BARR

# Sweeney Lake Aeration Study

Prepared for
Bassett Creek Watershed Management Commission (BCWMC)

October, 2018

4300 MarketPointe Drive, Suite 200
Minneapolis, MN 55435
952.832.2600
www.barr.com

Sweeney Lake Aeration Study

October, 2018

# Contents

## List of Tables



## List of Figures

# Certifications

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

Greg Wilson
PE #: MN 25782

October 9, 2018
Date

# 1.0 Project Background and Purpose

For 40 years Sweeney Lake homeowners have operated an aeration system year-round—intending to oxygenate the water, improve conditions for native fish and reduce the buildup of phosphorus and harmful algal growth. While the Sweeney Lake Total Phosphorus TMDL (Total Maximum Daily Load) study (SEH and Barr, 2011) established a path toward better water quality, there was still a question about whether the lake's aeration system is part of the problem or the solution. As a result, the Bassett Creek Watershed Management Commission (BCWMC) initiated this study to employ three-dimensional water quality modeling to simulate sediment phosphorus release and algal dynamics, with and without aeration, under different management efforts and climatic conditions. This study report presents the modeling results and recommends management actions that will meet the Minnesota Pollution Control Agency (MPCA) water quality standards and BCWMC goals, based on its classification as a BCWMC Priority 1 deep lake.

## 1.1 Lake and Watershed Characteristics

Figure 1-1 shows the watershed divides and drainage patterns for Sweeney Lake, including subcatchments. Table 1-1 shows the lake morphology/depth and other watershed/water body characteristics for the lake (as published in the TMDL report [SEH and Barr, 2011]).

**Table 1-1 Lake and Watershed Characteristics**

| Parameter | Sweeney Lake |
|---|---|
| Surface Area (acres) | 67 |
| Average Depth (feet) | 12 |
| Maximum Depth (feet) | 25 |
| Watershed Area (acres) | 2,397 |

The aerators in Sweeney Lake disrupt the normal stratification of the lake by placing eleven diffusers at the bottom of the lake throughout the deeper water areas of both the north and south basins. Each diffuser pushes air from a compressor into the bottom water of the lake and the movement of the air bubbles to the surface of the lake forms a vertical circulation pattern that prevents thermal stratification and allows for phosphorus to be distributed throughout the water column.

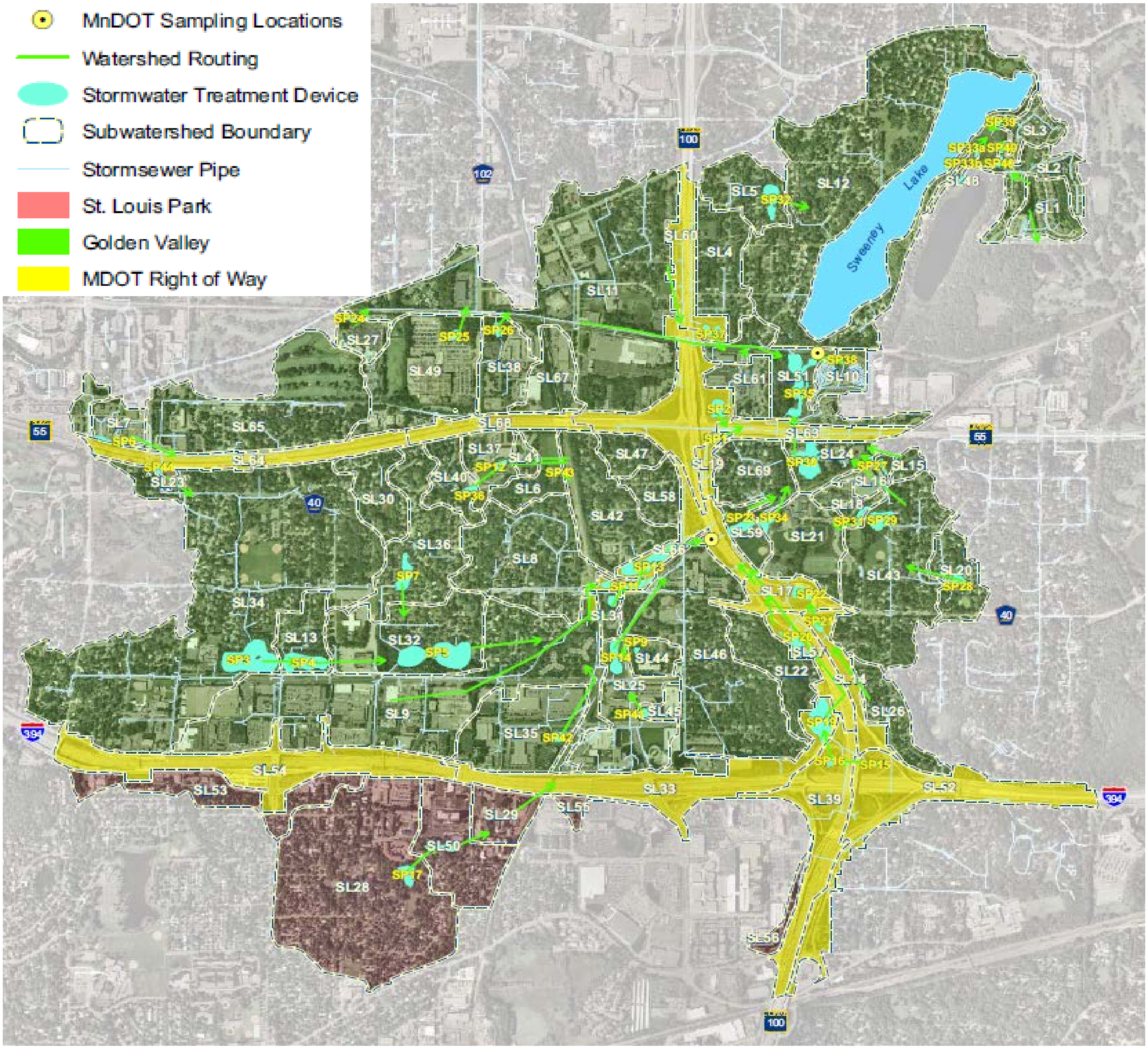



**Figure 1-1 Sweeney Lake Watershed**

## 1.2 Summary of Sweeney Lake TMDL and Past Studies

In preparing this study, Barr systematically reviewed reports and data collected on Sweeney Lake, including the TMDL report and implementation plan, fish and aquatic plant survey reports, bathymetric surveys, sediment core sampling analyses, aeration system design and operation data.

The TMDL report (SEH and Barr, 2011) estimated that internal load accounted for 32% of the summer phosphorus load during the baseline year (2004) and called for total phosphorus load reductions of 175 pounds from internal load and 99 pounds from the Sweeney Lake watershed load. The BCWMC/MPCA water quality standards identified that the following summer average criteria apply to Sweeney Lake:

- Total phosphorus (TP) ≤ 40 µg/L
- Chlorophyll-a ≤ 14 µg/L
- Secchi disc transparency ≥ 1.4 meters (4.6 feet)

The stakeholder process conducted as a part of the TMDL study established general consensus that the existing aeration system should be evaluated further to see if modifications can be made to better manage the system to avoid circulating nutrient-rich water (SEH and Barr, 2011). Discussions also related to the advantages and disadvantages of aeration during the growing season. Based on the 2007-2008 data, it was concluded that the aeration system may or may not be increasing the internal phosphorus loading to the lake. The water quality was better with the aerators turned off, but insufficient data was available to conclude what portion relates to reduced watershed load from the lower than normal precipitation and what portion relates to reduced internal loading from stratification of the lake and trapping phosphorus in the bottom layer. In either case, the recommended action was to conduct future years of monitoring with the aeration system off to see how the lake responds to a normal year of precipitation. There was also consensus that winter aeration is not a concern and likely represents a good long-term management strategy for the lake.

# 2.0 Historical Monitoring and Watershed Modeling

Background information, including Sweeney Lake watershed modeling and historical water quality monitoring data were evaluated for potential relationships in comparison to the MPCA criteria for summer average total phosphorus (TP), chlorophyll-a and Secchi disc transparency. Figure 2-1 shows a plot of the summer TP concentrations (since 2005) against the estimated P8 model watershed TP loads to evaluate potential patterns, with and without aeration. The figure shows that the three years of monitoring without aeration likely represent the best water quality that could be expected under varying climatic conditions, considering that increasing watershed TP loads correspond with slight increases in summer average TP concentrations (above the lake water quality criteria). Figure 2-1 also appears to show that aeration did not adversely impact water quality between 2011 and 2013, as it compares to aforementioned pattern without aeration.  However, aeration during the other five years (2005, 2006, 2009, 2010 and 2014) appears to exacerbate the impact that the available internal phosphorus load had on water quality.

Figures 2-2 and 2-3 show how summer average TP concentrations correspond with summer average chlorophyll-a and Secchi disc transparency, respectively. Figure 2-2 shows that the three years of monitoring without aeration resulted in water quality that met or very nearly met the criteria for TP and chlorophyll-a, while aeration during five years (2005, 2006, 2009, 2010 and 2014) appeared to exacerbate the problem with algae growth that greatly exceeded the chlorophyll-a criteria. Figure 2-3 shows that the three years of monitoring without aeration resulted in water quality that met or very nearly met the criteria for TP and Secchi disc transparency, while aeration during the remaining years (except for 2005) exacerbated the problem with algae growth that prevented attainment of the transparency criteria.

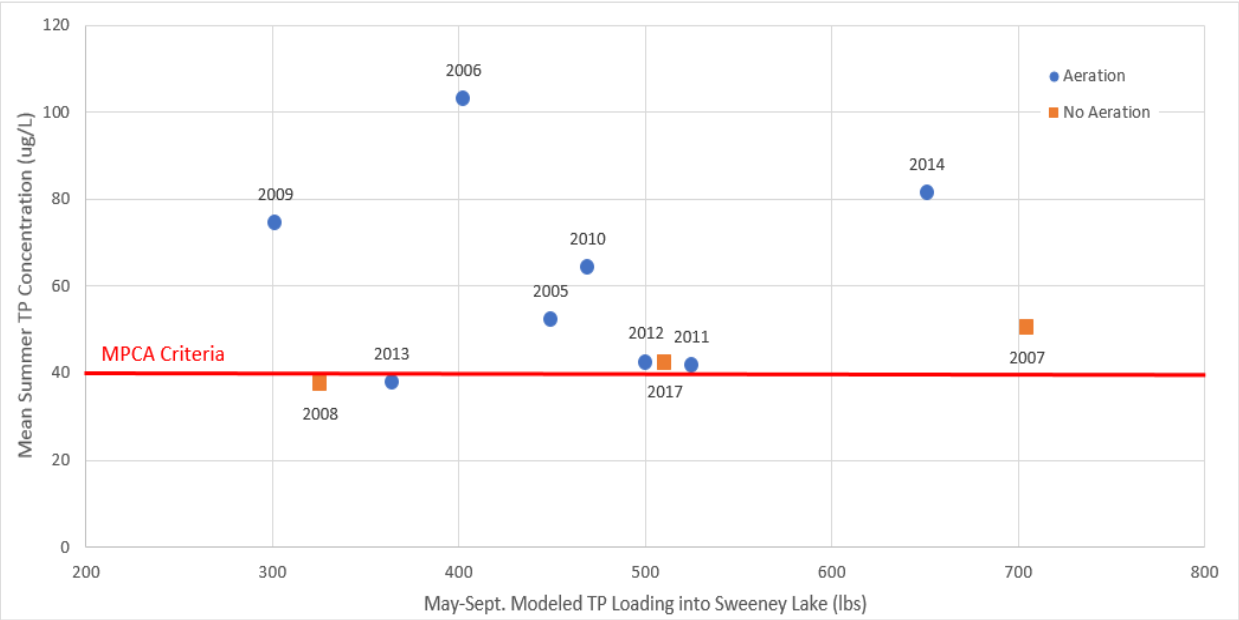



**Figure 2-1** **Relationship Between Summer Average (June-Sept.) Total Phosphorus Concentrations in Sweeney Lake and Modeled Watershed TP Loading**

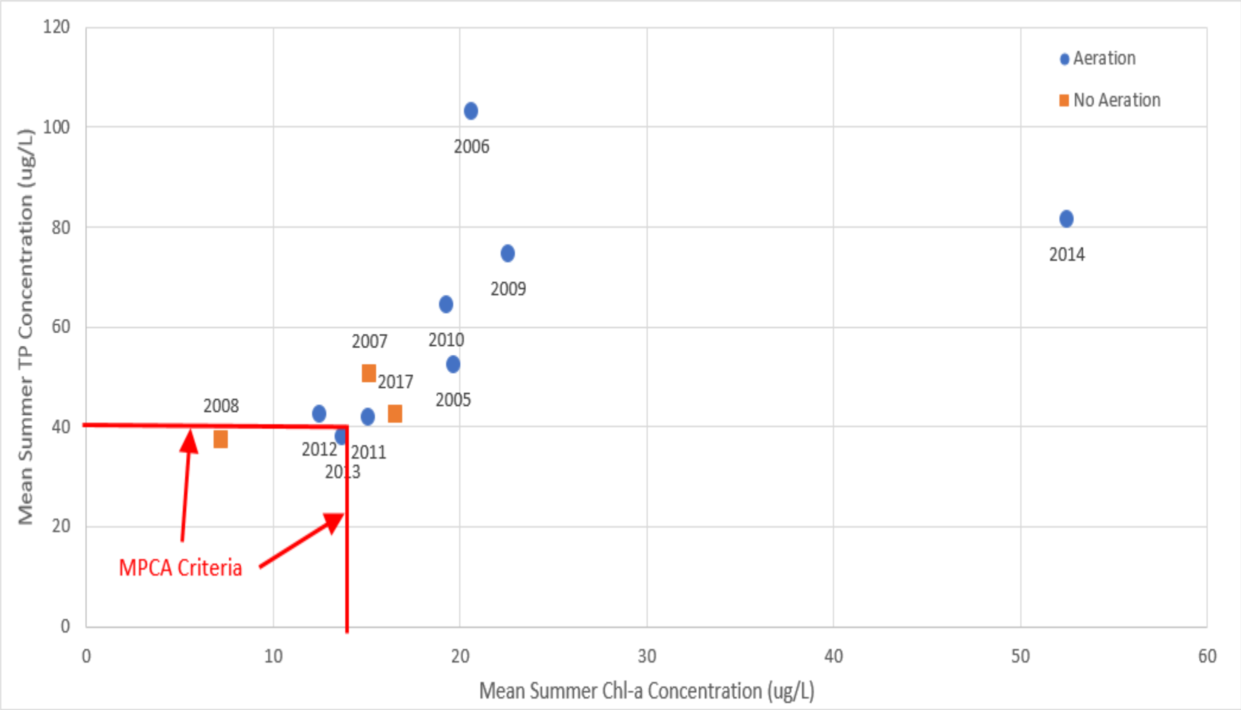



**Figure 2-2** **Relationship Between Summer Average (June-Sept.) Total Phosphorus Concentrations and Chlorophyll-a Concentrations in Sweeney Lake**

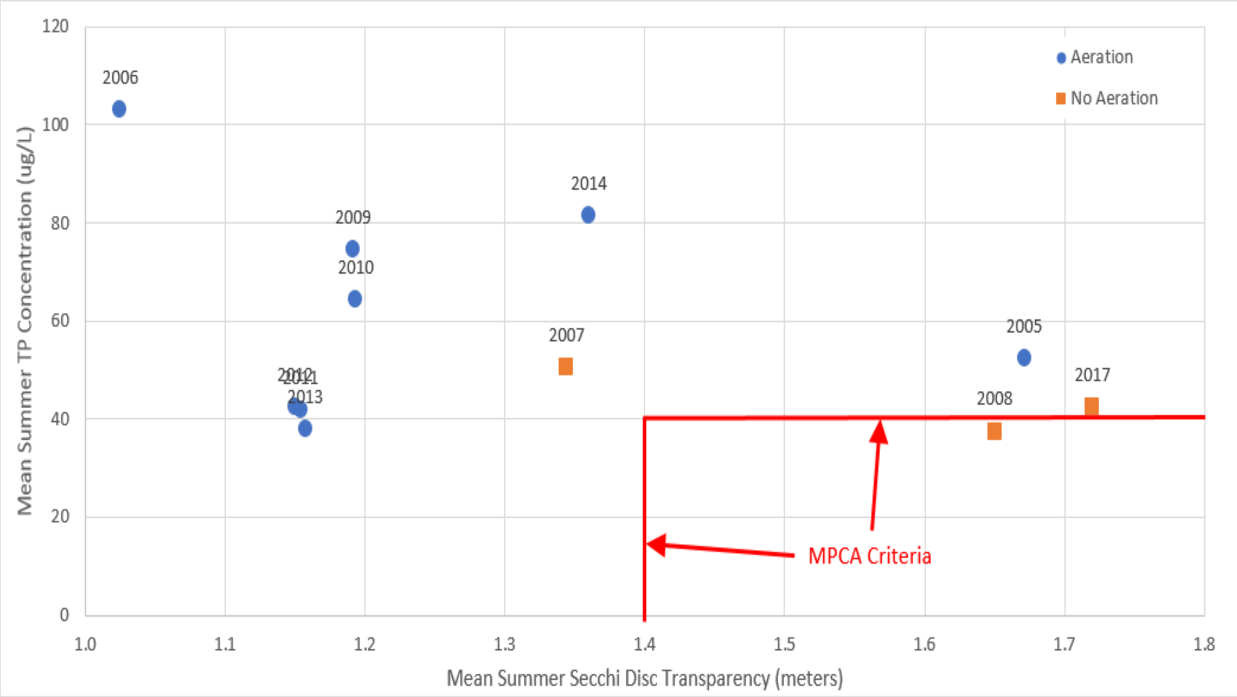


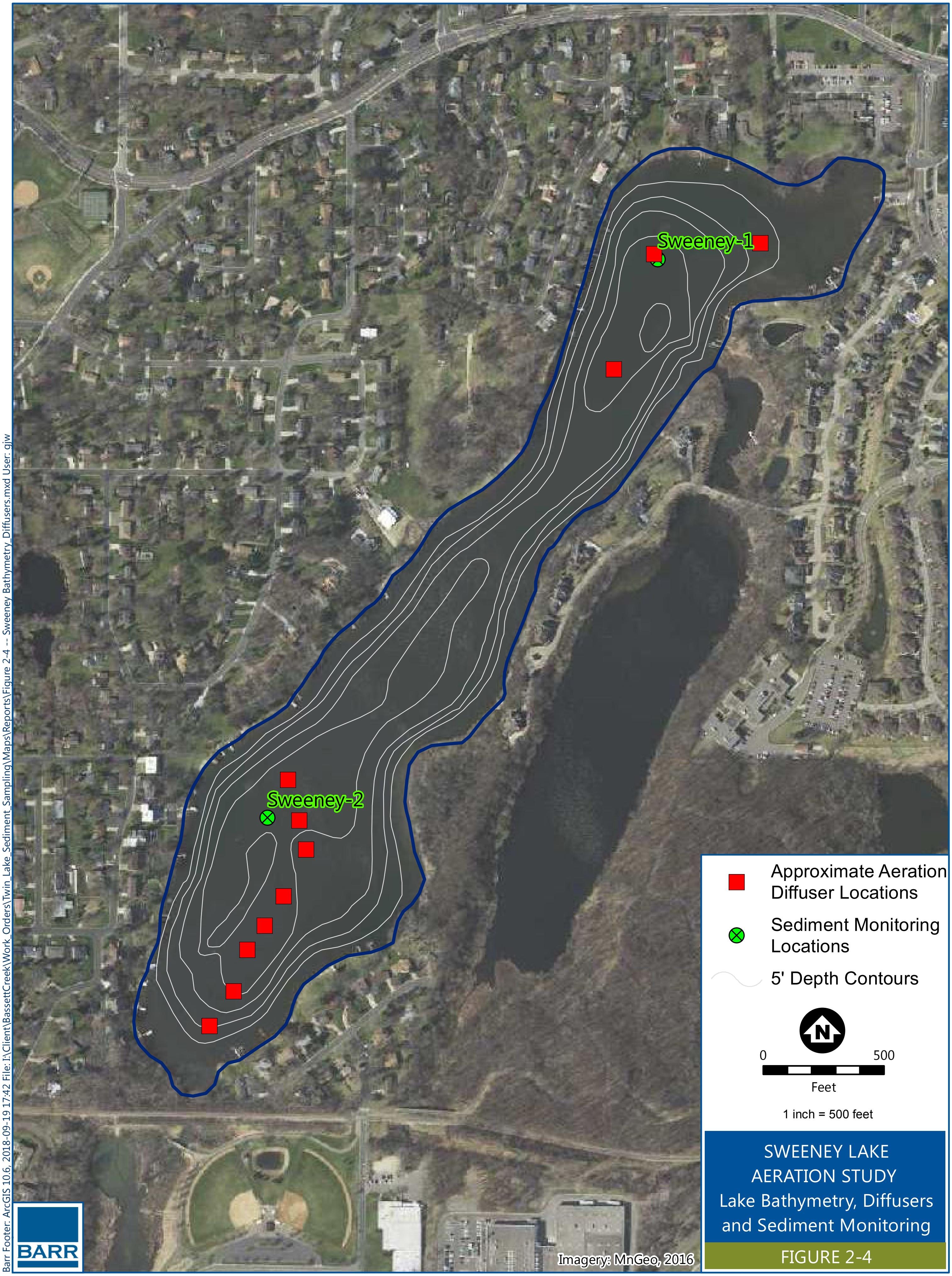

**Figure 2-3** **Relationship Between Summer Average (June-Sept.) Total Phosphorus Concentrations and Secchi Disc Transparency in Sweeney Lake**

## 2.1 Analysis of 2018 Lake Sediment Cores

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

The primary purposes of collecting sediment cores is to quantify the amount of Fe-P and Org-P in sediment. The more Fe-P and Org-P in sediment, the more alum will need to be applied to immobilize these phosphorus fractions as a part of an in-lake treatment project (further described in Section 4.1.1). In general, aluminum treatment (either as alum or sodium aluminate, for example), forces the Fe-P to bind to aluminum and form Al-P (the inert form of aluminum). In most cases, alum treatments are designed to also provide excess aluminum in sediment, which can then bind phosphorus years after the treatment. When aluminum in the form of alum or other solutions is added to a lake, it forms an aluminum hydroxide floc that settles to the lake bottom. The aluminum floc will mix into the top few to several inches of sediment over time and becomes diluted. The sediment phosphorus data collected at different depths was used to help determine the expected sediment mixing depth for each core location.

Two sediment cores were collected on May 18, 2018 in Sweeney Lake (see Figure 2-4). Each sediment core was sliced into 2-cm sediment samples down to a depth of 10 cm, and 4 cm intervals were collected down to 18 cm or deeper. Sediment samples were returned to the Barr Engineering laboratory and analyzed for the phosphorus fractions identified previously. The Fe-P concentration in the sediment of the south basin of Sweeney Lake was significantly higher than the north basin, while organic-P concentrations were similar in both basins of the lake (see Figure 2-5). While the physical characteristics were relatively similar among both cores of Sweeney Lake, the remaining phosphorus concentrations in the sediment of the south basin of Sweeney Lake were approximately twice as high as phosphorus concentrations in the sediment from the north basin.




SWEENEY LAKE AERATION STUDY
Lake Bathymetry, Diffusers and Sediment Monitoring
FIGURE 2-4

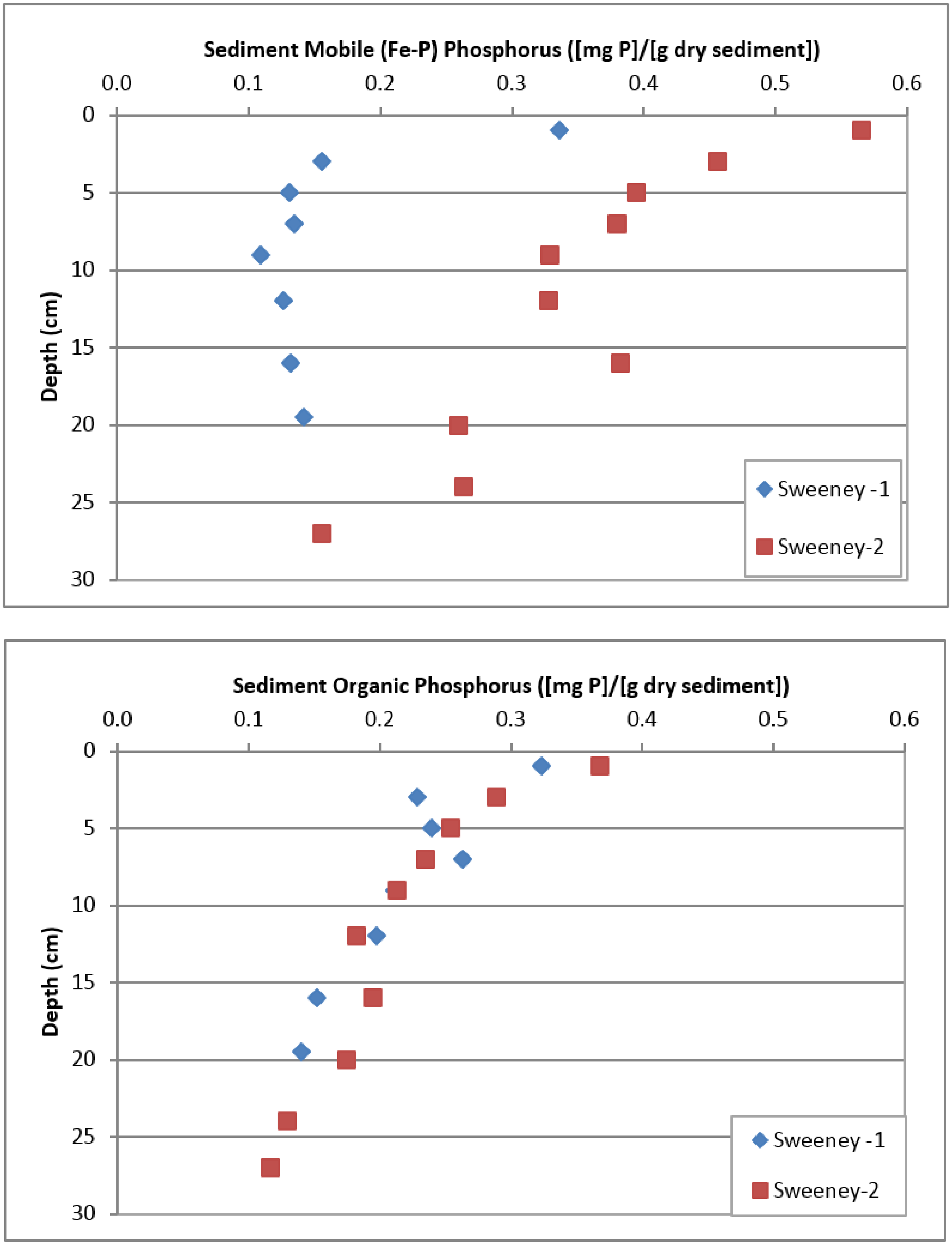



**Figure 2-5** **Results of Sweeney Lake Sediment Phosphorus Fractionations**

# 3.0 Three-Dimensional In-Lake Water Quality Modeling

A three-dimensional hydrodynamic and water quality model was developed to evaluate the cause of high phosphorus concentrations and phytoplankton (algae) blooms in Sweeney Lake and the role that the operation of aerators in the lake may have on observed phosphorus and phytoplankton blooms. The primary objective of the modeling was to identify how management of the aeration system and internal loading control will affect phosphorus and phytoplankton, as well as achievement of the BCWMC/MPCA water quality standards for Sweeney Lake.

## 3.1 Methods

The first step in model development was to identify years that are representative of two distinct operating conditions: (1) years with the aerators operating, and (2) years in which there was not aeration. We chose 2008 to represent a year in which the aerators were not operating and 2014 to represent a year in which aerators were operating. Model development was focused on those two years to ensure that the water quality modeling could also be applied to a range of climatic conditions, with 2008 representing a dry year and 2014 a wet year (as shown in Figure 2-1).

Model development consisted of the following steps:

- **Bathymetry**: Input of Sweeney Lake bathymetry (depth and volume) into the model.
- **Climate**: Development of climatic inputs (air temperature, solar radiation, wind speed, relative humidity).
- **Watershed Runoff**: Input of runoff volume and runoff quality (e.g., phosphorus, suspended solids, water temperature). This was estimated using the P8 model described previously.
- **Aeration**: Input of the aerators into the model. This was conducted such that location of the diffusers and the airflow rate of each aerator were identified in the model to simulate the actual location and air flow rate throughout Sweeney Lake.
- **Model Calibration**: This consisted of a series of model runs whereby the model is changed slightly. With each run, the in-lake monitoring data are compared to the model results. An example of the calibration results is provided in Figure 3-1 and Figure 3-2 below.

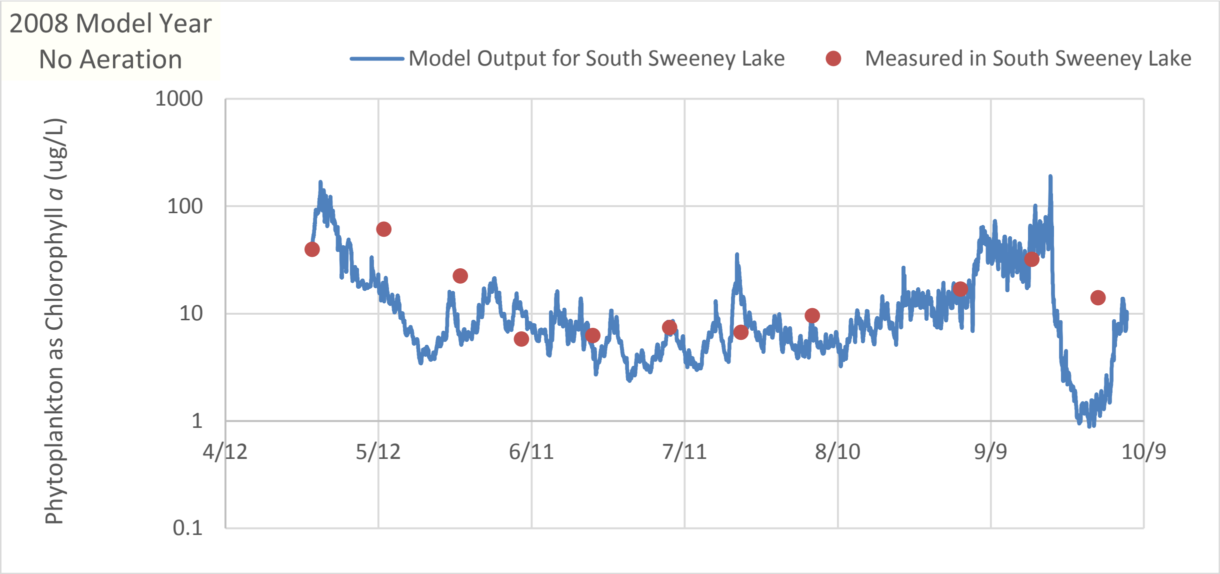



**Figure 3-1** **Example of 2008 measured and model-predicted phytoplankton in Sweeney Lake surface water**

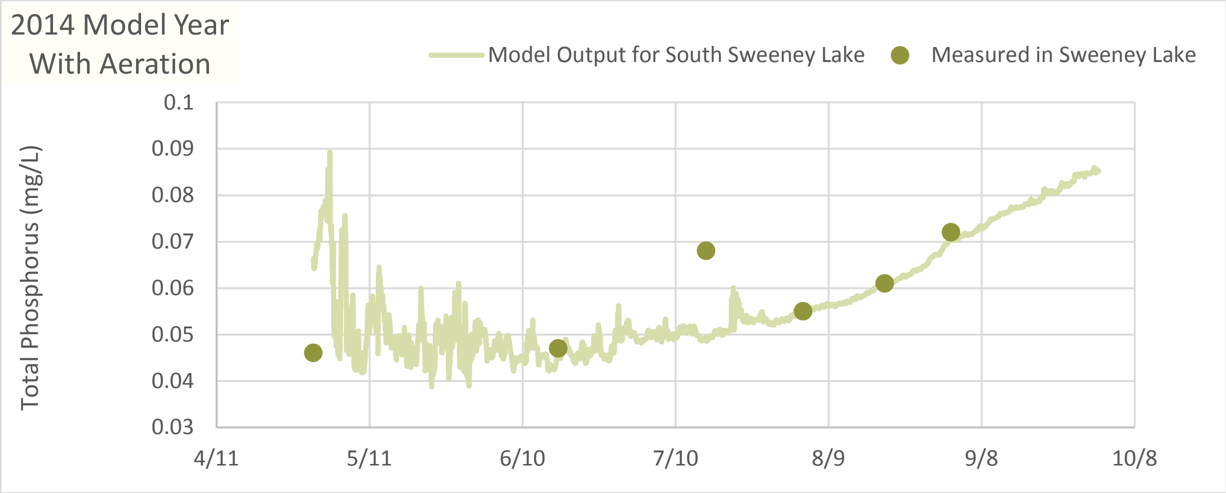



**Figure 3-2** **Example of 2014 measured and model-predicted phosphorus in Sweeney Lake surface water**

For modeling years 2008 and 2014, four modeling scenarios were conducted:

1. Existing conditions: for 2008 this is without aeration and for 2014 this is with aeration.
2. Alternative condition: for 2008 this is with aeration and for 2014 this is without aeration.
3. Existing conditions with an alum treatment to reduce phosphorus release from lake-bottom sediments (internal loading).
4. Alternative conditions with an alum treatment to reduce phosphorus release from lake-bottom sediments (internal loading).

All of the modeling scenarios assumed the same starting (spring) phosphorus concentration in the lake, which is conservative when considering that the implementation of an alum treatment would be expected to improve the lake water quality year-round.

## 3.2 Modeling Results

The model was able to properly simulate normal lake stratification without aeration (Figure 3-3) and the lack of stratification (destratification) with aeration (Figure 3-4). It can be seen that with stratification, water on the bottom of the lake is colder and does not mix with the surface waters. When there is aeration, the water column has a nearly uniform temperature indicating that the bottom waters are completely mixing with the surface waters. Figure 3-5 shows an example of the modeling output, which simulated aeration during the summer of 2008, where sediment phosphorus release from the south basin becomes entrained in the surface water of the lake.

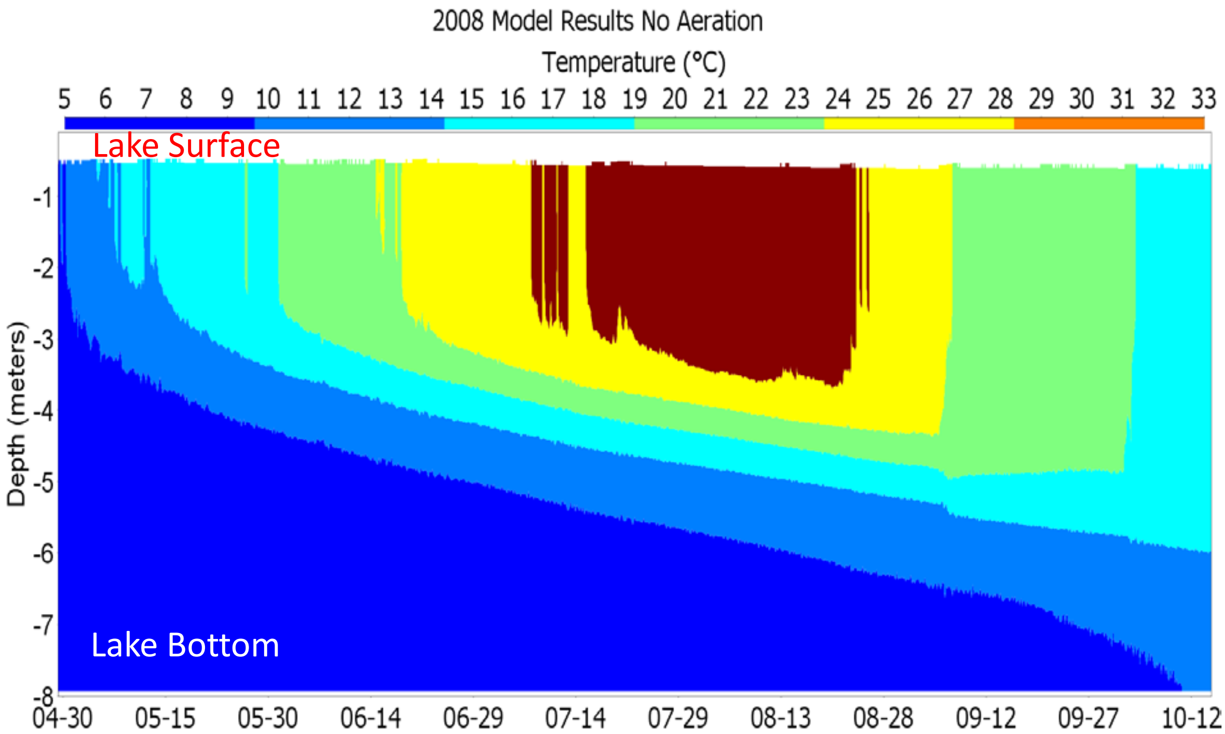



**Figure 3-3 Modeled 2008 temperature in Sweeney Lake without aeration**

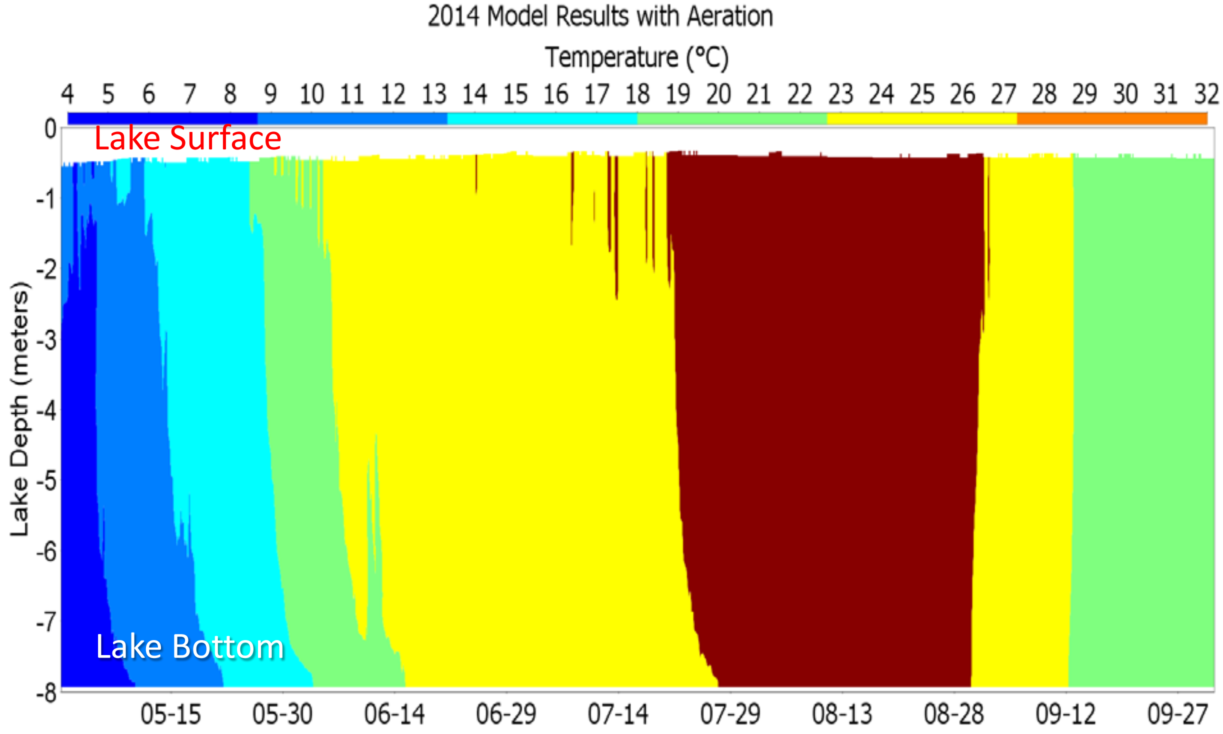



**Figure 3-4 Modeled 2014 temperature in Sweeney Lake with aeration**

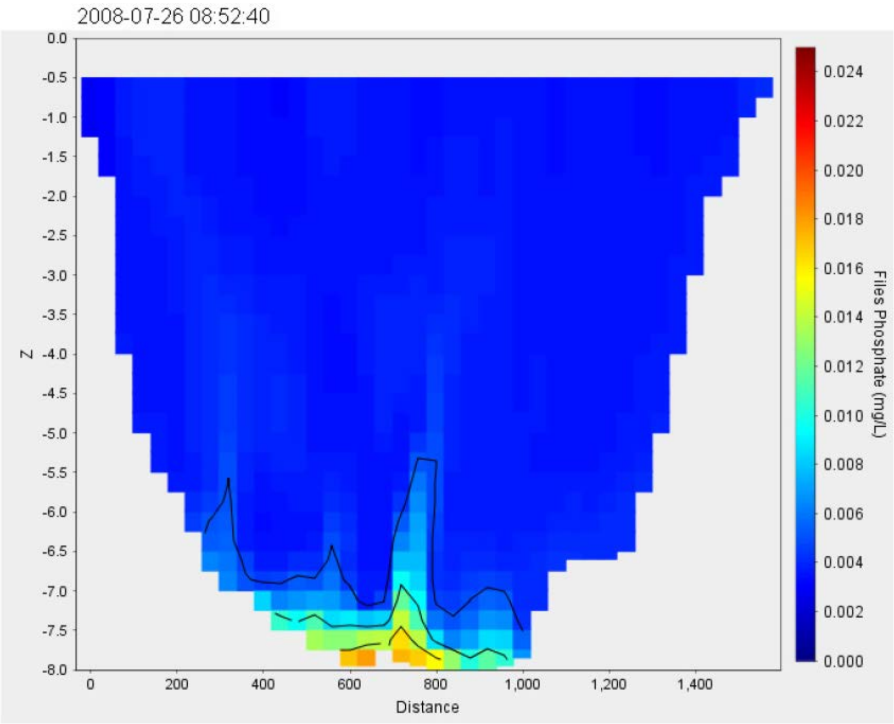



**Figure 3-5 Modeled example of phosphorus entrainment from aeration in Sweeney Lake**

The modeled effects of aeration, climate and the application of alum to inhibit the release of sediment phosphorus to the bottom water in Sweeney Lake are shown in Figure 3-6. The modeling results show:

- Internal loading is the largest source of phosphorus entering Sweeney Lake in the summer
- Aeration exacerbates summer water quality problems in Sweeney Lake, with surface water phosphorus concentrations that are 10 to 30% higher than the respective un-aerated condition
- An alum treatment will greatly improve water quality and ensure that MPCA/BCWMC standards/goals will be consistently met for Sweeney Lake
- Aeration following an alum treatment is not expected to substantially change the resulting lake water quality.

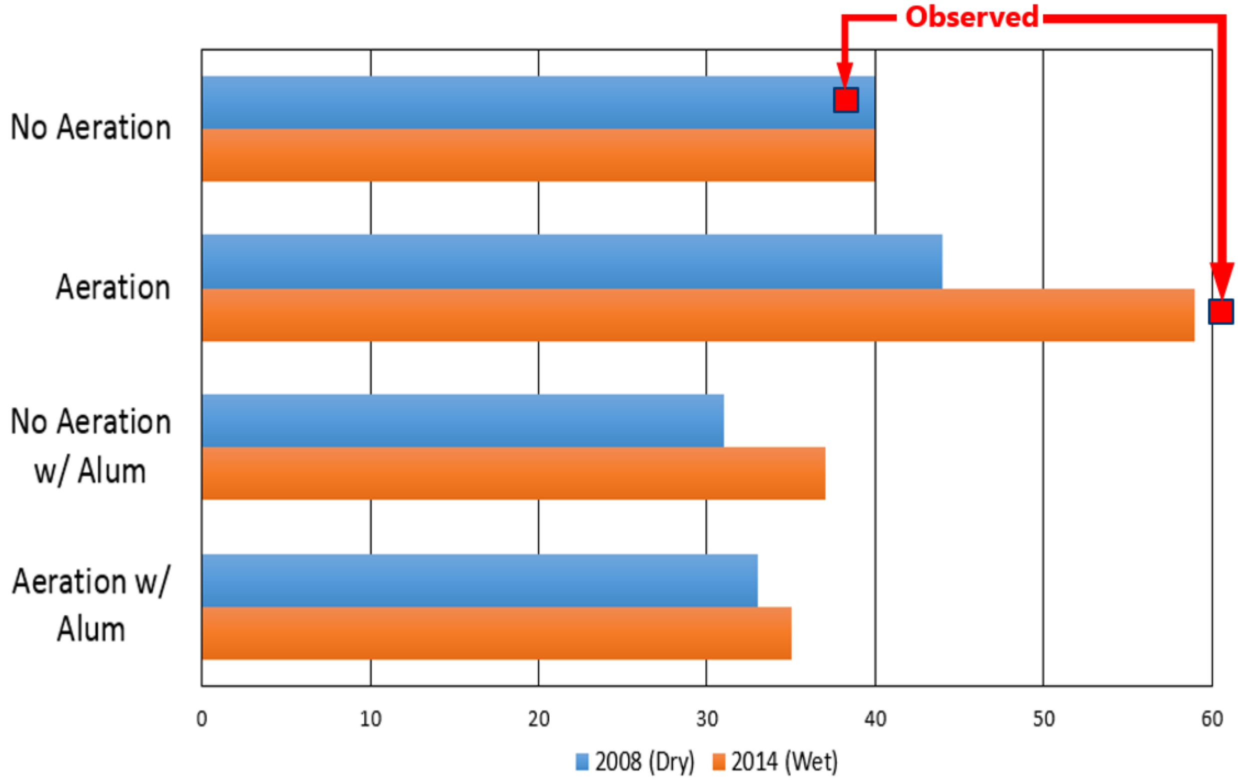



**Figure 3-6 Modeled and observed summer average total phosphorus concentrations (µg/L) in Sweeney Lake**

# 4.0 Summary

## 4.1 Water Quality Improvement Options

The monitoring data and modeling results indicate that phosphorus from watershed runoff and phosphorus that is released from lake-bottom sediments (internal phosphorus loading) are the cause of periodic phytoplankton blooms and low water clarity in Sweeney Lake. The modeling results indicate that aeration is not preventing internal loading but rather aeration prevents the capture (settling and assimilation) of phosphorus by the lake. The outcome is that aeration leads to higher phosphorus and phytoplankton concentrations and less clarity. The modeling also indicates that the treatment of lake sediments with alum will reduce phosphorus and phytoplankton blooms, regardless of whether aeration is used.

The modeling results reaffirm that compliance with Minnesota lake nutrient standards and the Sweeney Lake TMDL will require inactivation of phosphorus in the lake bottom sediments to significantly reduce internal phosphorus loading. There are a few options that were considered to meet the necessary internal phosphorus loading reduction targets. These options are discussed in more detail in the following sections.

### 4.1.1 Whole Lake Aluminum Treatment of Lake Bottom Sediments

The active ingredient in alum and sodium aluminate is aluminum. Aluminum binds phosphorus in sediment and stops it from migrating upward from the lake bottom to the lake surface. The aluminum-phosphate compound that is formed (Al-P), is unique in that it is stable even when oxygen is low (i.e., anoxia) in the bottom waters of the lake. This is not the case for phosphorus bound to iron (Fe-P). In the lake bottom sediments and when oxygen is low in the summer, phosphorus breaks away from iron and migrates into the lake water column (this is internal loading and the cause of most algal blooms). Aluminum (e.g., alum and sodium aluminate) is effective at stopping this process. The alum/sodium aluminate is typically applied to the surface of a lake using a treatment barge and the aluminum settles into the lake sediments as a floc. Aluminum treatment is typically expected to reduce phosphorus release from lake-bottom sediments for 10 to 20 years.

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

1. The mass of phosphorus in the Sweeney Lake sediments is higher in the south bay compared to the north bay. Hence, more alum/sodium aluminate is required to immobilize the phosphorus in the south bay sediment.
2. Phosphorus concentrations in the Sweeney Lake sediment are very high and the total amount of alum/sodium aluminate needed is on the high end of most aluminum treatments.
3. Treatment will consist of a mixture of alum and sodium aluminate (both chemicals contain the active ingredient—aluminum) to make sure that an in-lake pH of near 7 can be maintained in

Sweeney Lake during and after treatment.  This neutral pH will be protective of aquatic life. The overall dose of both chemicals is designed to reduce internal phosphorus loading by 85%.

4. It is recommended that a “split” treatment is conducted.  For a split treatment, a portion of the dose would be applied in one year and the remaining dose(s) would be applied after a number of years has transpired.  The initial treatment will bind what is called “mobile phosphorus” (Fe-P). The follow-up treatments will also bind mobile phosphorus, however, the treatments will also bind phosphorus that is released from organic phosphorus that has decayed since the initial treatment.  This approach will immobilize more phosphorus in the sediment, increase the longevity and make the overall treatment more cost effective. We recommend splitting the dose in half or in thirds.  The treatment sequence would be conducted as follows:
    a. 50% Split Dose: One half of the dose is applied in year 1 and the other half applied in year 5.
    b. 33% Split Dose: One third of the dose is applied in year 1, another third in year 3, and another third in year 6.

A synopsis of the aluminum doses and estimated chemical application costs for each treatment sequence are provided in the following tables.

**A. 100% of Total Prescribed Dose (not recommended)**

| Location | Mobile Phosphorus (g P $m^{-2}$ x $cm^{-1}$) | Depth of Sediment Treated (cm) | Treatment Area (acres) | Total Aluminum Dose After Completion of All Applications | | | Per Treatment Estimated Total Cost for Both Bays |
|---|---|---|---|---|---|---|---|
| | | | | g Al $m^{-2}$ | Total Alum Applied (gallons) | Total Sodium Aluminate Applied (gallons) | |
| South Sweeney | 0.60 | 8 | 37.5 | 178.8 | 50,302 | 25,151 | $365,000 |
| North Sweeney | 0.21 | 8 | 30.0 | 75.1 | 21,123 | 10,562 | |

**B. Split Treatment: 50% of Total Prescribed Dose**

| Location | Mobile Phosphorus (g P $m^{-2}$ x $cm^{-1}$) | Depth of Sediment Treated (cm) | Treatment Area (acres) | Aluminum Dose for the First Treatment (split treatment, 50% of total prescribed volume) | | | Per Treatment Estimated Total Cost for Both Bays |
|---|---|---|---|---|---|---|---|
| | | | | g Al $m^{-2}$ | Total Alum Applied (gallons) | Total Sodium Aluminate Applied (gallons) | |
| South Sweeney | 0.60 | 8 | 37.5 | 89.4 | 25,151 | 12,576 | $194,000 (Total for 2 treatments = $388,000) |
| North Sweeney | 0.21 | 8 | 30.0 | 37.5 | 10,562 | 5,281 | |

**C. Split Treatment: 33% of Total Prescribed Dose**

| Location | Mobile Phosphorus (g P $m^{-2}$ x $cm^{-1}$) | Depth of Sediment Treated (cm) | Treatment Area (acres) | Aluminum Dose for the First Treatment (split treatment, 33% of total prescribed volume) | | | Per Treatment Estimated Total Cost for Both Bays |
|---|---|---|---|---|---|---|---|
| | | | | g Al $m^{-2}$ | Total Alum Applied (gallons) | Total Sodium Aluminate Applied (gallons) | |
| South Sweeney | 0.60 | 8 | 37.5 | 59.6 | 16,767 | 8,384 | $135,000 (Total for 3 treatments = $405,000) |
| North Sweeney | 0.21 | 8 | 30.0 | 25.0 | 7,041 | 3,521 | |

### 4.1.2 Micro-floc injection

Micro-floc injection is a potential alternative to treating a lake with alum/sodium aluminate at one time (e.g., using a treatment barge that delivers the product). With the micro-floc approach, small volumes of alum are injected from a shore-based facility and via tubing into the bottom of a lake creating alum floc at the bottom of the lake. Aluminum from the floc builds up over time and incorporates into the sediment. This captures phosphorus that has accumulated on the bottom of a lake and it binds phosphorus in the sediment. Ultimately the aluminum binds enough phosphorus in the sediment and inhibits internal phosphorus loading.

The advantage of this system is that the alum can be freshly applied each year and throughout the summer months. Hence, internal loading is controlled on an ongoing basis. The disadvantage of this system is that the delivery of aluminum may be uneven and this system requires the operation and maintenance of a facility on land to house the alum and the feed pumps. Since the benefit of this approach is unpredictable, and the operation and maintenance would exceed that of the existing aeration system, this option was not considered for further implementation.

### 4.1.3 Direct oxygen injection

Direct oxygen injection is an approach to feed oxygen at the lake bottom with the intent to increase oxygen in the bottom waters without destratifying the lake. The bubbles are injected at low volume and dissolve into the water as they travel upward. The primary advantage of this system is that it can improve oxygen in the lake bottom waters without destratifying the lake and transporting potentially phosphorus rich bottom waters to the lake surface. The primary disadvantage of this system is that it will requires the construction of a facility on land to house the necessary equipment to generate oxygen and pump the oxygen to the bottom of the lake. Since the long-term cost-benefit of this approach is not expected to match an in-lake aluminum treatment, and the operation and maintenance would exceed that of the existing aeration system, this option was not considered for further implementation.

## 4.2 Recommendations

It is recommended that the aerators no longer remain in operation and that a whole lake alum treatment of bottom sediment be conducted with the total aluminum dose split in half, or in thirds, depending on the source of funding. The basis for these recommendations is:

- The TMDL requirements for internal load reduction will be met.
- In-lake phosphorus concentrations will be below the MPCA nutrient standards
- Phosphorus that accumulates in the bottom waters will not be mixed with surface waters.

If there is a need to manage the potential for winter kill, surface-type aerators that keep portions of the lake surface open during the winter may be a cost-effective option to improve oxygen concentrations during the winter.

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

# 5.0 References

Short Elliott Hendrickson Inc. (SEH) and Barr Engineering Company (Barr). 2011. Sweeney Lake Total Phosphorus TMDL. Prepared for Bassett Creek Watershed Management Commission (BCWMC) and the Minnesota Pollution Control Agency (MPCA). wq-iw8-06e.

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