Shady Oak Lake
Feasibility Study of
Best Management Practices

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Executive summary

This study was completed for the City of Minnetonka, to analyze the Shady Oak lakeshed for proactive measures to minimize pollutants within the lake. The storm water best management practices considered in the study include: in lake treatment, street sweeping, sumps, swales, bio-infiltration, and potential city ordinances. The goal of the study is to determine the most cost effective preventative measure for reducing phosphorus and total suspended solids. Based on the analysis, it was determined that increasing the frequency of street sweeping in the lakeshed would be the most effective best management practice.

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1. Introduction

The City of Minnetonka is a fully developed suburban community located in the southeastern portion of Hennepin County, eight miles west of Minneapolis, with approximately 51,400 residents. Home to an abundance of natural wetlands and water bodies, Minnetonka has four separate watersheds within the city: the Bassett Creek Watershed, the Minnehaha Creek Watershed, the Nine Mile Creek Watershed, and the Riley-Purgatory-Bluff Watershed. After witnessing great population growth in the last 20 years, the city has introduced the implementation of stormwater best management practices (BMPs) to ensure cleanliness and reduce phosphorus, total suspended solids and other pollutant levels found within their open water bodies.

Shady Oak Lake is part of the Nine Mile Creek Watershed and is located east of interstate 494 and south of Minnesota Highway 7. The lake is home to Shady Oak Beach, which is the only beach found within the city limits of Minnetonka. Surrounding the lake, there are residential neighborhoods to the north and south, and a commercial district to the east. The main roadway in this lakeshed is Shady Oak Road which runs north and south and is at one point directly adjacent to Shady Oak Lake. Across this road from the lake and to the southeast is a townhome complex.

The object of this feasibility study is to analyze and recommend stormwater BMPs to be implemented in the surrounding lakeshed as preventative measures to reduce pollution levels within Shady Oak Lake. Several BMPs were considered for this lakeshed and it was determined which method is most effective for reducing the levels of phosphorus and total suspended solids in the lake. The BMPs considered included: in lake treatment, street sweeping, in-line treatment structures, bio-infiltration and bio-filtration basins, and current and possible city ordinances.

2. Shady Oak Lake

2.1 Lakeshed Background

Shady Oak Lake resides in the eastern portion of the City of Minnetonka within the Nine Mile Creek Watershed. The lake's watershed is fully developed with neighborhoods to the north and south, and a commercial district directly to the east of the lake on the other side of Shady Oak Road. Figure 1 shows the watershed for Shady Oak Lake. The lake itself has an area of 95 acres with a maximum depth of 25 ft, a mean depth of 11 ft, and a volume of 1045 ac-ft (Barr, 2012). Shady Oak Beach, which is owned by the City of Hopkins and managed by the City of Minnetonka, is found on the southeast corner of the 'upper' portion of the lake. Shady Oak Lake appears to be three separate water bodies, but they are all connected through small waterways between the different sections. The 'upper' and 'middle' areas of the lake are separated by a walking path and walking bridges, while the 'middle' and 'lower' portions of the lake have railroad tracks running between them. Minnetonka classifies Shady Oak as a Level I lake. Level I classified lakes are required to support both aquatic life and recreation, which includes activities such as swimming.

The current BMPs employed in Shady Oak Lakeshed can be seen in Figure 2. On the north side of the lake, there is a slender small pond. A large portion of the stormwater that enters Shady Oak Lake first enters this pond prior to draining into the lake. This pond acts as pretreatment for the lake. There is also a smaller pond on the northeast side of the lake that receives a large amount of stormwater that then travels through a swale and into the pretreatment pond north of the lake. Other than the outlet from the northern pond, there are three known direct outlets to the lake from the stormwater system. The first outlet is on the east side of the 'upper' portion of the lake near the beach. This outlet receives overflow water from a wet pond on the east side of Shady Oak Road. The second outlet is on the east side of the 'lower' portion of the lake, and the third outlet is on the west side of the 'lower' portion of the lake. There was another outlet to Shady Oak on the northwest side of the 'upper' lake, but this was abandoned in 2009, and the stormwater was routed elsewhere.

A majority of the roads throughout the residential area contain a combination of roads with and without curbs, and only a few sidewalks along some of the more main roads. Although many of the roads don't have a curb and sidewalk system, they all contain storm drains and are connected to the storm sewer network within the city that eventually flows to Shady Oak Lake.

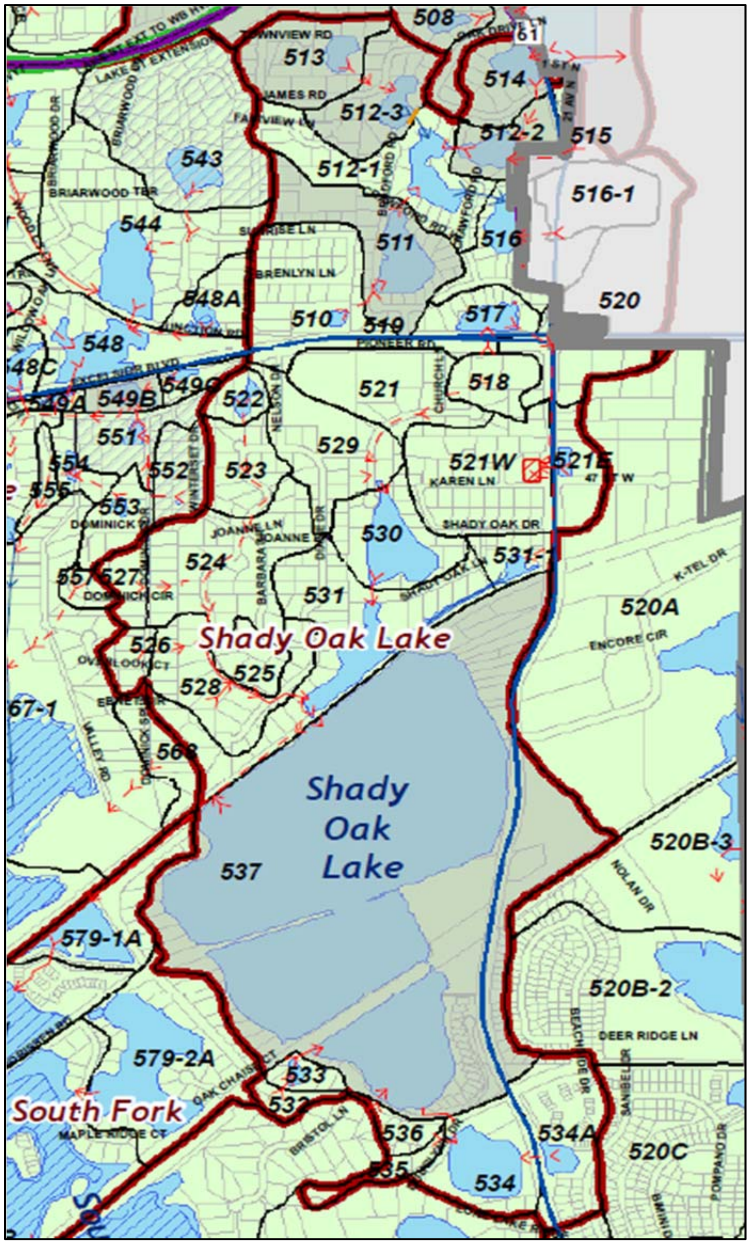

Figure 1: Shady Oak Lake Watershed (Barr, 2010)

Figure 2: Current BMPs in the Shady Oak Lakeshed

2.2 Required Pollution Levels

According to the City of Minnetonka's Water Resources Management Plan, the city has a goal to meet and/or exceed all water quality regulations and requirements as stated by the Federal Government, the State of Minnesota, Hennepin County, the Minnesota Pollution Control Agency (MPCA), the Bassett Creek Watershed Management Commission (BCWMC), the Nine Mile Creek Watershed District (NMCWD), Riley-Purgatory-Bluff Creek Watershed District (RPBCWD), Minnehaha Creek Watershed District (MCWD), and the Metropolitan Council (Barr, 2010).

Shady Oak Lake is classified as a Level 1 lake because the lake contains a beach. A lake classified as Level I consists of a water body that supports both aquatic life and recreation that includes full body water contact. As Shady Oak Lake lies within the Nine Mile Creek Watershed, the watershed has specific pollution level requirements for each lake. The water quality requirements for a Level I lake within the Nine Mile Creek Watershed can be found in Table 1 (Barr, 2010). The trophic state index (TSI) is a score used to rank open water bodies on a numerical scale based on the overall water quality. Decreasing water quality results in a higher TSI ranking, whereas increasing the water quality lowers the TSI ranking. The TSI score for a lake is computed based on the summer-average levels of total phosphorus, chlorophyll-a, and Secchi disc transparency conditions (Barr, 2012).

Table 1: Summary of Water Quality Requirements for the Nine Mile Creek Watershed District

Water Quality Category	Desired Recreational Use	Desired Total Phosphorus Concentration (mg/L)	Desired Chlorophyll-a Concentration (mg/L)	Desired Secchi Disc Depth (m)	Desired TSI*
I	Water bodies support aquatic life and recreation activities including full body contact	< 45	< 20	> 2	< 50
II	Water bodies support aquatic life and recreation activities not including full body contact	45 - 75	20 - 40	1.0 - 2.0	50 - 60
III	Water bodies support wildlife and waterfowl and may not support body contact recreation activities	75 - 105	40 - 60	0.6 - 1.0	60 - 70
IV	Water bodies are water resources generally for aesthetic enjoyment and intended for runoff management (i.e. stormwater detention)	> 105	> 60	< 0.5	> 70

2.3 Current pollution levels

According to the Hennepin County website, Barr Engineering Company found that Shady Oak Lake was graded A for water quality. Grade A indicates that the lake has low amounts of algae bloom and phosphorus levels, and high water clarity. Based on a 2012 study produced by Barr Engineering, the current level of total phosphorus found in the lake was 19µg/L, the chlorophyll-a was found to be 3.3µg/L, and the Secchi disc transparency was found to be 3.5m, as of the year 2010. This study has been ongoing for several years, as the study included data collected from several different years dating back to 1971 from various data collection sources. The historical polluting levels for Shady Oak Lake can be found in Table 2. This set of data is based on summer-averages from the period between the months of June and September (Barr, 2012).

Table 2: Historic Summer-Average Total Phosphorus, Chlorophyll-a, and Secchi Disc Transparencies (Barr, 2012)

Year	Total Phosphorus (µg/L)	Chlorophyll-*a* (µg/L)	Secchi Disc Transparency (m)
1971 (1)	30	5	2.4
1989 (1)	16	5	3.1
1993 (2)	16	4	3.0
1995 (1)	14	4	2.8
1999 (2)	14	5	2.3
2000 (2)	11	5	3.4
2003 (2)	16	4	3.5
2006 (2,3)	18	4	3.1
2009 (2,4)	16	2.3	3.7
2010 (4)	19	3.3	3.5
Historic Summer Average	17	4.1	3.1
10-Year Summer Average	17	3.3	3.5

(1) Data collected by the NMCWD
(2) Data collected by City of Minnetonka
(3) Using summer averaging period of June through August
(4) Data collected by Metropolitan Council's CAMP Program

Based on the above information, Shady Oak Lake currently has pollution levels less than those of a Level 1 lake. It has also met these requirements for at least 40 years prior, and the levels have stayed consistent for over 20 years. As seen in Table 2, the chlorophyll-a, and Secchi disc transparency levels have improved over the years, but since 2000, the levels of total phosphorus have increased. From the historical data, it is expected that Shady Oak Lake will continue to meet the required water quality goals and will remain in very good condition if the city maintains their current BMPs.

2.4 Current BMP Implementation

The City of Minnetonka currently employs an abundance of stormwater BMPs (Figure 2). Minnetonka owns and operates three street sweepers: two mechanical sweepers and one vacuum sweeper. These street sweepers are used on an annual basis in the spring and at varying points during the year to sweep parking lots and specified areas for certain events.

The city also employs the use of in-lake treatment on Shady Oak Lake at the location of the beach to ensure fitness for use. The treatment is meant to prevent against algae blooms and swimmers itch, specifically along the beach shoreline.

Several rain gardens and detention ponds have also been implemented in various areas throughout the watershed. These are mostly located near parking lots or other highly impervious areas and are found within the residential neighborhoods.

Sump manholes and sump catch basins are currently distributed throughout the city storm sewer system. It is found that these sumps are often placed upstream from outlets to either the lake, or other stormwater BMPs, such as retention basins and detention ponds. The city has a preventative maintenance plan to inspect the sumps throughout the city once a year, and provide the required maintenance on the structures as needed (Barr, 2010).

3. Method of analysis

3.1 How the analysis was completed

Biomass data were given for this lakeshed and were used to estimate the phosphorus loading to the lake. Therefore, aerial photos were used to determine the tree cover, which corresponds to biomass output at that particular location in the watershed. The biomass load estimates will help determine problematic areas of the watershed which will contribute the most phosphorus to the lake. Once the origin of the pollutants is identified, the BMP's considered may be implemented at those locations for optimal removal. Previous analyses of the BMP's considered were researched and their methodologies were applied to this lakeshed. Complete data for the pipe system were not given for this lakeshed so modeling the storm events in computer software programs was not a feasible method to estimate the performance of varying BMP's.

3.2 BMPs Considered

For this study, the BMPs being considered include in lake treatment, street sweeping, sumps, SAFL Baffles, swales, bio-filtration and bio-infiltration. Potential city ordinances are also considered which would further reduce the pollution input while minimizing the cost for Minnetonka.

This study did not look into: wet and dry ponds, porous pavement, bio-filtration, grit chambers, and underground retention. The Shady Oak lakeshed is a well-established area and several ponds already exist. The benefit of putting more ponds in the area did not seen substantial to the use of the land. Underground retention was determined to be more useful for prevention of flooding, so no further research was completed because this study is not concerned with flooding. The porous pavement was not considered because it would not be ideal for the area due to the large tree cover which would easily clog the system. Bio-filtration was not considered because it is less effective at removing phosphorus than bio-infiltration. Grit chambers were found to not be cost effective for this area.

4. Best Management Practices

4.1 In lake treatment

In-lake alum treatment is one form of reducing the amount of phosphorus in a lake or pond. There are a couple ways to treat the water, the first is a lake-wide injection of Alum, and the second is a treatment facility that injects the water as it enters a pond before the lake. The treatment can reduce the algae amount, and in turn clarify the water. The alum will floc with the water and bind with phosphorus and then settle to the bottom of the lake, preventing the phosphorus from being used as food for the algae organisms. The floc can also attract suspended solids as it settles, thus clearing up the water. The alum floc will form a phosphorus barrier at the bottom of the lake, which prevents the phosphorus from being released. This process has been completed for several lakes in the area. Some of these lakes in Hennepin County include Long Lake, Cedar Lake, Lake of the Isles, and Lake Calhoun.

There are disadvantages to this treatment that need to be considered. The lake or pond volume needs to be determined accurately because the dose of the Alum depends on the volume of water and an incorrect volume could lead to over dosage of the lake. The pH of the lake also has to be monitored before and after the treatment. The treatment could lower the pH of the water if done incorrectly. The phosphorus can potentially be released back into the lake by internal loading if the dissolved oxygen level is too low at the bottom layer of the lake. Depending on the lake's phosphorus level, the lake could need a retreatment which is dependent on the quality of the water entering the lake (Wisconsin Department of Natural Resources, 2003).

Alum treatment has shown not to have a large effect on people or aquatic life. The Wisconsin Department of Natural Resources suggests that as long as the pH of the lake is controlled in the range of 5.5 to 9.0 there should not be an effect on aquatic life. This will help preserve the aquatic life in the lake. There have not been any known issues with health affects in people, because aluminum is already part of our daily diet (Wisconsin Department of Natural Resources, 2003).

The cost of the alum treatment depends on the dose rate, area treated, volume of the lake, equipment rental, type of treatment and labor. The longevity of one treatment can range from 10-15 years according to the Minnesota Park and Recreation Board. The treatment can be extended longer by controlling the external phosphorus load entering the lake (Minneapolis Park & Recreation Board, 2013).

Green lake in Washington State was treated with sulfate aluminum and alum in order to reduce the phosphorus and suspended solids in the lake. The Seattle Parks and Recreation Study found there was an average treatment life of 10.5 years for seven well documented treatments to lakes in the Seattle area. These lakes had an average treatment dosage of 30 g/m^3 of alum ranging from 10 to 40 g/m^3. The dose and treatment life depended on each lakes water quality, geometry, and incoming water quality. The Green Lake treatment resulted in greater than an 84% removal of the phosphorus. The treatment cost for Green Lake was totaled to be $1.5 million, and estimated to last for 10 years (Herrera Environmental Consultants, 2003).

Tanner Lake in Ramsey-Washington Metro District was fitted with an Alum treatment plant upstream from Tanner Lake. The plant is designed to inject the alum into the incoming water at a proportional dose. The incoming water is directed to a detention pond, which serves as a settling basin for the flocs formed by the alum reaction and can easily be cleaned by dredging the bottom of the pond. This design was implemented so that the alum flocs will not enter the lake. The construction of the project was estimated to cost $665,000 with an annual cost of $30,000 to maintain the treatment and the facility which does not include maintenance of the pond. The treatment facility was found to have an average 47% phosphorus load reduction (Minnesota Pollution Control Agency, 2013).

In-lake treatment is effective at reducing the phosphorus levels. With the treatment also comes a high price. The current quality of the lake is high, so the water is not in need of the treatment. The number of disadvantages for in lake treatment outweighs the benefits for the lake at this time. The best way to reduce the phosphorus and suspended solid quantity is to prevent the pollution from entering the lake. A treatment facility could be a consideration for the detention pond located north of Shady Oak. The treatment facility would decrease the number of disadvantages for in-lake treatment. This treatment facility would treat the water before it enters the lake and reduce the amount of floc residue, phosphorus and alum in the lake. The treatment would also allow for a controlled dose that could be monitored and adjusted when needed, in order to ensure the proper pH level of the water in the lake.

4.2 Street sweeping

Street sweeping is a type of BMP that is used to remove sediment and debris that builds up along roadways. Generally used in urban areas, street sweeping can be used to remove road salt, sand, and grit after winter snowmelt. Street sweeping can also remove lawn debris and sediment which can reduce pollution in stormwater runoff and nutrient import to lakes and streams.

One of the most important factors dictating the effectiveness of street sweeping is the schedule which the area is swept. This schedule should be flexible enough to handle climate conditions as well as target areas of higher concern such as areas of high traffic and areas in close proximity to surface water. If records of past street sweeping are present, the schedule can be altered to target areas that will have high levels of pollution (such as highly impervious areas or industrial areas) or areas that typically have high amounts of material buildup between sweeps.

The major costs of street sweeping lie in the personnel and equipment costs. The cost for a conventional street sweeper can range from $60,000 to $120,000 (CASQA, 2003). The typical life of street sweepers is generally around 4 years, although the actual life span will be determined by the frequency of sweeping. Cities that plan on sweeping at a higher frequency should expect to spend more money on maintenance and replacement of sweepers. Hourly wages of sweeper operators, maintenance personnel, and parking officials to enforce parking restrictions will add to the overall cost. Additional costs may evolve from the need to train operators and educating the public to reduce litter and obey parking restrictions.

The material removed from the road by street sweeping generally includes: sand, road salt, leaves, and other debris. Before this material can be disposed of, testing must be conducted to determine whether the debris contains any hazardous material (MPCA, 2010). If the material is found to be hazardous, it should be treated according to federal and state regulations that apply to sweepings. If the sweepings are not found to be hazardous, they should be screened to remove any trash or compostable material such as leaves and grass. Once screened, there are several options for the reuse of the sweepings. They can be mixed with new sand and salt mixtures to be applied to roads, sidewalks, and parking lots. The sweepings can also be used as daily covering at a solid waste disposal site or as fill for road restorations or other construction projects. If the material is not screened it must be disposed of as solid industrial waste.

To begin the street sweeping analysis of this watershed, an aerial photograph of the watershed was analyzed to separate regions with different levels of vegetation. These regions were separated out so that areas that contribute more biomass to the system could be targeted with street sweeping. The results of this classification can be seen in Figure 3. The roads highlighted in yellow are those that do not have significant amounts of vegetation along them, so they will not contribute a significant amount of biomass to the lake. The roads highlighted in blue represent areas with higher levels of tree cover, and are thus more important when looking at nutrient loading to the lake.

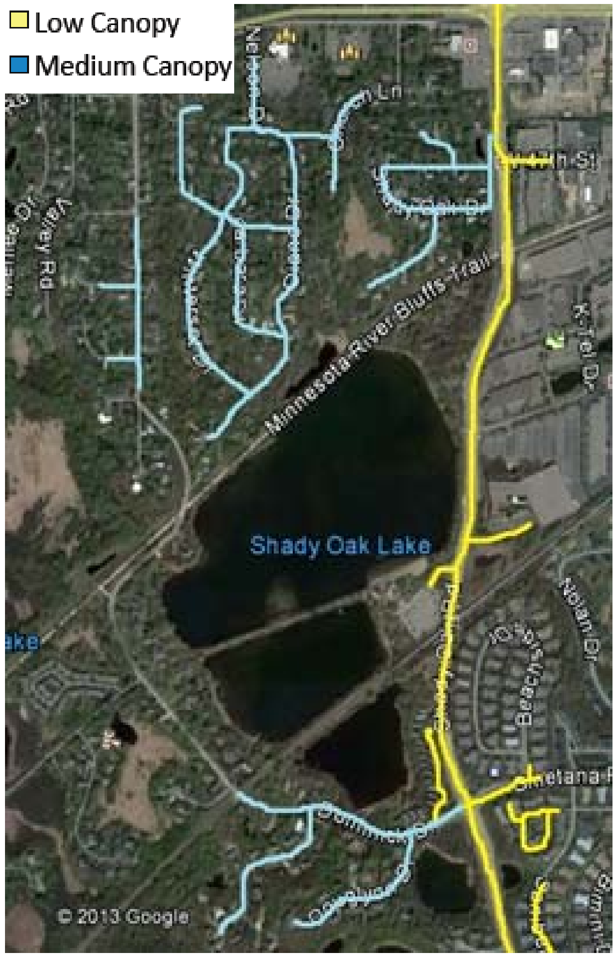

Figure 3: Aerial of Lakeshed with Vegetation Classifications

A map was then used to determine the length of each of the roads of interest to determine the total length of road that needs to be swept (Shady Oak Road was left out as it is not swept by Minnetonka). Typical values for the nutrient recovery were used to estimate the magnitude of nutrients that could be removed from the streets using different street sweeping scenarios (Kalinoksy, 2012). The results for the different sweeping schedules can be found in Tables 3-7. The cost for each of these scenarios was calculated by looking at the number of curb miles that needed to be swept and multiplying by the cost of sweeping a mile of curb. A value of $19.00 per curb mile was used, although values ranging from $15 to $40 were found depending upon the type of sweeper used (Schilling, 2005) (NPDES, 2013).

Table 3: Nutrient Removal and Cost Estimate for Street Sweeping Scenario #1

Canopy Density	Season	# of Sweeps	P Recovered (lbs/yr)	N Recovered (lbs/yr)	TSS Recovered (lbs/yr)	Cost ($/yr)
Medium	Spring	1	0.85	7.82	130.30	
	Fall	1	1.43	13.68	977.27	
Low	Spring	1	0.04	1.57	31.36	
	Fall	1	0.37	2.00	60.98	
Total			2.69	25.07	1199.92	314

Table 4: Nutrient Removal and Cost Estimate for Street Sweeping Scenario #2

Canopy Density	Season	# of Sweeps	P Recovered (lbs/yr)	N Recovered (lbs/yr)	TSS Recovered (lbs/yr)	Cost ($/yr)
Medium	Spring	1	0.85	7.82	130.30	
	Fall	2	2.87	27.36	1954.55	
Low	Spring	1	0.04	1.57	31.36	
	Fall	1	0.37	2.00	60.98	
Total			4.12	38.75	2177.20	406

Table 5: Nutrient Removal and Cost Estimate for Street Sweeping Scenario #3

Canopy Density	Season	# of Sweeps	P Recovered (lbs/yr)	N Recovered (lbs/yr)	TSS Recovered (lbs/yr)	Cost ($/yr)
Medium	Spring	1	0.85	7.82	130.30	
	Fall	2	2.87	27.36	1954.55	
Low	Spring	1	0.04	1.57	31.36	
	Fall	2	0.73	4.01	121.97	
Total			4.49	40.76	2238.18	471

Table 6: Nutrient Removal and Cost Estimate for Street Sweeping Scenario #4

Canopy Density	Season	# of Sweeps	P Recovered (lbs/yr)	N Recovered (lbs/yr)	TSS Recovered (lbs/yr)	Cost ($/yr)
Medium	Spring	1	0.85	7.82	130.30	
	Fall	3	4.30	41.05	2931.82	
Low	Spring	1	0.04	1.57	31.36	
	Fall	1	0.37	2.00	60.98	
Total			5.56	52.44	3154.47	561

The “Minnetonka Watershed Analysis” estimated that annually 7.8 kg (17.16 lbs) of phosphorus are discharged into the lake (Baldwin, 2012). Based upon this estimate, the percent of phosphorus recovered in street sweeping that could be diverted from the lake was calculated for each sweeping scenario. The results can be seen in Table 7. The lowest sweeping frequency proposed (scenario #1) removes about 16% of the phosphorus load to the lake. The highest sweeping frequency proposed (scenario #4) removes over 30% of the phosphorus load to the lake. The latter scenario removes roughly twice as much as the least aggressive sweeping schedule proposed and costs only about 80% more. So if phosphorus is a major concern for the lake, it appears that sweeping more often is a more efficient method of reducing phosphorus loading to the lake as the amount of phosphorus removed increases faster than cost.

Table 7: Percent Phosphorus Removal for Sweeping Scenarios

Sweeping Scenario	Cost ($/yr)	Percent Phosphorus Removal
1	314	15.7
2	406	24.0
3	471	26.2
4	561	32.4

4.3 In-Line Treatment Structures

Sump manholes are a type of structural BMP that is put in place directly in-line with the stormwater sewer system. Considered as one of the simplest BMPs, these structures consist of a concrete cylinder with an inlet and outlet pipe, and a base that is several feet below the invert of the outlet pipe. With the base of the structure placed at a lower elevation, water is captured inside the manhole where solids are able to separate out by settling to the bottom of the structure. More settlement is found to occur during low flow periods, while during high flow periods, circular flow patterns form in the sump causing scour, forcing previously settled particles to resurface resulting in washout of settled particles. The removal efficiencies of standard sumps can be found in Figure 4 and Figure 5.

Sediments such as leaves and suspended solids are most commonly found to become trapped in sumps. When biomass, such as leaves, is trapped in the sump, it can decompose and produce phosphorus. During high flow storm events, washout can cause settled particles and dissolved phosphorus to resurface and leave the sump. If sumps are not maintained and cleaned properly, they can become a source of suspended sediment when sediment levels build up inside the sump, and resurfaced particles and settled pollutants are washed out of the sump. Because of this, annual inspections of the structure are required for proper maintenance, and the sump will need to be cleaned periodically as sediment collects in the bottom. It is estimated that the cost to maintain a manhole annually is approximately $60 per manhole (Tucker, Young, Jackson, Tull Inc., 2003). This can be seen as a disadvantage because time and money must be spent every year to inspect and maintain the sumps so that they are in optimal working order.

Sump manholes are often not used as a stand-alone BMP, but instead within a system, as pre-settlement to another BMP such as an underground retention system, a rain garden, or a pond. The sump allows for sediments to settle out prior to reaching the following BMP in the system, allowing for less sediment to build up in the later BMP. This is found to be a great advantage because the maintenance and cleaning out of sump manholes is often much cheaper and easier than that of other BMPs.

By implementing a sump manhole in-line with a storm sewer system, a decrease in effluent concentrations occurs. It is found, as seen in Figure 4, that for very low flow rates, some sumps can actually provide near 100% removal efficiencies of larger sediment particles (545μm) and near 40% for smaller particles (110μm) at the same discharge. These efficiencies decrease linearly as discharge rates increase. Sumps that have a sump depth that is equal to the size of the diameter of the structure are found to perform much better than sumps that have depths smaller than the diameter size. Along with this, the removal efficiency increases as the general diameter and depth of the sump increases. Figure 5 shows that as discharge increases, the effluent concentration also increases, meaning that the sump is not performing as well. The performance of the sump decreases with the discharge until the discharge becomes so high that the inflow water is no longer being trapped into the sump, but instead skims across the top of the sump to the outlet. Once this occurs, the concentration of the effluent is found to decrease slightly.

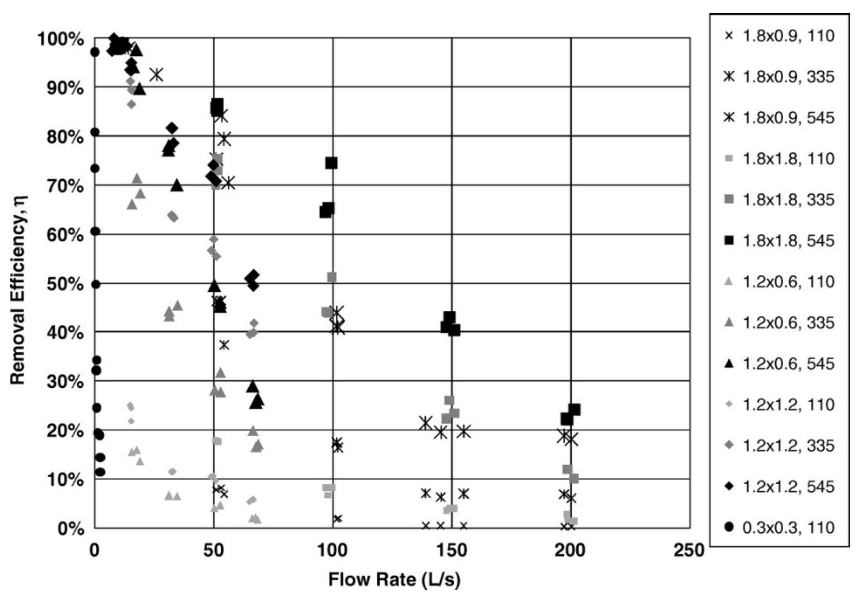

Figure 4: Sump Manhole Removal Efficiency at Low Flow Rates; Legend provides sump size (diameter x depth) in meters and sediment particle size in μm (Howard, 2012)

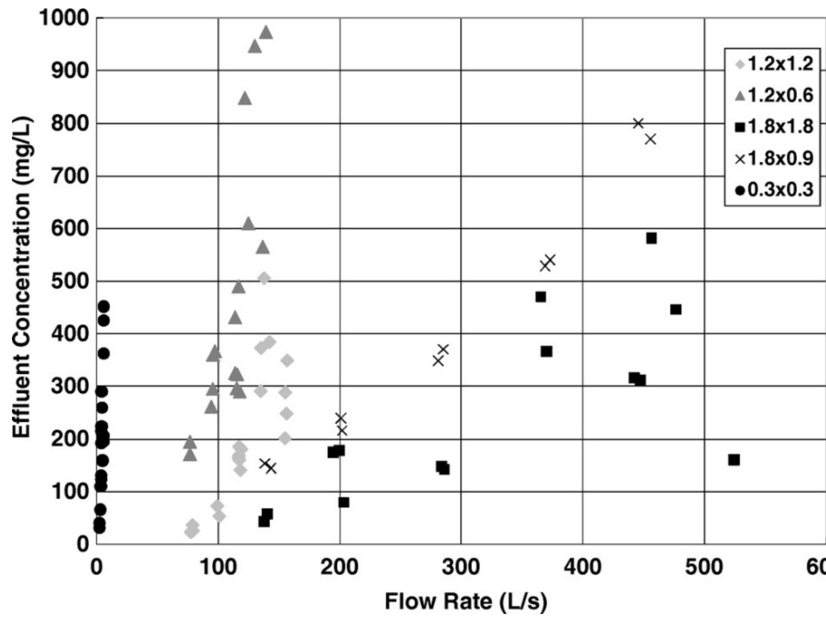

Figure 5: Sump Manhole Removal Efficiency at High Flow Rates; Legend provides sump size (diameter x depth) in meters (Howard, 2012)

Although sump manholes provide some treatment by reducing effluent concentrations, a sump can be retrofitted with an additional treatment structure such as the SAFL Baffle to improve its performance in settling out sediments. The SAFL Baffle is a porous baffle that fits inside the sump manhole and provides the benefit of reducing the frequency of maintenance needed for the sump and prevents the standard sump from becoming a source of sediment during high flow conditions. With correct dimensions and porosity of the baffle, the implementation of the device is found to greatly reduce and almost eliminate the occurrence of washout at high flow conditions as well as significantly increase the removal efficiency at low flow rates (Howard, 2011). One comparison study between a standard sump and one retrofitted with a SAFL Baffle can be found in Figure 6. The figure shows that the sump with the SAFL Baffle in place has much greater removal efficiencies of small, medium, and large particles. Upstream Technologies estimates that a SAFL Baffle increases the capture of sediments in a sump manhole by 10%-20% (2013). Figure 7 shows how significant of an effect the SAFL Baffle had on reducing the effluent concentration during washout conditions with high flow rates compared to the standard sump.

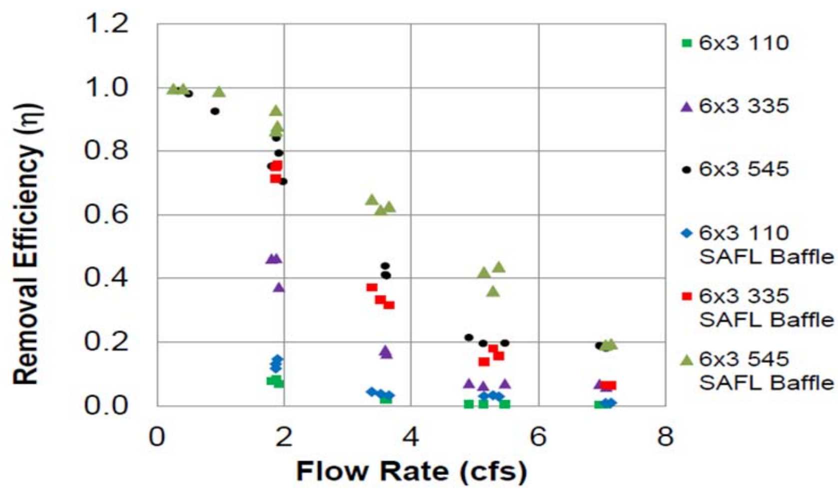

Figure 6: Performance Comparison between 6x3 ft Sump Manhole and Sump Manholes Retrofitted with a SAFL Baffle (Mohseni, 2012)

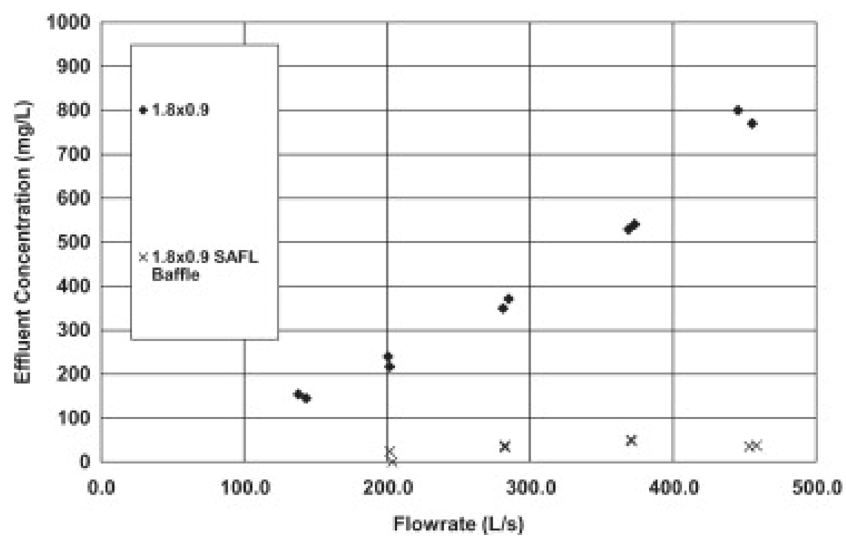

Figure 7: Performance Comparison between 6x3 ft Sump Manhole and SAFL Baffle Retrofit Effluent Concentrations during washout, high flow rates (Howard, 2011)

The City of Minnetonka currently has several sump manholes and catch basins near the site of Shady Oak Lake; specifically there are two sump manholes in place directly upstream from outlets to the most southern part of the lake. These structures are manholes 8661 and 16074, and their specific location can be found in Figure 8. Based on the Geographic Information System (GIS) data provided by the City of Minnetonka, manhole 8661 has a 60-inch diameter and manhole 16074 has a 72-inch diameter and both have a structure made of pre-cast concrete. Due to the large size of the structures, their close proximity to an outlet to the lake, and the pre-cast concrete structure, both of these sump manholes would be ideal candidates for a SAFL Baffle retrofit.

Based on the diameter of the manhole, the cost of the actual SAFL Baffle device can be approximated. A manhole with a 60-inch diameter ranges in price from $3,420 to $4,170 and a 72-inch diameter ranges from $3,720 to $4,470 (Upstream Technologies, 2013). With these retrofits in place, an additional amount of sediment would be removed prior to reaching the southern portion of Shady Oak Lake. There would be no additional cost in maintenance of these structures as they were already sump manholes, and require no different cleaning and maintenance procedures. According to the City of Minnetonka's BMP for sump manhole inspections, these structures are inspected on an annual basis, which is what is needed for a sump with a SAFL Baffle retrofit (Barr, 2010). A SAFL Baffle is expected to last approximately 20 years, and has a cost of $80 for maintaining the structure annually based on a cost of $200/hour for a maintenance crew and vacuum truck and a maintenance time of 24 minutes per structure (Upstream Technologies, 2013).

Another location within the watershed where a sump manhole fitted with a SAFL Baffle would be beneficial is in the storm sewer system that drains directly into the pond on the north side of Shady Oak Lake. This location is specified in Figure 8. Because the small pond just to the north drains into Shady Oak Lake, it would be optimal to provide pretreatment for the pond so that fewer pollutants reach the pond that would then reach the lake. Due to lack of data, it is unknown whether a structure already exists in this location, and if so, whether this structure contains a sump. If a sump manhole already exists in this location, the cost to retrofit the manhole with a SAFL Baffle would be comparable to that of the other two manholes discussed earlier. If a manhole does not exist in this location, or if a manhole does exist, but does not have a sump, the cost of building a sump in the manhole, and/or a manhole itself would be more expensive to implement. The cost of replacing a manhole with a sump would be around $7,000 per manhole, including construction. The cost of building a completely new sump manhole if no manhole already exists would be more expensive, as more digging and soil extraction would take place. Based on the cost of replacing the manhole, it is estimated that the cost to build a manhole would be approximately $10,000 (Tucker, Young, Jackson, Tull Inc., 2003).

The current pollutant levels of Shady Oak Lake are already very low and meet requirements. Implementing the SAFL Baffle on the two pre-existing sump manholes highlighted in Figure 8 would reduce TSS levels found in the lake at a fairly low cost, a total of approximately $8,000 for both of the structures. The addition of the baffles would not require any more maintenance and inspections than what Minnetonka already employs for their Sump Manhole BMP. The SAFL Baffle retrofit provides a long lasting BMP that will reduce TSS levels in Shady Oak Lake at an overall low cost. Although the standard sump and SAFL Baffle do not specifically target the removal of phosphorus, dissolved phosphorus can adhere to sediments that are removed by these practices.

Figure 8: Current Sump Manholes Optimal for a SAFL Baffle Retrofit

4.4 Bio-Infiltration

Swales are essentially roadside ditches which capture stormwater and its pollutants. Water is either infiltrated through the soil or filtered by the vegetation as it moves through the swale. The vegetation can consist either of grass (grass swales) or plants (bioswales). The selection of vegetation will mainly affect the removal efficiency and the cost of maintaining the BMP. An inherent benefit of bio-infiltration is that, while it is very effective at removing pollutants, it also reduces the peak flow observed at the outlet of the watershed because some of the water is rerouted from impervious area to pervious soil and will reach the outlet at a much later time in the form of groundwater.

The primary pollutant of concern in relation to algae growth is phosphorus. Phosphorus is a limiting nutrient for algae, and is usually retained by the soil in non-urbanized areas. In urban watersheds, pervious area is transformed into impervious area which often drains directly to the lake. This increases the amount of phosphorus reaching the lake, allowing algal blooms to occur. The primary goal of this study is to provide long-term preventative measures which maintain water quality for recreational use. Thus, phosphorus reduction is crucial if algal blooms are to be prevented. While swales are great at removing many pollutants, they would not remove an adequate amount of phosphorus in a large storm event.

The benefit of swales is that they are easily implemented if on public land. They are only a few feet wide and are located directly adjacent to roads. Not only do they help the water quality by infiltration, but they also help reduce the risk of flooding on the highways by quickly rerouting water from the impervious road to pervious area. The removal efficiency of the swale is highly dependent on the type of soil used. Engineered soils exist which contain water treatment residuals that greatly help reduce phosphorus effluent by adsorption. If these special soils are not used, dissolved phosphorus will leach from the BMP and eventually contaminate the lakeshed.

A long term solution would be to include this engineered soil in the BMP. In a 2008 study, no significant difference was observed between soils containing 40% or 20% engineered soil, so the mix need not contain a large amount of this more expensive soil. So, assuming that the cheaper option would be used (20% engineered soil), the total phosphorus reduction from the influent was determined to be around 40%, with the corresponding initial cost for a grassed swale of $0.64/ft^3 (Tanner et al. 2008).

For swales to be most effective, they should be placed near roads with high traffic volume, or adjacent to the lake itself. There are several of these locations indicated in Figure 9. The one located to the south would collect highway runoff as well as any runoff from the surrounding neighborhood, which would contain fertilizer. The one to the north would be most beneficial as the road currently drains directly to the beach area. From Figure 10, the estimated biomass load in the north location is about 300 kg/ha in the fall, whereas the one in the southern location has negligible biomass load. Thus, the best swale practice should be implemented in the north location. The estimated initial cost for this swale is $4520, with phosphorus influent of 0.0081 kg/yr. Considering annual maintenance costs and 40 percent phosphorus removal of the swale, the normalized cost of the swale is ($443,544/(lb P removed)/yr (Appendix A.1).

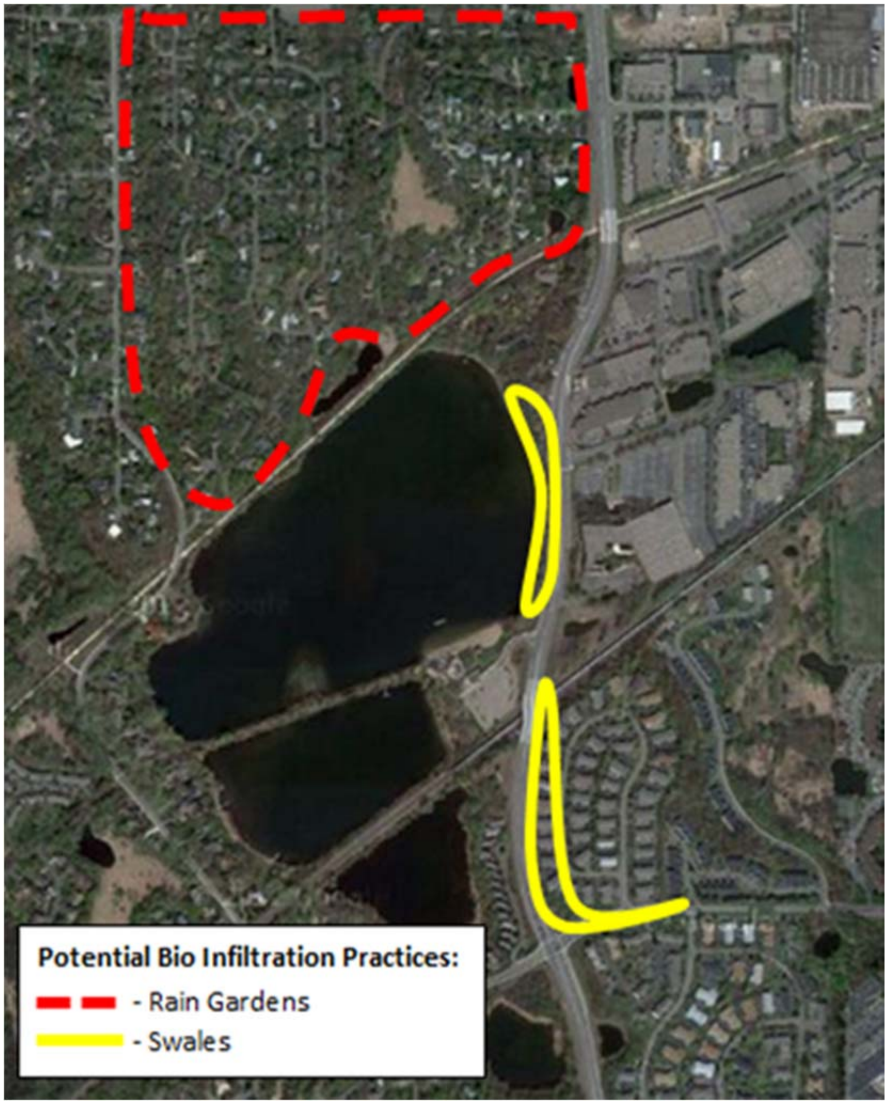

Figure 9: Proposed Bio Infiltration Locations

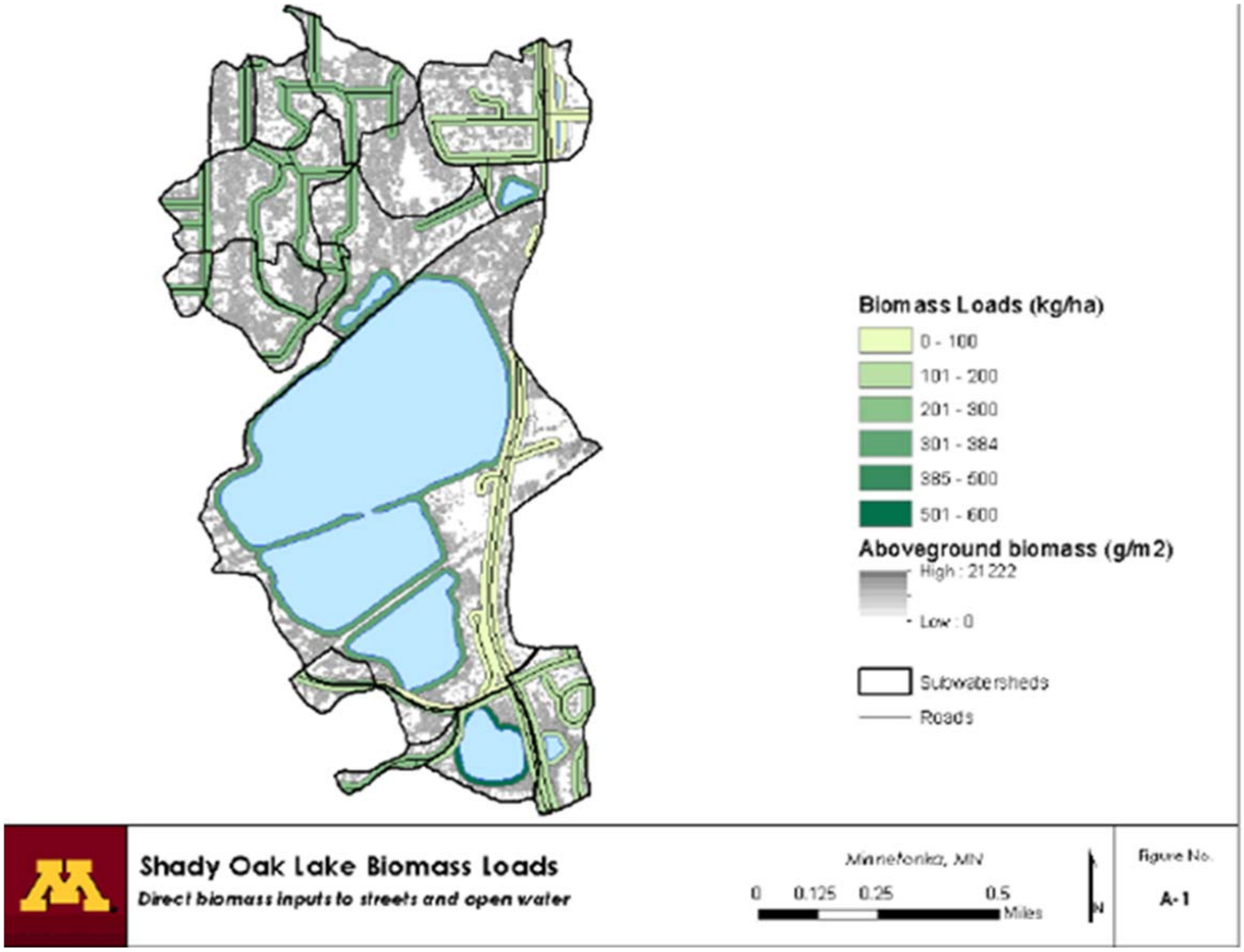

Figure 10: Shady Oak Lake Biomass Loads (Baldwin et al.)

Another possible solution is to design a detention pond, which is a large area that allows water to infiltrate. The problem with designing a detention pond is that it requires a large area. One possible solution would be to break up the required area for one designed detention pond into smaller areas that could be distributed throughout the watershed, such as rain gardens. Rain gardens are small scale detention ponds which reroute stormwater from impervious to pervious area. This stormwater is then allowed to infiltrate rather than runoff directly to the sewer system. As an alternative, an under-drain may be placed in the rain garden such that the TSS removal is still sufficient, but removal of dissolved and small particles is minimal. This BMP is known as bio-filtration. However, one of the primary goals is to remove phosphorus, which is most readily performed by infiltrating the runoff.

Not only are rain gardens excellent at removing pollutants, they are also aesthetically pleasing as they may be filled with a wide variety of plants. The other benefit of rain gardens when compared to other BMPs is that they can be distributed throughout the watershed. Several landowners may be interested in having a rain garden by their home for its aesthetic appeal and could be given incentives to have them installed. The city could certainly help design the BMP and offer a cost share to the client.

The typical initial cost for rain gardens is approximately $1.00/ft^3, with a removal efficiency of about 40 percent if using 20% engineered soil (Tanner et al. 2008). For a rain garden to be most effective, it should be placed in an area that will have high phosphorus loading. The map from Figure 10 shows that the highest biomass loads occur in the neighborhoods north of the lake (about 400 kg/ha in the fall). Since this is privately owned land, the city must work collaboratively with the residents to install the BMP. Due to the large amount of residents in the area, it is likely that the city will not have problems finding willing participants. The neighborhood in consideration is outlined in Figure 10. Per rain garden, it is found that the normalized cost is $92,698/(lb P removed) (Appendix A.2) if the residents perform maintenance on the rain garden.

Bio-infiltration practices are a relatively cheap and effective method to reduce the phosphorus levels in this lakeshed if the proper soil is used. Not only do they reduce the pollutant load to the lake, they also reduce the peak outflow in storm events by retaining runoff water. In the comparison of swales and rain gardens for this watershed, it was found that rain gardens would be more cost effective in reducing phosphorus if they are placed in the neighborhood just north of Shady Oak Lake. Surveys should be conducted to determine if the residents in this neighborhood are willing to work with the city to implement and maintain this BMP throughout its lifetime. Additionally, tests should be conducted on the current soil conditions in the area to determine if bio-infiltration is a feasible option.

4.5 City Ordinances

The city of Minnetonka currently has city ordinances which require residents to properly dispose of yard waste and they continuously educate the public on proper disposal. However, there are no current city ordinances requiring residents to rake their lawn in the first place. This would eliminate the leaf phosphorus load from the source, reducing the total amount that is washed into the storm sewers which then reaches the lake.

Through public education, the city also encourages residents to be mindful of the catch basins on the streets in front of their homes, as every catch basin is a shorefront. The City of Minnetonka already informs residents, through education programs and pamphlets, to be considerate of lawn debris in the streets. Currently, the city encourages residents to 'adopt' the storm drain in front of their homes; strongly recommending this would ensure that no additional waste or leaves are being washed into the storm sewer. If in place, residents would be responsible for cleaning the area surrounding the storm drains bordering their property so that no leaves or trash are washed into the drain. This would also eliminate phosphorus load and the contaminants of other solid wastes from the source which reduces the amount that reaches the lake.

5. Summary and Recommendations

Through the analysis of the BMPs, a comparison could be made with regard to total phosphorus removal and estimated cost. The results of these comparisons can be found in Table 8.

Table 8: Cost comparison of BMP's

BMP	TP Removal [%]	Cost of Initial Construction [$]	Cost of Maintenance [$]	Life Span [years]	Cost/Year [$/yr]	Normalized Cost/Year [($/yr)/lb P removed]
In lake Alum Injection	**84**	**1,500,000**	**-**	**10**	**150,000**	**-**
Alum Injection Plant	**47**	**655,000**	**30,000**	**1**	**-**	**-**
Street Sweeping	**32**	**-**	**561**	**-**	**561**	**101**
Sumps	**0[(1)]**	**7,000[(2)]**	**60**	**30**	**8,800**	**-**
Sump w/SAFL Baffle	**0[(1)]**	**3,500[(3)]**	**80**	**20**	**5,100**	**-**
Rain Gardens	**40**	**1,766**	**-**	**8[(4)]**	**221**	**92,700**
Swales	**40**	**4,520**	**2,613**	**8[(4)]**	**3,178**	**443,500**

[(1)] Sump manholes and SAFL Baffles do not remove phosphorus, but remove TSS.
[(2)] Cost assuming that manhole is already in place and is to be replaced with a sump manhole.
[(3)] This cost is averaged. Cost depends on sump manhole dimensions. This cost also does not include the cost of constructing a sump manhole.
[(4)] This is not the actual lifespan of the BMP, it is considered over eight years to compare to the other BMPs.

According to the cost estimates presented in Table 8, street sweeping is the most cost effective manner to reduce nutrient loading to the lake. It would be optimal to sweep the streets three times in the fall for those areas that are highly vegetated as well as once for areas with less vegetation. An additional sweeping in the spring is also recommended. This sweeping regime is estimated to reduce phosphorus loads to the lake by 32% and would only increase current annual operations and maintenance costs for the street sweeping operations by $561. The additional cost is low because the lakeshed is rather small and the city of Minnetonka already owns its own street sweepers.

Although more frequent street sweeping is the most highly recommended practice, there are several other BMPs that the city could implement to improve water quality depending upon the city's time and budget. The second most recommended practice would be to retrofit manholes 8661 and 16074 with SAFL Baffles. Although these structures do not target phosphorus removal, they can remove phosphorus indirectly by settling out phosphorus that adheres to sediments. SAFL Baffles are effective at removing significant amounts of suspended solids at a reasonable cost. A third option would be to initiate an "adopt a catch basin" program where residents can either sign up to clean catch basins throughout the city or are required to clean the catch basins adjacent to their property.

The other BMPs researched were not found to be cost effective or practical for removing phosphorus. Rain gardens and swales were not found to remove a significant amount of phosphorus and were not found to be a cost effective option for this lakeshed. In-lake treatment is effective, but costly, and not necessary for the lake in its current condition. The city ordinance requiring residents to rake their lawns was considered but found to be impractical and difficult to enforce.

References

"Alum Treatments to Control Phosphorus In Lakes." Wisconsin Department of Natural Resources, Mar. 2003. Web. 20 Apr. 2013. <http://www.littlesaint.org/misc_documents/alum_phosphorus_control_dnr.pdf>.

Baldwin, Patrick, Paula Kalinosky, and Molly Wynia. "City of Minnetonka Watershed Analysis." City Office, Minnetonka. 17 Dec. 2012.

Barr Engineering Company. "2011 Surface Water Quality Study for the City of Minnetonka." City of Minnetonka, Minnesota. April 2012.

Barr Engineering Company. "City of Minnetonka Water Resources Management Plan." City of Minnetonka, Minnesota. Jan. 2010.

Barr Engineering Company. "Shady Oak - Water Quality of Hennepin County Lakes." — *Hennepin County, Minnesota*. N.p., n.d. Web. 22 Apr. 2013.

California Stormwater Quality Association (CASQA). 2003. *Best Management Practices (BMP) Handbook, Municipal*.

Herrera Environmental Consultants. "Green Lake Alum Treatment Study." *Seattle Parks & Recreation: Green Lake Park Alum Treatment Study*. N.p., 5 June 2003. Web. 14 Apr. 2013.

Howard, Adam K., Omid Mohseni, John S. Gulliver, and Heinz G. Stefan. "Hydraulic Analysis of Suspended Sediment Removal from Storm Water in a Standard Sump." Journal of Hydraulic Engineering, ASCE. Jun. 2012.

Howard, Adam, Omid Mohseni, John Gulliver, Heinz Stefan. "SAFL Baffle Retrofit for Sediment Removal in Storm Sewer Sumps." Elsevier Ltd. 24 Aug. 2011.

"Minneapolis Park & Recreation Board - Alum Treatments." *Minneapolis Park & Recreation Board - Alum Treatments*. N.p., n.d. Web. 22 Apr. 2013.

Mohseni, Omid, Kurtis McIntire, Adam Howard, John Gulliver. "Assessment and Recommendations for the Operation of Standard Sumps as Best Management Practices for Stormwater Treatment (Volume 2)." Minnesota Department of Transportation Research Services. May 2012.

MPCA. “Managing Street Sweepings.” w-sw4-54•June 2010. <http://www.pca.state.mn.us/index.php/view-document.html?gid=13934>

National Pollutant Discharge Elimination System (NPDES). “Parking Lot and Street Cleaning.” [http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=99&minmeasure=]. Accessed April 15, 2013.

Olson, C. C., L. A. Roesner, and B. R. Urbonas. *A Tool for Determining Effectiveness and Whole Life Costs of BMPs*. Rep. N.p.: ASCE, 2009.

Paula Kalinosky,L. Baker, S. Hobbie. Quantifying Nutrient Load Reductions Through Targeted, Intensive Street Sweeping – A Field Study by the University of Minnesota in Partnership with the City of Prior Lake. Minnesota Water Resources Conference, October 17.

Schilling, J.G. 2005. Street Sweeping – Report No. 3, Policy Development & Future Implementation Options for Water Quality Improvement. Prepared for Ramsey-Washington Metro Watershed District (http://www.rwmwd.org). North St. Paul, Minnesota. June 2005.

"Tanners Lake - Alum Injection for Phosphorus Removal." - *Minnesota Stormwater Manual*. Minnesota Pollution Control Agency, 20 Mar. 2013. Web. 22 Apr. 2013.

Tanner, Hillary S., Jeffrey D. Mullen, David Gattie, and Forest Steglin. "Determining Cost and Treatment Effective Soil and Plant Combinations in Bioretention Cells for Storm Water Management in the Piedmont Region of Georgia." Georgia. 2007.

Tucker, Young, Jackson, Tull Inc. “Basis of Cost Estimates.” Wastewater Master Plan. Detroit Water and Sewerage Department. 8 May 2003.

Upstream Technologies. “SAFL Baffle.” Upstream Technologies. Web. 20 Apr. 2013. <http://revolutionarybaffle.com/safl-baffle/>

Appendix

A. Calculations

Estimate the ratio of biomass that is phosphorus: we are given that the watershed total fall input of phosphorus (P) is 4.6kg, and the total biomass load (BM) in the fall is 2189 kg + 928 kg + 3671 kg = 6788 kg biomass (BM)
Using 20% engineered soil to reduce leaching of phosphorus,

<u>A.1. Proposed Swale:</u>

$$V = l * w * d = 200m * 1m * 1m = 200\ m^3$$

where V is the volume, l is length, w is width and d represents the depth of the practice. The initial cost estimates are $\$0.64/ft^3$ (Tanner et al. 2008), with operating and maintenance (O/M) costs of $\$0.37/ft^3$ and replacement costs negligible (Olson et al. Tables 4,5).
For this swale, the pollutant influent (P_i) is (Baldwin et al.)

$$P_i = \frac{\frac{300\ kg\ BM}{ha}}{half\ year} * \frac{1\ ha}{10000\ m^2} * (200\ m^2) * \frac{2\ halfyears}{year} * \frac{4.6\ kg\ P}{6788\ kg\ BM} = 0.0081\ kg\ P/yr$$

With a removal efficiency of 40 percent (Tanner et al. 2008) the pollutant removal (P_r) is

$$P_r = 0.4 * \frac{0.00813\ kgP}{yr} = 0.00325 \frac{kgP}{yr}$$

So, the cost for this swale (C_s) is

$$C_s = \left(\frac{\$0.64}{ft^3} + \frac{\frac{\$0.37}{ft^3}}{yr} \right) * (200\ m^3) * \left(\frac{1\ ft}{0.3048\ m} \right)^3 = \$4520 + \frac{\$2613}{yr}$$

For an eight year period, this cost (C_{s8}) becomes

$$C_{s8} = \$4520 + \frac{\$2613}{yr} * (8\ yr) = \frac{\$25424}{8yr}$$

So, the normalized cost of the swale (NC_s) is

$$NC_s = \frac{\left(\frac{\$25424}{8yr\ period}\right)}{\left(\frac{0.00325\ kgP\ removed}{years\ considered}\right) * \left(\frac{2.20462\ lbs}{kg}\right) * (8\ years\ considered)} = \frac{\$443{,}544}{\frac{lb\ P\ removed}{yr}}$$

<u>A.2. Proposed Rain Garden:</u>

$$V = A * d = (50m^2) * (1m) = 50\ m^3$$

where V is the volume, A is area, and d is the depth of the rain garden. The initial cost estimates are $1.00/ft^3 (Tanner et al. 2008) with O/M costs and replacement costs negligible (Olson et al. Tables 4-5) if the residents are performing maintenance on their rain gardens.
For the area that these rain gardens are to be implemented, P_i is estimated as

$$P_i = \frac{\frac{400\ kgBM}{ha}}{halfyear} * \frac{1\ ha}{10000\ m^2} * (50m^2) * \frac{2\ half\ years}{year} * \frac{4.6\ kg\ P}{6788\ kg\ BM} = 0.00271\frac{kgP}{yr}$$

With a removal efficiency of 40 percent (Tanner et al. 2008), P_r is

$$P_r = 0.4 * \frac{0.00271\ kg\ P}{yr} = 0.00108\frac{kg\ P}{yr}$$

The cost for this rain garden (C_r) is equal to the eight year cost if O/M is negligible, so the cost is estimated as

$$C_r = C_{r8} = \frac{\$1.00}{ft^3} * 50m^3 * \left(\frac{1ft}{0.3048m}\right)^3 = \$1765.7$$

The normalized cost of the rain garden (NC_r) is

$$NC_r = \frac{\$1765.7}{\left(0.00108\ kg\ P\frac{removed}{year}\right) * \left(\frac{2.20462\ lbs}{kg}\right) * (8\ years\ considered)} = \frac{\$92{,}698}{lb\ P\ removed}$$