Glen Lake Watershed
Water Quality Control Measures

Prepared by

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Executive summary

The City of Minnetonka is considering augmenting and installing new best management practices (BMPs) for the Glen Lake watershed. Common BMPs are street sweeping, in-sewer treatment (such as hydrodynamic separators), and bio-retention low impact development (LID). Street sweeping and hydrodynamic separators were given priority in research. Since there was limited public land, research into the installation of bio-retention LIDs was limited.

Street sweeping was found to be an effective best management practice when it was performed on a regular basis. Also, it was concluded that the type of street sweeper greatly affects the amount and type of debris removal. Street sweeping as a best management practice was found to be very cost effective. With weekly sweeping, over 51,000lbs of solids can be removed annually at an estimated annual cost of $15,960.

Results of the study show that hydrodynamic separators, such as the SAFL Baffle, can greatly increase the amount of sediment reduction. With yearly maintenance, SAFLs Baffles can outperform regular sumps by a factor of 2 to 3. For a sump retrofit project estimated at $4,000, the SAFL Baffle can remove 53lbs of total suspended solids (TSS) annually. Also, it was found SAFL Baffles and sumps are more efficient in smaller watershed areas. In a study of 3, 10, and 30 acres, the 3 acre watershed provided the greatest performance in removal efficiency, in which case a $10,000 installation project can yield a 20lb annual TSS reduction.

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1.0 Introduction

1.1 Glen Lake Watershed

Glen lake watershed is located in the south central portion of the city of Minnetonka, Minnesota; the lake is situated south of Excelsior Blvd and west of interstate 494. The 1,062 acre watershed and 98 acre lake are shown in figure 1.1. The watershed is primarily low density residential (Appendix A.1), and is part of the larger Nine Mile Creek Watershed District. Having good current water quality, the lake is considered to be a level 1 lake, meaning it is safe for recreational use and full contact exposure (i.e. swimming). Of moderate concern is the cattail encroachment towards the center of the lake, which may be exacerbated by sediment deposits from urban runoff. The moderately clear lake has an overall trophic state, an index used to measure water quality, of 47. This value is obtained given various nutrient parameters, including those shown in figure 1.2. With a relatively urbanized watershed, the lake is in danger of high phosphorus levels due to urban runoff.

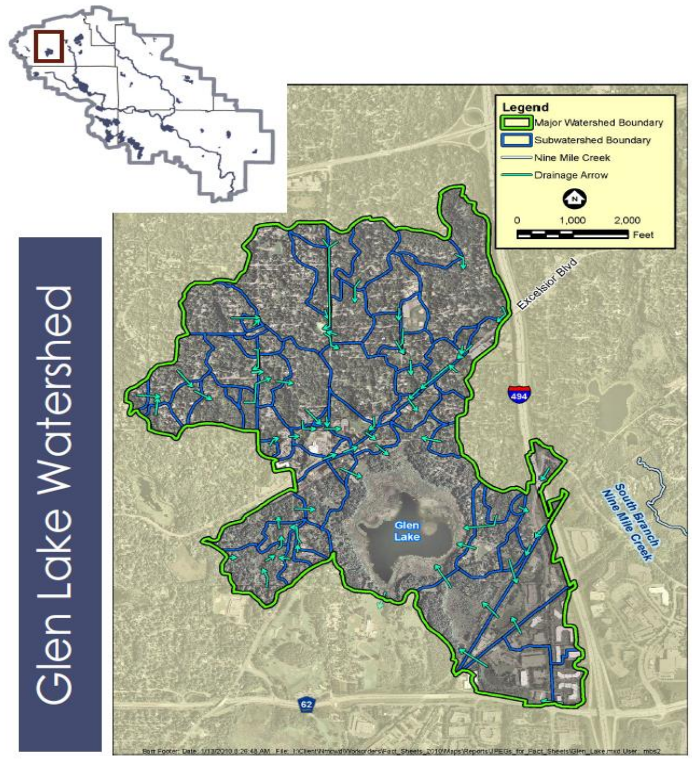

Figure 1.1: Glen Lake watershed in relation to 9 mile creek watershed shown in upper left, (Nine Mile Creek, 2011)

Since the lake itself is not high in nutrients, it is not subject to independent TMDL standards. However, the watershed is contained within the larger Nine mile creek watershed, which is high in chloride and forced to comply with TMDL standards. Since the lake itself is not known to have abnormally high chloride levels, it is unlikely that the watershed will be used for regulation. If the watershed needs to reduce chloride, the most effective strategy is reducing road salt usage within the watershed.

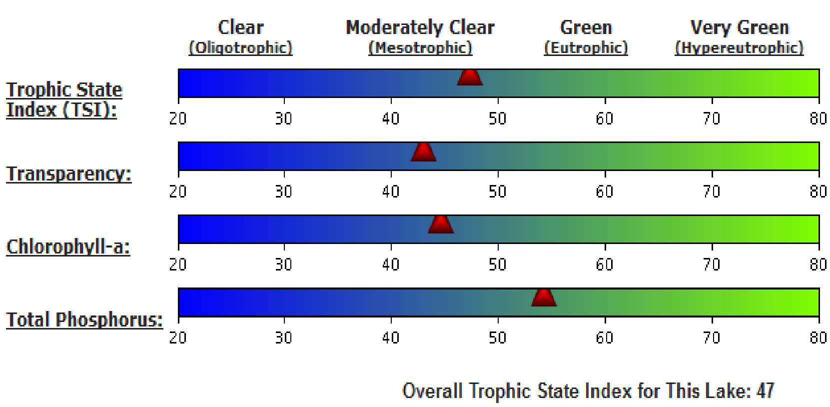

Figure 1.2: Nutrient levels and tropic state for Glen Lake, (MNPCA, 2012)

Given the conditions of the lake, stormwater management options were narrowed down to two main practices. Since there are no specific pollutants of primary concern, this report focuses on two emerging practices for general water quality improvement – street sweeping and SAFL Baffle installation. If the emergence of cattails is intensified by increased sediment deposits, the SAFL Baffle will reduce influent coarse solids to help alleviate the problem. Additionally, both practices will effectively reduce organic matter entering the stormwater system, thus limiting phosphorus and nitrogen levels.

Further sub-sections describe the selected BMPs in greater detail. Section two is the background and methods used for the Glen Lake watershed analysis. The results of the analysis are shown in section three; section four concludes with the results and recommendations.

1.2 Street sweeping

In the past, street sweeping has been used to "cosmetically" make the road look clean; however, the goal of street sweeping ideally should be to improve water quality and maintain air quality. This is achieved by having a high biomass removal rate and effective removal rate of pollutant loads, without losing fine particles into the air. Numerous studies have shown that the effectiveness of street sweeping depends on four major factors:

- sweeping operation (section 2.1.1)
- sweeping conditions (section 2.1.2)
- sweeper technology (section 2.1.3)
- frequency of street sweeping (section 2.1.4)

By taking into account each of these parameters, an effective street sweeping practice can be implemented.

Many factors add to accumulation of biomass and pollutant loads to the streets – run-on from lawns and commercial areas, vehicle emissions, the breakdown of the street surface, littering, sand transportation, and atmospheric deposition. In addition, elements that remove accumulation are wash-off due to storms and strong wind events. With this, in order to remove the largest amount of biomass and pollutant load, the streets should be swept between storm events.

1.3 Hydrodynamic Separators

Hydrodynamic separators (HDS) are a best management practice used for the treatment and pre-treatment of stormwater runoff. HDS systems often utilize cyclonic separation in order to remove coarse solids and floatable pollutants from stormwater. As cities adapt to meet TSS goals, HDS systems such as the SAFL Baffle (figure 1.3) have become a more prevalent best management practice, either as a standalone system or as part of a treatment train. Likewise, these systems may act as a pre-treatment practice, where finer solids and dissolved pollutants can be removed in downstream practices. Additionally, HDS systems are implemented in areas where the stormwater contains a high coarse solids concentration or at the structure entering into the receiving water body.

Oftentimes, HDS systems are used as an upgrade to sump manholes. While sump manholes are commonplace in stormwater management infrastructure for maintenance purposes, recent studies indicate the capacity for sumps to improve water quality. However, while sumps are able to remove some larger suspended solids in stormwater, much of the collected sediments are washed out and into the downstream water body during higher flows (i.e. storm events).

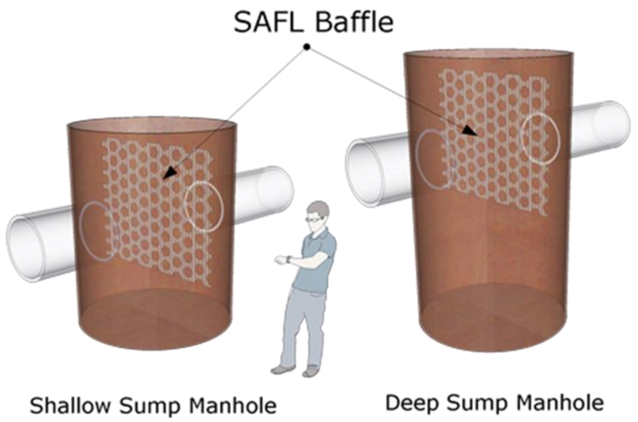

Figure 1.3: A schematic of two standard sump manholes retrofitted with SAFL Baffles. Left - A 6-ft diameter and 3-ft deep "shallow" sump; Right - A 6-ft diameter and 6-ft deep "deep" sump, (updates, 2012)

A relatively new, low-cost, low-maintenance alternative – the SALF Baffle – is able to capture similar amounts of total suspended solids as larger, more expensive HDS systems. The SAFL Baffle, a system developed by the University of Minnesota's St. Anthony Falls Laboratory, reduces sediment, reduces overall maintenance requirements, and improves downstream water quality.

2.0 Background

2.1 street sweepers

2.1.1 Street Sweeping operation

When using street sweeping to improve water quality, there are clear practices that can help improve efficiency. A study from 2007 in Madison, WI, showed that 75% of the biomass and pollutant loads a street sweeper can remove fall within three feet of the curb face (Sutherlan, 2011). Moreover, the curb has a considerable effect on the collection of the biomass and pollutant loads; this acts as a control that keeps the biomass and pollutant loads on the street surface. Additionally, the curb prevents the particles from being blown horizontally off the road during the process of street sweeping. This in turn forces the particles to be caught and captured by the gutter brooms. If the roadway lacked curbs, many of the particles would be removed from the road due to runoff or wind. This makes curbed streets ideal for street sweeping.

2.1.2 Street Sweep conditions

During the process of street sweeping, it is important to consider the types of roads that are being swept and how they are being swept. It is best to perform the task of street sweeping when there are few cars on the road. This allows for access to the curb and helps prevent traffic delays. When there is limited access to the curb, removal efficiencies can drop as much as 29%. To achieve the most ideal situations, residential areas should be swept during the day and commercial areas should be swept during the night. This will be possible for the Glen Lake area due to the low density residential area and few places for car to park on the street. With this, the city will not have to implement no parking restrictions.

In order to perform the best street sweeping job, it is important to drive slowly. A study done by Law et. Al. (2008) showed that the ideal speed for street sweeping was 6 to 8 miles per hour. It is also known that the better the condition the roads are in the higher the removal rate. The reason for this is that the fine particle cannot fall into the cracks of the street and become inaccessible to the street sweeper.

2.1.3 Street Sweeper technology

Another major factor in determining the effectiveness of street sweeping is the type of street sweeper that is being used. There are four major types of street sweepers: mechanical broom sweeper, vacuum sweeper, regenerative air sweeper, and high-efficiency sweeper. All of these street sweepers implement a different process or a combination of processes to remove debris from the road. Moreover, they all have their unique advantages and disadvantage.

Mechanical broom sweepers (figure 2.1) consist of a main broom that runs the width of the vehicle. This broom then sweeps the biomass and pollutant loads, which are on the road, onto a conveyor that transfers this debris to a storage unit. These sweepers are also equipped with a gutter boom that transfers the biomass and pollutant loads from the gutter to the main broom underneath the sweeper. To help prevent fugitive dust loss, this type of sweeper uses water spray. This spray helps keep the fine particles from becoming airborne. Advantages of this type a sweeper are that they are relatively inexpensive, good at collecting large debris, and they are easy to maintain. A disadvantage is that they are not effective at picking up fine particles.

Figure2.1 Mechanical broom Street sweeper

Vacuum sweepers (figure 2.2) are designed with an engine powered fan that creates a vacuum effect. The vacuum inlet is then located underneath the sweeper on the curb side of the vehicle. Furthermore, there is a gutter broom and/or a windrow broom to help brush the debris toward the inlet of the vacuum. These types of sweepers are designed to only collect debris that accumulates within 36 inches of the gutter. As with mechanical broom sweepers, the vacuum sweeper also uses water spray to prevent fugitive dust. An advantage of this type of sweeper is that it is effective at removing fine particles. Disadvantages are that the sweeper does not clean the entire lane, and it is less efficient at picking up heavy debris, and it releases some fine particles to the atmosphere.

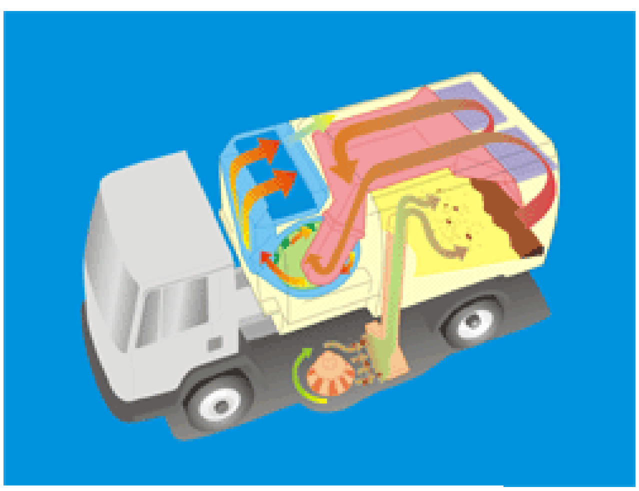

Figure 2.2 Vacuum Street sweeper

Regenerative air sweepers (figure 2.3) are similar to vacuum sweepers; however, the air they use is in a closed loop system. This helps reduce to amount of dust particles that are released into the atmosphere. The sweepers have a vacuum inlet located on the curb side of the sweeper. The air and particles that are sucked up through the vacuum inlet are then blown into a storage unit. The flow enters into the tank in such a way that a cyclonic effect ensues. This forces the debris to the bottom of the storage unit. The clean air at the top is then blasted down on the street to loosen fine particles from the street surface. This air is blown across the pickup head in the direction of the vacuum inlet. A majority of the debris in this path is then sucked up by the vacuum inlet. Like all of the other street sweepers, these are also equipped with gutter brooms. Advantages to this type of sweeper are that it can clean the entire width of the lane, it can pick up fine particles, and it does not require water spray as a fugitive dust loss control. A disadvantage to this type of sweeper is that it has a difficulty picking up heavy debris.

High-efficiency sweepers include various components of both a vacuum and regenerative air sweeper. The main goal of this type of street sweeper is to be efficient and environmentally friendly. This is obtained by controlling fugitive dust loss without the use of water spray. This makes the machines more fuel efficient since they are not carrying the weight of the water. An advantage to this sweeper is that it can pick up a wide range of debris, effectively picking up fine particles. Disadvantages to this type of sweepers are that it is expensive and hard to maneuver due to a longer vehicle length.

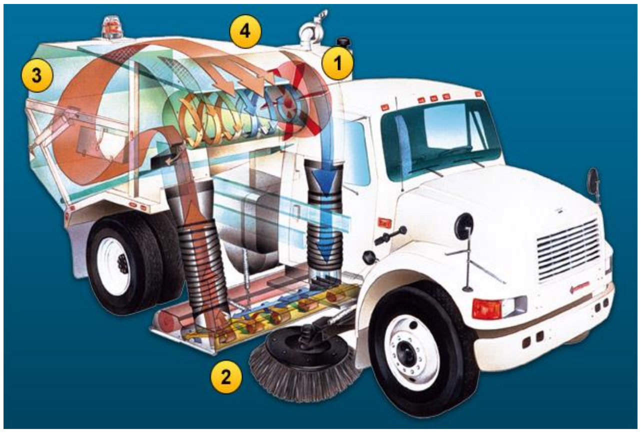

Figure2.3 Regenerative air Street sweeper 1) The closed-loop Regenerative Air System. 2) pick-up head. 3) Storage unit. 4) Clean air return

2.1.4 Frequency of Street Sweeping

The efficiency of street sweeping is greatly influenced by the frequency at which the roads are swept. As the street is swept more frequently the total debris removed from the street is increased. However, finding an efficient street sweeping frequency is the key. The studies analyzed look at the frequencies of twice weekly, once weekly, bi-weekly, and monthly. These results will give an insight to the most efficient street sweeping practice, and will be discussed in section 3.

2.2 Hydrodynamic separators

The SAFL Baffle was modeled by Sizes Hydrodynamic Separators and Manholes (SHSAM) software. SHSAM was developed by BARR engineering to model the efficiencies of hydrodynamic separators in removing suspended solids.

From the existing manholes and drainage basins, only features with pre-existing sumps have been taken into consideration for this study. Also limiting the field are sump locations that have inlet piping, since SALF Baffles work best when over 75% of the incoming flow is horizontal. These restrictions limited viable locations to the sumps 11050A and 13367 by northwest portion of the Glen Lake (figure 2.4). Sump 11050A had dimensions of 4 feet high, 4 foot diameter, with an 18 inch inlet; sump 13367 had dimensions of 4 feet high, 4 foot diameter, with a 12 inch inlet.

Analysis of total replacement of drainage basins into sumps that could support a SALF Baffle was restricted to the northern area of Glen Lake where large network storm sewers are in place (figure 2.5). The hope of the analysis is to show ideal locations of sumps with baffles based on watershed characteristics.

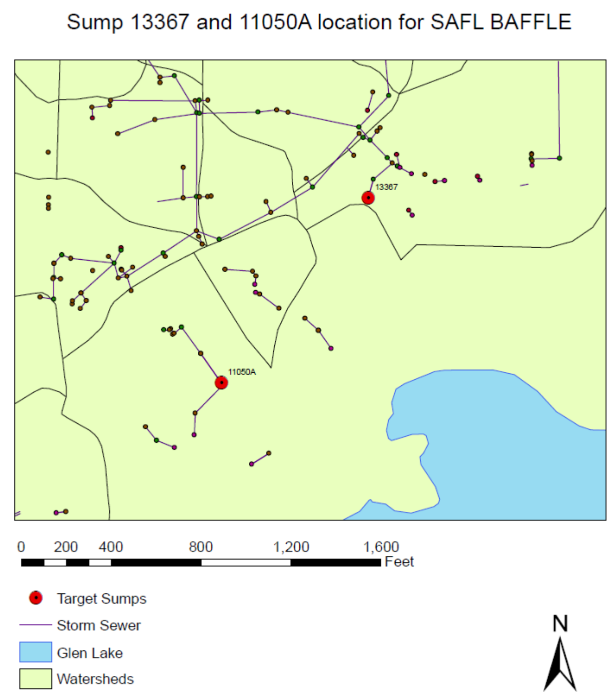

Figure 2.4 sump locations for existing SAFL Baffle retro-fit

Precipitation information was gathered in Golden valley MN from 1997-2007 and temperatures gathered from St. Paul, Minnesota, which was provided by SHSAM. When considering which sump sizes to incorporate, model 44 in SHSAM was a common sump size in much of the area. Model 44 is 4 feet high, 4 foot diameter, with a 12 inch inlet. A multitude of different model sizes and an average load removed will be used over the 10 years from 1997-2007.

2.2.1 Assumptions

In order to utilize SHSAM to model the watershed, various assumptions were established. Using curve numbers found in Mays (2011), the more developed areas of Glen Lake watershed had a higher curve number while residential areas are lower, which were 79 and 69 respectively. These curve numbers were found based on a United Stated Department of Agriculture (USDA) survey of soils in the region, which suggested the area of Glen Lake would have a silt loam or loam type soil, a type B soil. The average slope was also taken from the USDA soil survey (2013) which reported the slope to be between 6 and 12 percent. Taking the average the slope used in the analysis was 9%. The influent total suspended solid (TSS) was 180 milligrams per liter [mg/L] ,(Gulliver, 2008), and grain size distribution of National Urban Runoff Program (NURP) by Wu (1996).

Further assumptions were taken from a GIS study of the Glen Lake area which was performed by a student group at the University of Minnesota. From this study, average subwatershed areas and hydraulic lengths were estimated. The sub-shed areas were stratified into 3, 10, and 30 acres. The hydraulic lengths were estimated taking the assumption that the majority of the subwatersheds were fairly square in shape. Also, since delineation of the subwatersheds was unknown, the hydraulic length was estimated as being the diagonal of the square watershed. Impervious areas were taken to be 20% in residential areas and 75% in more industrially developed areas. (Alapati et. Al., 2012).

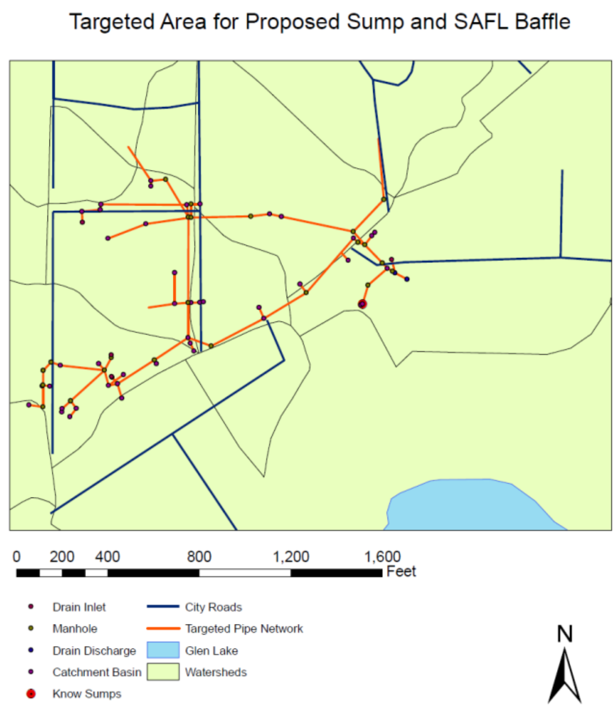

Figure 2.5 Target area for sump and SAFL Baffle complete reconstruction

3.0 results

3.1 Street Sweeping Performance Results

Street sweeping can be a viable option for storm water treatment due to the reduction in sediments and organic biomass that would otherwise run off into the storm sewers. The following results will show the effects of street sweeping in reducing TSS, TP, and metals off the streets before entering the storm sewer and how the frequency and technology of sweepers can affect the removal efficiencies. Published studies ranging from 1998 to 2012 were referenced to obtain efficiencies for different sweeper types along with the frequency to sweep. Additionally, the studies helped estimate the amount of nutrients removed from Glen Lake and the cost to remove these nutrients.

Jelen (1998) conducted street sweeping studies on parking lots and commercial container yards and showed that sweeping dry pavement verses wet pavement had very similar percentages of reduction. Sutherland's findings listed in Table 3.1 shows that biweekly sweeping can achieve TSS and TP reductions ranging from 40%-60% and 20%-40%. Street sweeping can also reduce metals such as lead, zinc, and copper that is found on streets from cars and commercial or residential runoff. Street sweeping can help with the removal of all of these pollutants if performed properly.

Table 3.1 Expected annual pollutant load reductions.

Parameter	Frequency of Sweeping		
	Twice Weekly	Weekly	Biweekly
TSS	45%-70%	45%-65%	40%-60%
TP	35%-60%	30%-55%	20%-40%
Total Lead	40%-60%	35%-60%	30%-50%
Total zinc	30%-55%	25%-50%	20%-40%
Total Copper	35%-60%	30%-55%	35%-45%

Sutherland (1998) also conducted studies using four different brands of street sweepers to determine the annual reduction in TSS. The four types of sweepers that were examined are the Schwarze EV, Elgin Regenerative, Tandem, and Mobile mechanical sweepers. Table 3.2 lists the frequencies of monthly, twice monthly, weekly, twice weekly, and the annual percent in reduction for single family residential areas. The Schwarze EV outperformed the rest of the sweepers with the regenerative air being the second most efficient sweeper. Sutherland found that the more frequent the sweeping frequency, the more reduction in TSS is achieved. The comparison of the Schawrze EV for monthly to weekly sweepings is a reduction in TSS of 51% to 87%. This is a wide range for different frequencies but shows that the most efficient sweeper needs to be used weekly to achieve a high TSS reduction. The mechanical sweeper was the least effective with removal percentages ranging from 17% to 29% for monthly and weekly sweeping frequencies. This percentage is much lower than the more efficient regenerative air sweepers and shows that frequent sweeping should be encouraged and can make a difference in reducing TSS in a watershed, even with less efficient sweepers.

The Schwarze EV had an efficiency of 70% for fine particles and up to 96% for coarse particles. The medium particles ranged in percentages depending on the particle type. The regenerative air sweeper had an efficiency of 32% for fine and up to 94% for coarse particles. Both of these types of sweepers are considered high efficiency sweepers and collect most of the large particles but varied in the percentage of finer particles picked up. The percentage of finer particles captured by the mechanical sweeper is not recorded but will be significantly less than 30%.

Table 3.2 Annual TSS reduction (%) for single family residential areas.

Sweeper Type	Frequency of Sweeping			
	Monthly	Twice Monthly	Weekly	Twice Weekly
Schwarze EV	51%	63%	79%	87%
Elgin Regenerative	43%	53%	65%	71%
Tandem	33%	41%	49%	53%
Mobil Mechanical	17%	23%	29%	33%

The City of San Diego conducted a street sweeping study that finished in 2010 to analyze their fleet of street sweepers – mechanical, regenerative air, and vacuum sweepers. Exact information on the sweeper brands and models can be found in Appendix B.1 (Figure 6.1). Figure 3.1 shows the debris weight per broom mile and shows that the vacuum sweeper will pick up much more material per mile than the regenerative air sweeper and the mechanical sweeper. (Weston Solution, Inc., 2010).

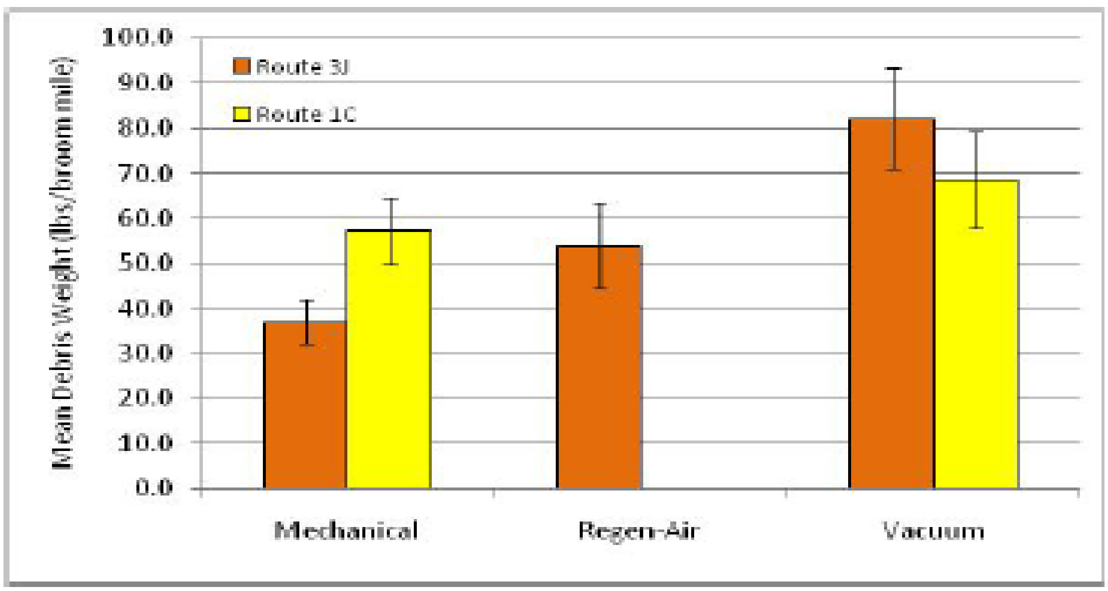

Figure 3.1 Mean debris weight per broom mile swept (Weston Solution, Inc. 2010).

The City of San Diego also tested stormwater before and after streets were swept by a mechanical and vacuum sweepers to show the concentration of copper, lead, zinc, and TSS in the water before and after sweeping for the same storm event. Table 3.3 shows the mean concentration in the stormwater before and after sweeping by the mechanical and the vacuum sweepers. There is a significant reduction in metals after sweeping, which can be toxic to the receiving bodies of water in high concentrations. Table 3.3 also shows that there was a significant reduction in TSS from the unswept condition to the swept condition. Samples only include the fine to coarse particles, but do not account for the large debris that is collected by the sweeper due to the lack of sampler measurements. The results from Table 3.3 show that with sweeping, especially vacuum sweeping, there is a significant reduction in metals and TSS in the storm water. Additionally, there is a larger debris reduction not included in the results that could prevent clogs and hinder other storm water practices.

Table 3.3 Total metals and TSS in storm water before and after sweeping (Weston Solution, Inc. 2010)

Storm Event	Type of Sweeping	Copper (µg/L)	Lead (µg/L)	Zinc (µg/L)	TSS (mg/L)
Mean of three storms	Unswept	145.0	121.7	1117.5	927.0
	Mechanical	63.1	49.0	469.2	243.8
	Vacuum	41.6	20.3	345.5	135.8

Figure 3.2 shows that by implementing street sweeping there can be a significant reduction in concentration of particles in the stormwater. This reduction can allow other practices the ability to clean the remaining stormwater and not get overwhelmed by the initial high concentration of pollutants. This figure shows that even with the lower efficiency mechanical sweepers, there is a positive effect per storm event and even more of a reduction in concentrations when a high efficiency sweeper is used.

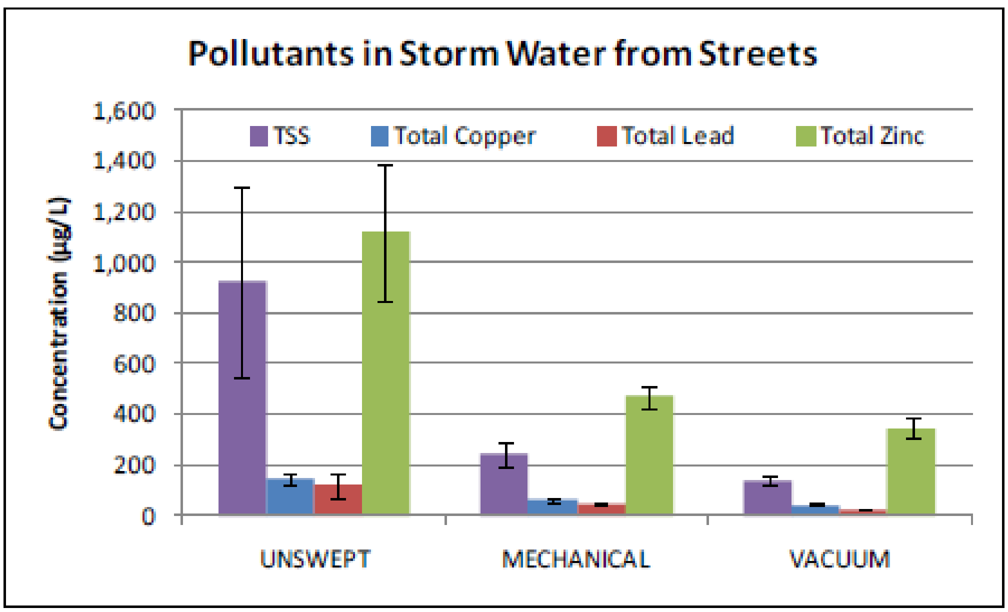

Figure 3.2 Pollutant in storm water from streets before and after sweeping (Weston Solution, Inc. 2010).

Sweeping studies from 1998 to 2010 agree that street sweeping can remove a significant percentage of pollutants annually. The percentage or removal will vary depending on the particles size, the street sweeper type, and the frequency of sweepings. Frequency of sweepings plays a large factor in the percentage of removal of TSS, with weekly sweepings averaging 79% to 29% reduction depending on the sweeper used. Although the range is large, weekly sweeping can create a significant reduction in TSS. The annual percent removal for TP is 50% for high efficiency sweepers and just below 30% for mechanical sweepers, but this result will vary on the amount of organic biomass that is on the roadway. The majority of this biomass is leaves and grass clippings that will decompose and create large phosphorus loads. TP reduction will vary during the months due to leaves falling in the fall and grass clippings in the summer.

The City of San Diego estimated the operating costs for the three types of sweepers that they use and the cost estimate per mile will vary depending on initial sweeper cost, fuel prices, and repair costs. The operation cost per mile swept includes estimated future replacement fees, fuel costs, preventative maintenance costs, and repair costs. This cost estimate does not include driver wages and benefits; it only compares the cost per mile of the three different sweeper types. Table 3.4 lists these estimated costs and shows that, in the long term, vacuum sweepers are more efficient and cost effective.

Table 3.4 Street sweeper operation cost per mile for three different sweepers (Weston Solution, Inc. 2010).

Sweeper Type	Operation Cost ($/mile)
Mechanical	$8.38
Vaccum	$5.39
Regenerative- Air	$5.60

Glen Lake watershed has an estimated 12 miles of roadway (24 curb-miles) with an assumed medium canopy density. This data was used in conjunction with the Prior Lake study to calculate the amount of nutrients recovered from streets with a medium density canopy and the estimated cost of this removal process, (Kalinoski, 2012). Tables 3.5 and 3.6 show the process and assumptions made to calculate the estimated nutrients that can be removed from Glen Lake watershed with monthly and weekly street sweeping. Assumptions that were made include sweeping only eight months ranging from April to November due to winter months hindering the ability to sweep. The nutrient removals were broken up into spring load, fall load, and other month loads to make a more accurate estimate of the amount of nutrients removed annually. Along with the nutrients removed, the cost per pound of sediment removal was estimated from the Prior Lake study. The cost is estimated at $19 and includes operation, fuel, vehicle maintenance, and driver wages from data conducted in 2011 and 2012.

Table 3.5 Estimated nutrients removed and cost for Glen Lake Watershed (monthly sweeping)

Curb Miles	Monthly	Season	Median P	Median N	Median TSS	Estimated Recovered P	Estimated Recovered N	Estimated Recovered TSS	Cost
(miles)	# of Sweeps		(lb/curb-mile)	(lb/curb-mile)	(lb/curb-mile)	(lb)	(lb)	(lb)	($)
24	3	s	0.13	0.9	20	9.36	64.8	1440	$ 1,368.00
24	2	f	0.22	1.15	150	10.56	55.2	7200	$ 912.00
24	3	o	0.1	0.45	40	7.2	32.4	2880	$ 1,368.00
					Total	27.12	152.4	11520	$ 3,648.00

Assumptions: Medium Canopy Density
S=Apr-Jun, F=Oct-Nov, O=all other
8 Month Study ranging from Apr-Nov

Table 3.6 Estimated nutrients removed and cost for Glen Lake Watershed (weekly sweeping)

Curb Miles	Weekly	Season	Median P	Median N	Median TSS	Estimated Recovered P	Estimated Recovered N	Estimated Recovered TSS	Cost
(miles)	# of Sweeps		(lb/curb-mile)	(lb/curb-mile)	(lb/curb-mile)	(lb)	(lb)	(lb)	($)
24	13	s	0.13	0.9	20	40.56	280.8	6240	$ 5,928.00
24	9	f	0.22	1.15	150	47.52	248.4	32400	$ 4,104.00
24	13	o	0.1	0.45	40	31.2	140.4	12480	$ 5,928.00
					Total	119.28	669.6	51120	$15,960.00

Assumptions: Medium Canopy Density
S=Apr-Jun, F=Oct-Nov, O=all other
8 Month Study ranging from Apr-Nov

Table 3.7 and 3.8 summarize the pounds of phosphorus, nitrogen, and TSS removed annually from Glen Lake watershed and the cost per pound to remove these nutrients. Also, the tables include the total cost to sweep monthly and weekly in order to compare an easily feasible monthly frequency and an aggressive weekly frequency. The cost per pound is similar in both frequencies, but the amount of nutrients removed by weekly sweepings is significantly greater.

Table 3.7 Estimated pollutant removals for monthly sweepings for Glen Lake Watershed.

Monthly Sweepings(Apr-Nov)	Operating cost: $19/curb-mile	
Estimated Annual Nutrients Recovered	(lb)	($/lb)
Phosphorus	27.1	$ 134.51
Nitrogen	152.4	$ 23.94
Estimated Annual Solids Recovered	(lb)	($/lb)
Dry TSS	11520	$ 0.32
Total Cost		$ 3,648.00

Table 3.8 Estimated pollutant removals for weekly sweepings for Glen Lake Watershed.

Weekly Sweepings (Apr-Nov)	Operating cost: $19/curb-mile	
Estimated Annual Nutrients Recovered	(lb)	($/lb)
Phosphorus	119.3	$ 133.80
Nitrogen	669.6	$ 23.84
Estimated Annual Solids Recovered	(lb)	($/lb)
Dry TSS	51120	$ 0.31
Total Cost		$ 15,960.00

3.2 Sumps with baffle results

With the assumptions explained earlier, the existing sumps and prospect sump locations were analyzed.

The existing sumps were analyzed with a Curve Number, Impervious area, and slope of 69, 20%, and 9% respectively. With an estimated watershed area and hydraulic length using ArcGIS software, which were areas of 0.7 and 3.5 acres with hydraulic length of 333 and 591 feet for sumps 13367 and 11050A, respectively.

Table 3.6 gives the results of this analysis. The cost assumption was based on an approximate retrofit cost of $4,000 and a ten year life span of the sump or SAFL Baffle (Upstreams Technology, 2013).

Table 3.6: SAFL baffle Analysis for retro-fit of current sumps

Sump ID#	Structure Type	Total Load (lbs)	Total Load Removed (lbs)	Average Load Removed (lbs/yr)	Removal Efficiency (%)	Cost of TSS Removed in a Ten Year Life ($/lb)	Model Height (ft)	Model Diameter (ft)	Pipe Diameter (in)
11050A	SAFLBaffle	8462	531	53.1	6.3	75	4	4	18
	StandardSumps	8462	230	23	2.7	174	4	4	18
13367	SAFLBaffle	1689	290	29	17.2	138	4	4	12
	StandardSumps	1689	159	15.9	9.4	252	4	4	12

A range of sumps were analyzed showing that smaller subwatershed areas would benefit more from both sumps and SALF Baffles. Table 3.7 demonstrates the most efficient catchment area for SHSAM model 44, and further information on different model performances can be seen in Appendix C.1. For modeling the northern Glen Lake area the Curve Number, Impervious area, and slope were taken as 69, 20%, and 9% respectively, with the assumed watershed characteristics. The cost assumption was based on an approximate manhole reconstruction cost of $10,000 and a ten year life span of the sump or SAFL Baffle (Upstream Technologies, 2013).

Table 3.7: Proposed Sump analysis by area

Area	Structure Type	Ten Year Total Load (lbs)	Ten Year Total Load Removed (lbs)	Average Load Removed (lbs/yr)	Removal Efficiency (%)	Cost of TSS Removed in a Ten Year Life ($/lbs)
3 Acre	SAFLBaffle	21953	200	20	0.9	500
	StandardSumps	21953	28	2.8	0.1	3571

4. 0 Conclusion

Street sweeping was found to be an effective best management practice when the streets were swept on a frequent basis. There were significant reductions found in TSS, TP, total lead, total zinc and total copper. It was determined that the streets should be swept on a monthly basis, at a minimum. If it is possible to sweep the streets more often, it is recommended that the streets be swept on a weekly basis or in-between storm events.

It was found that the vacuum and regenerative air sweepers were more efficient at picking up fine particles, whereas the mechanical broom sweepers were found to be more efficient at picking but coarse particle. With this, it is recommended that a mechanical sweeper be used for the first sweeps in the spring and a sweep in the fall when leaves are falling from the trees. Other than these specific times, a vacuum or regenerative air sweeper should be used.

With weekly sweeping, over 51,000lbs of solids can be removed annually at an estimated annual cost of $15,960. For monthly sweeping, over 11,000lbs can be removed at an estimated $3,648. For both cases, the removal of solids is estimated to cost just over $0.31/lb.

SAFL Baffles provide greater removal of sediment in the pre-existing sumps and standard sumps by a factor of 2 to 3 depending on the location and with annual maintenance. More frequent cleaning has been seen to increase the amount of pollutants removed. Further studies will be needed to relate the load removed to the removal of TS, TN, and TSS, but it would be good to assume that proper placement of sumps and SAFL Baffles can greatly reduce pollutants entering our lakes and streams.

Retro fitting existing sumps to SAFL baffles can cost between $3,000 and $5,000. A new manhole sump and SAFL Baffle installation would likely be between $8,000 and $12,000 (Upstream Technologies). Considering the existing and proposed areas, it would be recommended to install SAFL Baffles in the existing areas. The proposed areas would need more research on proper location to give any definitive recommendations based on the assumptions used in the analysis.

For a sump retrofit project estimated at $4,000, the SAFL Baffle can remove 53lbs of total suspended solids (TSS) annually. For manhole sump and SAFL Baffle installation estimated at $10,000, the system can remove roughly 20lbs of TSS within the proposed site.

5.0 References

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6.0 Appendix

Appendix A.1

Table 6.1: Glen Lake watershed land usage

Glen Lake Watershed Characteristics		
Type	Area	Proportion
[]	[acre]	[%]
low density residential	680	64
commercial entities/roads	149	14
open water and wetlands	127	12
parks/open spaces	32	3
other	74	7

Appendix B.1

Street Sweeping Machine	Machine Specifications
MECHANICAL STREET SWEEPER 	Modern mechanical street sweepers are equipped with water tanks and sprayers used to loosen particles and reduce dust. Mechanical brooms gather debris underneath the sweeper and the vacuum system pumps debris into the hopper (storage receptacle). BRAND: Johnston 4000 COST: $193,000 CAPACTIY: 6 cubic yards Number in Fleet: 24
REGENERATIVE-AIR SWEEPER 	Regenerative-air street sweepers use forced air to create a swirling knifing effect inside a contained area underneath the machine (sweeping head). The swirling knifing effect generates negative pressure on the suction side of the sweeping head, which transfers debris into the hopper. The debris-laden air is then cleaned and reused to start the process anew. Literature has shown these machines to be significantly better at removing total solids, nutrients, and metals than standard mechanical sweepers. BRAND: Schwartz A7000 COST: $165,000 CAPACTIY: 8 cubic yards Number in Fleet: 1
VACUUM SWEEPER 	Vacuum-assisted street sweepers use a high-powered vacuum to suction debris directly from the road surface and transfer the debris into the hopper. Literature has shown these machines to be significantly better at removing total solids, nutrients, and metals than standard mechanical sweepers. BRAND: Elgin Whirlwind COST: $203,000 CAPACTIY: 8 cubic yards Number in Fleet: 3* *The City originally procured one Elgin vacuum sweeper for the Targeted Aggressive Sweeping Pilot Study. Two additional vacuum sweepers were purchased in fiscal year (FY) 2009 based on preliminary results and considerations from FY2008.

Figure 6.1 Street sweepers used in San Diego study, Weston Solution, Inc (2010).

Appendix C.1

3 acre

cost 10000

Structure Type	Model	Total Load (lbs)	Total Load Removed (lbs)	Average Load Removed in 10 Years (lbs)	Removal Efficiency (%)	Cost of TSS Removed in a Ten Year Life ($/lbs)	Model Height (ft)	Model Diameter (ft)	Pipe Diameter (inches)
SAFLBaffle	42	21953	62	6.2	0.3	1613	2	4	15
SAFLBaffle	44	21953	200	20	0.9	500	4	4	15
SAFLBaffle	55	21953	539	53.9	2.5	186	5	5	18
SAFLBaffle	63	21953	728	72.8	3.3	137	3	6	24
SAFLBaffle	66	21953	1154	115.4	5.3	87	6	6	24
SAFLBaffle	86	21953	1802	180.2	8.2	55	6	8	30
SAFLBaffle	106	21953	2485	248.5	11.3	40	6	10	36

Structure Type	Model	Total Load (lbs)	Total Load Removed (lbs)	Average Load Removed in 10 Years (lbs)	Removal Efficiency (%)	Cost of TSS Removed in a Ten Year Life ($/lbs)	Model Height (ft)	Model Diameter (ft)	Pipe Diameter (inches)
StandardSumps	42	21953	1	0.1	0	100000	2	4	15
StandardSumps	44	21953	28	2.8	0.1	3571	4	4	15
StandardSumps	55	21953	152	15.2	0.7	658	5	5	18
StandardSumps	63	21953	205	20.5	0.9	488	3	6	24
StandardSumps	66	21953	464	46.4	2.1	216	6	6	24
StandardSumps	86	21953	848	84.8	3.9	118	6	8	30
StandardSumps	106	21953	1219	121.9	5.6	82	6	10	36

10 acre

Structure Type	Model	Total Load (lbs)	Total Load Removed (lbs)	Average Load Removed in 10 Years (lbs)	Removal Efficiency (%)	Cost of TSS Removed in a Ten Year Life ($/lbs)	Model Height (ft)	Model Diameter (ft)	Pipe Diameter (inches)
SAFLBaffle	42	73586	2	0.2	0	50000	2	4	15
SAFLBaffle	44	73586	3	0.3	0	33333	4	4	15
SAFLBaffle	55	73586	29	2.9	0	3448	5	5	18
SAFLBaffle	63	73586	77	7.7	0.1	1299	3	6	24
SAFLBaffle	66	73586	353	35.3	0.5	283	6	6	24
SAFLBaffle	86	73586	1139	113.9	1.5	88	6	8	30
SAFLBaffle	106	73586	2152	215.2	2.9	46	6	10	36

Structure Type	Model	Total Load (lbs)	Total Load Removed (lbs)	Average Load Removed in 10 Years (lbs)	Removal Efficiency (%)	Cost of TSS Removed in a Ten Year Life ($/lbs)	Model Height (ft)	Model Diameter (ft)	Pipe Diameter (inches)
StandardSumps	42	73586	1	0.1	0	100000	2	4	15
StandardSumps	44	73586	2	0.2	0	50000	4	4	15
StandardSumps	55	73586	4	0.4	0	25000	5	5	18
StandardSumps	63	73586	4	0.4	0	25000	3	6	24
StandardSumps	66	73586	15	1.5	0	6667	6	6	24
StandardSumps	86	73586	204	20.4	0.3	490	6	8	30
StandardSumps	106	73586	564	56.4	0.8	177	6	10	36

30 acre

Structure Type	Model	Total Load (lbs)	Total Load Removed (lbs)	Average Load Removed in 10 Years (lbs)	Removal Efficiency (%)	Cost of TSS Removed in a Ten Year Life ($/lbs)	Model Height (ft)	Model Diameter (ft)	Pipe Diameter (inches)
SAFLBaffle	42	220962	2	0.2	0	50000	2	4	15
SAFLBaffle	44	220962	4	0.4	0	25000	4	4	15
SAFLBaffle	55	220962	6	0.6	0	16667	5	5	18
SAFLBaffle	63	220962	8	0.8	0	12500	3	6	24
SAFLBaffle	66	220962	11	1.1	0	9091	6	6	24
SAFLBaffle	86	220962	83	8.3	0	1205	6	8	30
SAFLBaffle	106	220962	437	43.7	0.2	229	6	10	36

Structure Type	Model	Total Load (lbs)	Total Load Removed (lbs)	Average Load Removed in 10 Years (lbs)	Removal Efficiency (%)	Cost of TSS Removed in a Ten Year Life ($/lbs)	Model Height (ft)	Model Diameter (ft)	Pipe Diameter (inches)
StandardSumps	42	220962	2	0.2	0	50000	2	4	15
StandardSumps	44	220962	3	0.3	0	33333	4	4	15
StandardSumps	55	220962	5	0.5	0	20000	5	5	18
StandardSumps	63	220962	5	0.5	0	20000	3	6	24
StandardSumps	66	220962	8	0.8	0	12500	6	6	24
StandardSumps	86	220962	13	1.3	0	7692	6	8	30
StandardSumps	106	220962	19	1.9	0	5263	6	10	36