphorus loading.

- **Increase dissolved phosphorus removal.** The spent lime/CC17 chamber would increase the amount of dissolved phosphorus removed from the watershed runoff.

- **Improve or "build on" effectiveness of existing treatment systems.** The Point of France Pond and Swimming Pool Pond provide effective removal of sediment and particulate phosphorus from the 410-acre tributary watershed, but do not remove dissolved phosphorus. The proposed spent lime/CC17 would serve as a "treatment train" approach and provide a "polishing" step to a portion of the water flowing from Swimming Pool Pond prior to discharge to Lake Cornelia.

- **Include mix of structural and non-structural BMPs.** The spent lime/CC17 chamber would be considered a structural BMP, however, since the proposed implementation location is within a public park, signs could be posted near the BMP for educational benefit of the park users (non-structural/programmatic).

- **Provide reliable pollutant removal performance.** The proposed spent lime/CC17 would provide consistent, year-round treatment of low-flows from Swimming Pool Pond. However, high flows would bypass the system and flow directly to Lake Cornelia without treatment. Use of spent lime/CC17 to remove dissolved phosphorus from stormwater is still a relatively new and experimental technique; however, results from other regional applications have been promising.

- **Be reasonably cost effective.** The spent lime/CC17 chamber uses materials considered "waste" from previous applications helping to keep the construction costs reasonably cost effective.

- **Land Availability:** The proposed location for the spent lime/CC17 implementation is underneath an existing parking lot in a public park. Installation of the proposed BMP would not require re-purposing of the land area footprint.

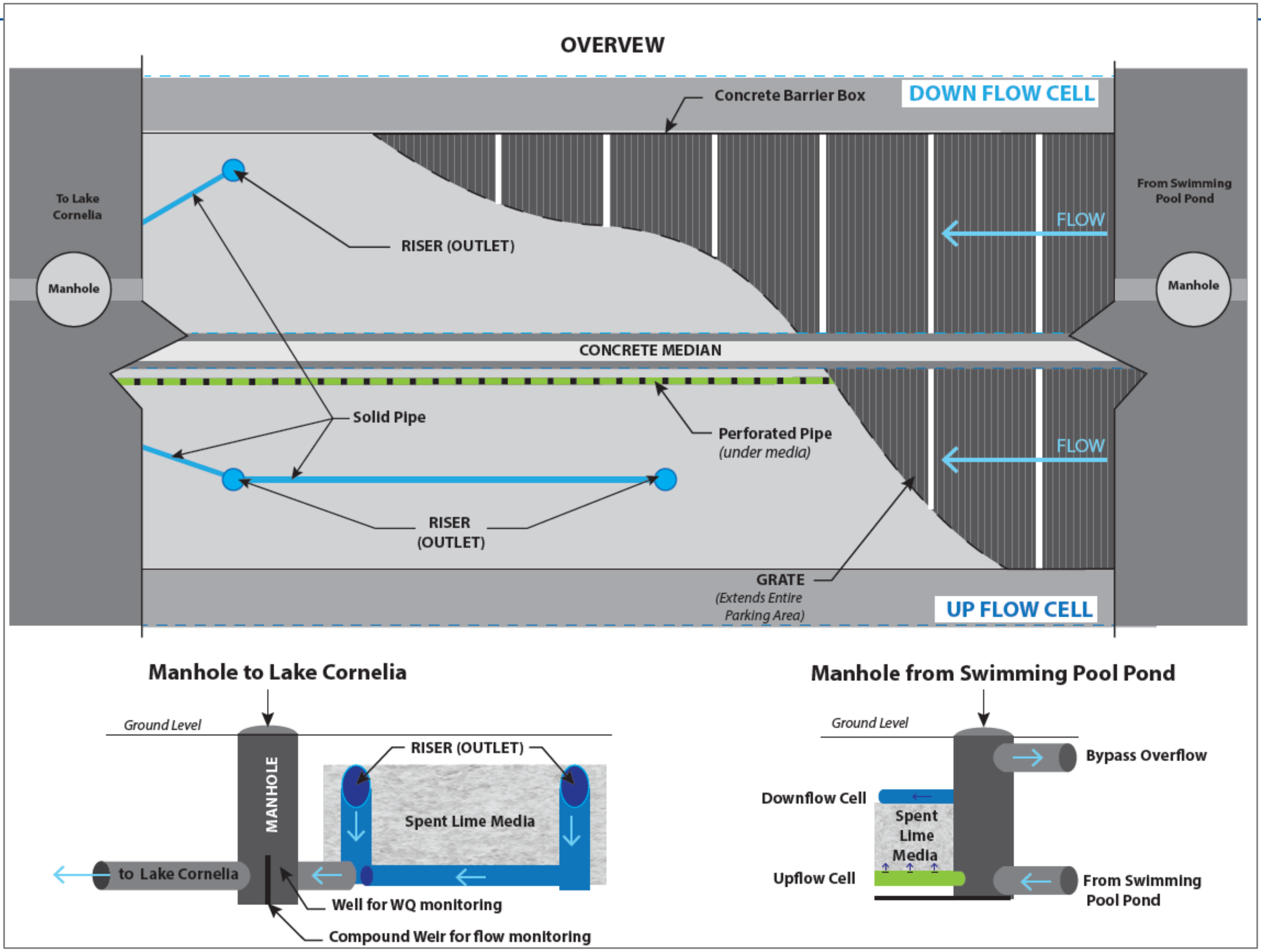


Figure 7-1 Conceptual design of the double-chamber spent lime/CC17 treatment cell

7.1.4 Weekly Street Sweeping

The fourth watershed management BMP scenario to reduce external phosphorus loading was weekly street sweeping of all public city roads and all private commercial lots. In 2015, the City of Edina developed a street sweeping management plan which establishes the following measurable goals and timeframes for using street sweeping as a BMP (Emmons & Olivier Resources, Inc. (EOR), 2015):

"The City will brush or vacuum sweep streets a minimum of twice annually in an effort to reduce the amount of sediment, trash, and organic material from reaching the storm sewer system and water resources."

Although this measurable goal identifies biannual sweeping, the city is interested in potentially implementing changes to the street sweeping program, such as more frequent and/or targeted sweeping, to further reduce stormwater pollutants. Thus, efforts were made in this UAA process to quantify the in-lake responses to an enhanced street sweeping program.

The city's street sweeping management plan investigated the water quality benefits of the current street sweeping program and the projected benefits of an enhanced street sweeping program (sweeping once a month, sweeping bi-weekly) (Emmons & Olivier Resources, Inc. (EOR), 2015). Annual pollutant load recoveries were estimated using the street sweeping planning calculator tool, 'Estimating Nutrient and Solids Load Recovery through Street Sweeping', developed by Kalinosky et. al (2014) as part of a Master's Thesis at the University of Minnesota. The calculator was used to predict annual pollutant recovery benefits for the City of Edina public streets. Watershed-wide tree canopy assessments and curb-mile summaries were completed to estimate annual total phosphorus reductions in pounds of total phosphorus per year. Three street sweeping scenarios were analyzed in the study (twice annually, monthly, bi-weekly) and estimated total phosphorus recoveries for a regenerative air street sweeper ranged from 48.8 to 181.7 pounds for the Lake Cornelia and Lake Edina watersheds.

The street sweeping load reduction calculator developed by Kalinosky et. al (2014) provides an estimate of the amount of annual total phosphorus removed from street sweeping, in pounds of TP recovered annually, calculated using regression equations based on data collected from nine street sweeping routes in Prior Lake, Minnesota from August 2010 to July 2012. The calculator does not translate the estimated amount of annual TP removed to a load reduction (i.e., the calculator reports pounds of TP removed but not a percent removal). Given this, it is difficult to extrapolate the average annual results to observed time series data used in the lake modeling analysis, due to differences in precipitation volume and frequency from year to year. Thus, for this UAA study a different approach was used to estimate the in-lake response to an enhanced street sweeping program.

The street sweeping scenario analyzed for this UAA study assumes public streets and private commercial parking lots were swept with a high-efficiency vacuum-assisted street cleaner on a weekly basis. It is recognized that this would be an extensive change to the street sweeping program already in place (twice annually). However, it sets a benchmark for the greatest potential of nutrient reductions from runoff through the removal of sediment, leaves, and other organic detritus from urban streets and commercial lots. A weekly street sweeping scenario would also align better with the BMP target criteria of providing reliable and consistent pollutant removal, as opposed to a bi-annually, monthly, or even bi-weekly street sweeping program.

For this weekly street sweeping scenario, the modeled efficiency of nutrient removal through street sweeping efforts was based on a paper by the U.S. Geologic Survey (USGS) William Selbig (Selbig, 2016). In this study, a paired catchment system was used to quantify the potential for a municipal leaf collection and street cleaning program in Madison, WI. One catchment area was established as a control with no effort to remove leaf litter or other organic detritus from streets and a second was established to serve as the test catchment in which removal of leaf litter and detritus was done through weekly street sweeping, leaf collection, and leaf blowing. In the period of April through September, weekly street cleaning was the only form of treatment in the test catchment. Selbig's results were grouped into seasonal categories (spring, summer, and fall). For spring samples, Selbig found that weekly street sweeping reduced total phosphorus loads by approximately 45% (phosphorus loads that reached monitored downstream catch basins). In the summer, total phosphorus loads were reduced by 36% for weekly street sweeping in the test catchment area. The extensive street cleaning efforts that occurred in the fall showed that total phosphorus concentrations could be reduced by 84% during the period when total phosphorus loading was the greatest. For UAA modeling efforts, a total phosphorus loading reduction of 36% was applied to inflows throughout the modeled time periods to predict in-lake responses to weekly street cleaning. This load reduction factor was selected in part because it best reflects the time period of interest (June through September) for the in-lake modeling. Selection of the 36% TP load reduction also reflects a somewhat conservative approach (versus using an increased load reduction assumption during the springtime). The characteristics of the test catchment included 19% streets, 4% driveways, 19% roofs, 3% sidewalks, 54% lawns, and 17% street tree canopy. Since not all of the street catchments in the City of Edina will have these same characteristics, using a more conservative loading reduction factor is appropriate. Nevertheless, since this study, as well as other studies (Kalinosky, 2015), show that street sweeping efforts have a greater capacity to reduce loadings in the spring and fall, it should be recognized that larger load reductions during those time periods than what are presented in this UAA study may be achievable with weekly sweeping efforts.

The same total phosphorus loading reduction factor found in the USGS study for an urban street was used to estimate the phosphorus load reductions for private, commercial parking lots. A literature search yielded no studies investigating the effects of street sweeping of commercial parking lots (versus streets). A few studies were found that assessed the nutrient characteristics of parking lots compared to streets/highways. However, these studies are inconclusive. A few studies showed that parking lots have reduced levels of phosphorus compared to highways or streets (Bannerman, Owens, Dodds, & Hornewer, 1993; Hope, Naegeli, Chan, & Grimm, 2004; Wei, et al., 2010), while others showed that phosphorus concentrations in parking lots were comparable or greater than streets/highways (Passeport & Hunt, 2009). Due to the limited and inconclusive studies completed for parking lot phosphorus concentrations and street sweeping efforts, a total phosphorus loading reduction factor of 36% (from impervious areas) was used for commercial properties for this study. In the future, a pilot study may be warranted to more accurately reflect the full impact of street sweeping private parking lots.

The weekly street sweeping scenario aligns well with the following target criteria:

- **Maximize benefits to chain of lakes.** The street sweeping scenario would have direct benefit to all three lakes.

- **Improve or "build on" effectiveness of existing treatment systems.** Regular street sweeping would reduce the amount of sediment and nutrients reaching downstream BMPs and/or water bodies. This reduction in sediment and nutrients could be expected to reduce maintenance frequency and extend the useful life of these other BMPs and/or water bodies.

- **Include mix of structural and non-structural BMPs.** Street sweeping would be considered a non-structural BMP.

- **Provide reliable pollutant removal performance.** One of the disadvantages of typical street sweeping programs is the infrequency of sweeping, and therefore the inconsistent treatment provided by the BMP. The weekly frequency of the modeled scenario reduces the inconsistency of treatment, but would be resource-intensive.

- **Be reasonably cost effective.**

- **Land availability.** One of the benefits of street sweeping is that a dedicated land footprint is not required. If pursuing sweeping of private land, special access agreements may be necessary.

7.2 Internal Load Reductions

A range of in-lake management scenarios were considered to help reduce the phosphorus concentrations in Lake Cornelia and Lake Edina, and in turn, improve water quality and habitat for aquatic communities. In-lake BMPs reduce phosphorus already present in a lake or prevent the release of phosphorus from the lake sediments. For this UAA study, two in-lake management scenarios were explicitly modeled for North and South Cornelia: (1) curly-leaf pondweed management, and (2) alum sediment treatments. No in-lake management processes were modeled for Lake Edina since the calibration models indicated that internal loading is not a major factor involved in phosphorus loadings to the lake. Despite Lake Edina having limited internal phosphorus loading, there are aquatic invasive species present in the lake that require management considerations. This is discussed further in Section 7.3.

7.2.1 Curly-leaf Pondweed Management

The presence of curly-leaf pondweed and its mid-summer die-off negatively impacts the water quality of Lake Cornelia and downstream Lake Edina. Modeling results indicate that curly-leaf pondweed contributes up to 17% of the annual phosphorus loading to North Cornelia and up to 23% of the annual phosphorus loading to South Cornelia. Accordingly, management of the curly-leaf pondweed is an important component of a long-term management plan for Lake Cornelia. Curly-leaf pondweed management was modeled as an in-lake management scenario. Several assumptions were applied to this modeling effort, including: (1) maximum curly-leaf biomass of 800 kilograms per hectare, (2) phosphorus content of pondweed tissue was 4.2 grams per kilogram dry plant material, (3) pondweed mortality rate of 0.10 to

0.15 per day, and (4) a decay rate of 0.10 to 0.15 per day. Phosphorus release occurred in the model during the decay phase.

The City of Edina has been conducting herbicide treatments in Lake Cornelia in 2017 and 2018 to reduce the impact of curly-leaf pondweed die-back on water quality in Lake Cornelia and downstream Lake Edina and promote a healthy native aquatic plant population. Continued curly-leaf management efforts would likely consist of continued herbicide treatments at a treatment dose such that a lethal dose is attained and sustained for the period of time sufficient to kill the curly-leaf pondweed.

7.2.2 Alum Treatment of Lake Sediments

Modeling results confirm that internal release of phosphorus from lake-bottom sediments is a significant source of phosphorus to Lake Cornelia, contributing an estimated 14%-40% of the annual phosphorus loading to North Cornelia during modeled years, and an estimated 14%-19% of the annual phosphorus loading to South Cornelia. Accordingly, control of the internal phosphorus release is an important component of a long-term management plan for Lake Cornelia and downstream Lake Edina.

A whole-lake alum treatment (aluminum is the active ingredient, and hence this can be considered an aluminum treatment) is proposed for both North and South Cornelia. The in-lake modeling scenario assumes internal phosphorus loading from lake sediments is reduced by 80 percent.

The proposed alum treatment should be conducted across the entire lake surface to depths as shallow as feasible. The dose in terms of alum (4.4% aluminum by weight) for North Cornelia is 1,539 gallons per acre for a total application of 29,238 gallons, and for South Cornelia the dose is 530 gallons per acre for a total application of 16,431 gallons. The doses for both North and South Cornelia were based upon treating the top 4 centimeters of lake-bottom sediment. Because Lake Cornelia is shallow and there is a potential for the pH to drop too low if only alum is applied, the aluminum should be applied as a mixture of alum (4.4% aluminum by weight) and sodium aluminate (10.4% aluminum by weight). Sodium aluminate acts as a buffer and will keep pH in an acceptable range. A summary of the proposed treatment is provided in Table 7-2. Note that the total gallons of alum and sodium aluminate are less than the total gallons of alum only as the mass of aluminum is much higher for liquid sodium aluminate, this reduces the total gallons of sodium aluminate that need to be applied to achieve the desired application mass of aluminum.

Table 7-2 Summary of alum and sodium aluminate application doses for North and South Cornelia

Location	Dose (g Al/ac)	Product	Application Ratio	Gallons/Acre	Total Gallons Applied
North Cornelia	84	Alum	2	673	12,791
		Sodium Aluminate	1	337	6,396
South Cornelia	29	Alum	2	232	7,188
		Sodium Aluminate	1	116	3,594

An alum treatment can be conducted before the other lake management activities are completed; however, there are aspects that should be considered. When alum (aluminum) is added to a lake surface, it settles to the bottom and temporarily there is a layer of aluminum floc (aluminum hydroxide) that covers the lake bottom. Due to benthic activity from fish and invertebrates, as well as wind and wave action, aluminum hydroxide mixes readily with benthic sediment and as it is mixed it has an opportunity to bind phosphorus in the sediment. Mixing is necessary for the aluminum hydroxide to bind phosphorus in the sediment. However, when conditions are such that mixing is extensive, then the aluminum can become diluted as it mixes deeper into the sediment. Because of the extensive benthivorous fish in Lake Cornelia, the longevity of the treatment may be reduced as the aluminum is mixed deeper into the sediment over time. If treatment is conducted before other activities, it can be expected that a second treatment will be needed in the relatively near future (5 to 10 years after treatment).

7.3 Other Lake Management Strategies

Several other lake management strategies were considered as part of this UAA study, but not explicitly included in the modeling analysis. These management strategies are described below.

7.3.1 Carp and goldfish tracking and benthivorous fish management

Review of the 2018 fishery data indicate that the Lake Cornelia fishery tends to be heavily influenced by frequent winterkill events, evidenced by a low number of bluegill and other predator fish. The frequency of winterkills and the availability of connected shallow waterbodies that winterkill which act as nurseries, are most likely preventing bluegills and other sunfish from effectively controlling carp, bullheads, and goldfish within the system. The abundant benthivorous fish population is likely negatively affecting water quality by stirring up the lake bottom sediments.

Several in-lake management activities to manage the abundant and unchecked population of benthivorous fish and promote a healthy and more diverse fishery were considered as part of this UAA study. One of the proposed management practices is installation of a winter aeration system using direct oxygen to prevent winterkill and promote survival of predator fish. This management option is discussed in further detail below. Other potential management activities could include a rotenone treatment of Lake

Cornelia and the upstream water bodies and subsequent fish stocking and/or installation of fish barriers. Prior to considering these fishery management activities collection of additional information is recommended regarding the migration and movement of carp and goldfish throughout Lake Cornelia and the series of connected upstream shallow waterbodies.

7.3.1.1 Winter aeration using direct oxygen injection

The purpose of winter aeration using direct oxygen injection is to prevent winter kill of predator fish, therefore maintaining a more balanced fishery. Winter aeration would be conducted by injecting oxygen under the ice. The system would consist of: (1) a unit that generates the oxygen and a structure that houses the generator, (2) a raft that holds the vertical aeration tubes in place, and (3) a bubbler that directs the oxygen upwards through the aeration tubes. The aeration tubes consist of an inner tube surrounded by an outer tube. Air is applied at the bottom of the inner tube, moving the air upward through the tube. Once the water reaches the surface of the inner tube, the water falls downward in the outer tube. Pure oxygen is either directed at the bottom of the inner tube or at the top of the outer tube. The inner tube draws in water at the bottom of the lake. The outer tube is shorter than the inner tube and aerated water is the delivered laterally across the lake.

The proposed direct oxygen system would be installed in North and South Cornelia at the deep holes of the lake contingent upon the availability of power. The system would be sized to be operated only in the winter when there is ice cover. Dissolved oxygen measurements were collected in North and South Cornelia during the winter of 2019 to inform the potential sizing and placement of winter aeration systems.

7.3.2 Lake Edina Aquatic Plant Management

Three non-native aquatic invasive species (AIS) are present in Lake Edina: purple loosestrife, curly-leaf pondweed, and Eurasian watermilfoil.

Purple loosestrife was observed along the perimeter of the lake during the 2008, 2012, 2015, and 2017 sampling periods. The current infestation is not considered problematic. However, the infestation will be evaluated periodically when aquatic plant surveys are completed. If the infestation becomes problematic in the future, it can be managed by introducing purple loosestrife eating beetles (Galerucella calmariensis and/or Galerucella pusilla) to the infested areas. The beetles manage purple loosestrife by inflicting damage to the plants.

7.3.2.1 Curly-leaf Pondweed

The invasive curly-leaf pondweed has been observed at low levels in Lake Edina since 2008. In June of 2017, the species was observed at two locations, both in the western area of the lake. In August, it was observed at a single location in the central western area of the lake. Although curly-leaf pondweed has remained at low levels in the lake since 2008, management of curly-leaf pondweed may be warranted to maintain its low occurrence and prevent the accumulation of turions (i.e., similar to seeds). The goals of treatment would be to prevent curly-leaf pondweed from establishing dominance to avoid the need for subsequent long-term annual treatments to reduce an established population that can rebound once larger numbers of turions are present in the sediments. Management of the current curly-leaf population would also minimize the potential for turions to be conveyed downstream to Normandale Lake, causing a resurgence of curly-leaf pondweed after completion of the Normandale Lake water quality improvement project.

The herbicide selected for the CLP treatment will depend upon CLP extent; when greater than 15 percent of the lake, endothall would be recommended to attain lake-wide control of CLP. When CLP extent is less than 15 percent of the lake, a cost and benefit analysis would be recommended to determine whether Endothall or diquat would be most appropriate. Based upon experience with other CLP management projects, the management of CLP would be expected to span several years. Management until neither CLP nor turions are observed in the lake would be most protective of the Lake Edina ecosystem as well as downstream Normandale Lake from the problems associated with a CLP infestation.

7.3.2.2 Eurasian Watermilfoil

Eurasian watermilfoil was first observed in Lake Edina during 2017, in which it was widespread and increased in extent between June and August. Unlike many other plants, Eurasian watermilfoil does not rely on seed for reproduction. It generally reproduces by fragmentation—each fragment can grow into a new plant. The plant produces fragments after fruiting at least once or twice during the summer. Eurasian watermilfoil's fast growth rate (up to 2 inches per day in spring and summer), its ability to spread rapidly by fragmentation, and its ability to effectively block out sunlight needed for native plant growth often results in monotypic stands which provide only a single habitat and threaten the integrity of aquatic communities in a number of ways.

Management of Eurasian watermilfoil in Lake Edina would control its rapidly expanding extent and prevent EWM from further threatening the integrity of the lake's aquatic community. Because Eurasian watermilfoil fragments could be carried downstream to Normandale Lake, managing Eurasian watermilfoil in Lake Edina would also protect the integrity of the Normandale Lake aquatic community. The herbicide selected for EWM treatment in Lake Edina will depend upon EWM extent; when greater than 15 percent of the lake, the herbicide 2,4-D would be recommended to attain lake-wide control of EWM. When EWM extent is less than 15 percent of the lake, a cost and benefit analysis would be recommended to determine whether 2,4-D or ProcellaCOR would be the most appropriate herbicide for the treatment. Based upon experience with other EWM management projects the management of EWM in Lake Edina would be expected to span several years, but the EWM extent to be managed would diminish annually to smaller and smaller levels. As EWM extent diminishes, management efforts and associated cost are expected to change accordingly. Management, until EWM is no longer observed in the lake, would protect the Lake Edina ecosystem as well as downstream Normandale Lake from the problems associated with an EWM infestation.

8.0 Lake Response to Management Strategies

Section 7.0 discussed the management strategies that were evaluated for North and South Cornelia and Lake Edina. This section outlines the predicted in-lake responses to these various management strategies, and combinations thereof.

8.1 Lake Response to Watershed (External) Management Strategies

The four external loading management strategies modeled were (1) infiltration BMPs on commercial properties, (2) filtration BMPs on commercial properties, (3) a spent lime/CC17 treatment chamber downstream of Swimming Pool Pond (North Cornelia watershed), and (4) weekly watershed-wide street sweeping.

The effectiveness of the various management strategies in reducing the predicted in-lake total phosphorus concentrations in Lake Cornelia and Lake Edina is summarized in the subsections below. It is important to note that the four watershed management strategies modeled represent a range in scale of treatments and costs. Accordingly, comparison of the water quality improvements resulting from the four scenarios should not be considered a like-for-like comparison, but rather should be used to provide a sense of how effective the management strategies are towards achieving the lake water quality goals. The cost-benefit analysis, presented in Section 9.0, allows for a more direct comparison of the effectiveness of the evaluated management strategies.

8.1.1 Changes in in-lake phosphorus concentrations

As described in Section 7.0, the P8 and calibrated in-lake models were used to predict the changes in total phosphorus concentrations in each of the lakes throughout the summer months as a result of the various watershed management activities. As an example, Figure 8-1 shows the predicted in-lake phosphorus concentration changes in North Cornelia in 2015 when the various external load management strategies were applied to the models. The black, dashed line represents North Cornelia's phosphorus concentrations under existing conditions and the red, dashed line represents the MPCA's water quality standard for shallow lakes in the north central hardwood forest ecoregion (60 µg/L). The goal of the various management efforts is to bring the summer average phosphorus concentration below this standard. As shown on Figure 8-1, in 2015 the external management efforts alone do not improve the in-lake phosphorus concentrations in North Cornelia enough to meet the MPCA standard, however, the external management efforts did result in notable changes to the in-lake phosphorus concentrations.

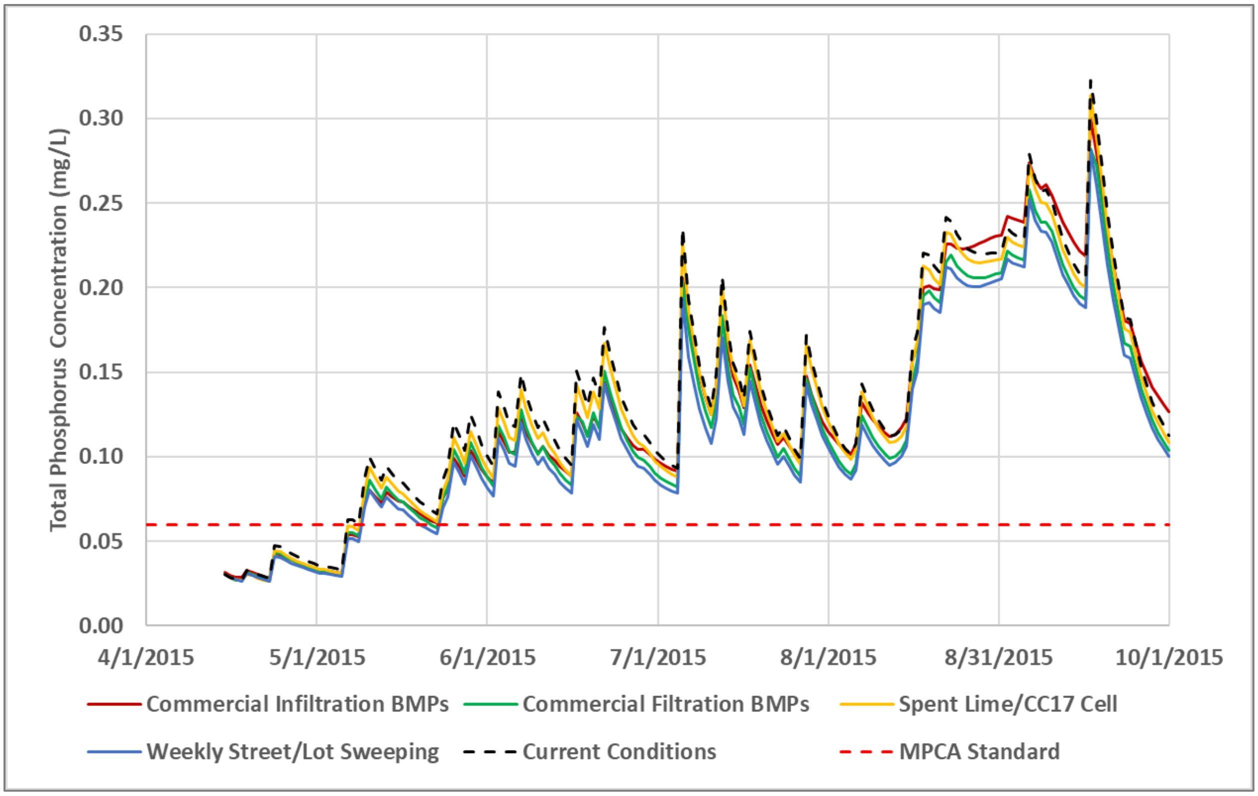


Figure 8-1 In-lake phosphorus concentrations that resulted from watershed management efforts in North Cornelia in 2015

8.1.2 Summer Average Total Phosphorus Concentrations

Figure 8-2, Figure 8-3, and Figure 8-4 summarize the current and predicted summer average total phosphorus concentrations in North Lake Cornelia, South Lake Cornelia, and Lake Edina, respectively based on the modeled watershed management strategies. The goal of the various management efforts is to bring the summer average phosphorus concentration below the 60 µg/L standard. As shown in the figures, while each of the four external management scenarios generally result in lower summer average total phosphorus concentrations in the lakes, none of the strategies improve the lake enough to meet the water quality standard.

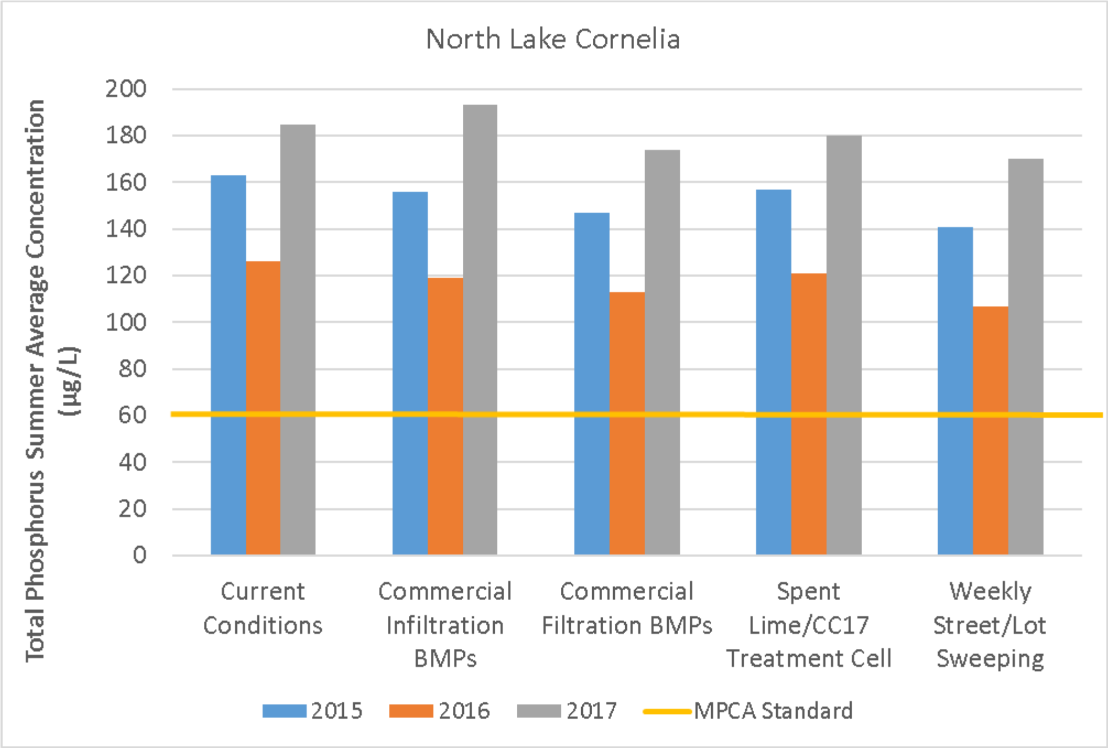


Figure 8-2 North Lake Cornelia In-Lake Summer Average Phosphorus Concentration Summary for Watershed Management Efforts

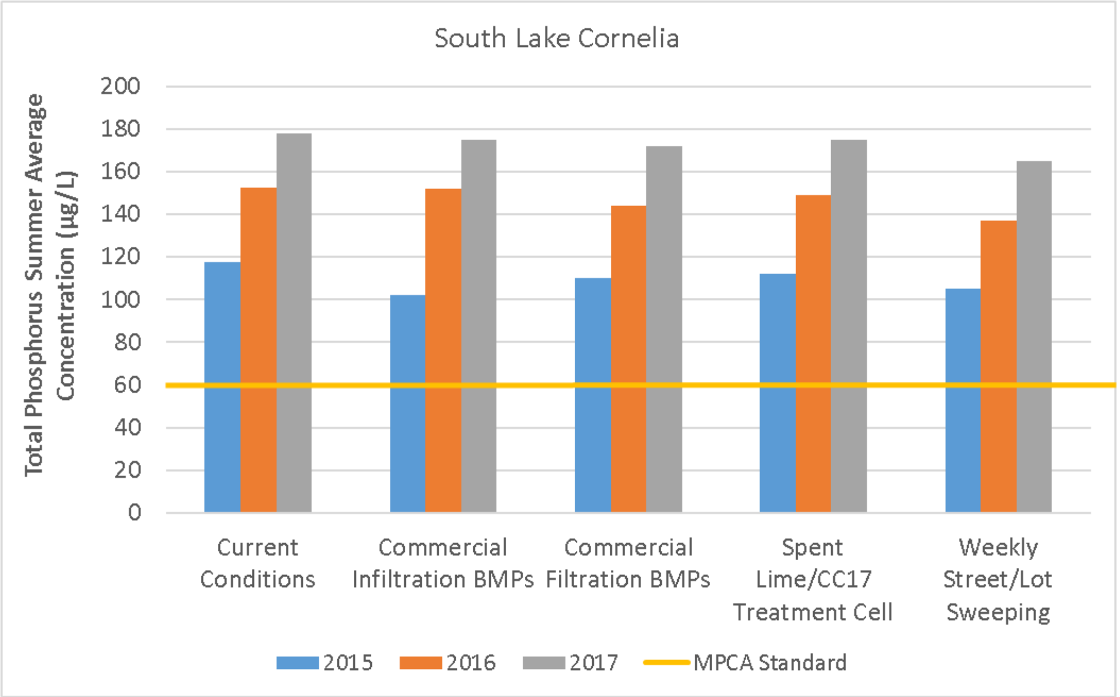


Figure 8-3 South Lake Cornelia In-Lake Summer Average Phosphorus Concentration Summary for Watershed Management Efforts

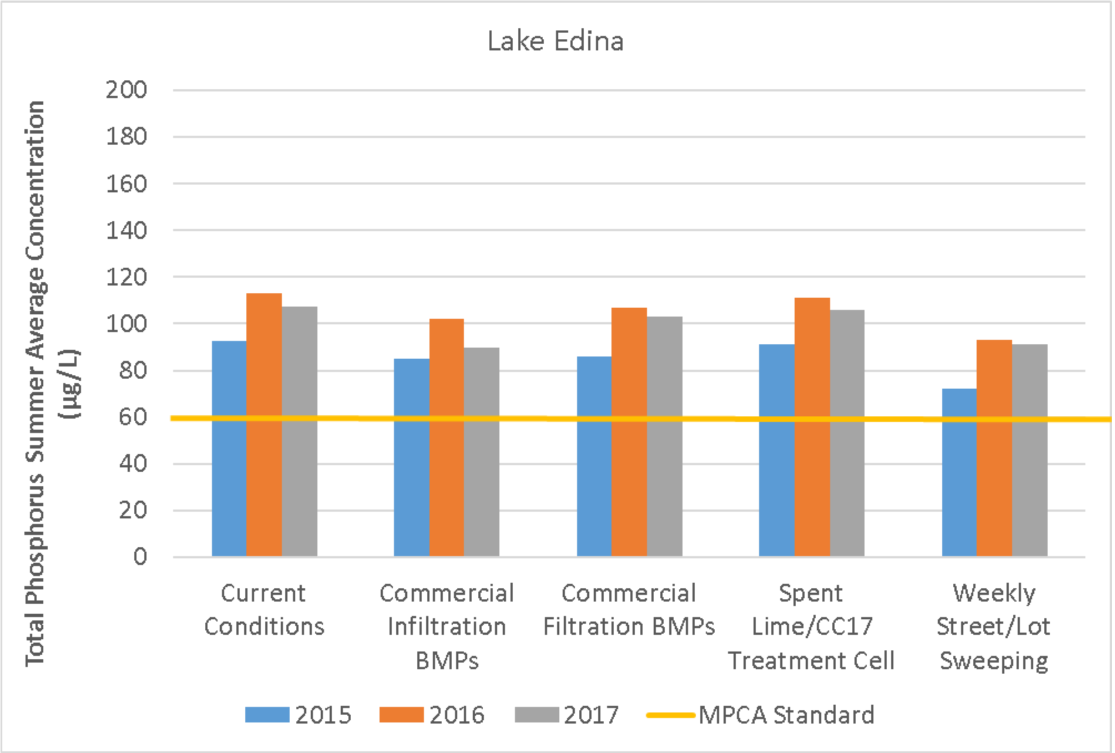


Figure 8-4 Lake Edina In-Lake Summer Average Phosphorus Concentration Summary for Watershed Management Efforts

8.1.3 Phosphorus Loading Reductions

The in-lake total phosphorus concentrations of North and South Cornelia and Lake Edina are influenced over time through loading reductions. Table 8-1 summarizes the total phosphorus loads and percent load reductions from the four watershed management strategies, in comparison with current conditions.

Table 8-1 Total Phosphorus Load Reductions resulting from Watershed Management Efforts

Lake	Model Year	Current Load (lbs TP)	Commercial Infiltration BMPs		Commercial Filtration BMPs		Spent Lime/CC17 Treatment Cell		Weekly Street/Lot Sweeping	
			Model Load (lbs TP)	Percent Reduction (%)	Model Load (lbs TP)	Percent Reduction (%)	Model Load (lbs TP)	Percent Reduction (%)	Model Load (lbs TP)	Percent Reduction (%)
North Cornelia	2015	456	329	28%	408	11%	438	4%	390	14%
	2016	489	337	31%	432	12%	467	4%	411	16%
	2017	673	514	24%	625	7%	652	3%	603	10%
South Cornelia	2015	442	341	23%	416	6%	433	2%	397	10%
	2016	444	347	22%	419	6%	433	2%	396	11%
	2017	525	406	23%	507	3%	516	2%	485	8%
Lake Edina	2015	306	217	29%	288	6%	299	2%	237	23%
	2016	430	321	25%	407	5%	424	1%	347	19%
	2017	410	290	29%	395	4%	405	1%	340	17%

8.1.4 Watershed BMP-specific Results

8.1.4.1 Infiltration BMPs on Commercial Properties

Infiltration BMPs not only remove particulate and dissolved phosphorus loads and reduce peak flows, but they also remove water loads to downstream water bodies, which can be an added benefit, reducing flood bounce and downstream erosion potential. Runoff that is captured in infiltration basins recharges the groundwater and can alter the water balance of a system. For this external management scenario, it was assumed that all commercial properties within the Lake Cornelia and Lake Edina watersheds that have soils conducive to infiltration would implement infiltration-based BMPs to capture and retain 1.1 inches of runoff from the impervious surface areas of the parcels. Through capturing stormwater runoff in infiltration basins, the volume of runoff reaching North Lake Cornelia was reduced by 38%, 39%, and 39% for the complete model years of 2015, 2016, and 2017 respectively. Total phosphorus loading from watershed runoff was reduced by 36%, 37%, and 37% for calibration periods 2015, 2016, and 2017 respectively due to enhanced infiltration practices.

As shown in Figure 8-2, implementation of this extensive BMP scenario resulted in only moderate reductions in summer average total phosphorus concentrations in 2015 and 2016 and actually increased the in-lake summer average phosphorus concentrations in 2017. Of the 3 years modeled for this UAA effort, 2017 was the model year with the least amount of precipitation that occurred during the growing season. While typically it would be expected that external phosphorus load reductions should improve water quality conditions of the downstream lake, for a lake that is not only receiving high external loads, but also significant internal loads, adjusting the water balance of a lake can have negative consequences on water quality. This outcome was predicted by the in-lake model in 2017 for North Cornelia. In 2017, lower-than-average precipitation occurred over the growing season. With lower-than-average runoff due to dry climatic conditions and increased infiltration, internal phosphorus loading has a greater capacity to affect water quality due to reduced predicted lake levels and reduced flushing.

The modeling results for this scenario indicate that if future adjustments in the watershed significantly alter the water balance of North Cornelia without addressing the enhanced internal loading, negative consequences to water quality could result (especially for years with low precipitation during the growing season). Section 8.3 discusses how the in-lake concentrations of North Cornelia might change based on combined external and internal management efforts. Additional information on model results for the Infiltration BMPs on Commercial Properties scenario, including plots of the in-lake model results for 2016 and 2017 for North Cornelia and the in-lake model results for South Cornelia and Lake Edina for all modeled years, is provided in Appendix D.

8.1.4.2 Filtration BMPs on Commercial Properties

Because model results indicated that the changes in hydrology caused by wide-spread implementation of infiltration BMPs on commercial properties can result in increased internal loading and periodic increases in North Cornelia's in-lake phosphorus concentrations, a modified external management scenario was considered using filtration BMPs. Under this scenario the commercial parcels were treated with filtration basins rather than infiltration basins. Filtration BMPs have a lower pollutant removal efficiency as compared with infiltration BMPs since water volume is not removed from the system. Filtration basins are effective at treating particulate phosphorus, but have limited capabilities to remove dissolved phosphorus.

For this watershed management scenario, it was assumed that commercial properties within the Lake Cornelia and Lake Edina watersheds would implement filtration-based BMPs to capture and filter 1.1 inches of runoff from the impervious surface areas of the parcels. Runoff volumes to North Lake Cornelia were not affected by the filtration basins, although slight adjustments in the timing of the runoff were noted. Total phosphorus loading from watershed runoff was reduced by 15%, 15%, and 14% for the 2015, 2016, and 2017 calibration periods respectively due to filtration practices.

As shown in Table 8-1, widespread implementation of filtration BMPs on commercial properties results in lower load reductions than the infiltration BMP scenario. However, the predicted improvements in summer average total phosphorus concentrations are similar or better under the filtration BMP scenario for North and South Cornelia (see Figure 8-2 and Figure 8-3). While widespread implementation of filtration basins improves the summer average total phosphorus concentrations in all three lakes, the improvements do not bring the summer average phosphorus concentration below the 60 µg/L standard. Additional information on model results for the Filtration BMPs on Commercial Properties scenario, including plots of the in-lake model results for 2016 and 2017 for North Cornelia and the in-lake model results for South Cornelia and Lake Edina for all modeled years, is provided in Appendix D.

8.1.4.3 Spent Lime/CC17 Treatment Chamber

A third external management scenario encompassed construction of a double-chamber spent lime/CC17 treatment chamber at the downstream discharge point of Swimming Pool Pond, which is directly upstream of North Cornelia. The proposed spent lime/CC17 treatment chamber would serve as a "polishing" step, diverting a portion of the discharge from Swimming Pool Pond through the spent lime filtration chamber to remove dissolved phosphorus before discharge to Lake Cornelia.

For the modeling analysis, the spent lime/CC17 treatment chamber was sized to treat 2.0 cfs of flow discharging from Swimming Pool Pond. This treatment capacity reduces the phosphorus load from Swimming Pool Pond by 15% to 16% depending on the model year. Overall, the spent lime/CC17 treatment chamber reduces the total external phosphorus load to North Cornelia by approximately 7%. As shown in Figure 8-2, Figure 8-3, and Figure 8-4, the spent lime/CC17 treatment chamber reduces in-lake summer average phosphorus concentrations for each lake. However, the improvements do not bring the summer average phosphorus concentration below the 60 µg/L standard. Additional information on model results for the Spent Lime/CC17 Treatment Chamber scenario, including plots of the in-lake model results for 2016 and 2017 for North Cornelia and the in-lake model results for South Cornelia and Lake Edina for all modeled years, is provided in Appendix D.

8.1.4.4 Weekly Watershed-wide Street Sweeping

The fourth external management scenario assumed public streets and private commercial parking lots were swept with a high-efficiency vacuum-assisted street cleaner on a weekly basis. It is recognized that this would be an extensive change to the street sweeping program already in place (twice annually).

However, it sets a benchmark for the greatest potential of nutrient reductions from runoff through the removal of sediment, leaves, and other organic detritus from urban streets and commercial lots. As shown in Figure 8-2, Figure 8-3, and Figure 8-4, weekly street and parking lot sweeping resulted in the most significant improvements in summer average total phosphorus concentrations in all three lakes. However, the improvements do not bring the summer average phosphorus concentrations below the 60 µg/L standard. Additional information on model results for the Weekly Watershed-wide Street Sweeping scenario, including plots of the in-lake model results for 2016 and 2017 for North Cornelia and the in-lake model results for South Cornelia and Lake Edina for all modeled years, is provided in Appendix D.

8.2 Lake Response to Internal Loading Management

Two in-lake management scenarios were explicitly modeled for North and South Cornelia: (1) curly-leaf pondweed management, and (2) alum sediment treatments. No in-lake management processes were modeled for Lake Edina since the calibration models indicated that internal loading is not a major source of phosphorus loading to the lake. However, internal management efforts applied to North and South Cornelia have downstream influences on water quality in Lake Edina.

8.2.1 Changes in in-lake phosphorus concentrations

As described in Section 7.0, the calibrated in-lake models were used to predict the changes in total phosphorus concentration in each of the lakes throughout the summer months as a result of the various in-lake management activities. As an example, Figure 8-5 shows the predicted in-lake phosphorus concentration changes in North Cornelia, South Cornelia, and Lake Edina in 2017 when the two internal loading management strategies, and combinations thereof, were applied to the models. The black, dashed line represents North Cornelia's phosphorus concentrations under existing conditions and the red, dashed line represents the MPCA's water quality standard for shallow lakes (60 µg/L).

The purple line represents the in-lake phosphorus concentrations that resulted when an alum treatment was applied to the sediments for North Cornelia in 2017. During late summer and early fall is when the alum treatment resulted in the largest percent changes in phosphorus concentrations due to the significant internal loading that occurred during that period under existing conditions. The effect of the alum treatment is not as notable in the spring as the benefits are masked by the extensive curly-leaf pondweed die-off that occurs in late spring/early summer.

The green line represents the in-lake phosphorus concentrations that resulted from applying curly-leaf pondweed management to the modeling. During late-spring and early-summer, when curly-leaf pondweed typically dies and decays, is when the curly-leaf pondweed treatments resulted in the largest percent changes in in-lake phosphorus concentrations. By the end of summer and into fall the in-lake phosphorus concentrations tended towards existing conditions due to significant internal loading from the sediments.

The greatest changes to the in-lake phosphorus concentrations resulted from combined internal management efforts. The yellow line on Figure 8-5 represents the predicted total phosphorus concentrations when an alum treatment is conducted and curly-leaf pondweed is managed.

Appendix E contains additional figures showing the effects of internal loading management on in-lake phosphorus concentrations in North Cornelia, South Cornelia, and Lake Edina for each modeled year.

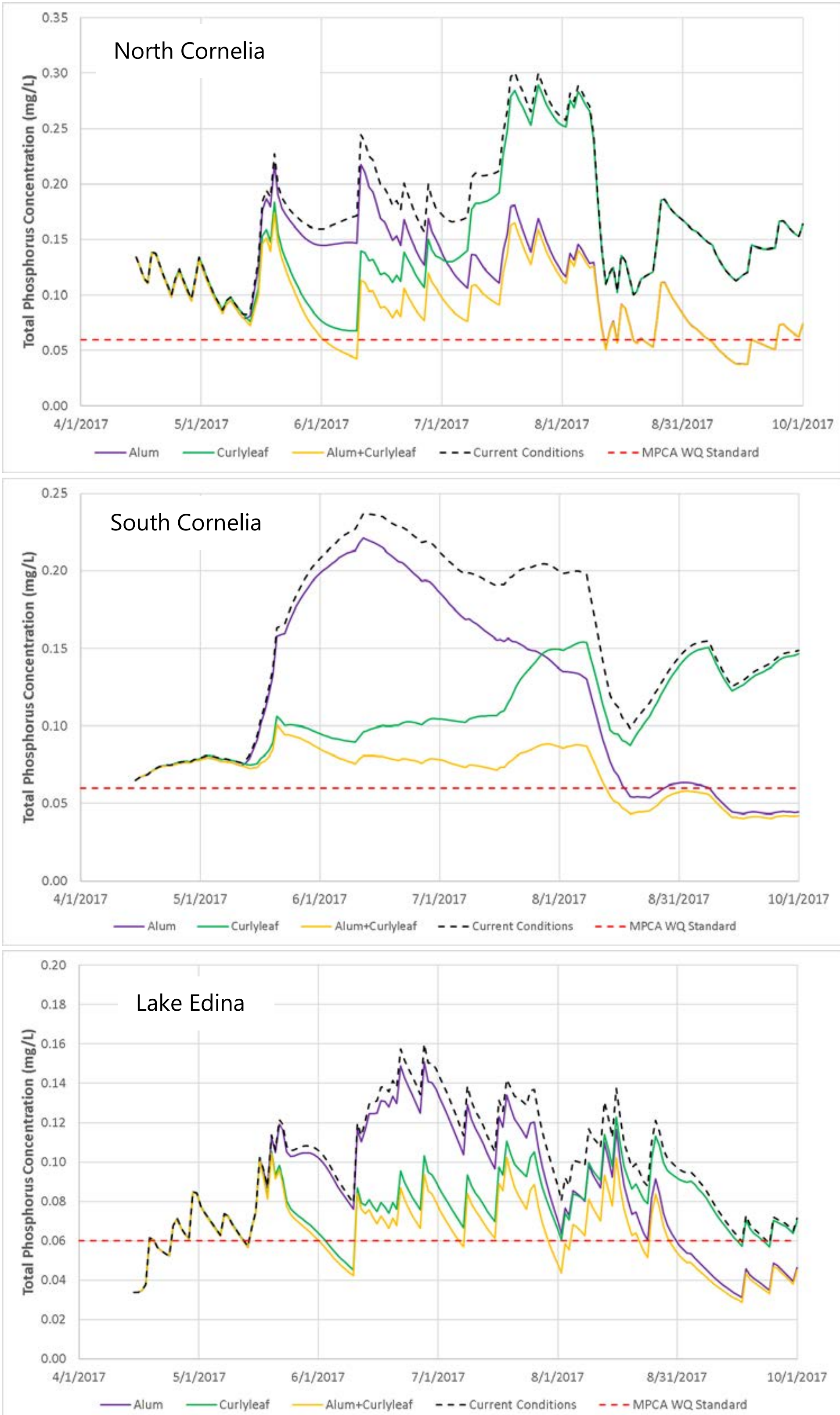


Figure 8-5 In-Lake Phosphorus Concentration Changes that resulted from internal management efforts in North Cornelia, South Cornelia, and Lake Edina in 2017

8.2.2 Summer Average Total Phosphorus Concentrations

Figure 8-6, Figure 8-7, and Figure 8-8 summarize the current and predicted summer average (June through September) total phosphorus concentrations in North and South Lake Cornelia and Lake Edina based on the modeled internal load management scenarios and combinations thereof.

In-lake modeling shows that combined internal management of alum treatment and curly-leaf pondweed management has the potential to reduce South Cornelia's summer average phosphorus concentration to meet MPCA's water quality standard (model year 2015). Significant improvements were also predicted for South Cornelia in 2016 and 2017, where the summer average phosphorus concentrations were reduced by 52% and 62% respectively. While notable decreases in summer average phosphorus concentrations were also observed for North Cornelia (23% to 53%), internal management efforts alone were not sufficient to reduce in-lake phosphorus concentrations within range of MPCA's water quality standard. Improvements in water quality may exceed model predictions if curly-leaf pondweed is controlled and the native aquatic plant population thrives, as these species can uptake phosphorus from the water column and compete with phytoplankton growth by increased shading (i.e., reduced light availability).

The internal load management efforts applied to North and South Cornelia also result in significant improvements in Lake Edina's water quality. Under combined internal management efforts (alum treatment and curly-leaf pondweed management in Lake Cornelia), summer average phosphorus concentrations ranged from 63-76 µg/L in Lake Edina for the three years modeled. Comparing these values to existing conditions, summer average phosphorus concentrations were reduced by 22% to 41% through upstream internal management.

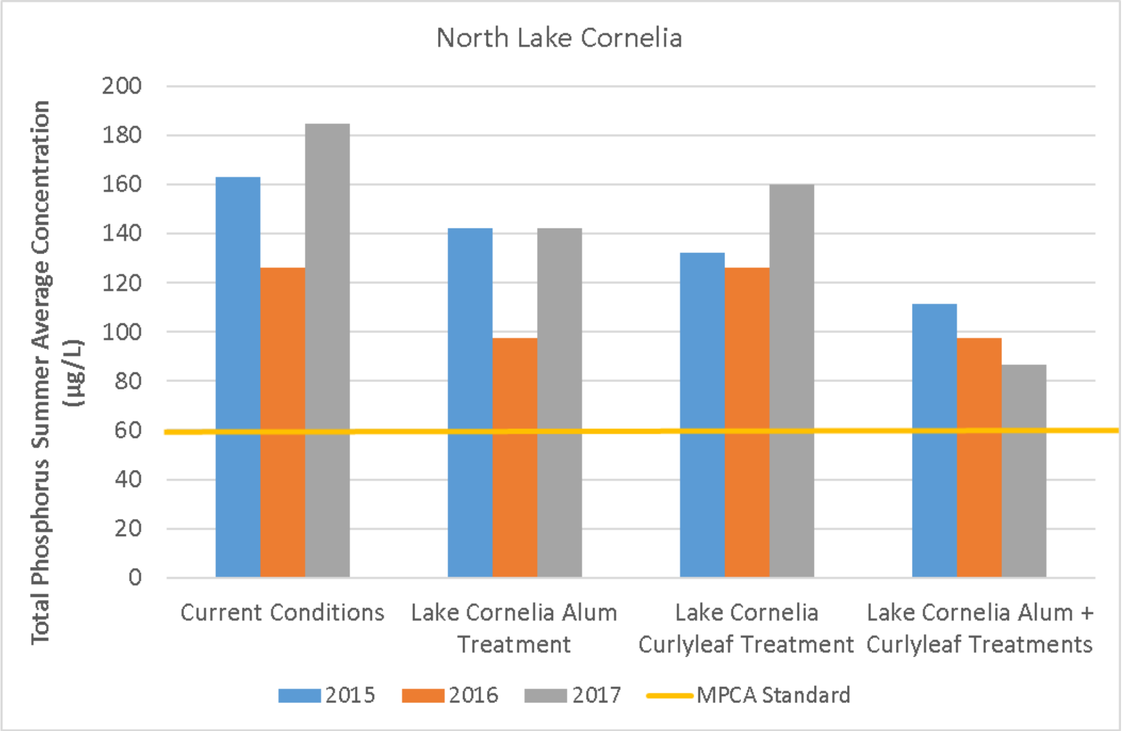


Figure 8-6 North Lake Cornelia In-Lake Summer Average Phosphorus Concentration Summary for Internal Management Efforts

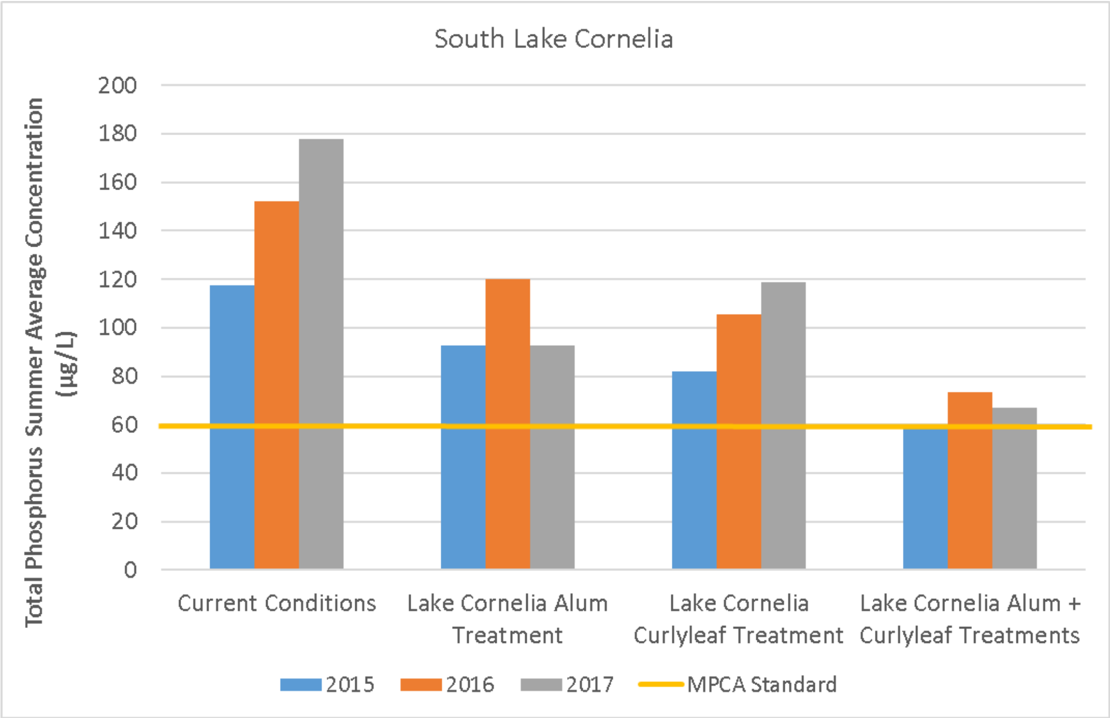


Figure 8-7 South Lake Cornelia In-Lake Summer Average Phosphorus Concentration Summary for Internal Management Efforts

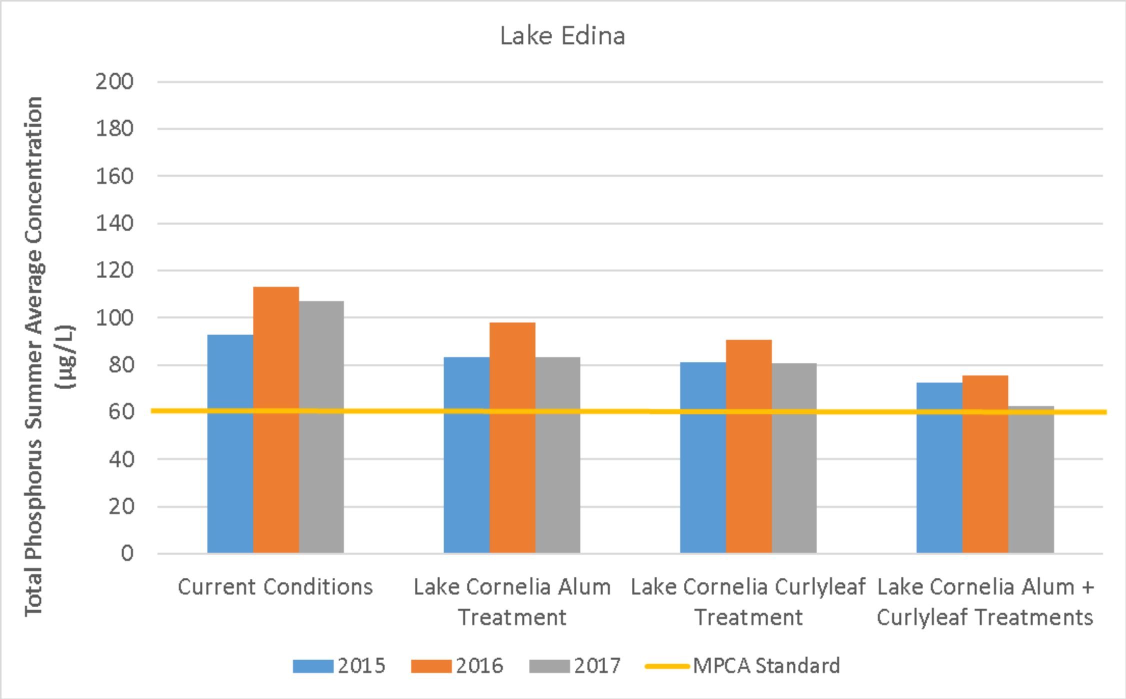


Figure 8-8 Lake Edina In-Lake Summer Average Phosphorus Concentration Summary for Internal Management Efforts

8.2.3 Phosphorus Loading Reductions

The in-lake total phosphorus concentrations of North and South Cornelia and Lake Edina are influenced over time through loading reductions. Table 8-2 summarizes the total phosphorus loads and percent load reductions from the two internal load management strategies, and combinations thereof, in comparison with current conditions. Overall, under the combined scenario where both alum treatment and curly-leaf pondweed management are conducted, a 19% to 44% reduction in total phosphorus loads to North Cornelia is predicted based on the years analyzed in this study. For South Cornelia, the predicted reduction in loading is approximately 48% to 59% based on the modeled years. For Lake Edina, the predicted reduction in phosphorus loads due to internal management efforts in the upstream lakes is approximately 22% to 33%.

The level of reduction observed in the total phosphorus load due to internal management is largely dependent on the amount of precipitation and associated runoff that occurs in a given year. For example, model year 2017 had the least amount of precipitation over the growing season. Therefore, a larger percentage of the phosphorus loading that occurred over that model year was due to internal sediment loading and curly-leaf die-off and decay. Thus, reductions in internal loading during that model year will have a larger percent change in the total load than for other model years that had more precipitation.

While the in-lake phosphorus concentrations and loading reductions show positive responses to internal loading management, it is important to note that internal loading improvements are only temporary if external loading is not addressed. Internal loading has become an issue in North and South Cornelia due in part to the significant external nutrient loads that the lakes have received over time. While internal loading management can help address the nutrients already present in the sediment, the short-term and long-term effectiveness of the treatments can be reduced if external load reductions aren't also achieved.

Table 8-2 Total Phosphorus Load Reductions resulting from Internal Loading Management Efforts

Lake	Model Year	Current Load (lbs TP)	Lake Cornelia Alum Treatment		Lake Cornelia Curly-leaf Pondweed Treatment		Lake Cornelia Alum + Curly-leaf Pondweed Treatments	
			Model Load (lbs TP)	Percent Reduction (%)	Model Load (lbs TP)	Percent Reduction (%)	Model Load (lbs TP)	Percent Reduction (%)
North Cornelia	2015	456	402	12%	384	16%	330	28%
	2016	489	397	19%	489[1]	0%	397	19%
	2017	673	451	33%	598	11%	376	44%
South Cornelia	2015	442	356	19%	309	30%	223	50%
	2016	444	335	25%	342	23%	233	48%
	2017	525	356	32%	386	26%	216	59%
Lake Edina	2015	306	274	10%	267	13%	239	22%
	2016	430	371	14%	364	15%	305	29%
	2017	410	356	13%	330	20%	276	33%

[1] A phosphorus loading specifically attributable to curly-leaf pondweed die-off was not observed in North Cornelia in 2016; therefore, treating for curly-leaf pondweed in North Cornelia in 2016 has no effect on the total phosphorus load.

8.3 Lake Responses to Combined Internal and External Management

The most effective approach to managing lakes with significant internal and external sources of phosphorus is to implement a combination of internal and external management strategies. For lakes that have been exposed to significant external nutrient loading for extended periods of time, appreciable sediment and nutrients have accumulated in the lake bottom sediments. As nutrients continue to build-up over time, internal loading potential is heightened exasperating water quality conditions in the lake. This section looks at the effects of combined external and internal loading management on in-lake total phosphorus concentrations. This section also discusses the effects of combined management on total phosphorus summer averages and the percent changes to phosphorus loads.

The combined management scenarios analyzed for this UAA study are described below. Modeling of combined management scenarios was complex and time intensive due to the chain of lakes and number of modeled years. Accordingly, it was necessary to limit the number combination scenarios evaluated. Two of the four watershed management BMP scenarios (infiltration BMPs on commercial properties and spent lime/CC17 treatment chamber) were explicitly modeled to evaluate the effects of combined internal and external load reductions. These two watershed management scenarios represent a wide range of external phosphorus load reduction.

1) Infiltration BMPs on commercial properties with:
    a. Alum treatments in North and South Cornelia
    b. Curly-leaf pondweed treatments in North and South Cornelia
    c. Alum and curly-leaf pondweed treatments in North and South Cornelia
2) Spent Lime/CC17 treatment chamber with:
    a. Alum treatments in North and South Cornelia
    b. Curly-leaf pondweed treatments in North and South Cornelia
    c. Alum and curly-leaf pondweed treatments in North and South Cornelia

8.3.1 Changes in in-lake phosphorus concentrations

The P8 and calibrated in-lake models were used to predict the changes in total phosphorus concentration in each of the lakes throughout the summer months as a result of the various combined watershed and internal load management activities. Appendix F contains figures showing the effect of different combined management efforts on in-lake phosphorus concentrations in North Cornelia, South Cornelia, and Lake Edina for each modeled year.

8.3.2 Summer Average Total Phosphorus Concentrations

Table 8-3 provides a summary of the summer average (June through September) in-lake phosphorus concentrations under existing conditions and with the proposed combined management scenarios. The ultimate goal of lake management is to reach a summer average that falls below the MPCA standard of 60 µg/L.

8.3.2.1 Infiltration BMPs on Commercial Property + Internal Load Management

The combination of widespread implementation of infiltration BMPs and internal load management (alum treatment and curly-leaf pondweed management) represents the highest level of management modeled. Under this scenario, the reduction in summer average total phosphorus concentration ranges from 32% to 56% for North Cornelia. Despite this level of reduction, summer phosphorus concentration averages did not fall below 60 µg/L for any of the years modeled in this study. In South Cornelia, the summer average total phosphorus concentration met the MPCA's water quality standard for all three modeled years under the highest level of management. The reduction in summer average total phosphorus concentration under this scenario ranged from 61% to 69%. In Lake Edina, the reduction in summer average total phosphorus concentration under this scenario ranged from 24% to 48%. In 2017, the predicted summer average total phosphorus concentration was below MPCA's water quality standard.

Table 8-3 Comparison of total phosphorus summer average concentrations under existing conditions to combined management (internal and commercial infiltration BMPs) conditions

Lake	Model Year	Total Phosphorus Summer Average Concentration (µg/L)							
		Current Conditions	Internal Management			External Management	Internal + External Management		
			Lake Cornelia Alum Treatment	Lake Cornelia Curly-leaf Treatment	Lake Cornelia Alum + Curly-leaf Treatments	Commercial Infiltration BMPs	Commercial Infiltration BMPs + Alum Treatment	Commercial Infiltration BMPs + Curly-leaf Treatment	Commercial Infiltration BMPs + Alum + Curly-leaf Treatments
North Cornelia	2015	163	142	132	111	156	132	121	97
	2016	126	97	126[1]	97	119	86	119[1]	86
	2017	185	142	160	87	193	110	164	81
South Cornelia	2015	118	93	82	60	102	79	68	46
	2016	152	120	105	73	152	118	93	59
	2017	178	93	119	67	175	124	105	56
Lake Edina	2015	93	83	81	72	85	78	78	71
	2016	113	98	91	76	102	90	80	68
	2017	107	83	81	63	90	78	67	56

[1] A curly-leaf pondweed phosphorus loading was not observed in North Cornelia in 2016; therefore, treating for curly-leaf pondweed in North Cornelia in 2016 has no effect on the total phosphorus summer average concentrations.

8.3.2.2 Spent Lime/CC17 Treatment Chamber + Internal Load Management

Through the combination of a spent lime/CC17 treatment chamber with internal management efforts, larger percent reductions in the in-lake phosphorus concentrations were observed than modeling with an external management or internal management scenario on its own. Under this scenario (spent lime/CC17 treatment chamber + curly-leaf pondweed management + alum treatment) the reduction in summer average phosphorus concentrations ranged from 27% to 55% for North Cornelia. Despite this level of reduction, summer phosphorus concentration averages did not fall below 60 µg/L for any of the years modeled in this study. In South Cornelia, the reduction in summer average phosphorus concentrations ranged from 51% to 64% reduction for this scenario. For model year 2015, South Cornelia's total phosphorus summer average fell under the MPCA's water quality standard. Under this combined scenario, the reduction in summer average total phosphorus concentration in Lake Edina ranged from 23% to 43%. Despite this level of reduction, Lake Edina summer phosphorus concentration averages did not fall below 60 µg/L for any of the years modeled under this scenario.

Table 8-4 Comparison of total phosphorus summer average concentrations under existing conditions to combined management (internal and spent lime/CC17 treatment chamber) conditions

Lake	Model Year	Total Phosphorus Summer Average Concentration (µg/L)							
		Current Conditions	Internal Management			External Management	Internal + External Management		
			Lake Cornelia Alum Treatment	Lake Cornelia Curly-leaf Treatment	Lake Cornelia Alum + Curly-leaf Treatments	Spent Lime/CC17 Treatment Cell	Spent Lime/CC17 Treatment Cell + Alum Treatment	Spent Lime/CC17 Treatment Cell + Curly-leaf Treatment	Spent Lime/CC17 Treatment Cell + Alum + Curly-leaf Treatments
North Cornelia	2015	163	142	132	111	157	136	126	105
	2016	126	97	126[1]	97	121	92	121[1]	92
	2017	185	142	160	87	180	107	155	82
South Cornelia	2015	118	93	82	60	112	90	79	58
	2016	152	120	105	73	149	117	102	70
	2017	178	93	119	67	175	123	116	64
Lake Edina	2015	93	83	81	72	91	82	80	71
	2016	113	98	91	76	111	96	89	74
	2017	107	83	81	63	106	88	80	62

[1] A curly-leaf pondweed phosphorus loading was not observed in North Cornelia in 2016; therefore, treating for curly-leaf pondweed in 2016 has no effect on the total phosphorus load.

8.3.3 Phosphorus Loading Reductions

The in-lake total phosphorus concentrations of North and South Cornelia and Lake Edina are influenced over time through loading reductions. Table 8-5 provides a summary of the changes in total phosphorus loads to the lakes through the combined internal (alum treatments, curly-leaf pondweed treatments) and external management (commercial infiltration BMPs, spent lime/CC17 treatment cell) efforts.

Figure 8-9 shows the total phosphorus loads (in pounds) contributed to North Cornelia in 2017 after the various watershed and in-lake management practices are applied. In 2017, the existing conditions phosphorus load to North Cornelia was approximately 673 pounds, whereas when applying a management scenario that included commercial infiltration BMPs, alum treatment, and managing for curly-leaf pondweed (brown bar) the remaining load to North Cornelia in 2017 is approximately 251 pounds (a 63% reduction). Figure 8-10 shows the total phosphorus loads (in pounds) contributed to North Cornelia in 2017 after combinations of internal management and the spent lime/CC17 treatment chamber are applied to the models. The combination of a spent lime/CC17 treatment chamber with internal management efforts (alum treatment and curly-leaf pondweed management) results in a 48% phosphorus load reduction (in 2017).

A comprehensive summary of all of the loading bar graphs for the three lakes and three model years can be found in Appendix G.

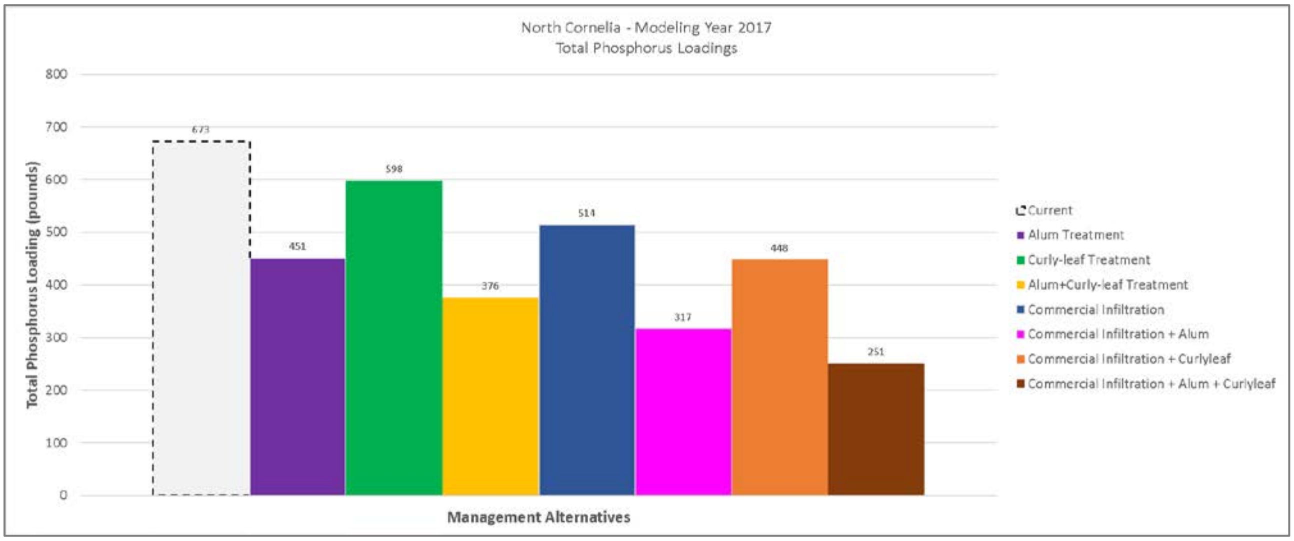


Figure 8-9 Remaining Total Phosphorus Load to North Cornelia in 2017 with various combinations of internal and external commercial infiltration management

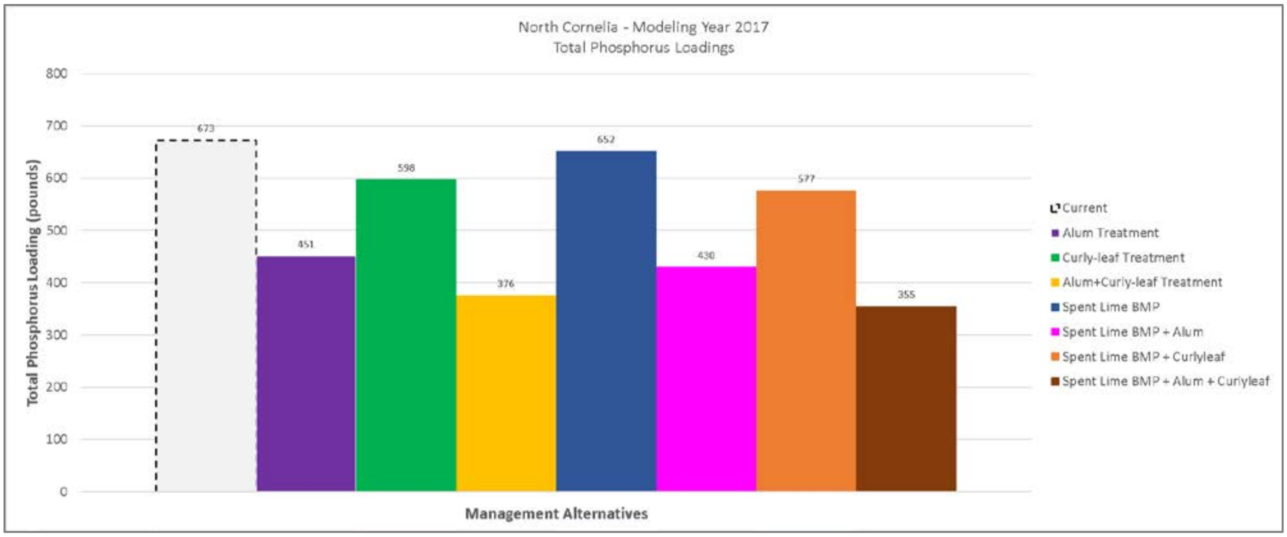


Figure 8-10 Remaining Total Phosphorus Load to North Cornelia in 2017 with various combinations of internal and external spent lime/CC17 management

Table 8-5 Total phosphorus load reductions summary for combined management (internal and external) conditions

Lake	Model Year	Current Load (lbs TP)	Total Phosphorus Load Percent Reductions (%)										
			Internal Management			External Management		Internal + External Management					
			Lake Cornelia Alum Treatment	Lake Cornelia Curly-leaf Treatment	Lake Cornelia Alum + Curly-leaf Treatments	Commercial Infiltration BMPs	Spent Lime/CC17 Treatment Cell	Commercial Infiltration BMPs + Alum Treatment	Commercial Infiltration BMPs + Curly-leaf Treatment	Commercial Infiltration BMPs + Alum + Curly-leaf Treatments	Spent Lime/CC17 Treatment Cell + Alum Treatment	Spent Lime/CC17 Treatment Cell + Curly-leaf Treatment	Spent Lime/CC17 Treatment Cell + Alum + Curly-leaf Treatments
North Cornelia	2015	456	12%	16%	28%	28%	4%	38%	42%	53%	16%	20%	32%
	2016	489	19%	0%[1]	19%	31%	4%	48%	31%[1]	48%[1]	23%	4%[1]	23%[1]
	2017	673	33%	11%	44%	24%	3%	53%	33%	63%	36%	14%	47%
South Cornelia	2015	442	18%	30%	50%	23%	2%	41%	51%	69%	21%	32%	52%
	2016	444	25%	23%	48%	22%	2%	44%	45%	67%	27%	25%	50%
	2017	525	32%	26%	59%	23%	2%	50%	48%	74%	34%	28%	61%
Lake Edina	2015	306	10%	13%	22%	29%	2%	35%	36%	42%	12%	14%	23%
	2016	430	14%	15%	29%	25%	1%	35%	38%	47%	15%	17%	30%
	2017	410	13%	20%	33%	29%	1%	36%	43%	50%	14%	20%	34%

[1] A curly-leaf pondweed phosphorus loading was not observed in North Cornelia in 2016; therefore, treating for curly-leaf pondweed in North Cornelia in 2016 has no effect on the total phosphorus load.

8.4 Management Alternatives Summary

Section 8.1, 8.2, and Section 8.3 discussed the various management alternatives that were modeled for North Cornelia, South Cornelia, and Lake Edina. These management alternatives included:

- External (Watershed) Management
  - Commercial Infiltration BMPs (treatment in North Cornelia and Lake Edina watersheds)
  - Commercial Filtrations BMPs (treatment in North Cornelia and Lake Edina watersheds)
  - Spent Lime/CC17 treatment chamber downstream of Swimming Pool Pond (North Cornelia watershed)
  - Weekly public street and private parking lot sweeping (North Cornelia, South Cornelia, and Lake Edina watersheds)
- Internal Management in North and South Cornelia
  - Alum Sediment Treatments
  - Curly-leaf Pondweed Treatments
  - Combined alum sediment and curly-leaf pondweed treatments
- Combined Internal and External Management
  - Commercial Infiltration BMPs (treatment in North Cornelia and Lake Edina watersheds) with:
    - Alum Sediment Treatments (North and South Cornelia)
    - Curly-leaf Pondweed Treatments (North and South Cornelia)
    - Combined alum sediment and curly-leaf pondweed treatments (North and South Cornelia)
  - Spent Lime/CC17 treatment cell downstream of Swimming Pool Pond (North Cornelia watershed) with:
    - Alum Sediment Treatments (North and South Cornelia)
    - Curly-leaf Pondweed Treatments (North and South Cornelia)
    - Combined alum sediment and curly-leaf pondweed treatments (North and South Cornelia)

Table 8-6 provides a summary of the summer average total phosphorus concentrations observed for each modeled alternative. Table 8-7 provides a summary of the total phosphorus loads observed for each modeled alternative. These loading values provided in the table represent the remaining load to the lakes after the listed treatment is applied to the models. As discussed in previous sections, comparing the phosphorus load reduction results to the summer average total phosphorus concentration results were not always straightforward. When a proposed management alternative included water balance adjustments (e.g., reduced runoff through enhanced infiltration in the watershed), reductions in phosphorus loads did not always correspond to comparable reductions in summer average total phosphorus concentrations. If the volume of water in the lake was reduced to a greater extent than the total phosphorus load in the lake, the summer average concentration could increase or not decrease as much as anticipated. For example, when viewing the management alternative that included commercial infiltration BMPs with alum sediment treatments, the average total phosphorus load reduction to North Cornelia was approximately 47% for the three modeled years (existing average load = 539 pounds; management average load = 285 pounds). Of the management alternatives investigated in this study, commercial infiltration BMPS with alum sediment treatment resulted in the second highest reduction in total phosphorus loads to North Cornelia. The only management alternative that resulted in a greater reduction in total phosphorus loads was the alternative that included commercial infiltration BMPS with combined alum sediment and curly-leaf pondweed treatments. However, the percent reduction in the mean summer average total phosphorus concentration of the three modeled years for the commercial infiltration BMPS with alum sediment treatments scenario was approximately 31% (existing average summer average concentration = 158 µg/L; management average summer average concentration = 109 µg/L). Of the management alternatives investigated in this study, commercial infiltration BMPS with alum sediment treatment resulted in the fourth highest reduction in total phosphorus summer average concentrations in North Cornelia. Management alternatives, such as alum sediment + curly-leaf pondweed treatments, which resulted in lower load reductions to North Cornelia, resulted in higher percent reductions in summer average phosphorus concentrations.

Discrepancies in North Cornelia's in-lake concentrations and total phosphorus load reductions occurred in the models when lake volume reductions arose from enhanced infiltration and when all internal loading was not managed. Continuing with the example above, in-lake phosphorus concentrations where not reduced to the same extent as phosphorus loads because curly-leaf loading was permitted in the models under this management scenario. Commercial infiltration BMPs reduced the volume of runoff reaching North Cornelia and as a result, the volume of water in North Cornelia was less under proposed conditions. When the lake volume was reduced and when the same loading (as calibrated for existing conditions) from curly-leaf pondweed death/decay occurred, the model resulted in increased concentrations during this time period. This suggests that if water balance adjustments are expected for the lakes, management of internal loads will be imperative to control in-lake concentrations. Water balance adjustments would not only include runoff reductions due to infiltration practices, but would also include water volume changes due to climate impacts. Adjustments to the water balance from climate could include more frequent, high-intensity precipitation events coupled with prolonged dry periods. Alterations to snowpack accumulations is another example. This was observed in 2015 when lower-than-average snowpack accumulated resulting in lower-than-average spring snowmelt and reduced lake levels.

Table 8-6 and Table 8-7 show the relative changes to in-lake phosphorus concentrations and phosphorus loads that could occur from applying various management scenarios. The next section will look into the costs and benefits of the different management alternatives.

Table 8-6 Comparison of total phosphorus summer average concentrations for all modeled management scenarios

Lake	Model Year	Total Phosphorus Summer Average Concentration (µg/L)													
			Internal Management			External Management				Internal + External Management					
		Current Conditions	Lake Cornelia Alum Treatment	Lake Cornelia Curly-leaf Treatment	Lake Cornelia Alum + Curly-leaf Treatments	Commercial Infiltration BMPs	Spent Lime/CC17 Treatment Cell	Commercial Filtration BMPs	Weekly Street/Lot Sweeping	Commercial Infiltration BMPs + Alum Treatment	Commercial Infiltration BMPs + Curly-leaf Treatment	Commercial Infiltration BMPs + Alum + Curly-leaf Treatments	Spent Lime/CC17 Treatment Cell + Alum Treatment	Spent Lime/CC17 Treatment Cell + Curly-leaf Treatment	Spent Lime/CC17 Treatment Cell + Alum + Curly-leaf Treatments
North Cornelia	2015	163	142	132	111	156	157	147	141	132	121	97	136	126	105
	2016	126	97	126[1]	97	119	121	113	107	86	119[1]	86	92	121[1]	92
	2017	185	142	160	87	193	180	174	170	110	164	81	107	155	82
	Average	**158**	**127**	**139**	**98**	**156**	**153**	**145**	**139**	**109**	**134**	**88**	**112**	**134**	**93**
South Cornelia	2015	118	93	82	60	102	112	110	105	79	68	46	90	79	58
	2016	152	120	105	73	152	149	144	137	118	93	59	117	102	70
	2017	178	93	119	67	175	175	172	165	124	105	56	123	116	64
	Average	**149**	**102**	**102**	**67**	**143**	**145**	**142**	**136**	**107**	**89**	**53**	**110**	**99**	**64**
Lake Edina	2015	93	83	81	72	85	91	86	72	78	78	71	82	80	71
	2016	113	98	91	76	102	111	107	93	90	80	68	96	89	74
	2017	107	83	81	63	90	106	103	91	78	67	56	88	80	62
	Average	**104**	**88**	**84**	**70**	**92**	**103**	**99**	**85**	**82**	**75**	**65**	**89**	**83**	**69**

[1] A curly-leaf pondweed phosphorus loading was not observed in North Cornelia in 2016; therefore, treating for curly-leaf pondweed in North Cornelia in 2016 has no effect on the total phosphorus summer average concentrations.

Table 8-7 Comparison of total phosphorus loads for all modeled management scenarios

Lake	Model Year	Total Phosphorus Load (lbs)												
			Internal Management			External Management				Internal + External Management					
		Current Conditions	Lake Cornelia Alum Treatment	Lake Cornelia Curly-leaf Treatment	Lake Cornelia Alum + Curly-leaf Treatments	Commercial Infiltration BMPs	Spent Lime/CC17 Treatment Cell	Commercial Filtration BMPs	Weekly Street/Lot Sweeping	Commercial Infiltration BMPs + Alum Treatment	Commercial Infiltration BMPs + Curly-leaf Treatment	Commercial Infiltration BMPs + Alum + Curly-leaf Treatments	Spent Lime/CC17 Treatment Cell + Alum Treatment	Spent Lime/CC17 Treatment Cell + Curly-leaf Treatment	Spent Lime/CC17 Treatment Cell + Alum + Curly-leaf Treatments
North Cornelia	2015	456	402	384	330	329	438	408	390	281	264	216	384	366	312
	2016	489	397	489[1]	397	337	467	432	411	256	337[1]	256	375	467[1]	375
	2017	673	451	598	376	514	652	625	603	317	448	251	430	577	355
	Average	**539**	**417**	**490**	**368**	**393**	**519**	**488**	**468**	**285**	**350**	**241**	**396**	**470**	**347**
South Cornelia	2015	442	356	309	223	341	433	416	397	262	218	139	347	299	213
	2016	444	335	342	233	347	433	419	396	250	245	148	324	331	222
	2017	525	356	386	216	406	516	507	485	265	275	136	347	377	207
	Average	**470**	**349**	**346**	**224**	**365**	**461**	**447**	**426**	**259**	**246**	**141**	**339**	**336**	**214**
Lake Edina	2015	306	274	267	239	217	299	288	237	199	195	176	270	263	235
	2016	430	371	364	305	321	424	407	347	280	267	226	365	358	299
	2017	410	356	330	276	290	405	395	340	261	233	205	352	326	272
	Average	**382**	**334**	**320**	**273**	**276**	**376**	**363**	**308**	**247**	**232**	**202**	**329**	**316**	**269**

[1] A curly-leaf pondweed phosphorus loading was not observed in North Cornelia in 2016; therefore, treating for curly-leaf pondweed in North Cornelia in 2016 has no effect on the total phosphorus load.

9.0 Cost-Benefit of Management Efforts

9.1 Opinions of Probable Cost for Modeled Scenarios

Planning-level opinions of probable cost were developed for each of the evaluated management alternatives. These opinions of cost are intended to provide assistance in evaluating and comparing alternatives and should not be assumed as absolute values. The estimated costs are summarized in Table 9-1. Detailed opinions of probable cost are included in Appendix H.

The opinions of probable cost summarized in Table 9-1 generally correspond to standards established by the Association for the Advancement of Cost Engineering (AACE). Class 5 feasibility-level opinions of costs were used for most of the management practices based on the limited project definition, wide-scale use of parametric models to calculate estimated costs (i.e., making extensive use of order-of-magnitude costs from similar projects), and uncertainty, with an acceptable range of between -30% and +50% of the estimated project cost. The opinions of probable cost for the alum treatment and curly-leaf pondweed treatments are considered Class 2 level cost estimates, with an acceptable range of between -10% and +20%.

Table 9-1 Planning-level cost estimates for modeled management alternatives

Description	Planning-Level Cost Estimate[1]	Planning-Level Cost Range	Estimated Life of Project
Lake Cornelia Alum Treatment	$161,000	$145,000 - $194,000	5 years
Lake Cornelia Curly-leaf Pondweed Management (annual)	$12,000	$11,000 - $15,000	1 year
Commercial Infiltration BMPs	$15,855,000	$11,100,000 - $23,780,000	30 years
Commercial Filtration BMPs	$15,855,000	$11,100,000 - $23,780,000	30 years
Spent Lime/CC17 Treatment Chamber	$588,000	$412,000 - $882,000	30 years
Weekly Street/Lot Sweeping	$1,060,000[2]	$742,000 - $1,590,000	10 years

[1] Planning-level cost estimates do not include annual costs for operations and maintenance, with exception of the weekly street sweeping which includes annual operational costs.
[2] Cost estimate includes $727,000 capital costs plus $333,000 annual operation costs

9.1.1 Cost Details for Modeled

9.1.1.1 Sediment Alum Treatments

The opinion of cost for the alum treatment of the North and South Lake Cornelia sediments is based on correspondence with an alum application contractor and previous project applications. The assumptions for the alum treatment opinion of costs are:

- Dose equivalent of 29,238 gallons of alum applied to North Cornelia
- Dose equivalent of 16,431 gallons of alum applied to South Cornelia

9.1.1.2 Curly-leaf Pondweed Management

The opinion of cost for the management of curly-leaf pondweed in North Lake Cornelia and South Lake Cornelia is based on recent herbicide treatment efforts conducted by the City of Edina. The cost estimate assumes that management will be coordinated by the City of Edina (as is conducted currently), and that a dose of 5.0 ppm active ingredient will be used for 7.4 acres of treatment area. The opinion of cost does not include costs related to permitting or monitoring and reporting that may be required as part of permitting (e.g., temperature monitoring, herbicide residual monitoring, follow-up aquatic plant surveys, and/or water quality monitoring).

9.1.1.3 Commercial Infiltration and Filtration BMPS

The opinion of costs for the commercial infiltration and filtration BMPs used a planning-level unit cost of $15 per cubic foot of storage area. This unit cost assumes that all infiltration and filtration BMPs are constructed as subsurface treatment areas. A construction contingency of 30% and an engineering and design percentage of 30% was applied to the construction cost. Maintenance costs were estimated to be approximately 10% of the total project cost.

9.1.1.4 Spent Lime/CC17 Treatment Chamber

An itemized opinion of cost was developed for the Spent Lime/CC17 Treatment Chamber based on correspondence with manufacturers and previous project implementation. A construction contingency of 30% and an engineering and design percentage of 30% was applied to the construction cost. An estimated accuracy range of -30% to 50% was applied to the final project cost due to the limited design work completed for the treatment chamber. Maintenance costs assumed a debris removal estimate of $200 per year and assumed that the treatment material (spent lime and CC17 aggregate) would need full replacement every 2 years.

9.1.1.5 Weekly Street and Lot Sweeping

The weekly street and lot sweeping unit costs were based, in part, on the values summarized in the City of Edina, MN Street Sweeping Management Plan (Emmons & Olivier Resources, Inc. (EOR), 2015). The assumptions used to develop the opinion of cost are:

- The cost of a new Crosswind 4-Wheel Regenerative Air Sweeper is approximately $210,000 and the buy-back cost after 10 years of use is approximately $20,000.

- Within the North Lake Cornelia, South Lake Cornelia, and Lake Edina watersheds there is approximately 67.3 miles of sweepable public street curb and 80.4 miles of sweepable parking lot area.
- Sweeper operation speed is estimated at 4.5 miles per hour and average fuel consumption is 5 miles per gallon.
- The sweeping path width of a high efficiency, two-sided broom sweeper with a pick-up head is approximately 12 feet.
- 1.5 hours of labor is needed for every 4 hours of sweeping time.
- Total transit (brush off) is about 3 times the total amount of swept miles.
- The maximum number of hours worked in one week by a single worker is 40 hours.
- Sweeping occurs on a weekly basis May through November (~30 weeks).
- Labor cost = $75/hour
- Fuel cost = $3.00/gallon
- Sweeper Maintenance cost = $4,800/year
- The City of Edina is responsible for the operations and maintenance of the street sweeping program.
- The City of Edina already owns one high efficiency sweeper.

Using the outlined assumptions, to sweep all of the public streets and private parking lots in the Lake Cornelia and Lake Edina watersheds on a weekly basis, four high efficiency regenerative air sweepers would be needed. Since the City of Edina currently owns one high-efficiency regenerative air sweeper, the opinion of cost assumes three additional high-efficiency regenerative sweepers would be purchased. Vehicle maintenance, labor, and fuel costs as summarized as annual costs.

9.2 Cost-Benefit Analysis

The management strategies considered to help improve water quality in Lake Cornelia and Lake Edina are wide ranging in type, scale, cost, and effectiveness. Some strategies include structural BMPs with large, upfront capital costs, whereas others are more programmatic or may require periodic or annual repeat. To account for these variations, a comparison of cost-benefit of the potential management strategies was conducted. Results of the cost-benefit analysis help to understand the value derived, and associated costs, for each management practice and combinations thereof.

Estimated costs for the evaluated management activities were annualized to help compare the cost-benefit ratio. The annualized cost for each management alternative is based on anticipated maintenance, replacement costs, and anticipated useful life-span of the projects/treatments. A 3% inflation rate was assumed. The annualized cost for each alternative is calculated as the value of ‘n’ equal, annual payments, where 'n' is the anticipated useful life-span of the project or treatment. The annualized cost estimates for each management alternative are summarized in Table 9-2.

For the cost-benefit analysis, two approaches were considered to quantify the benefits of each of the evaluated management activities. The first approach quantifies the benefit in terms of phosphorus removed (in pounds) during the time period of April through September (i.e., phosphorus that did not enter the lake system as a result of the management practice). The second approach quantifies the benefit in terms of reduced summer average total phosphorus concentration in the respective lakes (June through September). Table 9-2 summarizes the results of the cost-benefit analysis for both of these cost-benefit approaches, since total phosphorus load reductions to the lakes did not always result in the same level of in-lake phosphorus concentration reductions.

Figure 9-1 compares the cost-benefit of each of the individual modeled management activities in terms of lake water quality improvement (reductions in respective in-lake summer average total phosphorus concentrations in µg/L). The internal loading management alternatives (curly-leaf pondweed treatment and alum treatment in Lake Cornelia) result in the lowest annualized costs per unit reduction in summer average in-lake phosphorus concentrations. Of the four watershed management alternatives evaluated in this UAA study, the spent lime/CC17 treatment chamber is the most cost effective, with the lowest annualized cost per unit benefit for all three lakes. While the street sweeping alternative has higher costs per unit benefit in comparison with the spent lime/CC17 treatment chamber, it has a much lower cost per unit benefit than the infiltration and filtration BMPs on commercial property scenarios. Estimated costs for these scenarios assumed that all infiltration/filtration practices would be subsurface, which corresponds with stormwater management trends observed in recent years as redevelopment has occurred throughout the watershed. Promoting impervious area reduction (less parking lot) and installation of surface BMPs could reduce costs and improve the cost-benefit.

As described in Section 8.3, the most effective approach to managing lakes with significant internal and external sources of phosphorus is to implement a combination of internal and external management strategies. Figure 9-2 compares the cost-benefit of the combined internal and external watershed management activities that were modeled in terms of lake water quality improvement. As compared to Figure 9-1, the watershed management activities have a significantly lower cost per unit benefit when combined with internal loading activities. Of the combined internal and external load management scenarios modeled, the spent lime/CC17 treatment chamber with curly-leaf pondweed management and alum treatment provides the lowest annualized cost per unit benefit in lake water quality for all three lakes.

Table 9-2 Cost-Benefit Summaries for North Cornelia, South Cornelia, and Lake Edina for Modeled Management Alternatives

Lake	Description	Management Type	Estimated Annualized Cost	Average Pounds of TP Load Removed (April - Sept)	Annualized Cost per Pound of TP Removed (April - Sept)	Summer Average TP Concentration Reduction in µg/L (June - Sept)	Annualized Cost per µg/L Reduction in Summer Average TP Concentration (June - Sept)
North Cornelia	Lake Cornelia Alum Treatment	Internal	$35,000	123	$300	31	$1,100
	Lake Cornelia Curly-leaf Treatment	Internal	$12,000	49	$200	19	$600
	Lake Cornelia Alum + Curly-leaf Treatments	Combined	$47,000	172	$300	59	$800
	Commercial Infiltration BMPs	External	$2,394,000	146	$16,400	7[1]	$342,000
	Spent Lime/CC17 Treatment Cell	External	$31,000	20	$1,500	5	$5,900
	Commercial Filtration BMPs	External	$2,394,000	51	$46,900	13	$180,100
	Weekly Street/Lot Sweeping	External	$418,000	71	$5,900	19	$22,400
	Commercial Infiltration BMPs + Alum Treatment	Combined	$2,429,000	255	$9,500	49	$49,900
	Commercial Infiltration BMPs + Curly-leaf Treatment	Combined	$2,429,000	190	$12,800	23	$103,500
	Commercial Infiltration BMPs + Alum + Curly-leaf Treatments	Combined	$2,441,000	298	$8,200	70	$34,800
	Spent Lime/CC17 Treatment Cell + Alum Treatment	Combined	$66,000	143	$500	46	$1,400
	Spent Lime/CC17 Treatment Cell + Curly-leaf Treatment	Combined	$43,000	69	$600	24	$1,800
	Spent Lime/CC17 Treatment Cell + Alum + Curly-leaf Treatments	Combined	$78,000	192	$400	65	$1,200
South Cornelia	Lake Cornelia Alum Treatment	Internal	$35,000	121	$300	47	$700
	Lake Cornelia Curly-leaf Treatment	Internal	$12,000	125	$100	47	$300
	Lake Cornelia Alum + Curly-leaf Treatments	Combined	$47,000	246	$200	83	$600
	Commercial Infiltration BMPs	External	$2,394,000	106	$22,700	6	$382,900
	Spent Lime/CC17 Treatment Cell	External	$31,000	10	$3,200	4	$7,900
	Commercial Filtration BMPs	External	$2,394,000	23	$104,100	7	$330,100
	Weekly Street/Lot Sweeping	External	$418,000	44	$9,400	14	$30,800
	Commercial Infiltration BMPs + Alum Treatment	Combined	$2,429,000	211	$11,500	42	$57,400
	Commercial Infiltration BMPs + Curly-leaf Treatment	Combined	$2,429,000	224	$10,800	61	$40,100
	Commercial Infiltration BMPs + Alum + Curly-leaf Treatments	Combined	$2,441,000	329	$7,400	96	$25,500
	Spent Lime/CC17 Treatment Cell + Alum Treatment	Combined	$66,000	131	$500	39	$1,700
	Spent Lime/CC17 Treatment Cell + Curly-leaf Treatment	Combined	$43,000	135	$300	50	$900
	Spent Lime/CC17 Treatment Cell + Alum + Curly-leaf Treatments	Combined	$78,000	256	$300	85	$900
Lake Edina	Lake Cornelia Alum Treatment	Internal	$35,000	48	$700	16	$2,200
	Lake Cornelia Curly-leaf Treatment	Internal	$12,000	62	$200	20	$600
	Lake Cornelia Alum + Curly-leaf Treatments	Combined	$47,000	109	$400	34	$1,400
	Commercial Infiltration BMPs	External	$2,394,000	106	$22,600	12	$198,600
	Spent Lime/CC17 Treatment Cell	External	$31,000	6	$5,200	2	$18,000
	Commercial Filtration BMPs	External	$2,394,000	19	$128,300	6	$418,200
	Weekly Street/Lot Sweeping	External	$418,000	74	$5,600	19	$21,900
	Commercial Infiltration BMPs + Alum Treatment	Combined	$2,429,000	135	$17,900	22	$108,800
	Commercial Infiltration BMPs + Curly-leaf Treatment	Combined	$2,429,000	150	$16,200	29	$82,700
	Commercial Infiltration BMPs + Alum + Curly-leaf Treatments	Combined	$2,441,000	180	$13,600	40	$61,500
	Spent Lime/CC17 Treatment Cell + Alum Treatment	Combined	$66,000	53	$1,200	16	$4,200
	Spent Lime/CC17 Treatment Cell + Curly-leaf Treatment	Combined	$43,000	66	$600	22	$2,000
	Spent Lime/CC17 Treatment Cell + Alum + Curly-leaf Treatments	Combined	$78,000	113	$700	36	$2,200

[1] Value reported represents the 2015 and 2016 summer average TP concentration reduction (µg/L). Water volume changes were significant in model year 2017, which negatively impacted in-lake TP concentrations due to existing internal loading. It is recommended that internal loading management occur concurrently with watershed infiltration practices.

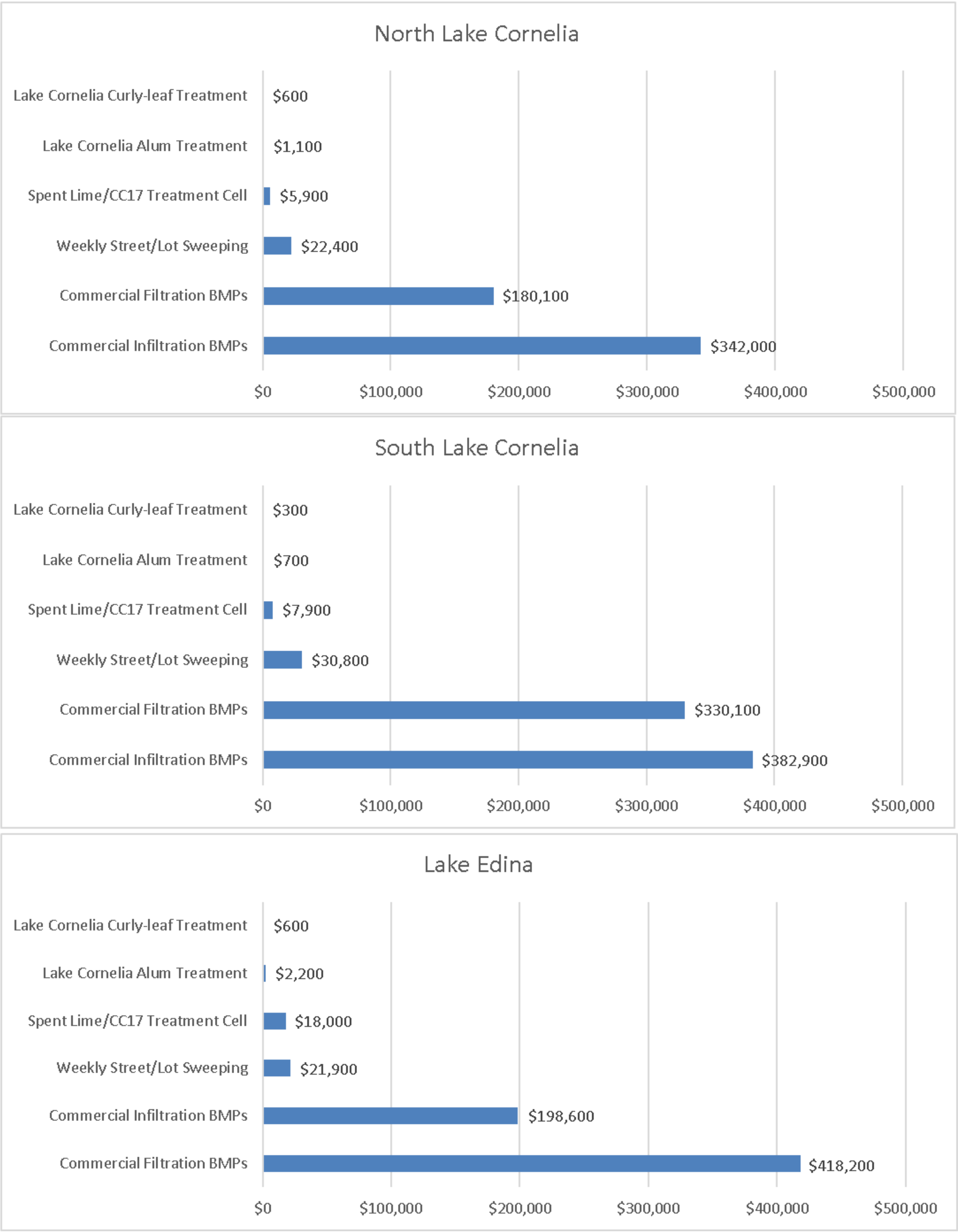


Figure 9-1 **Annualized cost per unit reduction (µg/L) in summer average total phosphorus concentration for individual management practices**

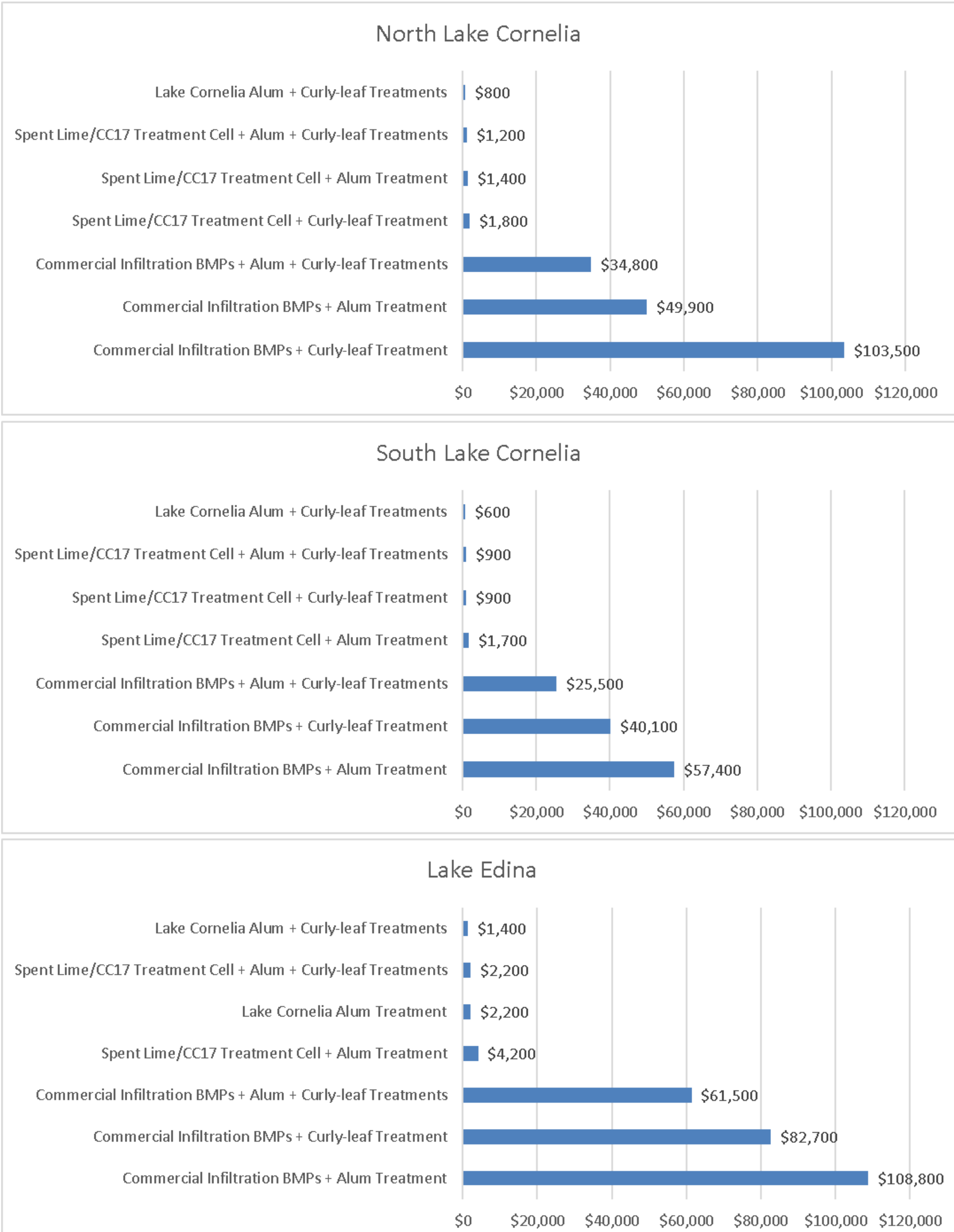


Figure 9-2 Annualized cost per unit reduction (µg/L) in summer average total phosphorus concentration for combined management practices

10.0 Conclusions and Recommendations

Water quality in Lake Cornelia is poor, with summer average total phosphorus and chlorophyll *a* concentrations well above the state standard for shallow lakes. The poor water quality is a result, in part, of excess phosphorus in the lake, which fuels algal production and decreases water clarity. Fish activity, specifically the disruption caused by bottom-feeding species such as bullhead and goldfish, may also be hampering water clarity. Poor water clarity (cloudy water) and the pervasive presence of invasive curly-leaf pondweed are stressors on the aquatic plant community, which generally fails to meet the MDNR Lake Plant Eutrophication Index of Biologic Integrity due to the limited number of species and quality of the plant community.

Water quality in Lake Edina is also poor, with summer average total phosphorus and chlorophyll *a* concentrations generally not meeting the state standard for shallow lakes. The aquatic plant community also does not meet the MDNR Lake Plant Eutrophication Index of Biologic Integrity due to the limited number of species and quality of the plant community. Invasive curly-leaf pondweed and Eurasian watermilfoil are both present within the lake. In recent years, curly-leaf pondweed was observed at low levels in two areas on the west side of the lake. Eurasian watermilfoil is widespread throughout the shallow lake.

10.1 Phosphorus Sources

Watershed and in-lake modeling was conducted to quantify the sources of phosphorus for Lake Cornelia and Lake Edina. External phosphorus loading from the watershed is the major contributor of phosphorus to North Cornelia, ranging from 48% to 76% in modeled years. Internal sediment loading (14% to 40%) and curly-leaf pondweed die-off/decay (0% to 16%) also contribute significant amounts of phosphorus to North Cornelia.

The main contribution of phosphorus to South Cornelia comes from North Cornelia, ranging from 54% to 56% of the total phosphorus load in modeled years. The second major contribution of phosphorus to South Cornelia is from the die-off and decay of curly-leaf pondweed (19% to 23%) and the third is sediment internal loading (14% to 19%). For South Cornelia, direct watershed phosphorus loading does contribute phosphorus, but to a much smaller extent than the other sources due to the relatively small size of the direct watershed (13% of the size of the direct watershed to North Cornelia).

The two main sources of phosphorus loading to Lake Edina are the upstream lakes (North and South Cornelia) and the direct watershed runoff. Internal phosphorus loading from sediments or curly-leaf pondweed die-off/decay is minimal in Lake Edina.

10.2 Management Strategies

The watershed and in-lake models were used to predict changes in in-lake phosphorus concentrations in North Lake Cornelia, South Lake Cornelia, and Lake Edina as a result of various external (watershed) and internal management strategies. The four external management strategies modeled were (1) infiltration BMPs on commercial properties, (2) filtration BMPs on commercial properties, (3) a spent lime/CC17 treatment chamber downstream of Swimming Pool Pond (North Cornelia watershed), and (4) weekly watershed-wide street sweeping. The internal management strategies modeled were (1) alum sediment treatment in Lake Cornelia and (2) curly-leaf pondweed management in Lake Cornelia.

The internal phosphorus load reduction strategies were limited to Lake Cornelia and did not include Lake Edina. Model calibration and sediment cores retrieved from Lake Edina in 2018 indicate that internal phosphorus loading from sediments is minimal. Furthermore, while small growths of curly-leaf pondweed were discovered in Lake Edina in recent years, no curly-leaf pondweed phosphorus loading response was found during model calibration for model years 2015, 2016, and 2017. Although, internal management strategies were only applied to North and South Lake Cornelia, Lake Edina water quality is heavily influenced by Lake Cornelia discharges. Therefore, any management efforts focused on North and South Cornelia (whether internal or external) will have an impact on the water quality of Lake Edina.

10.2.1 In-lake Phosphorus Management

Model results indicate that management efforts directed at treating the sources of the internal phosphorus loading will result in significant water quality improvements. Based on the 3 years modeled in this study (2015, 2016, and 2017), the treatment of the lake's sediments with alum and the management of curly-leaf pondweed reduces the summer average total phosphorus concentrations by 23%, 34%, and 20% in North Lake Cornelia, South Lake Cornelia, and Lake Edina respectively (Figure 10-1). These percent reductions are based on the average reductions modeled for 2015, 2016, and 2017. While large reductions in the summer average total phosphorus concentrations are achieved with dual internal management of the sediments and curly-leaf pondweed, these management efforts alone do not improve the lake water quality enough to meet the MPCA's water quality standard (<60 µg/L). This indicates that external management efforts should also be considered within the watersheds.

10.2.2 External (Watershed) Phosphorus Management

Reducing external phosphorus loading is an important part of any lake management strategy. For lakes like Lake Cornelia that have been exposed to significant external nutrient loadings for extended periods of time, appreciable sediment and nutrients have accumulated in the lake bottom sediments. As contributions from the watershed continue, phosphorus will continue to build-up over time in the lake sediments; increasing the internal loading potential and worsening water quality conditions in the lake.

Several external management practices were evaluated to assess their effectiveness in reducing the phosphorus concentrations in Lake Cornelia and Lake Edina. While each of the watershed management practices resulted in predicted improvements in water quality in Lake Cornelia and Lake Edina, the spent lime/CC17 treatment chamber located upstream of North Cornelia results in the greatest predicted improvements per unit cost.

Model results indicate that implementation of external phosphorus load reductions results in improved water quality; however, the predicted incremental improvements are not as significant as those achieved by the internal load reductions. Figure 10-1 shows the predicted summer average total phosphorus concentrations for the spent lime/CC17 treatment chamber in combination with alum treatment and curly-leaf pondweed management in comparison with existing conditions and the dual internal management scenario. While the incremental improvements in predicted lake water quality are not sufficient to meet the state standard (<60 µg/L), the spent lime/CC17 treatment chamber does substantially reduce the phosphorus load to the lakes. The phosphorus load from the 410-acre tributary watershed is reduced by approximately 15% and the total external phosphorus load to North Cornelia is reduced by approximately 7%.

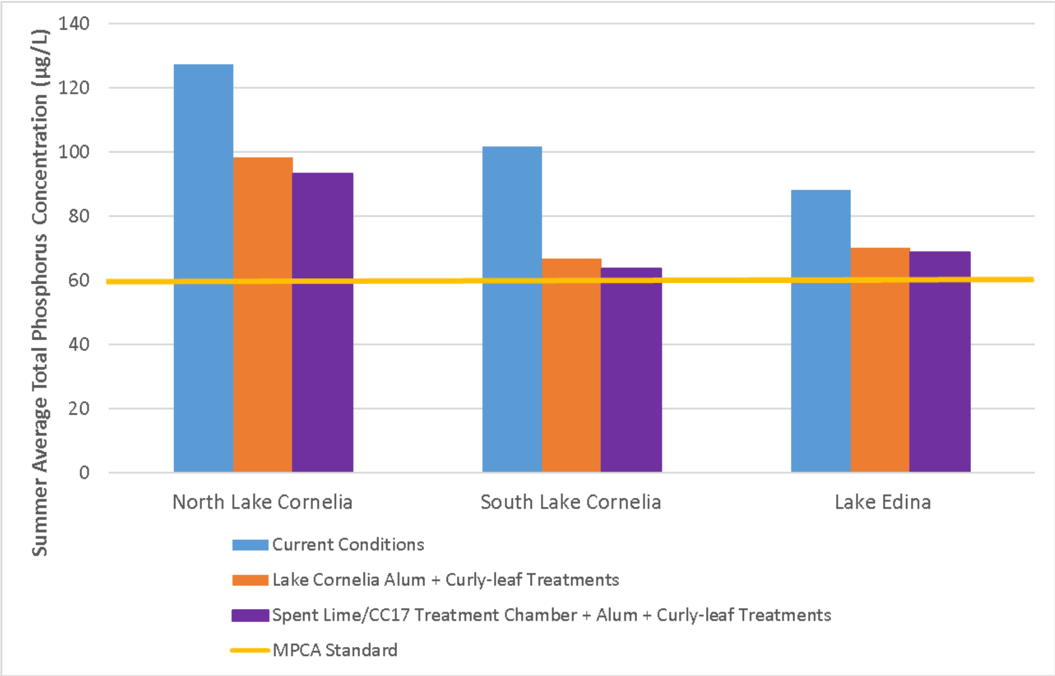


Figure 10-1 Comparison of summer average total phosphorus concentrations (µg/L) for recommended management alternatives

10.2.3 Responses in Chlorophyll *a* Concentrations and Water Clarity

The in-lake model developed for this study predicts changes in phosphorus concentration as a result of various management scenarios. Lake-specific regression relationships were used to estimate the corresponding changes in chlorophyll *a* concentrations and Secchi disc transparency based on the management efforts. Figure 10-2 shows the estimated improvements in summer average chlorophyll *a* concentrations for the internal phosphorus management scenario (alum treatment and curly-leaf pondweed management) and the spent lime/CC17 treatment chamber plus internal management scenario. Figure 10-3 shows the estimated improvements in summer average water clarity for the internal phosphorus management scenario (alum treatment and curly-leaf pondweed management) and the spent lime/CC17 treatment chamber plus internal management scenario.

It should be noted that the response of chlorophyll *a* and Secchi disc depth to total phosphorus changes is highly variable. Due to the high variability, the regression equations can be expected only to provide general indication of the lake response to changing total phosphorus concentrations, and the predicted chlorophyll *a* and Secchi disc depth values should not be construed as absolute.

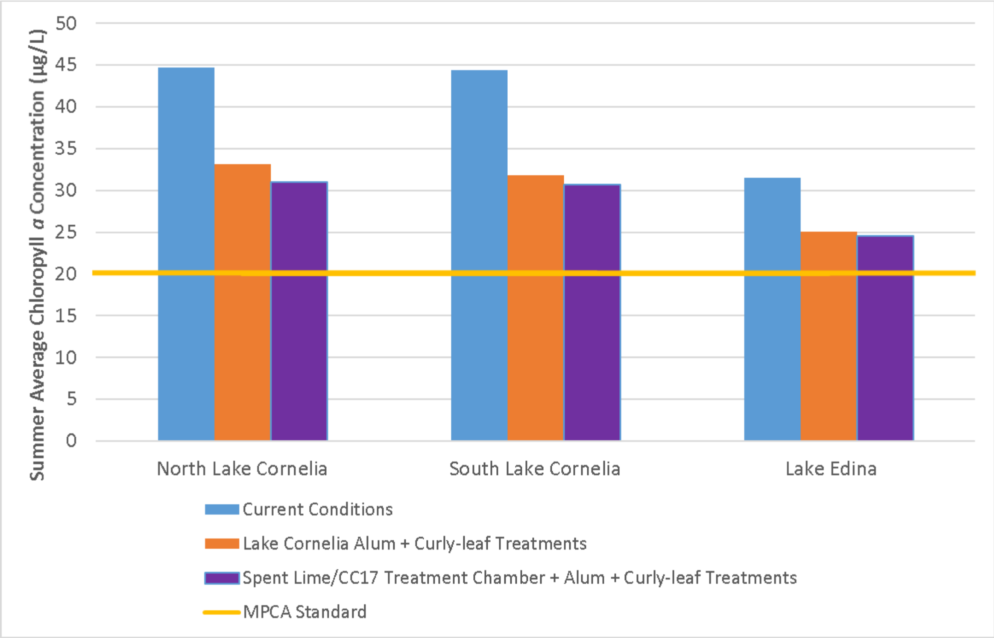


Figure 10-2 Summer average chlorophyll *a* concentrations (µg/L) for recommended management alternatives

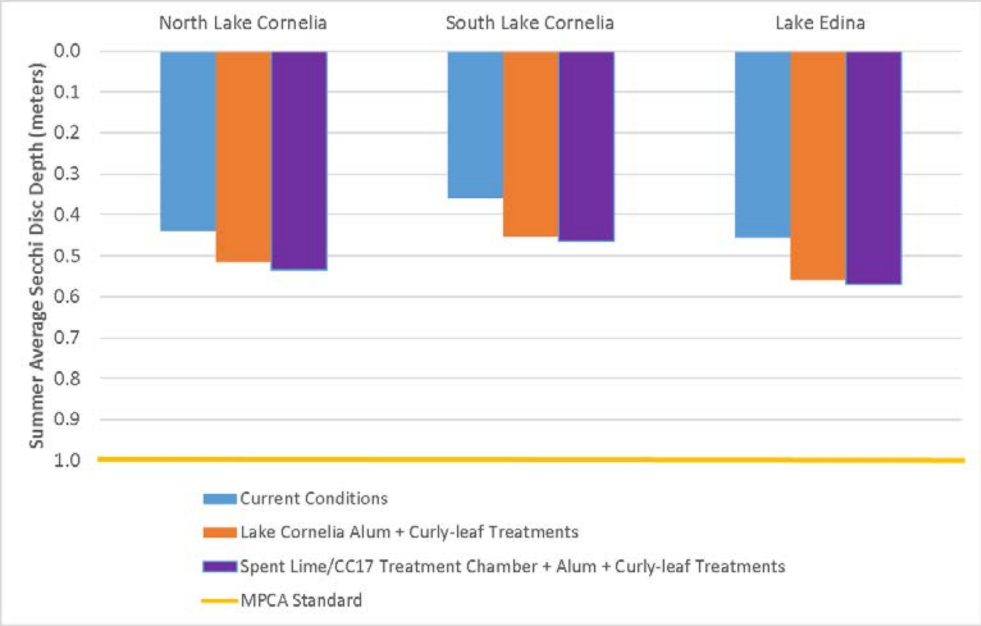


Figure 10-3 Summer average Secchi disc depths (m) for recommended management alternatives

10.2.4 Recommended Management Practices

The recommended management practices to improve water quality in Lake Cornelia include alum treatment and curly-leaf pondweed management in Lake Cornelia (North and South) to target internal phosphorus sources and watershed management practices to target external phosphorus sources. Management of the benthivorous fish community is also recommended to reduce the disturbance of bottom sediments and promote a healthy and more diverse fishery. While model results indicate that alum treatment and curly-leaf pondweed management in Lake Cornelia, in combination with implementation of watershed management practices, do not result in attainment of the water quality goals for Lake Cornelia (see Figure 10-1), benthivorous fish management and enhancement of the native aquatic plant population may result in significant additional gains in water quality improvement.

Water quality in Lake Edina is highly influenced by the water quality of Lake Cornelia. Accordingly, the recommended management strategy for improving the water quality in Lake Edina is to implement the management practices recommended for Lake Cornelia. In addition to upstream improvements, opportunities to reduce the phosphorus loading from the direct watershed to Lake Edina should be considered. Management of the invasive aquatic plants, curly-leaf pondweed and Eurasian watermilfoil, in Lake Edina is also recommended. These management practices are discussed in further detail below.

Table 10-1 summarizes the planning-level opinions of probable cost for each of the recommended management practices. These opinions of cost are intended to provide assistance in evaluating and comparing alternatives and should not be assumed as absolute values. All estimated costs are presented in 2019 dollars and include costs for engineering and project administration.

Table 10-1 Planning-level cost estimates for recommended management alternatives

Description	Management Type	Planning-Level Cost Estimate[1]
Lake Cornelia Alum Treatment	Internal	$161,000
Lake Cornelia Curly-leaf Pondweed Management (annual)	Internal	$12,000
Spent Lime/CC17 Treatment Chamber[2]	Watershed	$588,000
Direct Oxygen Injection System	Internal	$122,000
Lake Edina Curly-leaf Pondweed and Eurasian Watermilfoil Management (annual, as needed)	Internal	$30,000

10.2.4.1 In-lake Phosphorus Management

Curly-leaf Pondweed Management

The City of Edina has been conducting herbicide treatments in Lake Cornelia in recent years to reduce the impact of curly-leaf pondweed die-back on water quality and promote a healthy native aquatic plant population. Continued curly-leaf pondweed management is recommended, which would likely consist of continued herbicide treatments at a treatment dose such that a lethal dose is attained and sustained for the period of time sufficient to kill the curly-leaf pondweed. The planning-level cost estimate for annual curly-leaf pondweed management is $12,000, based on recent City of Edina herbicide treatments (see Table 10-1).

Alum Treatment of Lake Sediments

A whole-lake alum treatment is recommended for both North and South Cornelia. Because Lake Cornelia is shallow and there is potential for the pH to drop too low if only alum is applied, the aluminum should be applied as a mixture of alum (4.4% aluminum by weight) and sodium aluminate (10.4% aluminum by weight), as sodium aluminate acts as a buffer to keep pH at an acceptable range. The planning-level cost estimate for an alum treatment of Lake Cornelia (North and South) is $161,000 (see Table 10-1).

An alum treatment can be conducted before the other lake management activities are completed. However, given the extensive benthivorous fish community in Lake Cornelia, the longevity of the treatment may be reduced as the aluminum floc that covers the lake bottom is mixed deeper into the sediment over time. If treatment is conducted before other activities, it can be expected that a second treatment will be needed in the relatively near future (5 to 10 years after treatment). Although a repeat alum treatment may be necessary every 5 to 10 years, the annualized cost-benefit is still low in comparison with the evaluated watershed management practices.

In recent years, the City of Edina has conducted algaecide treatments in Lake Cornelia and Lake Edina at the request of residents and lake users, to reduce phytoplankton (algae) blooms. The algaecide treatments, in the form of copper sulfate, kill phytoplankton, which settle to the lake bottom, along with the phosphorus in the phytoplankton cells. While this can result in a temporary reduction in phosphorus in the water column, the dead phytoplankton cells decay over time at the lake bottom and re-release phosphorus. The decomposition process can also create anoxic conditions, which could promote sediment phosphorus release. Upon completion of an alum treatment, it is recommended that the algaecide treatments be suspended to more accurately measure the impacts of the alum treatment on water quality and phytoplankton populations and assess whether future algaecide treatments are warranted.

10.2.4.2 Watershed Management Practices

Spent Lime/CC17 Treatment Chamber

A significant portion of the watershed to North Cornelia (47%) flows through the Swimming Pool Pond located just south of TH 62 and west of Valley View Road near the Edina Aquatic Center. Swimming Pool Pond is effective in removing sediment and associated particulate phosphorus; however, little to no dissolved phosphorus is removed as runoff flows through this waterbody into North Cornelia. The proposed spent lime/CC17 treatment chamber would serve as a "polishing" step, diverting a portion of the discharge from Swimming Pool Pond through the spent lime filtration chamber to remove dissolved phosphorus before discharging to Lake Cornelia.

Using spent lime to treat stormwater is a relatively new and innovative approach to removing dissolved phosphorus that several watershed management organizations throughout the Twin Cities metro area have been experimenting with in recent years. The primary component of spent lime, a byproduct of the water treatment process, is calcium carbonate. A spent lime treatment chamber uses chemical substitution to exchange phosphate for carbonate. As runoff filters through spent lime, calcium will preferentially bind to phosphate (over carbonate) and calcium phosphate will form. One drawback of spent lime is that the material has limited capacity for prolonged inundation. Therefore, it is recommended that the bottom layer of the spent lime treatment chamber be supplemented with CC17, a crushed limestone material, due to the potential for periodic high water levels in North Cornelia. CC17 is more soluble that most limestone aggregates and thus, provides calcium that can bind phosphate and create calcium phosphate.

The planning-level cost estimate for installing a spent lime/CC17 treatment chamber upstream of North Cornelia is $588,000 (see Table 10-1). Although the capital cost of the spent lime/CC17 system is significant, the unit cost per benefit achieved is relatively low compared to other evaluated watershed management practices due to the regional nature of the treatment practice and the large amount of water treated. The cost estimate is based on treating a flowrate of 2 cfs; however, the design could be modified to reduce the capital cost, as necessary.

The spent lime/CC17 treatment chamber scenario aligns well with several of the target criteria that were used when selecting and evaluating potential watershed management practices, including:

- **Maximizes benefits to chain of lakes.** The proposed spent lime/CC17 chamber is directly upstream of North Cornelia, so all three lakes within the chain would benefit from the reduction in phosphorus loading.
- **Increases dissolved phosphorus removal.** The spent lime/CC17 chamber would increase the amount of dissolved phosphorus removed from the watershed runoff.
- **Improves or "builds on" effectiveness of existing treatment systems.** The proposed spent lime/CC17 system offers a "treatment train" approach, providing additional phosphorus removal from the water flowing from Swimming Pool Pond prior to discharge to Lake Cornelia.
- **Includes mix of structural and non-structural BMPs.** The spent lime/CC17 chamber would be considered a structural BMP, however, since the proposed implementation location is within a public park, signs could be posted near the BMP for educational benefit of the park users (non-structural/programmatic).
- **Provides reliable pollutant removal performance.** The proposed spent lime/CC17 would provide consistent, year-round treatment of low-flows from Swimming Pool Pond. However, high flows would bypass the system and flow directly to Lake Cornelia without treatment. Pilot studies conducted with spent lime and CC17 filters have demonstrated effective removal of phosphorus. However, use of spent lime/CC17 to treat stormwater is still relatively new and should be considered experimental.
- **Reasonably cost effective.** The spent lime/CC17 chamber uses materials considered "waste" from previous applications helping to keep the construction costs reasonably cost effective.

- **Land Availability:** The proposed location for the spent lime/CC17 system is underneath an existing parking lot in a public park. Installation of the proposed BMP would not require re-purposing of the land area footprint.

Street Sweeping

The street sweeping scenario analyzed for this study assumed public streets and private commercial parking lots were swept with high-efficiency vacuum-assisted street cleaners on a weekly basis from May through November. While this scenario results in significant phosphorus load reduction (assumed 36% during the modeled time period), it is recognized that this would be an extensive change to the street sweeping program already in place (twice annually) and may not be feasible for the City of Edina in terms of capital costs to purchase additional high-efficiency sweepers and annual labor, operations, and maintenance costs.

Alternatively, an enhanced sweeping program, scaled back in frequency or in the total miles swept, could be considered. While a scaled-back program would reduce the consistency of phosphorus removal achieved, it could still be effective in periodically reducing phosphorus loading to Lake Cornelia and Lake Edina. An enhanced sweeping program could be focused in the residential areas, where runoff currently receives little or no treatment prior to discharge to Lake Cornelia or Lake Edina. Another option for consideration is a pilot program targeting private parking lots to assess the phosphorus removal potential. Large portions of the commercial parcels in the North Lake Cornelia watershed discharge to downstream stormwater ponds. While stormwater ponds are effective at removing particulate phosphorus, they have limited potential for removing dissolved phosphorus. A pilot program could be used to assess the effectiveness of an enhanced street sweeping program in private lots to remove detritus and leaf litter prior to it leaching dissolved nutrients.

Continued Implementation of NMCWD Stormwater Rules

Based on the results of this study, it is recommended that NMCWD continue its regulatory program to protect local water resources through promotion of infiltration practices from tributary watersheds through the permitting program. As additional infiltration BMPs are installed as redevelopment occurs, it will be important to reassess internal loading potential of the downstream lakes to ensure that water balance changes will not negatively impact water quality due to enhanced internal loading. If internal loading is managed through alum sediment treatments and curly-leaf pondweed management negative water quality impacts induced from infiltration practices are not anticipated.

10.2.4.3 Benthivorous Fish Management

Fish activity, specifically the disruption caused by benthivorous species such as the bullhead and goldfish found in Lake Cornelia, can influence phosphorus concentrations in a lake. These fish feed on decaying plant and animal matter found at the sediment surface and transform sediment phosphorus into phosphorus available for uptake by algae through digestion and excretion. Benthivorous fish can also cause resuspension of sediments, causing reduced water clarity and poor aquatic plant growth.

Winter Aeration Using Direct Oxygen Injection

A recommended in-lake management activities to manage the abundant and unchecked population of benthivorous fish is installation of a winter aeration system using direct oxygen to prevent winter kill of predator fish, thereby reducing the number of benthivorous fish and maintaining a more balanced fishery. Winter aeration would be conducted by injecting oxygen under the ice. The system would consist of: (1) a unit that generates the oxygen and a structure that houses the generator, (2) a raft that holds the vertical aeration tubes in place, and (3) a bubbler that directs the oxygen upwards through the aeration tubes.

The proposed direct oxygen system would be installed in North and South Cornelia at the deep holes of the lake contingent upon the availability of power. The system would be sized to be operated only in the winter when there is ice cover. The planning-level cost estimate for installing a direct-oxygen injection aeration system is $122,000 (see Table 10-1).

Other Benthivorous Fish Management Options

Other potential management activities to reduce the benthivorous fish population could include a rotenone treatment of Lake Cornelia and the upstream water bodies and subsequent fish stocking and/or installation of fish barriers. However, prior to considering these fishery management activities collection of additional information is recommended regarding the migration and movement of carp and goldfish throughout Lake Cornelia and the series of connected upstream shallow waterbodies.

10.2.4.4 Lake Edina Aquatic Plant Management

Invasive curly-leaf pondweed and Eurasian watermilfoil are both present in Lake Edina. In recent years, curly-leaf pondweed was observed at low levels in two areas on the west side of the lake. Eurasian watermilfoil is widespread throughout the shallow lake. The sections below discuss management recommendations for these invasive plant species.

Curly-leaf Pondweed

The invasive curly-leaf pondweed has been observed at low levels in Lake Edina since 2008. In June of 2017, the species was observed at two locations, both in the western area of the lake. Although curly-leaf pondweed has remained at low levels in the lake since 2008, management of curly-leaf pondweed may be warranted to maintain its low occurrence and prevent the accumulation of turions (i.e., similar to seeds). The goals of treatment would be to prevent curly-leaf pondweed from establishing dominance to avoid the need for subsequent long-term annual treatments to reduce an established population that can rebound once larger numbers of turions are present in the sediments. Management of the current curly-leaf population would also minimize the potential for turions to be conveyed downstream to Normandale Lake, causing a resurgence of curly-leaf pondweed after completion of the Normandale Lake water quality improvement project.

The herbicide selected for a curly-leaf pondweed treatment would depend upon the extent; when greater than 15 percent of the lake is covered, Endothall would be recommended to attain lake-wide control of the invasive species. When the extent of curly-leaf pondweed is less than 15 percent of the lake, a cost and benefit analysis would be recommended to determine whether Endothall or diquat would be most appropriate. Based upon experience with other curly-leaf pondweed management projects, the management of CLP would be expected to span several years. Management until neither curly-leaf pondweed nor turions are observed in the lake would be most protective of the Lake Edina ecosystem as well as downstream Normandale Lake.

Eurasian Watermilfoil

Eurasian watermilfoil was first observed in Lake Edina during 2017, in which it was widespread and increased in extent between June and August. Management of Eurasian watermilfoil in Lake Edina would control its rapidly expanding extent and prevent it from further threatening the integrity of the lake's aquatic community. Because Eurasian watermilfoil fragments could be carried downstream to Normandale Lake, managing Eurasian watermilfoil in Lake Edina would also protect the integrity of the Normandale Lake aquatic community.

The herbicide selected for Eurasian watermilfoil treatment in Lake Edina would depend upon the extent; when greater than 15 percent of the lake, the herbicide 2,4-D would be recommended to attain lake-wide control of Eurasian watermilfoil. When the extent is less than 15 percent of the lake, a cost and benefit analysis would be recommended to determine whether 2,4-D or ProcellaCOR would be the most appropriate herbicide for the treatment. Based upon experience with other Eurasian watermilfoil management projects, the management of EWM in Lake Edina would be expected to span several years, but the extent to be managed would diminish annually to smaller and smaller levels. As the extent diminishes, management efforts and associated cost would be expected to change accordingly. Management, until EWM is no longer observed in the lake, would be most protective of the Lake Edina ecosystem as well as downstream Normandale Lake from the problems associated with an Eurasian watermilfoil infestation.

11.0 References

Bannerman, R., Owens, D., Dodds, R., & Hornewer, N. (1993). Sources of pollutants in Wisconsin stormwater. *Water Science and Technology*, 241-259.

Barr Engineering Co. (2007). Kohlman Lake Dredging Feasibility Study. *Prepared for Ramsey-Washington Metro Watershed District*.

Barr Engineering Co. (2015). *Memorandum: Lake Edina - Evaluation of Water Levels.*

Barr Engineering Co. (2018). *City of Edina 2018 Comprehensive Water Resources Management Plan.*

Barr Engineering Co., & MPCA. (2018). *Lower Minnesota River Watershed TMDLs - Draft.*

Cayan, D. (2013). Future climate: projected average. *Assessment of climate change in the southwest United States: a report prepared for the National Climate Assessment.*, 101-125.

City of Edina. (2017). Bathymetric Survey. Edina, Minnesota, USA.

Cooke, G., Welch, E., Peterson, S., & Newroth, P. (1993). *Restoration and Management of Lakes and Reservoirs, Second Edition.* Boca Raton, FL: Lewis Publishers.

Dettinger, M., Udall, M., & Georgakakos, A. (2015). Western water and climate change. *Ecological Applications*, 2069-2093.

Dokulil, M. (2013). Old wine in new skins - eutrophication reloaded: Glogal perspectives of potential amplification by climate warming, altered hydrological cycle and human interference. *Eutrophication: Causes, Economic Implications and Future Challenges*, 95-125.

Dokulil, M. (2014). Impact of climate warming on European inland waters. *Inland Waters, 4*, 27-40.

Dokulil, M. (2016). Climate impacts on ecohydrological process in aquatic systems. *Ecohydrology and Hydrobiology, 16*, 66-70.

Dokulil, M., & Teubner, K. (2011). Eutrophication and climate change: Present situation and future scenarios. *Eutrophication: Causes, Consequences, and Control*, 1-16.

Emmons & Olivier Resources, Inc. (EOR). (2015). *City of Edina, MN Street Sweeping Management Plan.* City of Edina, MN.

Giorgi, F., Im, E., Coppola, E., Diffenbaugh, N., Gao, X., Mariotti, L., & Shi, Y. (2011). Higher hydroclimatic intensity with global warming. *Journal of Climate, 24*, 5309-5324.

Heiskary, S., & Wilson, C. (1990). Minnesota Lake Water Quality Assessment Report Second Edition. *A Practical Guide for Lake Managers. MPCA.*

Hope, D., Naegeli, M., Chan, A., & Grimm, N. (2004). Nutrients on asphalt parking sufaces in an urban environment. *Water, Air, and Soil Pollution, 4*, 371-390.

Huisman, J., Matthijs, H., & Visser, P. (2005). Harmful cyanobacteria. *Springer*.

Huser, B., & Pilgrim, K. (2014). A simple model for predicting aluminum bound phosphorus formation and internal loading reduction in lakes after aluminum addition to lake sediment. *Water Research, 53*, 378-385.

I.E.P, Inc. (1990). *p8 Urban Catchment Model. Version 3.5*. Providence, RI: Prepared for the Narragansett Bay Project. .

Indiana Department of Natural Resources. (2019, April 13). *Aquatic Invasive Species (AIS) Eurasian Water Milfoil*. Retrieved from https://www.in.gov/dnr/files/EURASIAN_WATERMILFOIL.pdf

Jeppesen, E., Kronvang, B., Meerhoff, M., Søndergaard, M., Hansen, K., Andersen, T., . . . Olesen, J. (2009). Climate change effects on runoff, catchment phosphorus loading and lake ecological state, and potential adaptations. *Journal of Environmental Quality, 38*, 1930-1941.

Jeppesen, E., Meerhoff, M., Davidson, T., Trolle, D., Søndergaard, M., Lauridsen, T., . . . Nielsen, A. (2014). Climate change impacts on lakes: An integrated ecological perspective based on a multi-faceted approach, with special focus on shallow lakes. *Journal of Limnology, 73*, 88-111.

Kalinosky, P. (2015). Quantifying solids and nutrient recovered through street sweeping in a suburban watershed. *A Thesis submitted to the faculty of the University of Minnesota*.

Kalinosky, P., Baker, L., Hobbie, S., Binter, R., & Buyarski, C. (2014). *User Support Manual: Estimating Nutrient Removal by Enhanced Street Sweeping*. Minneapolis, MN.

Kharin, V., Zwiers, F., Zhang, X., & Wehner, M. (2013). Changes in temperature and precipitation extremes in the CMIP5 ensemble. *Climatic Change, 119*, 345-357.

LaMarra, V. J. (1975). Digestive activities of carp as a major contributor to the nutrient loading of lakes. *Verh. Int. Verein. Limnol. 19*, 2461-2468.

Maxwell (RPBCWD), J. (2018). *Lake Cornelia System Fisheries Assessment.* Riley Purgatory Bluff Creek Watershed District.

Maxwell, J. (2018, October 9). *Lake Cornelia System Fisheries Assessment.*

MDNR. (2017). *How the Climate of Minnesota is and is not Changing.* (K. Blumenfeld, Performer) State Climatologist Office, at the City Engineers Association of Minnesota (CEAM) Annual Meeting, Minnesota.

Metropolitan Council. (2016). Metropolitan Council Land Use Coverage Dataset (GIS database).

MPCA. (2008). *Minnesota Rules Chapter 7050: Standards for Protection of Water of the State.*

MPCA. (2019, April 13). *Eurasian Water Milfoil*. Retrieved from https://www.pca.state.mn.us/eurasian-water-milfoil

NMCWD. (2017, amended 2019). *Nine Mile Creek Watershed District Water Management Plan.*

NOAA, N. O. (2013). Atlas 14. Volume 8.

Passeport, E., & Hunt, W. (2009). Asphalt parking lot runoff nutrient characterization for eight sites in North Carolina, USA. *Jounral of Hydrologic Engineering, 14(4)*, 352-361.

Pilgrim, K., Huser, B., & Brezonik, P. (2007). A method for comparative evaluation of whole-lake and inflow alum treatment. *Water Research, 41*, 1215-1224.

Sahoo, G., Forrest, A., Schladow, S., Reuter, J., Coats, R., & Dettinger, M. (2016). Climate change impacts on lake thermal dynamics and ecosystem vulnerabilities. *Limnology and Oceanography, 61*, 496-507.

Schueler, T. (1987). *Controlling Urban Runoff: A practical manual for planning and designing urban BMPs.* Washington D.C., USA: Prepared for Washington Metropolitan Water Resources Planning Board. Metropolitan Washinton Council of Governments.

Selbig, W. (2016). Evaluation of leaf removal as a means to reduce nutrient concentrations and loads in urban stormwater. *Science of the Total Environment*, 124-133.

Trenberth, K. (1999). Conceptual framework for changes of extremes of the hydrological cycle with climate change. *Climatic Change, 42*, 327-339.

Trenberth, K. (2011). Changes in precipitation with climate change. *Climate Research, 47*, 123-138.

Trenberth, K., Smith, L., Qian, T., Dai, A., & Fasullo, J. (2003). The changing character of precipitation. *Bulletin of the American Meteorological Society, 84*, 1205-1217.

Vighi, M., & Chiaudani, G. (1985). A Simple Method to Estimate Lake Phosphorus Concentrations Resulting from Natural, Background, Loadings. *Water Resources, 19(8)*, 987-991.

Walsh, J. (2014). Our changing climate. In *Climate Change Impacts in the United States: the Third National Climate Assessment.* Washington D.C., USA: U.S. Global Change Research Climate Program.

Wei, Q., Zhu, G., Wu, P., Cui, L., Kaisong, Z., Zhou, J., & Zhang, W. (2010). Distributions of typical contaminant species in urban short-term storm runoff and their fates during rain events: A case of Xiamen City. *Journal of Environemntal Sciences, 22(4)*, 533-539.

WI-DNR. (2004). Wisconsin Lake Modeling Suite (WILMS).

WI-DNR. (2012). *Aquatic Plant Eurasian Watermilfoil*. Retrieved from Wisconsin Department of Natural Resources: http://dnr.wi.gov/topic/Invasives/documents/classification/Myriophyllum%20spicatum.pdf

WI-DNR. (2012). *Eurasian Watermilfoil - Beaver Dam Lake*. Retrieved from Wisconsin Department of Natural Resources: http://dnr.wi.gov/lakes/invasives/AISDetail.aspx?roiseq=1228

Wisconsin Wetlands Association. (2017). *Invasive Plant Profile: Cattails*. Retrieved from https://wisconsinwetlands.org/updates/invasive-plant-profile-cattails/

World Health Organization. (2003). Guidelines for Safe Water Environments. In *Coastal and Fresh Waters. Volume 1* (p. 219). Geneva, Switzerland.

Appendices

(in Separate PDF)