Managing Storm Water: Emerald Pond Project Report

Prepared by
Brendan Barth, Griffin Dempsey, Emily Erhart, Megumi Muramoto-Mathieu, and Kara Yetter

Students in CEGE 5511: Urban Hydrology and Water Quality
Instructor: Dr. John Gulliver
College of Science and Engineering

Prepared in Collaboration with
Bruce Westby, PE
City Engineer
City of Ramsey

City of RAMSEY

Resilient Communities Project
University of Minnesota
Building community-university partnerships for sustainability

The project on which this report is based was completed in collaboration with the City of Ramsey as part of the 2017–2018 Resilient Communities Project (RCP) partnership. RCP is a program at the University of Minnesota's Center for Urban and Regional Affairs (CURA) that connects University faculty and students with Minnesota communities to address strategic projects that advance local resilience and sustainability.

Resilient Communities Project
University of Minnesota
330 HHHSPA
301—19th Avenue South
Minneapolis, Minnesota 55455
Phone: (612) 625-7501
E-mail: rcp@umn.edu
Web site: http://www.rcp.umn.edu

BDEMY Engineering
Civil Engineering Building
500 Pillsbury Dr. SE
Minneapolis, MN 55455

December 13, 2017

Resilient Communities Project (RCP)
University of Minnesota
330 HHHSPA
301 19th Ave. S.
Minneapolis, MN 55455

Results of Emerald Pond Study for RCP and the City of Ramsey

Dear Bruce, Mark, and Dan,

We have concluded our study of Emerald Pond and have produced recommendations for addressing resident complaints, as requested.

Water test results revealed reasonable phosphorous levels in Emerald Pond and high phosphorous levels in the neighboring Storm Pond. Phosphorous is considered a pollutant in freshwater and often the cause algae blooms and eutrophication in lakes and ponds. The Storm Pond is separated from Emerald Pond and receives the majority of the runoff from the surrounding neighborhood. This small pond is likely a major contributing cause to resident complaints.

We recommend taking the following steps to reduce the phosphorous in the Storm Pond: water sampling in the spring and summer months, chemical treatment to reduce the phosphorous already present in the pond, raingardens to reduce stormwater and nutrient flow into the pond, foster community involvement by informing surrounding residents about good landscaping practices and ways to reduce phosphorous from entering the pond.

Thank you for your commitment to the RCP program, it was a pleasure working with you!

Sincerely,

Brendan Barth, Griffin Dempsey, Emily Erhart, Megumi Muramoto-Mathieu and Kara Yetter

Emerald Pond Project Report

December 13th, 2017

Brendan Barth

Griffin Dempsey

Emily Erhart

Megumi Muramoto-Mathieu

Kara Yetter

Table of Contents

Executive Summary

Emerald Pond is recreational pond located in Emerald Pond Park in Ramsey, MN. Residents in the area have been experiencing foul odors and unsightly aesthetics due to annual algal blooms in the ponds on site. There are two ponds of concern, Emerald Pond and the Storm Pond to the east. High concentrations of phosphorous, the limiting nutrient for algal growth were found in this Storm Pond. Samples were taken in the winter, and do not represent year-round concentrations in both ponds.

This report aims to outline the extent of the phosphorous contamination and explore a variety of solutions for reducing the current and influent concentration of phosphorous in both ponds.

It is recommended by our team that the City of Ramsey:

1) Install a fox decoy, to scare away migratory birds from the park
2) Encourage residents to make adjustments to their landscaping routines to reduce the nutrients entering the pond.
3) Treat the Storm Pond with alum. Emerald Pond may also benefit from this.
4) Install multiple BMPs so as to reduce further loading in Emerald Pond and the Storm Pond, in order to prevent future TP contamination.

This strategy is capable of remediating the phosphorous contamination in the ponds in a cost effective manner. The method prioritizes prevention of contaminant transport, low cost operation and maintenance, and resident participation.

Introduction

Emerald Pond is recreational pond located in Emerald Pond Park in Ramsey, MN. Residents in the area have been experiencing foul odors and unsightly aesthetics due to annual algal blooms in the pond. Directly to the east of Emerald Pond there is a smaller Storm Pond that experiences the same issues to a larger degree. Both of these ponds are believed to have high levels of nutrient loading that contribute to the eutrophication of these waterbodies. The objective of this project is to identify ways in which the nutrients loading the ponds can be reduced. The current state of the pond will also be assessed in this project to determine the extent of nutrient impairment, the location of best management practices to be implemented, and the location for which they can be implemented. The possible solutions to decrease nutrient input will be evaluated based on cost effectiveness.

Algal blooms are prevalent in summer months, when temperatures are high and are ideal for algal growth. In order to produce biomass, algae requires nutrients to form new cells. These nutrients come in the form of bioavailable phosphorous, nitrogen, and organic carbon. In freshwater systems, bioavailable phosphorous is the nutrient that limits the production of new algal biomass. Bioavailable phosphorous has many forms and sources. In residential neighborhoods, the most common sources of phosphorous include yard waste, leaves, animal feces, and dissolved phosphorous that is absorbed to sediment. These different sources of phosphorous contribute to the Total Phosphorous (TP) of a water body, or influent water. Removal of phosphorus from runoff before it enters a receiving water body is vital to reducing algal blooms, 1 pound of phosphorus can produce 400 pounds of wet algae (Vallentyne, 1974). Reduction in TP loading to the stormwater ponds via BMP will decrease the likelihood of algal blooms by decreasing the rate of TP accumulation. If TP concentrations are high enough, stormwater ponds will need to be treated to reduce the bioavailability of phosphorous to limit algal growth.

Background & Site Information

Emerald Pond receives stormwater from a 12.49 acre area of residential neighborhood located directly west of the pond via a culvert at the south end of the pond. This culvert feeds an area that drains into Emerald Pond and the wetlands to the south. Flow between the two waterbodies was not quantified in this report, and the exchange between the two is largely unknown. In the Northeast corner of Emerald Pond Park the smaller Storm Pond receives stormwater from a much larger, 35.65 acre area of residential neighborhoods located directly to the north of the park. There is no interflow between the two ponds, and the Storm Pond does not connect to the wetlands to the south. The Storm Pond is significantly smaller in volume and surface area than Emerald pond but receives approximately triple the stormwater input. Land along the south banks of both ponds is owned by the city, with the opposite banks being privately owned by residents.

Both ponds are believed to have high concentrations of nutrient pollution. Specific inputs that contribute to the nutrient loading are unknown, however, there are many likely sources. The surrounding residential lawns provide a hydraulic path without a vegetative buffer between the property and the pond. Often residential properties have sprinklers are not efficiently used and contribute municipal water as runoff into the ponds. This runoff not only contains higher levels of phosphorous from the municipal water, but may carry nutrients from lawn fertilizer as well. Improper care of lawns in the autumn months will load the ponds with nutrient rich yard waste in the form of grass clippings and fallen leaves. Animal fecal matter, specifically from Canadian Geese has been blamed for high nutrient content by residents. Municipal stormwater carries suspended solids with bound phosphorous, debris from leaves containing high amounts of organic phosphorous, and other organic matter from the streets and deposits in the lake.

Several observations were noted during a visual inspection of the site on 11/03/2017

- There are many unmaintained trees and plants around the edges of both ponds.
- Thick portions of dead plant material lined the base and sides of both ponds.
    - Decaying leaves and plant mater provide large sources of organic phosphorous mass.
- The plots owned by the residents have sloped yards steeper than 3%, providing increased runoff to the pond.
- On a majority of properties, grass covered lawns run directly up to the pond edges without a buffer.
- The two ponds were determined not to be connected by any device.
- There is a closed system water pump in Emerald Pond that creates an artificial stream directly back into the pond.
    - Within this faux stream there contains a large amount of decaying plant material, sediment, and other nutrient rich material.
- There are spaces for rain gardens and buffer strips in the park area and surrounding neighborhoods.

Phosphorus Testing & Results

Phosphorus Sampling

The site was visited in early November for a visual inspection and to collect phosphorus samples. Five samples were collected for total phosphorus analysis; two samples were collected from the smaller Storm Pond and three samples were collected from Emerald Pond. The sampling locations are shown in Figure 1. It should be noted that sampling was conducted during the late autumn, and conditions of the lake will vary throughout the year. Determinations of the lake quality during the summer months can be loosely predicted, but it is recommended that further sampling be collected in the spring and summer months.

Figure 1.Phosphorus sampling locations in Emerald Pond (EP) and the smaller Storm Pond (SW).

Phosphorus Test Results

The samples were tested at the Saint Anthony Falls Laboratory (SAFL) at the University of Minnesota. The results of the total phosphorus testing are shown in Table 1.

Table 1.Phosphorus testing results from Emerald Pond and the Storm Pond.

Sample	Total Phosphorus [µg/L or ppb]
Emerald Pond 1 (EP1)	16
Emerald Pond 2 (EP2)	62
Emerald Pond 3 (EP3)	29
Storm Pond 1 (SW1)	231
Storm Pond 2 (SW2)	151

These results can be compared to background values for lakes and water in Minnesota. According to the Phosphorus DNR Factsheet, for Minnesota, the TPconcentration of a pristine lake might fall between 10 and 50 ppb. Effluent from Minnesota wastewater plants typically contains 200-300 ppb of TP. It is hypothesized that the wetlands provide a buffer for nutrient loading in Emerald Pond. This is supported by studies conducted at the University of Minnesota (Deering 2016).

Modeling Methods

To better understand the sources of nutrients and the behavior of surface water flow in the Emerald Pond Park drainage area, it was necessary to delineate the watershed and estimate the impervious areas and canopy.

Watersheds

The two feet LIDAR contours shown in Figure 2 were used to delineate the two subwatersheds which empty into Emerald Pond and Storm pond.

Watershed A is the most extensive subwatershed covering 31.65 acres and represents the drainage area that empties into the Storm Pond. The pond receives water from most of the surrounding residential area through the stormwater system and from direct runoff from the park south of the pond and resident's backyards along the north and east shorelines. The pond has one inlet where the stormwater network enters the pond through a flared end section on the west side of the pond and one outlet through a conduit on the northeast side that flows into a neighboring wetland (see Figure 2).

Watershed B is small in comparison covering, only 12.49 acres that flow into Emerald Pond from two sources: a stormwater junction at the south end of the pond, and direct runoff from the park south of the pond and resident's backyards which are located along the north and west shoreline. The inlet at the south end of the pond is a T shaped junction which empties stormwater into Emerald pond to the north and into a wetland area to the south. When water levels are high, water flows between Emerald Pond and the wetland area. There are no other

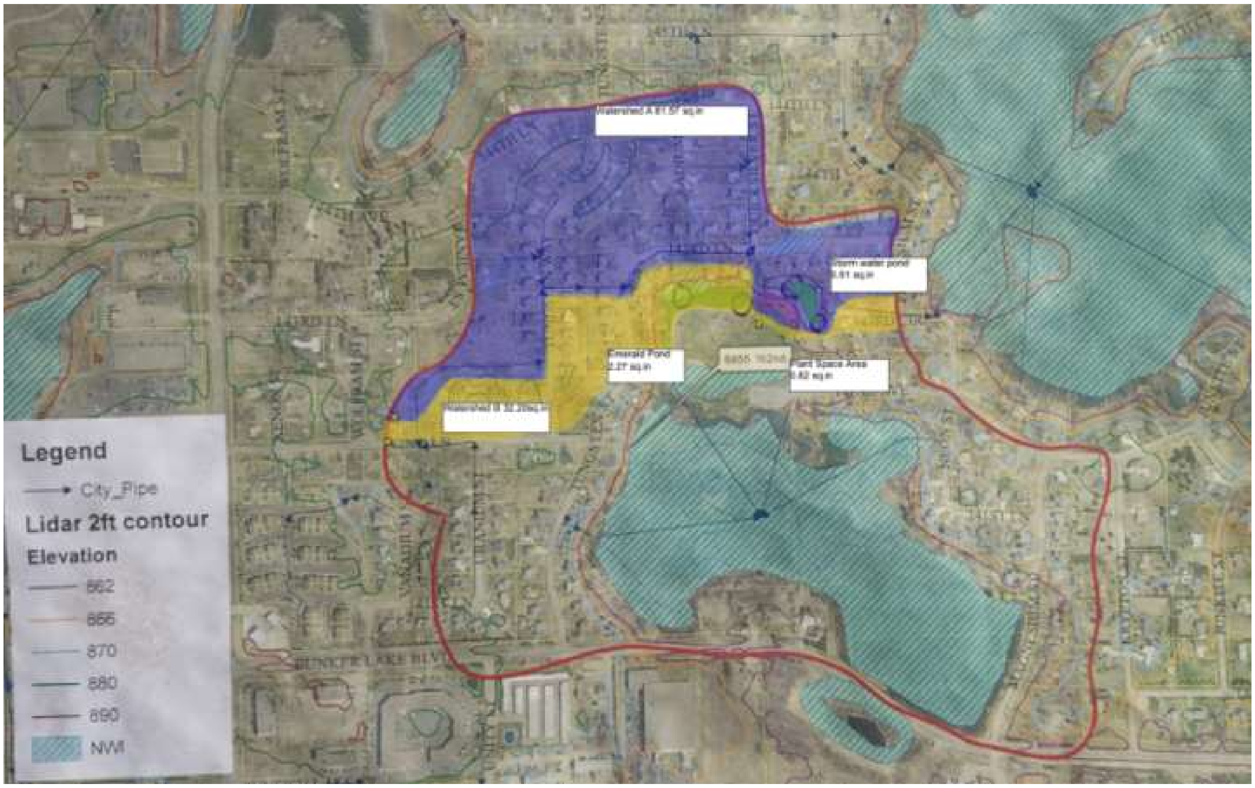


Figure 2.Subwatershed delineation. Watershed A in blue empties into Stormwater Pond. Watershed B in yellow empties into Emerald Pond.

inlets or outlets. A pump is located in the park just south of the pond on the eastern side. The pump pulls water out of Emerald Pond through two PVC pipes and empties water directly back into the pond through a manmade stream which passes under the walking path. The pump has no apparent function other than aesthetics.

Impervious Area and Curve Number

An impervious area of 35% was approximated for subwatershed A and 23% was for subwatershed B using an aerial view of the Emerald Pond drainage area taken from map provided by the City of Ramsey. The impervious area considered included roads, driveways, and buildings. All roads and paths were outlined and the area was calculated using google maps' built in feature. The impervious area on residential lots was approximated by assuming an average house size of 0.18 acres, an average driveway of 0.06 acres, an average street width of 0.235 inches, and path width of 0.10 inches on the map, which was used to calculate the impervious area. Watershed A contains approximately 81 houses and 81 driveways and Watershed B contains approximately 27 houses and 27 driveways. The number of lots is approximation because many lots likely contribute to both watersheds judging by the LIDAR contours. See sample calculations in Appendix 3.

The curve number for both subwatershed A and B are determined to be 57 from Table 2-2a of Urban Hydrology for small watershed (United States Department of Agriculture Natural Resources Conservation Service Conservation Engineering Division 1986) and the soil type analysis performed using the Soil Survey Geographic Database (SSURGO) determined the entire watershed to be type A soil (see Table 3E on Appendix 3 for results).

Canopy

The canopy for both watersheds was estimated to be 14% using an aerial view of google maps. Individual trees were outlined and the area was calculated using the area tool in Google Earth for canopy areas of both watershed A and watershed B. A ratio of the total canopy area and that of the watershed was used to determine the percent canopy (see Appendix 3 for canopy coverage map and sample calculations).

Modeling the Watershed and BMPs in P8

The watershed modeling tool P8 (Program for Predicting Polluting Particle Passage through Pits, Puddle & Ponds) was used to obtain the TP values in Storm Pond and Emerald Pond. As previously mentioned, the watershed was divided into two subwatersheds named Watershed A and B. Original general case specifications defined by the program were used along with the following inputs: hourly precipitation file and daily air temperature file (msp_4989.ppc) and (msp_4889.temp). The TP analysis was conducted over a 10-year period between April 1st, 1970 to September 30th, 1979. The results were saved starting on October 1st, 1970. P8 makes it possible to see effects of treatment in a watershed by providing pretreatment and post treatment TP values. Treatment devices, rain garden, was used in the P8. An infiltration rate of 0.8 inches per hour was applied to all the devices as suggested by the Minnesota Stormwater Manual (Minnesota Pollution Control Agency 2017) and particle removal scale factor is set to the default value of 1. Sample calculations for the physical parameters (area and volume) of each device are shown in Appendix 3. The model was run with two scenarios using various devices and routing options to analyze the maximum TP removal (see Table 2).

Table 2.Two routing scenarios were considered. Watershed (WS) and Pond (PND).

Scenarios	Devices	Routing
1	Original Condition	WS →PND
2	Rain gardens (RG)	WS→RG→PND

All input information is summarized in the Table 3D (Appendix 3).

The impervious fraction of each subwatershed was 35% and 23% for A and B respectively. The assumptions were that all impervious areas were directly connected, and no vacuum sweeping was performed. Next, the Storm Pond and Emerald Pond parameters were added.

The Storm Pond area was obtained from the aerial view of the map, see Figure 3 and scaled up calculations were performed, see Appendix 3. The shape of the pond was modeled as a rectangle; thus, a value of 0.237 acres was used for bottom, permanent pool, and flood pool area and normal depth of the pond determined to be 3 feet. The permanent pool outlet type was orifice with 12-inch diameter outlet pipe and an orifice discharge coefficient of 0.6 which was recommended by Minnesota Stormwater Manual (Minnesota Pollution Control Agency 2017). The Emerald Pond area was input into p8 modeled similar to Storm Pond, however, using area parameters unique to Emerald Pond. Modeling parameters for both ponds are provided in Table 3D (Appendix 3).

Rain gardens were proposed to be installed on the resident's yard and neighborhoods are denoted as green lines on Figure 3 are the suggested locations. Calculations were performed for two different sizes of rain gardens, 150 sq. feet and 300 sq. feet, which is less than 10% of resident's front yard. The expected residential participation percentages for the rain garden installation are 10% (8 households per subwatershed), 50% (40 households), and 70% (57 households) (see the table of specified area in the Appendix 3). The shape of the rain gardens was modeled as square with 0.54 (acre-ft) storage pool volume.

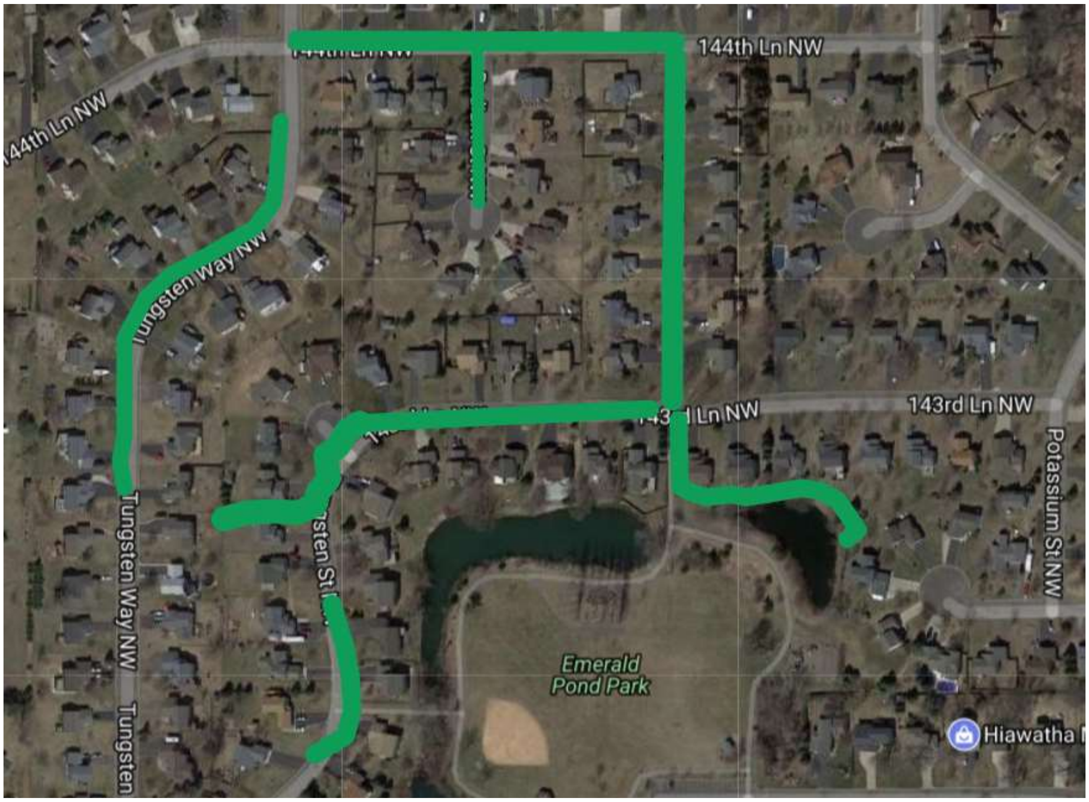
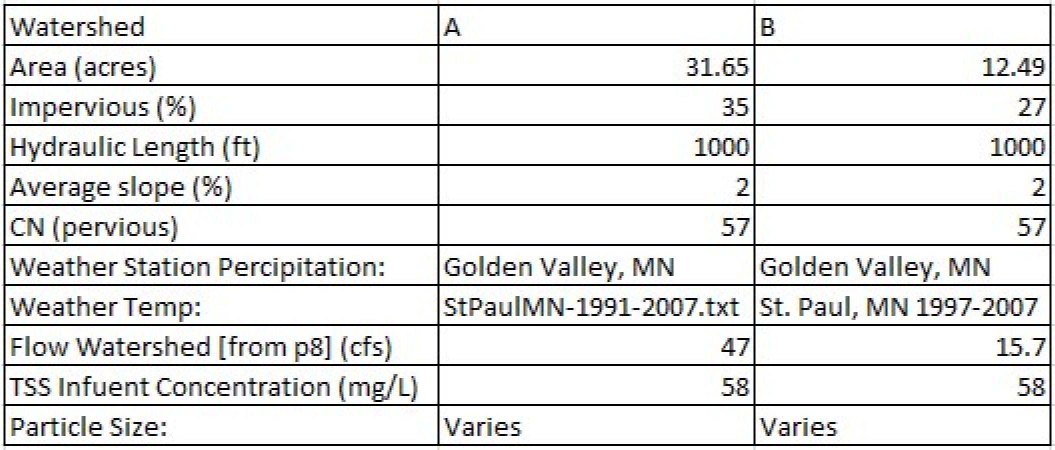


Figure 3: Possible Rain garden locations.

SAFL Baffle Modeling

To determine the cost effectiveness of implementation of the SAFL Baffle, it was necessary to develop a model of the influent stormwater the SAFL Baffle would treat such that a removal efficiency for TSS could be determined. Barr Engineering has developed, SHSAM, a modeling software for a variety of pretreatment BMP's including SAFL Baffles. This program was used, in conjunction with; watershed characteristics outlined in this report, temperature and precipitation data for the Twin Cities metropolitan area, a variety of particle size distributions, and hydraulic estimations as inputs into the model. Watershed area, impervious areas, and curve number were chosen via the methods described. Hydraulic length is the estimated maximum length that a drop of water would travel on a surface before reaching the stormwater system. Average slope was approximated using Barr Engineering suggested values. Precipitation and temperature data from the metro area was selected from SHSAM options. Influent TSS concentration was chosen from the MPCA's Minnesota Stormwater manual for mean municipal TSS concentration. Table 2 outlines the input parameters for SAFL Baffle models for watersheds A and B. These values were obtained from the P8 model of the watershed. SAFL Baffles were modeled in SHSAM such that influent flow to the structure is a percentage of the total flow, based on the number of SAFL Baffle Units modeled in each scenario.

Table 3.SHSAM model inputs for SAFL Baffle implementation in Watersheds A and B, as pretreatment for Emerald Pond and the Storm Pond.



Watershed	A	B
Area (acres)	31.65	12.49
Impervious (%)	35	27
Hydraulic Length (ft)	1000	1000
Average slope (%)	2	2
CN (pervious)	57	57
Weather Station Percipitation:	Golden Valley, MN	Golden Valley, MN
Weather Temp:	StPaulMN-1991-2007.txt	St. Paul, MN 1997-2007
Flow Watershed [from p8] (cfs)	47	15.7
TSS Infuent Concentration (mg/L)	58	58
Particle Size:	Varies	Varies

Particle size distributions were provided by SHSAM. The distribution "Janna-Omid-PSD" was modeled in this instance, and reflects the range of particles that can be transported through municipal stormwater. The particle size distribution can be seen in Appendix 2B.

Internal Load Reduction Solutions Considered

Based on the results of our total phosphorous (TP) testing, concentrations of the limiting nutrient, phosphorous, are an order of magnitude higher in the Storm Pond than in Emerald Pond. Concentrations in Emerald Pond were about 50 ppb, versus the Storm Pond's average of 190 ppb. For comparison, to the Phosphorus Minnesota DNR Factsheet the total phosphorus concentration of a pristine lake might fall between 10 and 50 ppb. Effluent from Minnesota wastewater plants typically contains 200-300 ppb of total phosphorus.

The results of the TP testing support the watershed characteristics modeled in P8. With higher impervious surface area, and more stormwater directed to the Storm Pond, this pond should experience worse water quality than Emerald Pond. Furthermore, canopy cover around the Storm

Ponds is much denser than Emerald, and the trees contribute a large volume of leaf matter, to the pond every year. This organic material has nutrients that promote the growth of algae.

It is hypothesized that the internal loading within the Storm Pond due to these high concentrations is the main cause of algal blooms and odor problems in the area. Treating the Storm Pond for its high nutrient load would reduce the potential for algal growth.

Alum Dosing

Alum (Aluminum Sulfate) may be added to lakes to clear the water and reduce phosphorus recycling from sediment on the lake bottom. As alum mixes with water, if forms a fluffy precipitate (floc) composed of aluminum hydroxide. The floc bonds with phosphorus to form insoluble aluminum phosphate compounds. As the floc settles, it also sweeps suspended particles down to the lake bottom to improve water clarity. A floc layer deposited across the lake bottom acts as a barrier to trap phosphorus released from underlying sediments. This process will reduce phosphorus levels via the chemical bonds with the floc. This bond makes the phosphorous unavailable for biomass production.

Alum treatment does not address salinity stratification. As salty winter melt water from roads flows into a lake, it sinks to the bottom and forms a dense bottom layer. So, when the surface waters cool in fall or spring, the salinity stratification may delay or completely prevent the lake from overturning and mixing. Consequently, a lake's bottom layer may remain persistently anoxic for most of the year. This is a problem because phosphorus can escape from anoxic sediment much faster than oxygenated sediment. During periods of bottom water anoxia phosphorus can build up in deeper water layers. When the lake eventually overturns, the excess phosphorus built up can then result in massive algal blooms. To combat the issue of lake anoxia, aeration devices may be installed and the lake would be artificially aerated during winter months.

The dosage rate required is a function of the phosphorous removal required. The efficiency of coagulation falls as the concentration of phosphorous decreases. In practice, an 80-90% removal rate is achieved at coagulant dosage rates between 50 and 200 mg/l (Wisconsin Wastewater Operators' Association 2017). Costs can be estimated for low and high doses of alum (Osgood 2003):

Low Dose, Emerald Pond: 30g Alum/m^2 applied to 0.881 acres = 107 kg Al

107 kg Al = 236 lbs Al = 484 gallons alum

Low Dose, Storm pond: 30g Alum/m^2 applied to 0.237 acres = 29 kg Al

29 kg Al = 64 lbs Al = 132 gallons alum

High Dose, Emerald Pond: 100g Alum/m^2 applied to 0.881 acres = 357 kg Al

357 kg Al = 788 lbs Al = 1614 gallons alum

High Dose, Storm pond: 100g Alum/m^2 applied to 0.237 acres = 96 kg Al

96 kg Al = 212 lbs Al = 434 gallons alum

Cost of alum delivered and applied, including labor, is estimated at $0.85 per gallon (2003 dollars). Adjusted for 2017 dollars this would be $1.13 per gallon.

Low, Emerald: 484 gallons @ $1.13 = $546.92

High, Emerald: 1614 gallons @ $1.13 = $1,823.82

Low, Stormwater: 29 gallons @ $1.13 = $32.77

High, Stormwater: 96 gallons @ $1.13 = $108.48

There may be additional costs if a professional inspection is desired before the alum application. If an aeration device were to be installed, prices depend on the size of the pond or lake. For a pond with an area of approximately 0.5 acres, an aeration device would cost approximately $750 (CQUENSE LLC 2017), and see Table 3F on Appendix 3 for complete list.

Dredging

Dredging, removal of sediments from bottom of pond, is a good option for reducing internal load of sediments and nutrients in the pond. Runoff carried by the stormwater system deposits sediments which accumulate at the base of the pond. These sediments contain nutrients, which under the right condition, can be released into water and excessive nutrients are contributing factor of algae growth.

Dredging can be expensive and is often a last resort for pond remediation. The total cost for the dredging construction is approximately $81,7500. This cost includes: site preparation, site formation, and site restoration, see Table 3H in Appendix 3 for detailed cost analysis. The cost estimate does not include soil analysis and disposal fees, which can vary depend on the composition of soil and pollution concentration. This cost estimate is based on the area of the pond and length of vegetative benches measured on Google map. The annual operation and maintenance fee were calculated with recommended 1 to 2 site-visit per year from Minnesota Stormwater Manual (Minesota Pollution Control Agency 2016). Total annual operation and maintenance cost is $ 60,506.00, see Table 3I on Appendix 3 for detail.

Rain Gardens

Rain gardens have gained popularity and prominence for their reputation as a cost effective alternative of reducing the flow of water and improve water quality in neighborhoods. Many cities in Minnesota have successfully implemented programs to entice residents to install rain gardens on their property and have experienced positive results. Burnsville installed rain gardens in a residential lot in the fall of 2003 and monitoring data revealed an 80 percent reduction in runoff for 49 rain events in 2004 (Minnesota Pollution Control Agency 2016).

Rain gardens are “planted depressions that collect stormwater runoff from impervious surfaces, such as roofs and streets, and filter pollutants out of the runoff water” (Minnesota Pollution Control Agency 2017). With strategic placement in locations where runoff from impervious surfaces can be intercepted, rain gardens will reduce the flow of water into the stormwater network. Pollutants such as phosphorous, nitrogen, PAHs and toxic metals are also captured during the infiltration process, which can improve the water quality in Storm Ponds. The soil used in rain gardens must be permeable with a proper mixture of sand, compost and topsoil to allow for vegetation growth and infiltration. Planting specific vegetation will allow effective capture of phosphorus, further reducing the nutrient loading in the stormwater system. The best types of vegetation include plants with deep roots that can tolerate saturated and dry soil with little required maintenance (see Appendix 3 for pictures of rain gardens).

The neighborhood surrounding Emerald Pond has soil with a high infiltration capacity. This makes the location favorable for nutrient reduction via infiltration. In the neighborhoods surrounding Emerald Pond Park there is little city owned property that could provide the space necessary for a rain garden, but there is plenty of yard space. It may be necessary to gain the cooperation of residents to implement a cost sharing rain garden installation program. While this can be challenging, it is possible to encourage resident participation through proper education of the benefits of rain gardens and cost sharing of installation and maintenance. Getting residents involved with the plant selection and planting process can also bring a sense of ownership to the project and will also help ensure that the gardens receive the maintenance required.

It is important to note that rain gardens do require maintenance to ensure that they continue to function properly. Routine maintenance such as visual inspections, liter removal, and vegetation management should ideally be performed periodically throughout the summer to keep vegetation healthy and to keep nutrient release by the plants to a minimum. Occasional non-routine maintenance may be required if high sediment loading results in clogging which can cause rain gardens to lose their ability to infiltrate. Consult the Minnesota Stormwater Manual for further information about suggested maintenance.

The P8 model results for the installation of residential rain gardens are shown in Table 4.

Table 4.Results from P8 Total Phosphorus Analysis

Total Phosphorous Removal [Load lb/yr]			
Scenarios		Storm pond [Load lb/yr]	Emerald Pond [Load lb/yr]
Original Conditions		3.1	N/A
Rain Garden Size and Percent of Resident Participants			
	150 [sq. feet]		
	10%	0.6	N/A
	50%	1.5	N/A
	70%	1.7	N/A
	300 [Sq. feet]		
	10%	1.0	N/A
	50%	1.9	N/A
	70%	2.1	N/A

Total cost of the addition of rain gardens was estimated by determining the volume of water infiltrated by the rain gardens, water quality volume (WQV) and the following equation.

$$Cost\ of\ Raingarden\ installation = \$1989 * (WQV)^{0.776}$$

Many online sources estimate the cost of rain gardens to be about $3-4 per square foot, however, the article “Cost and pollutant removal of storm-water treatment practices” (Weiss 2007) pulled data from many different projects to determine a more accurate cost estimation for rain garden installation. The equation was adjusted for 2017 dollars assuming an inflation rate of 29 percent since 2005 (see Appendix 3 Table 3J for cost estimate results).

Grass Barriers and Buffer Strips

Buffers remove sediment from runoff by decreasing the flow velocity and allowing particles to settle. Vegetation within grass barriers and buffer strips will trap sediment and enhance filtration of nutrients, such as phosphorus. Grass barriers differ from buffer strips in that they are narrower and require less land use. Stiff grasses have robust stems which offer important advantages in areas of concentrated flow; however, they may be less effective than standard buffer strips where flow rates are relatively low. It is recommended that the grasses chosen for these barriers be stiff, tall, and have deep roots, and the slope leading down to the barrier should be no more than 5% (For every 5 horizontal feet, drop 1 vertical foot). It was observed from field observations that the slopes of the residential lots surrounding both Emerald Pond and Storm Pond were approximately 3%. At a slope of 3% as compared to 5%, sediment and runoff will have more time to infiltrate and filter. The lots surrounding both ponds have slopes which are less than what is suggested for effective grass barrier filtration. These findings therefore support the installation of this grass barriers as a best management practice. Grass barriers should be planted in dense strips 2 to 4 feet wide (Yuan et al., 2009). It has been shown that grass barriers of this size possess the capacity to reduce up to 63% of sediment loading (Yuan et al., 2009).

Modeling the effectiveness of grass barriers at removing TSS and TP was conducted using P8, see Table 3K and 3L on Appendix 3 for P8 input parameter. There are approximately 11 residential properties bordering the western and northern edges and 0.3 acres of city land bordering the eastern and southern edges of Emerald Pond. It was assumed that only the backyards of the residential properties contributed phosphorus from sediment and grass clippings. It was also assumed that 50 percent of residents bag their grass clippings. It has been estimated that 1 kg of sediment contains 400 mg adsorbed Phosphorus (Berretta et al., 2011). It has also been estimated that lawn clippings contain about 0.13 pounds of phosphorus per 1000 ft^2 during the growing season (Spetzman et al., 2004). Switchgrass is hardy, tall, and has deep roots making it a great option for use in planting the grass barrier. The barrier will need to be planted perpendicular to the slope and be no more than 2 ft in width. The 2 ft barrier width was chosen to limit the intrusion into residential properties. The cost of installation of grass barriers or buffer strips varies based on width, soil type, and vegetation. The estimated cost is $0.50 per square foot (Minnesota Pollution Control Agency), not included in this estimate are costs associated with labor and supplies for necessary maintenance.

Calculations for this analysis can be viewed in the Appendix 3. The results show that implementation of a switchgrass barrier will reduce the total phosphorus load to Emerald pond by 1.45 pounds per year. This is equivalent to approximately 116 pounds of dry algae per year.

Table 5. TP and Algea weight reduction per year with the installation of Grass Barriers and Buffer Strips

400 mg P	per	1 kg TSS	80 lb algae (dry weight)	per	1 lb P	**TP reduction per year**	**=**	**1.45 lb P**
0.13 lb P	per	1000 ft^2 grass during growing season	Grass Barrier removal efficiency	=	63 % TSS	**Dry weight algae reduction per year**	**=**	**116 lb dry algae**

Street Sweeping

Coarse organic material such as leaves are a major source of nutrients entering storm drains. Total phosphorus concentrations spike in late spring and fall due to pollen and falling leaves, respectively. Targeted, enhanced sweeping may be a cost effective way to reduce phosphorus inputs to storm sewers.

Street sweeping is gaining popularity as a method of pollutant source reduction for lakes and ponds in Minnesota. Impervious areas (impervious surfaces are surfaces which do not allow water to infiltrate into the ground), such as streets and sidewalks collect pollutants in the form of grass clippings, leaves, sediments, road salts, and metals deposited by vehicle traffic. When rain falls on impervious surfaces, pollutants are flushed down the street and into the stormwater system, ultimately ending up in lakes or ponds downstream.

For street sweeping to be an effective method of pollutant load reduction the following conditions must be considered: percent canopy cover near impervious areas, sweeper type, sweeping frequency and schedule.

Sweeping is most effective in places with dense canopy cover because more leaves end up in the stormwater system. In this study, canopy coverage over streets in the watershed surrounding Emerald Pond Park is low, estimated by comparing google map images of the watershed to the examples of canopy cover provided in the 2014 Street Sweeping Guidance Manual (Kalinosky, et al. 2014). It is recommended to use a vacuum type sweeper that can pick up fine particles over the typical mechanical brush sweepers that are used for compacted material and large debris. Sweeping frequency and schedule is important when considering the cost effectiveness of street sweeping. Too few sweepings mean less pollutant removal, but sweeping too frequently is not cost effective either. Sweeping a couple times in the spring when all the trees are dropping pollen and seeds and a couple times again in the fall when trees are shedding their leaves has been found to be the most cost effective.

Estimated annual phosphorous removal and cost estimates for three different sweeping scenarios defined below. Estimated input values: total curb-mile swept is 4.1 miles, low canopy cover (1%), $ 24.25 /curb-mile (cost estimate is in 2017 dollars and includes amortization cost of the sweeper).

Scenario A: Sweep x1 per month for 2 months: April, October.

Scenario B: Sweep x1 per month for 4 months: March, April, October, November.

Scenario C: Sweep x1 per month for 10 months: All months EXCEPT December and January.

Table 6. Predicted annual removal of phosphorous and cost efficiency for Scenarios A, B and C via Street Sweeping

	Predicted Annual		
Sweeping Scenario	Phosphorous removal [lb]	Cost [$2017]	Average Cost per Pound Phosphorous removed [$ / lb P]
A	1.7	$ 198.85	$ 117.01
B	3.3	$ 397.70	$ 121.11
C	6.2	$ 943.00	$ 151.85

All three sweep scenario estimates were calculated using the Planning Calculator for Estimating Nutrient Removal through Street Sweeping. Input values were entered for curb-mile swept, sweep frequency, and months swept. Default cost value adjusted for inflation was used for predicted annual cost estimates which include total time of operation and swept miles and depreciation of the sweeper, does not include initial sweeper purchase cost or rental fee. See

Table 2A in Appendix 2 for table showing estimates of all other nutrients removed for the three different sweeping scenarios (Kalinosky, et al. 2014).

As shown in Table 6, all three street sweeping options provide fairly low cost per pound even with only 1% canopy cover. Scenario A is the most cost effective because research indicates that these months tend to have the greatest potential for nutrient removal by sweeping (Kalinosky, et al. 2014). Present worth value of street sweeping scenario A over 10 years using a 5% compound interest factor is $1,536 (Newman 1988).

$$\mathrm{PW} = \left(\frac{\mathrm{P}}{\mathrm{A}}\right) * \mathrm{A} = 7.722 * \$199 = \$1{,}437$$

$$\frac{\mathrm{P}}{\mathrm{A}} = \text{uniform payment series of annuity over 10 years at 5\%}$$

$$\mathrm{A} = \text{annual payment of 2x sweepings per year}$$

Phosphorous removal increases with increased sweeping events; however, the cost per pound removed increases as well. Street sweeping may be an effective option considering the low estimated costs. A caveat to this method is the effectiveness of the sweeper used. It is likely that the phosphorous removal will be lowered if a mechanical sweeper is used, driving up the average cost per pound phosphorous removed.

SAFL Baffles & Snouts

The SAFL Baffle is a pretreatment device installed within a sump, which is used to encourage the sedimentation of particles within the sump by preventing sediment scour. The SAFL Baffle improves downstream water quality by reducing the amount of sediment that can pass through a sump, loading a lake with TSS. As previously discussed, nutrients such as phosphorous adsorb to the surface of organic sediment at a rate of 400 mg TP per kg of sediment, and contribute to the TP loading of waterbodies. The SAFL Baffles requires no additional maintenance than that of a preexisting sump and has a life expectancy up to 20 years. Additional advantages of the SAFL Baffle include reduced maintenance for downstream BMPs such as detention ponds and rain gardens, due to the reduced sediment loading on those practices (Berretta et al., 2011).

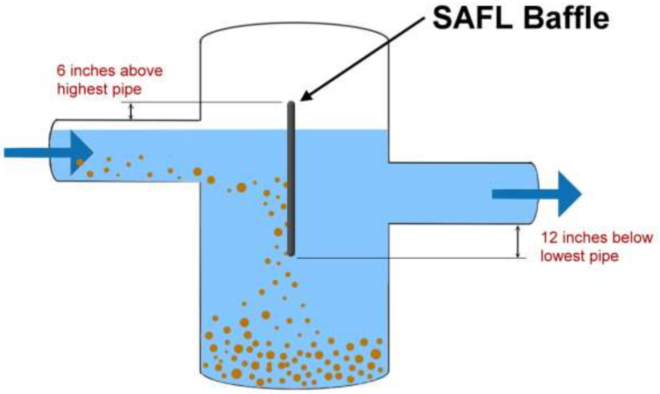
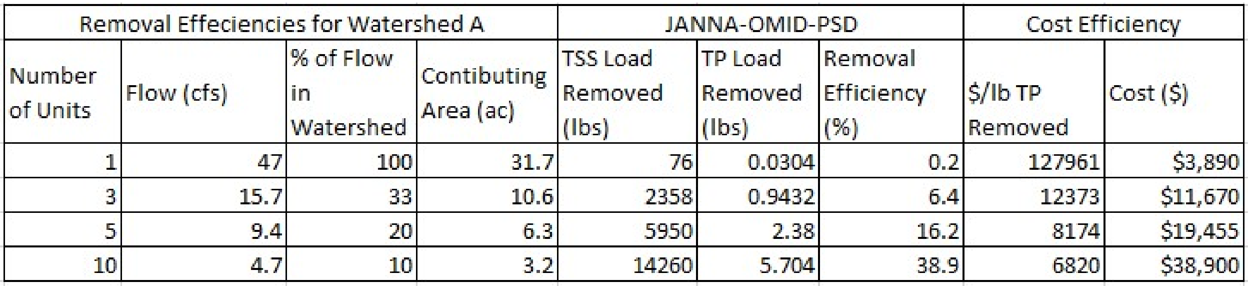


Figure 3. Diagram of SAFL Baffle's design and mechanism of removing sediment in municipal stormwater sumps

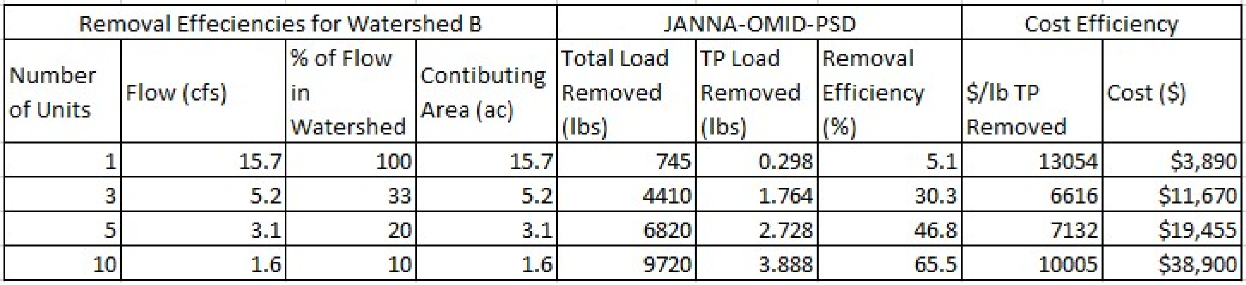
BMP Snouts with Trash Screens can be added to SAFL Baffles to provide a low cost solution to help improve stormwater quality. The snout reduces the discharge of floatable pollutants and organic material from the sump. Clean water at mid depth of the sump exits from under the snout into the receiving waterbody. Performances of a variety of sized SAFL Baffle unit implementations for each watershed and pond can be seen in Tables 7 and 8.

Table 7.SHSAM model outputs for SAFL Baffle implementation in Watershed A given two particle distributions, as pretreatment for the Storm Pond.



Removal Effeciencies for Watershed A				JANNA-OMID-PSD			Cost Efficiency	
Number of Units	Flow (cfs)	% of Flow in Watershed	Contibuting Area (ac)	TSS Load Removed (lbs)	TP Load Removed (lbs)	Removal Efficiency (%)	$/lb TP Removed	Cost ($)
1	47	100	31.7	76	0.0304	0.2	127961	$3,890
3	15.7	33	10.6	2358	0.9432	6.4	12373	$11,670
5	9.4	20	6.3	5950	2.38	16.2	8174	$19,455
10	4.7	10	3.2	14260	5.704	38.9	6820	$38,900

Table 8.SHSAM model outputs for SAFL Baffle implementation in Watershed B with a variety of units implemented as pretreatment for Emerald Pond.



Removal Effeciencies for Watershed B				JANNA-OMID-PSD			Cost Efficiency	
Number of Units	Flow (cfs)	% of Flow in Watershed	Contibuting Area (ac)	Total Load Removed (lbs)	TP Load Removed (lbs)	Removal Efficiency (%)	$/lb TP Removed	Cost ($)
1	15.7	100	15.7	745	0.298	5.1	13054	$3,890
3	5.2	33	5.2	4410	1.764	30.3	6616	$11,670
5	3.1	20	3.1	6820	2.728	46.8	7132	$19,455
10	1.6	10	1.6	9720	3.888	65.5	10005	$38,900

Note that the SHSAM model for calculating the removal of TP only includes a SAFL Baffle. Removal of TP is predicted to be higher, as floatable organics will be removed from each sump with a SNOUT installed. SNOUT cost varies with sizing, but is on the order of $500 and will only improve cost effectiveness.

Recommendations

In Table 9, the cost of each explored solution to reduce odors and algal blooms is displayed. The Algae reduction was calculated using the conversation from TP to Dry weight of Algae that was explored previously in this report.

Table 9.Cost and Reduction Results for the most cost effective scenarios explored for each potential solution. All solution costs are listed as total cost except street sweeping.

Solutions	Total cost ($)	TP Reduction (lb/yr)	Algae Reduction (lb/yr)
Alum			
Emerald Pond	$547	Unknown	Unknown
Storm pond	$33	Unknown	Unknown
Rain Garden (50% contribution 150 ft^2)	$157,000	1.5	120
SAFL Baffles and Snouts	$50,570	7.47	597
Switchgrass Barrier			
Emerald Pond	$1,718	1.45	116
Storm pond	$790	0.67	53
***Street Sweeping (Scenario A)**	$1,437	1.7	136
Dredging	$81,750	Unknown	Unknown

*Street sweeping Present Worth is over 10 years of sweeping and does not include purchase or rental costs of a vacuum sweeper as they vary depending on type and vendor.

Resident involvement is an important part in solving pollution problems in Storm Pond and Emerald Pond. Encouraging residents to make a few small adjustments to their landscaping routines can have a large impact on reducing nutrients entering the pond. Some things the city can do to encourage resident participation include:

1) Supply residents with information regarding the following practices in the form of brochures, web pages, and information booths at public events:
    a. Collect all grass clippings and leaf debris that fall in yards and on driveways, streets and sidewalks by sweeping, raking, or utilizing leaf bagging attachment on lawn mower.
    b. Collect and dispose of all pet waste.
    c. Maintain vegetation in yards surrounding Emerald and Storm Pond to keep leaves and lawn debris from falling directly into the ponds.
    d. Dispose of all leaf debris and grass clippings by dropping off at a local composting facility or by enrolling in the yard waste program provided by the local sanitary waste removal company.
        i. Refer to the following page on the Anoka County website for details on local compost facilities: http://www.anokacounty.us/359/Compost-Sites

        ii. The City of Ramsey has a contract with ACE SOLID WASTE, INC. for residential solid waste. See following webpage for information regarding the yard waste program: http://acesolidwaste.com/residential/yard-waste\

2) Implement a program to encourage rain garden installation on private property. The program should include the following:
    a. Funding for residents who consent to rain garden installation on their property.
    b. Contractor to design and install rain gardens on property.
    c. Provide classes and information for residents regarding proper raingarden maintenance. *It is recommended the city oversees maintenance for the first couple years to ensure rain gardens are functioning properly.
    d. Regular inspections in the fall and spring to address any maintenance issues that may be required.
3) To combat resident fears regarding Canada Geese and their impact on water quality it is recommended that the park install a fox decoy, to scare away migratory birds from the park. Also inform residents that the actual geese pollution contributions may be small considering the other nutrient sources mentioned.

In addition to this, it is recommended that the city take steps to reduce the current concentration of phosphorous in the storm water pond.

1) The Storm Pond should be treated with alum. Emerald Pond may also benefit from this.
    a. This would treat the current phosphorus concentration and reduce the suspended solids concentration.
    b. Implementation of an aeration device would prevent anoxic conditions, improving treatment and reducing odors.

All, or a combination of the following BMPs should also be implemented to reduce further loading in Emerald Pond and the Storm Pond, in order to prevent future TP contamination.

1) SAFL Baffles are another cost effective way to reduce the phosphorus load into the ponds
    a. As many as 10 SAFL Baffles should be installed as possible in the northern section of the neighborhood (Watershed A). The more Baffles, the more cost effective.
    b. Three SAFL Baffles be installed in the western neighborhood (Watershed B).
2) Grass barriers be installed along the edges of the ponds to catch particles and nutrients that runoff from the residents' lawns into the ponds.
    a. The current leafy vegetative buffer surrounding the ponds should be replaced with native switchgrass, such as to reduce the TP loading from these leaves every autumn.
    b. Areas currently lacking vegetative buffers be planted with switchgrass to form a unified buffer perimeter encircling the ponds. In addition to functioning as a

filter, the switchgrass barrier will provide stability thus reducing bank soil erosion.

3) Street sweeping in fall and spring months. A mechanical sweeper will likely reduce some phosphorus loading but a vacuum type sweeper is recommended to achieve the best results.

Appendix 1. Watershed Delineation

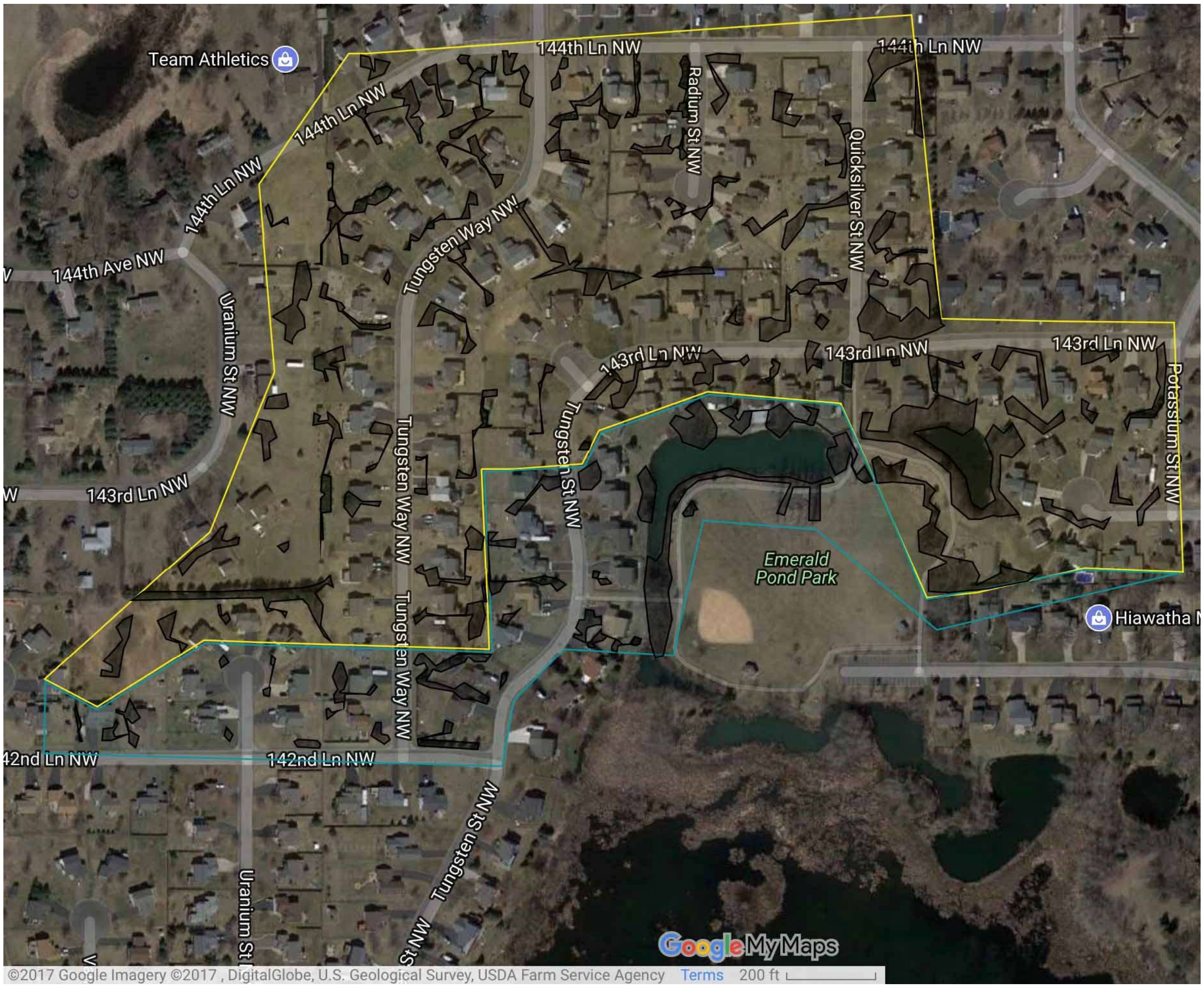
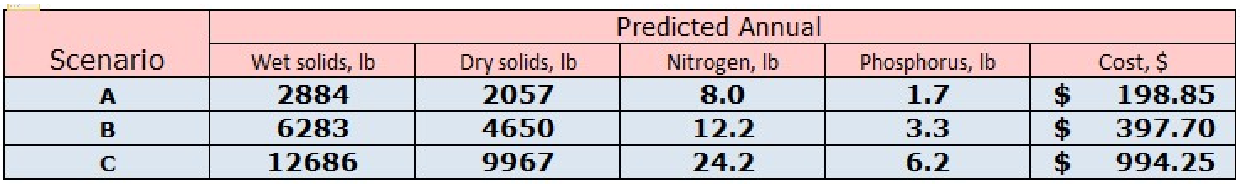


Figure 1A: Watershed delineation and canopy coverage. Watershed A (Yellow), Watershed B (Teal), canopy (Gray).

Appendix 2. Considered Solutions Supplemental Material

2A. Street Sweeping

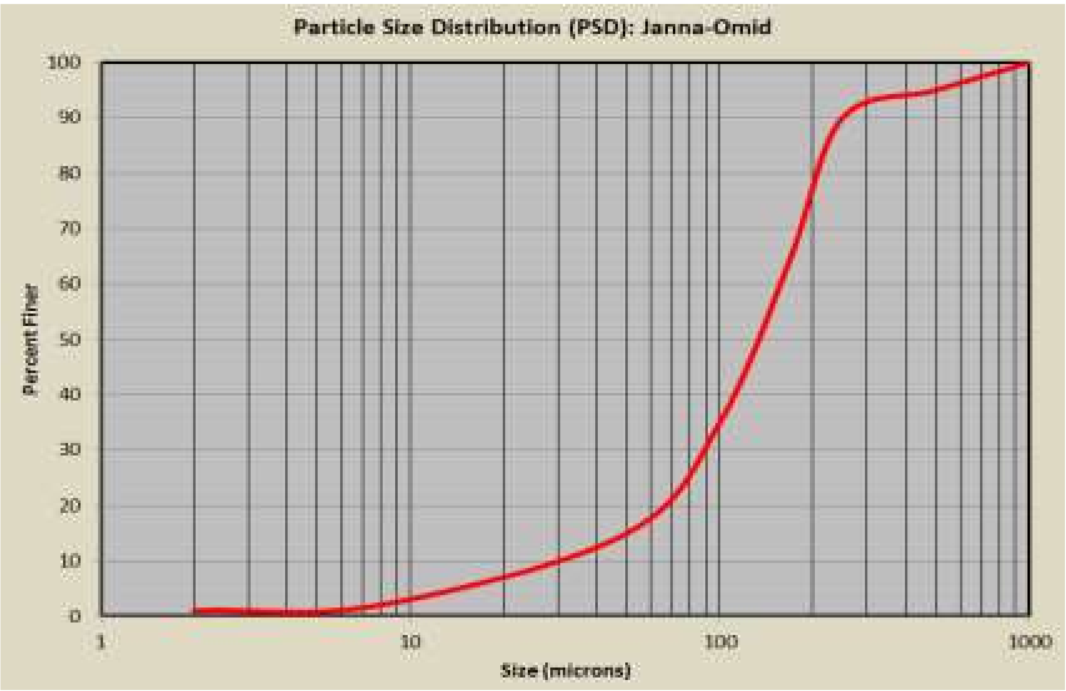
Table 2A Predicted annual removal of nutrients and total estimated cost of three different street sweeping scenarios calculated using the Planning Calculator for Estimating Nutrient Removal through Street Sweeping (Kalinosky, et al. 2014).



Scenario	Predicted Annual				
	Wet solids, lb	Dry solids, lb	Nitrogen, lb	Phosphorus, lb	Cost, $
A	**2884**	**2057**	**8.0**	**1.7**	**$ 198.85**
B	**6283**	**4650**	**12.2**	**3.3**	**$ 397.70**
C	**12686**	**9967**	**24.2**	**6.2**	**$ 994.25**

2B. SAFL Baffle

Table 2B: Particle Distribution Janna-Omid-PSD



Appendix 3. Sample Calculations and Results

Watershed Calculations

The following calculations were used to determine watershed characteristics. Sample calculations are for Watershed A.

Total Area

The measured subwatershed A area: 81.57 [sq.in]

Scaling Factor form the map: 130 [feet per inch]

Conversion from sq. feet to acres: 1 Acre per 43560 sq. feet

$$81.57in^2 * (\frac{130ft}{in})^2 * \frac{1\,Acre}{43560\,ft^2} = 31.65\,acres$$

Impervious Area Calculations

$$\begin{aligned} Total\ Area\ Impervious \\ &= total\ area\ street\ and\ paths + (\ number\ approx.house\ area \\ &+\ approx.driveway\ area) \end{aligned}$$

$$Percent\ Impervious\ Watershed\ A = \frac{Total\ Area\ Impervious}{Total\ Area\ Watershed\ A} * 100$$

$$Total\ Area\ Impervious = 9.217\ sq.in +\ (19.44\ sq.in) = 28.66\ sq.in$$

$$Percent\ Impervious\ Watershed\ A = \frac{81.57\ sq.in}{28.66\ sq.in} * 100 = 35\%$$

Canopy Calculations

$$Percent\ Canopy = \frac{approx.canopy\ area}{Total\ Watershed\ Area} * 100$$

Calculations for Watershed A:

$$Percent\ Canopy = \frac{5.9\ acres}{41.8\ acres} * 100 = 14\%$$

Rain gardens

To approximate the cost of rain garden installation is calculated using the following equations:

$$WQV = A_s * D_o$$

$WQV = volume\ of\ water\ infiltrated\ by\ raingardens$
$A_s = surface\ area\ of\ raingarden$
$D_o = depth\ of\ ponded\ area\ in\ raingarden$

$$Cost\ of\ Raingarden\ installation = \$1989 * (WQV)^{0.776}$$

$WQV(in\ m^3) = water\ quality\ volume\ in\ SI\ units, volume\ infiltrated$
$for\ 20m^3 < WQV < 1000\ m^3$

Sample calculation for 70% resident participation. Installation of 57 rain gardens with an area of 150 square feet each. A one-hour storm was used with Type A soil (infiltration rate of 0.8 inches per hour) was used in the approximation.

$$WQV = 8550\ ft^2 * 0.5\ ft = 4275\ ft^3 = 397\ m^3$$

$$Cost\ of\ installation\ of\ 57\ raingardens = \$1989 * (397\ m^3\ )^{0.776} = \$207{,}739$$

Grass Barrier Calculations for Emerald Pond

$$(10.9\ lb)\left(\frac{1\ kg}{2.2\ lb}\right)(0.63) = 3.12\ kg\ TSS\ removed$$

$$\frac{400\ mg\ P}{1\ kg\ TSS} * 3.12\ kg\ TSS = 1248\ mg\ P$$

$$(1248\ mg\ P)\left(\frac{1\ kg}{10^6\ mg}\right)\left(\frac{2.2\ lb}{1\ kg}\right) = 0.00275\ lb\ P\ removed$$

$$0.3\ acre + \frac{7}{75 * 2}acre * (11\ residences) = 35{,}153\ ft^2$$

$$\frac{0.13\ lb\ P}{1000\ ft^2\ grass}(35{,}153\ ft^2) = 4.6\ lb\ P\ from\ grass\ clippings$$

$$Assume\ 50\%\ of\ residents'bag\ grass\ clippings; therefore, 2.3\ lb\ P\ from\ grass\ clippings\ removed$$

$$2.3\ lb\ P * 0.63 = 1.45\ lb\ P\ removed\ from\ grass\ clippings$$

$$1.45\ lbs\ P\ removed\ per\ year = 116\ lbs\ dry\ algae\ removed\ per\ year$$

Figure 3A. Before and after photos of a rain garden project in Burnsville, MN. Notice the curb cut in the forefront of the picture on the right, this allows for capture of water during a storm event. Once the garden is at maximum capacity, water will bypass the garden and continue to flow down the curbside to either the next garden or into the stormwater network (Minnesota Pollution Control Agency 2016).

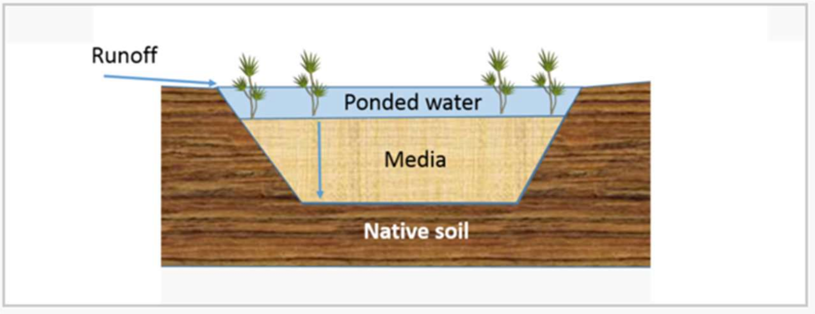


Figure 3B. Diagram of a typical rain garden design. Runoff is captured in the vegetated depression and infiltrates through the rain garden media directly into the native soil. Typical residential rain garden dimensionsvary from 100-300 square feet and the depth pf the ponded water should never exceed 1.5 feet to ensure that water infiltrates quickly enough so the vegetation does not become fully submerged (Minnesota Pollution Control Agency 2017)

Rain Garden Area

Table 3A. Area for 150 [sq. feet] Rain Garden Design

150 [sq. feet] Rain garden design			
Participants	**Households/ watershed**	**Total Rain garden Area [sq. feet]**	**[ac]**
10%	8	1200	0.0275
50%	40	6000	0.138
70%	57	8550	0.196

Table 3B. Area for 300 [sq. feet] Rain Garden Design

300 [sq. Feet] Rain garden design			
Participants	**Households/ watershed**	**Total Rain garden Area [sq. feet]**	**Area [ac]**
10%	8	2400	0.055
50%	40	12000	0.275
70%	57	17100	0.393

Table 3C.Subwatershed Parameters

Watershed ID	Total Area [acres]	Directly connected impervious fraction	Pervious Area Curve Number
Watershed A	31.65	35%	57
Watershed B	12.49	23%	57

Table 3D. P8 Device Parameters

Device	Storm pond	Emerald Pond	Rain garden
Bottom Area [ac]	0.237	0.881	Information provided on Table 4 and 5
Permanent Pool Area [ac]	0.237	0.881	Information provided on Table 4 and 5
Flood Pool Area [ac]	0.237	0.881	NA
Permanent Storage Volume [ac-ft]	0.711	2.643	0.54 (100% Void volume)
Flood Storage Volume [ac-ft]	0.119	0.441	NA
Perm Pool Outlet Type, size, and coefficient	12-inch Orifice 0.6	12-inch Orifice 0.6	NA

Table 3E Soil Type Analysis Results

Main soil type and Hydrologic Soil Group (NRCS)	%	Group
Hubbard Loamy Sand (D67B, D67C, D90B)	61	A
Duelm Loamy Sand (Dp)	4.8	A
Marsh (Mc)	4.3	A/D
Nymore Loamy sand (Nyc)	30	A

Cost Analysis

Table 3F Cost Estimate of Alum Dosage

Estimated Alum Dosage cost		
	High	Low
Emerald Pond	$1,823.82	$546.92
Storm pond	$108.48	$32.77

Table 3H. Cost Analysis of Dredging Pond. Modified cost sheet from (Minnesota Stormwater Manual 2015)

Dredging Pond Cost Estimate			**Unit Cost**	**Total Estimated Cost**
Site Preparation				
Clear and grub brush	387.2	[sq yard]	$1.50	$580.80
Tree protection - temp. fence	80	[ft]	$3.00	$240.00
Total				$820.80
Site Formation				
Excavation – deep water zone	344.124	[sq. yard]	$5.00	$1,720.62
Excavation - marsh zone	802.956	[sq. yard]	$1.00	$802.96
Grading	1147.08	[sq. yard]	$1.50	$1,720.62
Hauling off-site 5' depth	338.8	[sq. yard]	$5.00	$1,694.00
Total				$5,938.20
Structural Components				
Inlet structure	1	[each]	$2,000.00	$2,000.00
Outlet structure	1	[each]	$3,500.00	$3,500.00
Total				$11,438.20
Site Restoration				
Sod -above vegetative bench	784.08	[sq. yard]	$4.50	$3,528.36
Soil preparation	1147.08	[sq. yard]	$25.00	$28,677.00
Seeding -vegetative bench	784.08	[sq. yard]	$0.50	$392.04
Planting	784.08	[sq. yard]	$30.00	$23,522.40
Total				$56,119.80
subtotal				$74,316.99
10% Contingencies				$7,431.70
Total				$81,748.69

*Table 3I. Anural Operation and Maintenance Estimated Cost for Dredging Pond. *Frequency suggested by (Minesota Pollution Control Agency 2016)*

Annual Operation and Maintenance			**Unit Cost**	**Total Estimated Cost**
Debris removal	2	[per visit]*	$100.00	$200.00
Invasive plants removal	2	[per visit]	$500.00	$1,000.00
Repair erosion	784.08	[sq. yard]	$75.00	$58,806.00
Gate/ valve operation	2	[pre visit]*	$125.00	$250.00
Inspection	2	[pre visit]*	$125.00	$250.00
total				$60,506.00

Table 3J. Total Cost of Rain Garden Installation

Estimated Rain garden Costs (Installation only)			
Rain garden Size	**Participants**	**Number of Rain gardens**	**Total Cost [$]**
150 [sq. feet]	10%	8	45046
	50%	40	157058
	70%	57	206739
300 [sq. feet]	10%	8	77136
	50%	40	268943
	70%	57	354014

Table 3K. Grass Barrier Emerald Pond Parameters used for P8

	Flow Path Length [ft]	Flow Path Slope [%]	Bottom Width [ft]	Side Slope [ft-h/ft-v]	Maximum Depth [ft]	Manning's n
Buffer strip	1374	3	2.5	3	0.5	0.3

Table 3L. Grass Barrier Stormwater Pond Parameters used for P8

	Flow Path Length [ft]	Flow Path Slope [%]	Bottom Width [ft]	Side Slope [ft-h/ft-v]	Maximum Depth [ft]	Manning's n
Buffer strip	632	3	2.5	3	0.5	0.3

References

Association, Wisconsin Wastewater Opertors'. 2017. December 1. https://www.wwoa.org/files/News/134.pdf.

CQUENSE LLC . 2017. *Aeration Source* . December 9. https://www.aerationsource.com/.

Deering, Emily. 2016. "Floating Treatment Wetlands in a Northern Climate: Examination of Phosphorous and Nitrogen Removal." *University of Minnesota Digital Conservancy.* http://hdl.handle.net/11299/181829.

Minesota Pollution Control Agency. 2016. *Cost-benefit consideration for stormwater wetlands.* Jan 5. Accessed Dec 11, 2017. https://stormwater.pca.state.mn.us/index.php?title=Cost-benefit_considerations_for_stormwater_wetlands.

Minnesota DNR. n.d. "FACTSHEET SUSTAINING MINNESOTA™S LAKES Phosphorus Concentration." Accessed December 1, 2017.

Minnesota Pollution Control Agency. 2016. *Burnsville rain gardens - retrofitting for water quality.* June 1. https://stormwater.pca.state.mn.us/index.php?title=Burnsville_rain_gardens_-_retrofitting_for_water_quality.

—. 2017. *Design criteria for stormwater ponds.* Septermber 18. Accessed November 27, 2017. https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_stormwater_ponds.

—. 2017. *Design infiltration rates.* May 22. Accessed November 25, 2017. https://stormwater.pca.state.mn.us/index.php?title=Design_infiltration_rates.

—. 2017. *Raingardens (Bioretention) 101.* January 19. https://stormwater.pca.state.mn.us/index.php?title=Rain_gardens_(bioretention)_101.

—. 2015. *Requirments, recommendations and information for using swale without an underdrain as a BMP in the MIDS calculator.* December 8. Accessed November 27, 2017. https://stormwater.pca.state.mn.us/index.php?title=Requirements,_recommendations_and_information_for_using_swale_without_an_underdrain_as_a_BMP_in_the_MIDS_calculator.

Minnesota Stormwater Manual. 2015. *Stormwater Wetland cost estimate worksheet.* July 15. Accessed December 11, 2017. https://stormwater.pca.state.mn.us/index.php?title=Stormwater_wetland_cost_estimate_worksheet.

Osgood, Dick. n.d. "Lake McCarrons Management Plan." Accessed December 8, 2017. www.capitolregionwd.org/wp-content/uploads/2012/09/LakeMcCarronsMgmtPlan.pdf.

n.d. *Surface Areators.* Accessed December 2017. https://www.aerationsource.com/collections/surface-aerators.

United States Department of Agriculture Natural Resources Conservation Service Concervation Engineering Division. 1986. *Urban Hydrology for Small Watersheds.* June. Accessed November 27, 2017. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf.

Weiss, P.T., Gulliver, J.S., Erickson, A.J. 2007. "Cost and pollutant removal of stormwater treatment practices." *Journal of Water Resources Planning and Management* 133 (3): 218-229.

William W. Walker, Jr., Ph.D. Jeffrey D. Walker,Ph.D. 2007. *Device Type -Swale, Buffer, Emergent Wetland (Overland Flow Area).* October. Accessed 11 26, 2017. http://www.wwwalker.net/p8/webhelp/p8HelpWebMain.html.

Wisconsin Wastewater Operators' Association. n.d. "Chemical Phosphorous Removal and Online Analysis." Accessed December 1, 2017. https://www.wwoa.org/files/News/134.pdf.