Feasibility Study
Casey Lake, North St. Paul

CE 5511 Urban Hydrology and Land Development
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Executive Summary

The City of North Saint Paul is looking to provide stormwater treatment to reduce pollutant loading into Casey Lake. The content of this report provides an analysis and evaluation of five low-impact development (LIDs) practices used to reduce the pollutant loading from total phosphorous (TP) and total suspended solids (TSS). These five designs included using permeable pavement in adjacent trails or parking lot, constructing an infiltration basin in the adjacent park, providing routine street-sweeping and installing SAFL Baffles in designated sump structures to capture sediment. A SAFL Baffle is a stormwater pretreatment system installed in existing sump structures to retain sands and large silt sediments for clean out.

Three different software programs were utilized in this analysis. For the permeable pavement and the infiltration basin, designs were performed using a program called P8 (Program for Predicting Polluting Particle Passage thru Pits, Puddles, and Ponds). A Street Sweeping Planning Calculator, developed by Stormwater U, was used to analyze the effects of street sweeping and a program called SHSAM (Sizing Hydrodynamic Separators and Manholes) was used to model the results of sediment capture from the SAFL Baffles. A cost-benefit analysis was also performed for each alternative in order to make recommendations to remove pollutants from stormwater in a cost-effective manner.

Results from our analysis compared the amount of pollutants removed and the cost per year for each alternative. These results were also compared to a previous study on bioretention cells in North Saint Paul titled "Casey Lake: Urban Subwatershed Stormwater Retrofit Assessment". This study was used as a comparison for the removal of total phosphorus. Street sweeping was found to be the most the most cost effective method to reduce TSS and TP in the Casey Lake watershed and is the most highly recommended practice that North Saint Paul could consider.

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1. Introduction

The purpose of this report is to analyze four different low impact developments (LID practices) to help mitigate pollutant loading into Casey Lake, located in North St. Paul, Minnesota. The City of North St. Paul is situated on the east side of Ramsey County, Minnesota. This city of 11,694 residents occupies 3 square miles of area encompassed by Maplewood on its north, west and south sides and Oakdale in Washington County on its east side. The Casey Lake watershed consists of approximately 240 acres and is a part of the Kohlman Lake watershed (Barr Engineering, 2007). The area is primarily developed and consists of mostly low-density residential units.

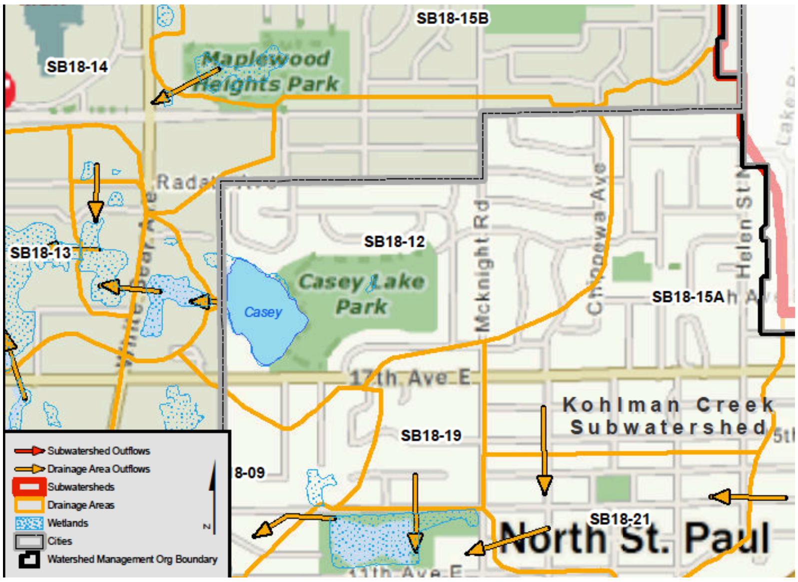

Figure 1: Drainage Areas of North St. Paul

The pollutants that were examined for removal included total suspended solids (TSS) and total phosphorous (TP). Since Casey Lake is considered a wetland rather than a lake, it falls under the District's wetlands management classification system into Management Class B. Wetlands under this class are considered high-quality wetlands that require a minimum 25 foot buffer from development (Barr Engineering, 2007). Currently, as a guide for water quality, the goals for TP are based on the limits for shallow lakes, where TP should be less than 60 µg/l. The current concentration of TSS and TP in Casey Lake are unknown since no water quality data is available for this wetland. A cost-benefit analysis was prepared for each option over a 20-year design life and the most cost-effective removal for each pollutant is discussed in this report.

Five solutions have been evaluated: Two options of permeable pavements (trail along the south part of the lake and southern Casey Lake Park parking lot), an infiltration basin located in Casey Lake Park, street sweeping, and sump cleaning.

1.1 Permeable Pavements

Permeable pavements allow stormwater runoff to filter through surface voids into an underlying stone reservoir for temporary storage and/or infiltration. Long term research on permeable pavers shows their effective removal of pollutants such as total suspended solids, total phosphorous and total nitrogen (Capital Regional District, Victoria, British Columbia). According to the University of New Hampshire Stormwater Center (2008), the efficiency of this technology to remove pollutants is: 85% to 95% of TSS and 65% to 85% of TP.

The most commonly used permeable pavement surfaces are pervious concrete, porous asphalt, and permeable interlocking concrete pavers (PICP) (Minnesota Stormwater Manual). Porous asphalt has been found to work well in cold climates as the rapid drainage of the surface reduces the occurrence of freezing puddles and black ice; additionally infiltration rates are not negatively affected. Melting snow and ice infiltrates directly into the pavement facilitating faster melting (Gunderson, 2008).

There are two possible locations where porous asphalt can be used in this site: the trail along Casey Lake and the southern parking lot in Casey lake Park. Both have low to medium traffic and the conversion of the existent impervious areas to pervious areas would decrease the concentration of TSS and TP in the lake by infiltrating stormwater runoff.

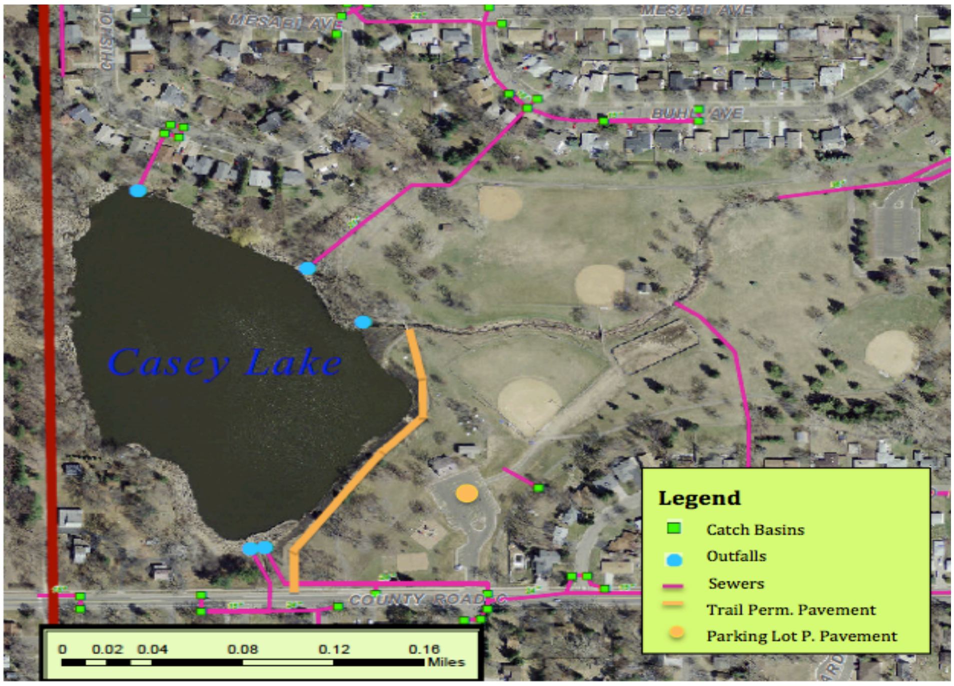

Figure 2: Map with the Two Locations for Permeable Pavements Used for the Design

1.2 Infiltration Basin

The second LID examined involved the design of an infiltration basin for the park east of Casey Lake. Infiltration basins are large vegetated depressions in the ground that typically range from 2 to 10 feet deep and have gentle sloping sides. Stormwater will pond in the infiltration basin, and then slowly infiltrate into the soil which removes pollutants from the water and replenishes the groundwater table below. It should also be noted that infiltration basins have a higher failure rate than most other stormwater management practices. Due to this, many soil tests need to be done in the proposed construction area to ensure that the infiltration basin will drain in 48 hours, and if it does not, engineered soils will need to be placed beneath the infiltrating surfaces, at additional expense. Infiltration basins require land area, and in urban areas this is often hard to come by. The only location in the Casey Lake watershed that appeared to have enough room for an infiltration basin was in Casey Lake Park, as seen below in Figure 3. In the northwest corner of the park there is adequate room for an infiltration basin that would not interfere with the sports fields or the park appearance. Also, it would be very easy to route polluted stormwater into this infiltration basin since there are two mainline storm sewers that run right by this portion of the park. These two storm sewers currently outlet into a ditch that feeds directly into Casey Lake. Therefore, by building an infiltration basin in this location, stormwater could be infiltrated rather than being discharged into Casey Lake.

Figure 3: Proposed Infiltration Basin Area (marked in red)

1.3 Street Sweeping

The third LID examined for the removal of pollutants was to implement regular street sweeping in the Casey Lake watershed. Street sweeping offers municipalities like North St. Paul an opportunity to reduce pollution at the source, by removing leaves, sediment and other debris that otherwise would enter the stormwater system. One of the major benefits of street sweeping is the pollutants it removes. Leaves make up a large portion of the total phosphorus content in urban stormwater. Loose sediment plays a huge role in the amount of total suspended solids as well. By removing a significant portion of these two pollutants before they even enter the stormwater system, less treatment is needed for the storm water and pollutant levels can be decreased. By using non-structural best management practices such as increased street sweeping frequency, and optimized equipment, North St. Paul can see a dramatic decrease in total phosphorus and total suspended solids in Casey Lake.

1.4 SAFL Baffle and Sump Cleaning

The fourth LID method that was studied looked at limiting the amount of total phosphorous into Casey Lake by regular sump cleaning of catch basins or manholes that were retrofitted with a SAFL Baffle. A SAFL Baffle is a post-construction stormwater pretreatment system that can be installed in existing sump structures. The baffle keeps sediments from moving through the system (“SAFL Baffle”, 2010). The SAFL Baffle captures sediments through settling and mainly captures sands and heavy silts. A vacuum truck is used to remove the sediments on a regular basis or whenever needed. One of the major benefits to installing a SAFL Baffle is that it has a very low maintenance cost for the amount of sediment it can remove. Reports from Upstream Technologies, a manufacturer of SAFL Baffles, has found that they can improve a sump structures’ ability to capture sediments by 10-20% and only need to be maintained once or twice per year, depending on watershed size and land use. Together, a sump manhole equipped with a SAFL Baffle is a cost effective, small footprint option for pretreating rain gardens, detention ponds and underground vaults and it will reduce the downstream maintenance frequency of other stormwater best management practices (BMPs); hence, reducing total maintenance costs (“SAFL Baffle”, 2010).

2. Methods

2.1. Permeable Pavements

The design of the porous asphalt pavements follows the criteria of the Minnesota Stormwater Manual. The load-bearing, infiltration capacities of the subgrade soil, and infiltration capacity of the porous asphalt, are key to apply this technology correctly (Hunt and Collins, 2008). The basic section of porous asphalt is shown in Figure 3. For the design, the thicknesses of the layers were as follows: 3'' of porous asphalt, 1'' choker course and 18'' of base. Total depth: 22''= 1' 10''. Both solutions have low to medium load of traffic and use a geofabric to separate the base from the subgrade soil. Porous asphalt was chosen for the permeable pavement for being a less expensive solution (0.5-1 \$/ft^2), used in low-medium traffic areas, speed of construction (24 hour cure) and installer availability.

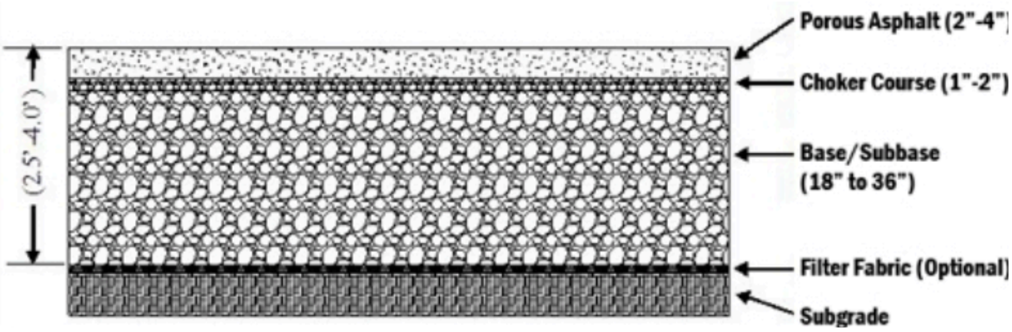

Figure 4: Cross Section of the Porous Asphalt Pavement (US EPA)

Periodic maintenance is critical and surfaces should be cleaned with a vacuum sweeper at least three times per year (Massachusetts LID Toolkit). Studies of the long-term surface permeability of porous asphalt have found high infiltration rates initially, followed by a decrease, and then leveling off with time (Bean, et al., 2007). The lifespan of a northern parking lot is typically 15 years for conventional pavements; porous asphalt parking lots can have a lifespan of more than 30 years because of the reduced freeze/thaw stress. The lifespan assumed in this study is 20 years. In this report, two different solutions of permeable pavements are studied. Both of the solutions have been modeled using P8, however there are some significant differences between them.

Option 1: Trail

This solution consists of converting a directly connected impervious area (paved trail) into permeable pavement. The area of drainage is 8.7 ac. See Figure 4 for a visual. Less than 1 acre of the drainage area is impermeable and includes a parking lot, two buildings and the current trail. The width of the trail is 2.85 m and the length is 266 m. The proposed area of permeable pavement is 800 m^2. The subgrade soil is 302C- Rosholt sandy loam; class A Hydrologic Soil Group (HSG), which means no underdrains are needed, and there is full exfiltration to soil. The bottom of the pavement should be 3 feet above the groundwater level. In this case the limit is close but the requirement is met.

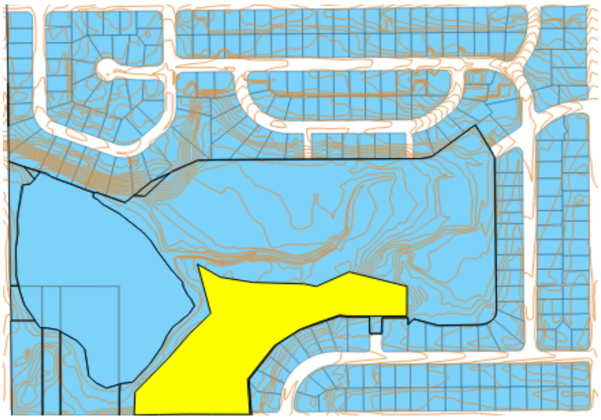

Figure 5: Area of Drainage of the Porous Asphalt Trail. Area of drainage is marked in yellow.

Permeable pavements need specific treatment to capture a higher percentage of TP. According to the MN Stormwater Manual, using an iron enhanced sand as base can increase the TP removal. Results indicate that sand mixed with 5% iron filings (in weight) can capture 88% phosphate for at least 200 m of treated depth (Erickson et al. 2012).

In order to model both options, P8 software and ArcView GIS with the subcatchment information have been used. The current conditions have been modeled with one watershed (8.7ac) and a pipe as outflow device to control the total load going to the lake. The pervious area (Casey Lake Park) has an extension of 7.7 ac and a CN of 61. The impervious area (CN=98) directly connected is the present trail (2.3%). The rest of impervious area is indirectly connected (9.3% of drainage area). The new case scenario after installing the porous asphalt pavement has been modeled with 1 watershed (8.5ac), an infiltration basin representing the permeable pavement, and a pipe as outflow device. In this model, there is no impervious area directly connected. The data introduced for the infiltration basin include: Area 1.2 ac, Volume 0.366 ac-ft, Void volume 0.45 and Infiltration rate 0.8 in/hr. The load coming out of the pipe has been used to calculate the load of TSS removed. As the efficiency of the iron enhanced sand filter cannot be introduced in P8, an assumption that 88% of the TP calculated in the model for the current conditions is removed was made. Although water is infiltrated, the estimated depth to groundwater is about 4 ft, consequently a 100% TP removal has not been considered in this case.

Option 2: Parking Lot

This solution consists of converting an indirectly connected impervious area, the parking lot, into pervious area. The area of drainage is 0.75 ac, 97.3% of which is impervious. The proposed area of permeable pavement is 0.73 ac. The subgrade soil is 153C-Santiago silt loam; class B Hydrologic Soil Group (HSG), which means no underdrains are needed. Due to the area of the permeable pavement and the extra cost of incorporating an iron enhanced sand filter, the base consists of aggregates.

The current conditions have been modeled with P8 as one watershed with 0.75ac, 0.73 ac of which were impervious (CN=98) and a pipe as the outflow device. In order to model the new situation where the parking lot is made out of porous asphalt, the CN of the pervious area (0.75 ac) was changed to 40, as suggested by the Water Environmental Research Foundation (WERF) in their Stormwater BMP Model.

The cost was determined by taking into account volume excavated ($9/yd^3), surface of porous asphalt ($0.75 /ft^2), surface of geofabric ($0.85 /ft^2), and type of base used (aggregates or iron enhanced sand). The iron enhanced base is more expensive because of the cost of the sand C-33 ($129.6/ton), compared to aggregate ($32.5/yd^3). Please refer to Table 5 in the Appendix for a detailed cost break down.

2.2. Infiltration Basin

In order to size the infiltration basin appropriately, a number of factors were taken into consideration. Because there were two storm sewer pipes running through Casey Lake Park and discharging into a ditch that feeds into Casey Lake, it was necessary to determine if there was enough room to route both pipes to an infiltration basin or just one pipe or none of the pipes. It was determined that the northernmost pipeshed contained a drainage area of 69 acres and the southernmost pipeshed contained a drainage area of 217.5 acres. It was deemed that it was unreasonable to try to infiltrate the stormwater that discharges from the southernmost pipe outlet. Therefore, focus was shifted to the discharge from the northernmost pipeshed. Infiltration basins are designed to infiltrate a water quality storm. In this case, that means the basin will be sized to infiltrate a 1.1 inch storm event that falls on the pipeshed of interest. In order to determine how much water that is, the "Simple Method for Water Quality Volume (WQV)" was used. This method uses the following equations.

$$WQV = CPA$$

$$C = 0.05 + 0.009(\%\ of\ Impervious\ Area\ of\ Pipeshed)$$

Where P= the precipitation depth of the water quality storm, 1.1 inches in this case, and A= the area of the entire pipeshed. The pipeshed area lies within a residential district of North St. Paul with 0.25 acre lots on average. According to the Minnesota Stormwater Manual, this type of land use has a 38% impervious area. It was determined that the WQV was 108,522 cubic feet which is equal to 2.49 acre-feet.

Next, the known WQV allows for the size of the detention basin to be calculated. It is required that detention basins infiltrate all of the WQV in at least 48 hours. This places an additional constraint on the size. To determine the proper depth of the infiltration basin, the Green-Ampt method was used. In order to use the Green-Ampt method, several assumptions or field-verified variables need to be determined. Based on the Casey Lake Soils Report prepared by the NRCS, assumptions should be made that the infiltration basin will be built over sandy loam soils. With the soil type known, average values for porosity, suction head, and hydraulic conductivity were used. After using the Green-Ampt method, it was determined that the infiltration basin should be built to a depth 1.90 feet and have a plan area of 57, 550 square feet or 1.32 acres. Due to the fact that a lot of assumptions were initially made, a sensitivity analysis was done on sizing the basin, see Table 7 of the appendix for details. The basin was also preliminarily sized based upon there being loamy sand soils or silt loam soils in the field. Tables 1, 2, and 3 show the results and input values for the Green-Ampt Method.

With the given characteristics of the pipeshed and the calculated dimensions and characteristics of the infiltration basin, a P8 model could be built to describe the amount of pollutants that would be captured in the infiltration basin from different storm events. The model included a representation of the pipeshed with a curve number of 75 which was then routed to the proposed infiltration basin. The P8 model gave values for the amount of TSS and TP discharging from the pipeshed, and how much of that was captured in the infiltration basin. A pollutant load reduction percentage was also determined.

Finally, it was important to determine a cost to build the infiltration basin to see if it would even be feasible for the city to implement. The final cost was determined by using a cost analysis guide provided by the Minnesota Stormwater Manual on infiltration basins. A cost check was implemented by doing a quick cost estimate based upon average infiltration basin costs provided by the EPA. See Table 3 and Table 4 for cost summary and Table 6 and Table 8 in the Appendix for a detailed breakdown of the cost estimates.

2.3. Street Sweeping

In order to estimate the amount of phosphorus and suspended solids that could be removed by street sweeping, the Street Sweeping Planning Calculator, (Baker), developed by Professor Baker with others through the University of Minnesota Extension, was utilized. This calculator was developed initially for Prior Lake Minnesota, based on a study of the effects of street sweeping, making it an ideal tool to use in the Twin Cities area. The study found that the debris removed by street sweeping, such as leaves and sediment, contains large amounts of phosphorus and nitrogen. By removing these pollutants before they enter the stormwater system, levels of pollutants in receiving bodies of water will be effectively reduced. The two pollutants of interest for this case were total phosphorus and total suspended solids. For the purposes of this report, the weight of dry solids removed was considered to be representative of the weight of total suspended solids removed.

To begin using the calculator, street sweeping routes first needed to be delineated. The drainage area immediately around Casey Lake was considered for this report. Two separate routes were chosen, as seen in Figure 6 below. From here the number of curb miles and average canopy cover for each route were needed. In order to find the number of curb miles for each route, QGIS, an open source GIS program, was used. Route 1 was 6.1 curb miles, Route 2 was 4.4 curb miles long. The average over street canopy coverage plays a vital role in the amount of leaves that will be in each street. For both routes Google Map images were used to estimate overstreet canopy coverage for each street segment.

Figure 6: Street Sweeping Routes in the Casey Lake Drainage Area

Route One had an average canopy cover of 48%, while Route Two had 59%. From here, the curb length and canopy cover were input into the street sweeping calculator. In this calculator, any canopy greater than 30% is treated at 30% cover, making both routes differ only in their length. For each route the frequency of street sweeping can be personalized. Sweeping frequency was based on Minnesota Pollution Control Agency's 2005 guidelines (MPCA), which suggested that for residential areas streets should be swept between 6 and 9 times per year. In order to select a sweeping frequency the calculator was run under a number of different scenarios. Sweeping rates of 6, 7, and 8 times per year were compared. In the winter months when snow is on the ground street sweeping is unnecessary since most surface water is frozen, so sweeping was only considered an option between April and October. Sweeping is most cost effective, in terms of cost per pound of phosphorus removed, in the fall when leaves are falling. Since it was seen that October was the month in which street sweeping had the lowest cost per pound, streets were swept twice in the 8 sweepings per year scenario. By varying the frequency of street sweeping, it was found that the most economical solution was to sweep each once per month from April until October for a total of 14 sweepings per year.

In terms of overall cost a number of factors need to be considered. The type of sweeper used, number of hours spent sweeping, cost of gasoline, and maintenance of the sweeping vehicle are the biggest concerns. As previously mentioned, the street sweeping calculator was calibrated for use in Prior Lake Minnesota. Assuming the use of a regenerative air sweeper, these cost estimates were considered valid for the city of North St. Paul. According to the Prior Lake study, using a TYMCO 600 regenerative air sweeper the average cost per curb mile was $23. This includes operation and maintenance costs such as vehicle maintenance, but does not include the cost to purchase a regenerative air sweeper. Cost of a new sweeper was estimated to be $165,000 based on prices of similar sweepers (Weston Solutions Inc).

2.4. SAFL Baffle and Sump Cleaning

In order to determine the amount of total phosphorous that could be removed via sump cleaning, a program by Barr Engineering called Sizing Hydrodynamic Separators and Manholes, SHSAM, was used to model the results. SHSAM is a computer program used for predicting the amount of total phosphorus removed from stormwater runoff by a given standard pump over a given period of time. This program is comprised of a simple continuous runoff model, a generic sediment removal response function and a sediment washout function ("SAFL Baffle", 2010). This software is based on testing performed by St. Anthony Falls Laboratory at the University of Minnesota. Total phosphorous was the only pollutant calculated for this scenario as total load of TP into Casey Lake was the only influent data available.

For this scenario, a standard sump was used in the model with the addition of a SAFL Baffle. Washout was included in this calculation. Washout occurs when sediment is flushed out of the sump due to a large storm, but the SAFL Baffle helps to prevent this type of sediment washout during the more intense storms. The particle size distribution used was from the Nationwide Urban Runoff Program (NURP). Weather station precipitation data was taken from Golden Valley, MN, and temperature data was taken from St. Paul, MN. The data from these three inputs were already given in the SHSAM program. The year 2000-2001 was used, as Barr Engineering classified this as an average climatic year. Watershed data was also needed for use in the SHSAM program. SHSAM does not simulate snowfall, snowpack, and snowmelt and therefore, the winter data for precipitation is not included in these calculations. Table 1 below gives the watershed data for Casey Lake. Flow and TP values for 2000-2001 were taken from the Casey Lake: Lake Status report from Barr Engineering. A CN Pervious value of 75 was used as the area consists of mostly B type soils and is low-density residential lots. Influent concentration of sediment was calculated by using the TP load divided by the flow per year.

Table 1: Watershed Data for Casey Lake

Total Area	240 acres
Average Slope	4.15%
Percent Impervious	40%
CN Pervious	75
Hydraulic Length	4050 feet
Flow (2000-2001)	188.61 ac-ft
TP Load (2000-2001)	239.97 lbs
Influent Concentration (per year)	468 ug/L

Criteria for installing and maintaining SAFL Baffles were taken from Upstream Technologies. SAFL Baffles should be installed only for structures with a minimum sump depth of 36 inches and inlet and outlet pipes less than 48 inches in diameter. SAFL Baffles are also currently installed prior to discharge points at flared end sections and in locations that can easily be accessed by the vacuum truck. Based on these criteria, five current structures were deemed suitable locations where North St.

Paul could install SAFL Baffles. is a map that shows an overview of these locations. Other locations in the Casey Lake watershed could also be examined further for potential SAFL Baffles.

Figure 7: SAFL Baffle Locations

Cost estimations for SAFL Baffles also came from Upstream Technologies. For a SAFL Baffle, the maintenance cost for each was around $80. This includes labor and use of the vacuum truck, which North St. Paul already owns. SAFL Baffles themselves cost around $3,495 for pipe diameters between 18” and 28”. Installation tends to take around 45 minutes and costs around $45 per SAFL Baffle, wage rates were taken from the Bureau of Labor Statistics. Over a 20-year design life, the cost of a SAFL Baffle should be around $1285 per year. Maintenance and cost of caring for the vacuum truck is not included in this estimate.

3. Results and Discussion

3.1 Results

The following tables summarize the results obtained from the five designed solutions: Street Sweeping in the streets, Infiltration Basin located in Casey Lake Park, two options of Permeable pavements (trail along the south part of the lake and southern Casey Lake Park parking lot) and Sump Cleaning. Additionally, the tables include information from a bioretention cell included in the report "Casey Lake: Urban Subwatershed Stormwater Retrofit Assessment". This bioretention cell was designed to treat the water coming from the same southern of Casey Lake Park parking lot as in the second permeable pavement solution; consequently, this information could be used as a comparison between methods to remove Total Phosphorus.

Table 2 presents the load of Total Suspended Solids, TSS, and Total phosphorus, TP, that each of the Storm Control Measures (SCM) can reduce per year. Furthermore, taking into account Casey Lake characteristics, the change in these loads would result in a drop in the lake's concentration of TSS and TP, expressed in Table 2 as well. Changes in concentrations were determined using the following equations.

$$\Delta C_{TSS} = \frac{\Delta\, TSS}{(Q + V_s\, A)}$$

$$\Delta C_{TP} = \frac{\Delta TP}{(Q + V_s A)}$$

Where Q is the flow rate, 232,647 m^3/y, A is the area, 61,512 m^2, and V_s is the settling velocity for each pollutant. For TSS, this was based on 50% of a NURP particle distribution, and for TP the average size of phytoplankton was the basis for finding settling velocity. As it was mentioned in the Introduction, the goal for Casey Lake is achieving a concentration of TP lower than 60 µg/l; however there is no data available of the current levels of TSS and TP in the lake. The designs for sump cleaning and the bioretention cell are focused only on the elimination of TP, so TSS information is not included in these two cases. Further studies will be needed to relate the load removed to the removal of TSS in sumps. For further comparison, results from a bioretention cell located in Casey Lake Park designed by the Ramsey Conservation District were included in Table 2 as well.

Table 3 shows the costs of these SCM, divided into installation and operation & maintenance costs. To be able to compare all the options, a total cost per year has been established dividing the installation cost by the lifetime and adding the cost of O&M per year. There is no information available about the O&M cost for the Bioretention cell solution. Finally, Table 4 shows a comparison of the cost-effectiveness of these methods in terms of the cost to reduce one pound of TSS or TP. The lower cost per pound treated, the more cost-effective the technique is.

Table 2: Load and Concentration of TSS and TP Removed Per Year

Method	TSS Removed/Year (lb /year)	TP Removed/Year (lb /year)	ΔC_{TSS} (µg/l)	ΔC_{TP} (µg/l)
Street Sweeping	91,652.00	96.40	-214.05	-7.99
Infiltration Basin	17,513.30	54.80	-40.90	-4.54
Permeable Pavement Trail	265.60	1.14	-0.62	-0.09
Permeable Pavement Lot	292.20	1.10	-0.68	-0.09
Bioretention Cell	-	0.40	-	-0.03
SAFL Baffle and Sump Cleaning	-	8.00	-	-0.66

Table 3: Summary of Costs

Method	Cost of Installation ($)	Cost of O&M ($/year)	Total Cost/Year (for a specified lifetime) ($/year)
Street Sweeping	$40,000.00	$1,690.50	$9,940.50
Infiltration Basin	$238,326.00	$11,409.33	$23,326.63
Permeable Pavement Trail	$196,980.00	$400.00	$5,768.26
Permeable Pavement Lot	$128,651.96	$500.00	$6,932.60
Bioretention Cell*	$54,000.00	-	$2,700*
SAFL Baffle and Sump Cleaning	$17,700.00	$480.00	$1,365.00

* The Total Cost of the Bioretention Cell only includes Installation cost divided by 20 years of lifetime. There is no information about the Cost of O&M.

Table 4: Total Cost to Reduce One Pound of TSS and TP in One Year

Method	TSS ($/(lb /year))	TP ($/(lb /year))
Street Sweeping	0.11	103.12
Infiltration Basin	1.33	425.49
Permeable Pavement Trail	21.72	5,059.88
Permeable Pavement Lot	23.73	6,302.36
Bioretention Cell*	-	6,716.42*
SAFL Baffle and Sump Cleaning	-	170.63

- The Total Cost used for the Bioretention Cell only includes Installation cost divided by 20 years of lifetime. Costs of O&M are not included.

3.2. Discussion

Based on the results on Table 3 Street Sweeping on a frequent basis has been found to be the most cost-effective method to reduce TSS and TP in the subwatershed, with 0.12 and 103.12 $/lb of TSS and TP, respectively. The reduction in the load of TSS and TP removed is substantial (91,652 and 96.4 lb/year), probably due to the fact that this method eliminates the source of contamination before precipitation washes it out and contaminants get diluted in the runoff.

Although more frequent street sweeping is the most highly recommended practice, there are several other SCMs that the city of North St. Paul could implement to improve water quality depending upon the city's budget and schedule. Cleaning sumps once per year combined with the implementation of SAFLE Baffles in the sumps has been seen to increase the amount of pollutants removed effectively. It is the second most cost-effective option with 170.63 $/lb of TP removed. This Stormwater Control Measure is another technique that eliminates the source of pollution, without the need of treating TP once it is dissolved in water.

The infiltration basin option cost-effectiveness is similar to sump cleaning. While the total load removed per year (17,513.3 lb of TSS and 54.8 lb of TP) is significantly higher than the load removed with Sump Cleaning (8 lb of TP), the Total Costs of installation and O&M are seventeen times higher.

The other SCM researched, permeable pavement, is not cost effective or practical for removing phosphorus or suspended solids. Using permeable pavement in either the permeable trail or the parking lot only removes about one pound of TP per year. This can be due in part to the smaller amount of runoff (smaller drainage area) that was flowing to the particular permeable pavement area. Additionally, this practice is fairly expensive. In comparison, the permeable trail (with iron enhanced sand) is more cost-efficient than the permeable pavement in the parking lot.

It is also worth mentioning that installing a bioretention cell next to the southern Casey Lake Park parking lot is almost as cost-effective as converting it into a permeable surface. Without including costs of maintenance, the bioretention cell's efficiency is 6,716 $/lb, while in the case of the permeable pavement in the lot, the efficiency is 6,302 $/lb including maintenance. However, neither option is actually efficient eliminating TP because of the high costs of installation. Overall, the impact of these practices on a large scale is minimal.

Finally, before implementing any solution, it is necessary to monitor Casey Lake and obtain its current TSS and TP concentrations. Only then, the data concerning ΔC_{TSS} and ΔC_{TP} can be used to establish optimal solutions. Street sweeping, as designed in this report, can withdraw to the current concentration of TP about 8 μg/l and sump cleaning 5 μg/l. The number of streets being swept or the frequency could be optimized if the difference between the final objective and the present conditions was known.

4. Conclusion

Casey Lake is an important body of water as it provides a relaxing park atmosphere in North St. Paul, but it also drains into larger bodies of water like Kohlman Creek, which then runs into the Phalen Chain of Lakes Watershed. Taking care of this water resource should be a high priority for the community of North St. Paul. Phosphorous is the limiting nutrient in lakes, and if phosphorous is provided to the lake in excess, algal blooms will occur and decrease the overall appeal of the lake. This report shows the effectiveness of several different methods to ensure that the water quality of Casey Lake is upheld and improved.

While the methods in this report for improving the quality of water flowing into Casey Lake are not the only possible methods, they are practical and have been suggested with sound methodology backing them up. Two of the methods that were suggested in the report were street sweeping as well as sump retrofitting and cleaning. The first method was street sweeping. This method provided the best overall water quality results by having the lowest cost per pound of TSS and TP. Street sweeping requires little start-up cost, and little additional training. Due to the fact the city is already doing it, sweeping is simply optimized and used to its full advantage. This practice is recommended, and the proper methodology as indicated above should be followed. The second method was to retrofit sumps with SAFL Baffles and clean them out once a year in the Casey Lake watershed. Again, this method can be implemented almost immediately with not much startup cost. Even though no data was able to be generated on the amount of TSS that sump cleaning will be removed, the amount of TP makes up for it, and there will indeed be some TSS removed in the process. This practice provided the second best price per pound of TP removed next to street sweeping. It is strongly recommended that these two practices be implemented.

Several other practices were also considered in this report. The next best practice, in terms of cost per pound of pollutant removal, was the infiltration basin. The infiltration basin allows for pollutants to be removed before reaching the water's edge. The concerns with this practice are that infiltration basin soils need to be analyzed very thoroughly before any construction takes place. Ensuring that proper drainage takes place is a must. Also, the public may not agree with the placement of an infiltration basin in the park green space, and this issue should be addressed. The permeable pavement options were fairly expensive and did not provide as much load reduction as the other practices. The only possible way to receive more benefit is to investigating funding or cost-sharing opportunities that may be available. It also does not appear that the construction of the bioretention cell would be cost-effective.

It is believed that street sweeping optimization and sump cleanout practices should be given full consideration as stormwater control measures to utilize in reducing pollution to Casey Lake. The infiltration basin could provide very good pollutant removal service, but a lot of unknowns would need to be addressed before going ahead on this project.

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Appendix

Table 5: Cost of Installation of Permeable Pavements

Cost of installation of Permeable Pavements

Trail

Porous asphalt+ Iron Enhanced Sand filter

	Units		Cost/Unit		Total Cost ($)
Excavation	583.64	yd^3	9	$/yd3	5,252.76
C-33 Sand	486460.8	kg	0.1296	$/kg	63,045.32
Iron fillings (5% weight)	25.6	ton	900	$/ton	23,040.00
Porous asphalt	8,611.13	ft^2	0.75	$/ft2	6,458.35
Geofabric	11,257.44	ft^2	0.85	$/ft3	9,568.82
				TOTAL	$107,365.25

Parking Lot

Porous asphalt+ aggregates

	Units		Cost/Unit		Total Cost ($)
Excavation	2159.9	yd^3	9	$/yd3	19,439.10
Aggregate	1766.6	yd^3	32.5	$/yd3	57,414.50
Porous asphalt	31,798.80	ft^2	0.75	$/ft2	23,849.10
Geofabric	32,881.49	ft^2	0.85	$/ft3	27,949.26
				TOTAL	$128,651.96

Table 6: Cost Check Measure for Infiltration Basin Sizing

Quick Study based on a cost consideration by EPA					
use as a cost check					
Construction	Estimation	$2.00	per ft^3 of storage		
Maintenance	Estimation	5-10%	of Total Construction Cost		
Infil Basin	Area	57550	ft^2		
	Depth	1.9	ft		
	Volume	109345	ft^3		
	Construction Cost	**$218,690.00**			
Lower - 5%	Maintenance	**$10,934.50**			
Upper - 10%	Maintenance	**$21,869.00**			
	Total Cost	**$229,624.50**	Lower		
		$240,559.00	Upper		

Table 7: Sensitivity Analysis for Infiltration Basin

Sandy Loam	Expected					
td	47.99999993	hours		WQV	3075	m^3
Ks	1.09	cm/hour				
n porosity	0.453					
theta	0.145					
delta theta	0.308					
psi Ψ	11.01	cm				
Ho	57.5133846	cm	1.886922			
Area	5346.581533	m^2	57550.07			
	1.32116703	acres				

Loamy Sand	Lower Limit					
td	48.00000099	hours		WQV	3075	m^3
Ks	2.99	cm/hour				
n porosity	0.437					
theta	0.12					
delta theta	0.317					
psi Ψ	6.13	cm				
Ho	146.7095928	cm				
Area	2095.977462	m^2				
	0.517926511	acres				

Silt Loam	Upper Limit					
td	47.99999982	hours		WQV	15657.6	m^3
Ks	0.65	cm/hour				
n porosity	0.501					
theta	0.22					
delta theta	0.281					
psi Ψ	16.68	cm				
Ho	37.85615941	cm				
Area	8122.852524	m^2				
	2.007197473	acres				

Table 8: Infiltration Basin Final Cost Estimates (Based on MN Stormwater Manual)

Cost Estimate					
	Total Construction Cost				
	Description	**Units**	**Quantity**	**Unit Cost**	**Price**
	Site Prep				
	Tree Removal	each	6	$350.00	$2,100.00
	Silt Fence	lineal foot	1040	$2.00	$2,080.00
	Topsoil- 6" depth salvage on site	square yard	6400	$4.50	$28,800.00
	Site Formation				
	Excavation 6' depth	square yard	6400	$8.00	$51,200.00
	Grading	square yard	6400	$1.50	$9,600.00
	Hauling off site 6' depth	square yard	6400	$10.00	$64,000.00
	Structural Components				
	Inlet Structure	each	1	$1,500.00	$1,500.00
	Multi-stage Outlet Structure	each	1	$2,500.00	$2,500.00
	Site Restoration				
	Soil Preparation	square yard	6400	$5.00	$32,000.00
	Seeding	square yard	6400	$0.50	$3,200.00
				Total	**$196,980.00**
	Annual Operation and Maintenance				
	Mowing	per visit	20	$50.00	$1,000.00
	Sediment Removal	per year	1	$500.00	$500.00
	Replace Planting Media (replace grass, new topsoil etc.)	square yard	640	$12.00	$7,680.00
	Inspection	per visit	2	$125.00	$250.00
				Total	**$9,430.00**
				Grand Total	**$206,410.00**
		20 year life		**Cost per year**	**$10,320.50**

Note: numbers above based on 2005 prices. Infiltration basin costs in the results section of the report reflect adjustment to 2014 dollars based on the CPI calculator.