Crane Lake Watershed Study

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Executive Summary

The Minnesota Pollution Control Agency has required that phosphorous, suspended sediments and water volume must be reduced in cities through the use of stormwater BMPs. The scope of this project is the analysis of the Crane Lake Watershed in the City of Minnetonka and a feasibility study to evaluate the use and cost of different best management practices (BMPs). The feasibility study utilizes stormwater modeling to evaluate the BMPs of street sweeping and rain gardens (bioretention devices). The BMPs of in-line ditch treatment and stormwater detention ponds are also analyzed outside of a model. There will also be a full life-cycle analysis that will look at maintenance costs, life spans, and effectiveness of these different BMPs. The ideal locations of the BMPs within the watershed will also be analyzed. In order to more effectively and completely analyze different BMPs in the watershed, a SWMM computer model was constructed from available GIS data.

The results of the SWMM simulations helped determine how much TSS, phosphorous, nitrogen, and runoff volume were removed for street sweeping and rain gardens. The results indicated that street sweeping proved to be the most cost-effective option. Detention ponds and inline treatment were not modeled in SWMM, but average expected results were used as a comparison. For the Crane Lake Watershed, which consistently meets water quality goals for a Level III water body, we advise implementing the most cost-effective options from this study. We recommend increasing the frequency of street sweeping from the current annual interval to monthly or bimonthly sweeping, including sweeping of commercial parking lots when feasible. Increasing the frequency of street sweeping to a monthly or bimonthly interval would remove enough sediment, phosphorus, and nitrogen to ensure that Crane Lake doesn't degrade in the near future. In addition, if increased water quality of Crane Lake is desired, we strongly recommend a wet detention pond within the Ridgedale subcatchment. The Crane Lake Watershed depends on pollutant reduction from the highly-impervious Ridgedale campus, and wet detention basins and street sweeping are the most cost-effective options.

Introduction

Project Scope

The Minnesota Pollution Control Agency has required that phosphorous, suspended sediments and water volume must be reduced in cities through the use of stormwater BMPs. The scope of this project is the analysis of the Crane Lake Watershed and a feasibility study to evaluate the use and cost of different best management practices (BMPs). The feasibility study will utilize stormwater modeling to evaluate BMPs such as increased street sweeping, in-line treatment, rain gardens, and stormwater detention ponds. There will also be a full life-cycle analysis that will look at maintenance costs, life spans, and effectiveness of these different BMPs. The ideal locations of the BMPs within the watershed will also be analyzed. In order to more effectively and completely analyze different BMPs in the watershed, a SWMM computer model was constructed from available GIS data.

Study Site: Crane Lake

The study site, Crane Lake, drains a total of approximately 500 acres of northeastern Minnetonka that includes undulating forested residential neighborhoods and the Ridgedale Shopping Center. The Crane Lake watershed is a subwatershed of the Bassett Creek Watershed, ultimately draining into the Mississippi River. Crane Lake itself has a surface area of approximately 70 acres, an average depth of two feet, and a maximum depth of five feet. Crane Lake is a Level III water body, suitable for non-contact recreation and capable of supporting wildlife. The target levels for Level III water bodies are 75-105 μg/L Phosphorus and 0.6-1.0 meters of transparency. While it is not recommended for body contact, Crane Lake has consistently met established water quality standards for its classification, neither showing signs of improvement or deterioration over the past several decades (Barr Engineering, 2012).

Crane Lake has been closely monitored since the 1970s through a combined effort between the Bassett Creek Watershed Management Commission, the Ridgedale Shopping Center property owners, and the City of Minnetonka. Over its monitoring history Crane Lake has been classified as Eutrophic (having relatively high levels of fertility or algal activity) based on a standardized lake rating system known as Carlson's Trophic State Index, TSI. This index combines phosphorus concentration, chlorophyll-a concentration, and secchi disk depth (a value of turbidity). In addition to its eutrophic classification, Crane Lake has had high values of specific conductivity, a measure of dissolved solids (Barr Engineering, 2012). Since Crane Lake receives runoff from Ridgedale, it is likely that salt applied to roads and parking lots during the winter accounts for the high conductivity. An analysis of the Crane Lake Watershed would not be complete without an account of nearby Ridgedale's influence.

Methods

Best Management Practices

Stormwater Detention Ponds

In the past, stormwater detention ponds have been effective in removing certain pollutants and providing enough storage volume to ensure no flooding around the pond during large storm events, if maintained properly. If these ponds are improperly maintained, they increase the amount of pollutants downstream and lead to aesthetic and nuisance problems like unpleasant odors, insects, and algal blooms. Things that could cause pond failure are clogged inlets (trash, debris, and sediments), mowing and weed control (poor vegetation maintenance), or failed side slopes.

For each community, the Homeowners Association (HOA) is responsible for completing maintenance on the detention ponds. The routine HOA maintenance includes inspections, vegetation management, trash, debris, and litter removal, a mechanical equipment check, and a structural component check. Non-routine HOA maintenance includes bank erosion/stabilization, sediment removal, and structural repair/replacement (Maintaining Detention Ponds). The annual cost for routine maintenance is estimated typically to be 3-5% of the construction cost. The sediment should be removed if the sediment depth is over 25% of the original design depth of the pond.

Generally, both dry and wet detention ponds need a larger continuous area for placement. This differs from other practices that use filters or swales which are typically sited in smaller unusable strips of land. However, the pond area is usually only 2-3% of the total drainage area that they treat, which increases its effectiveness. The lifespan of a typical detention pond is a little longer than 20 years, if maintained properly. The typical cost of dry detention ponds is estimated based on the volume of water to be treated and the construction costs ("Dry Detention Ponds"). Dry ponds are usually both less expensive and smaller than wet ponds.

$$C = 12.4V^{0.760}$$

where: C = construction, design, and permitting cost
V = volume needed to control 10-year storm [ft^3]

The cost for wet detention ponds is represented by the following equation, taking into account that the construction cost for wet ponds varies significantly ("Wet Ponds").

$$C = 24.5V^{0.705}$$

where: C = construction, design, and permitting cost
V = volume needed to control 10-year storm [ft^3]

The EPA estimates the following pollutant removal efficiencies for dry detention ponds ("Dry Detention Ponds") and wet detention ponds ("Wet Ponds");

Pollutant	**Removal Efficiency, Dry Pond**	**Removal Efficiency, Wet Pond**
TSS	61%	67%
Total Phosphorous	19%	48%
Total Nitrogen	31%	31%
Nitrate	9%	24%
Metals	26-54%	24.73%
Bacteria	-	65%

There are some limitations to dry ponds compared to other practices that should be noted. Compared to other BMP's, dry detention ponds only have a moderate pollutant removal because they are not able to remove soluble pollutants. Dry detention ponds have also been known to reduce home values by 3 to 10%, if the homes were adjacent to the pond ("Dry Detention Ponds"). However, wet detention ponds have been known to increase the value of homes by 15-25 % ("Wet Ponds"). Even though dry and wet ponds do not contribute to overall volume reduction during a storm, they can both provide flood control, channel protection, and pollutant removal.

By looking at the numbers, wet ponds seem to be a better choice over dry ponds for various reasons, but they have their limitations as well. If they are placed in an improper location, they may cause the loss of wetlands or forests. They also aren't the best choice to put in highly urbanized areas because they require a large space. If streams nearby a wet pond are cold water streams, it would be a bad idea to put a wet pond there because it would cause the water temperature to rise, affecting the surrounding ecosystem. Lastly, wet ponds are more of a safety hazard than dry ponds because of the risk of drowning.

Rain Gardens

To improve the quality of runoff entering Crane Lake, rain gardens will be implemented with the help of the community to help soak up and treat rainwater before it enters the lake. In residential areas, gardens will be implemented where there is space as well as resident interest in keeping the gardens maintained after the initial two-year start up. The area of the rain gardens will be approximately 5-10% of the drainage area. Looking at a summary of studies on rain garden pollutant removal in Maryland, the EPA summarized effectiveness in removing pollutants as follows;

Pollutant	Removal Efficiency
Copper	43-97%
Lead	70-95%
Zinc	64-95%
Phosphorous	65-87%
TKN	52-67%
Ammonium	92%
Nitrate	15-16%
Total Nitrogen	49%
Calcium	27%

Rain garden maintenance for the first one to two years will be more extensive as the garden and ground cover become established. After the garden becomes established, inspections will be necessary after large storm events, as well as occasional weeding and watering to maintain garden integrity. Through preventative maintenance practices, the life of the garden will be extended. By adding new mulch once a year, replacing dead vegetation twice per year, and monitoring soil conditions (erosion) and removing litter and debris on a monthly basis, the garden life will be extended with regular garden care. The EPA estimates the typical cost of a rain garden using the volume of water it treats;

$C = 7.30V^{0.99}$ where: C = construction, design, and permitting cost
V = volume of water treated by the facility [ft^3]

In general, rain gardens in residential areas cost approximately $3-$4 per square foot and in commercial areas cost $10-$40 per square foot due to the extra cost of drainage for the system ("Bioretention").

Street-Sweeping

Street sweeping is one of the few BMPs that can reduce sediments and associated pollutants prior to them becoming entrained in runoff. Minnetonka currently sweeps its streets once per year in the spring, when the sediment in streets is evenly spread throughout the road surface as a result of winter sand application. There is a wide range in the effectiveness of street sweeping throughout the year and between years owing to a wide range in weather conditions (Selbig and Bannerman, 2007). The amount of sand loaded onto streets varies as a function of winter weather and local practice, and the extent to which urban runoff captures the loose sediment varies with storm intensity and timing. Additionally, street sweeping equipment varies in its efficiency of removing sediment. Compared to more efficient machines, some less expensive traditional machines are incapable of removing larger particles which comprise three quarters of the sediment mass (Waschbusch et al, 1999; Minton et al, 1998).

While the exact impact of street sweeping on water quality is not easily predicted for a given season, the greatest long-term benefit is the reduction of overall sediment, with some additional benefits on removal of metals from runoff (Rochfort et al, 2009). Streets are the largest source of suspended solids within a typical watershed. They also combine with lawns to contribute over 80% of the total phosphorus load (mainly from large particulates and leaf matter) within a watershed (Waschbusch et al, 1999). Thus, street sweeping can reduce these loads when concentrated on residential areas with a lot of organic debris. Research suggests that significant measurable reductions of total sediments and total phosphorus can be achieved by increasing the frequency of street sweeping with high-efficiency equipment (Minton et al, 1998; Tetra Tech, 2001). By using the most efficient street sweeping equipment, 75-80% reduction in sediments can be achieved by sweeping twice a month, with a 50% reduction through monthly sweeping. Less expensive equipment could be used to achieve reductions of 50% or less with frequent sweeping.

Pollutant	Removal Efficiency
TSS	50 - 80%
Total Phosphorus	30-60%
Total Nitrogen	20-50%
Metals	45-55%

In-Line Treatment

Roadside ditches, which are already designed to direct the runoff from roads, can be fitted with relatively low-cost inline BMPs to reduce runoff volume and pollutant loads. These BMPs are designed to work within the framework of traditional road engineering, and being built into existing roadside ditches to capture runoff from roads as the water flows down the existing slope. The system is composed of check dams (made of rock, modified rock, or anything that can disrupt flowing water) and cells filled with a medium (compost or sand) suitable for water quality or volume control. The check dams dissipate energy from the runoff, and the cells either treat or infiltrate water from small storm events. These inline BMPs can be small (one or two cells) or extend linearly along the length of a road.

Normal ditch storage function is preserved for large storms, as the BMPs maintain ditch capacity (King County, 2011).

Inline treatment BMPs have been found to significantly reduce transported concentrations of total suspended solids, total nitrogen, polyaromatic hydrocarbons, and metals (arsenic, chromium, copper, lead, nickel, and zinc) along with reducing turbidity in receiving surface water bodies. In addition, flow reductions were observed, indicating that these BMPs store runoff from smaller storms and promote infiltration. In the state of Washington, the cost to construct each BMP (combining materials, equipment, and labor) averaged approximately $700, with the cost per BMP decreasing as more were installed for a given stretch of road. The in-line ditch BMPs are intended to function with minimal maintenance requirements and minor repairs to the check dams might be required. The removal efficiencies can be found in the following table (King County, 2011).

Pollutant	Removal Efficiency
TSS	13-45%
Copper	8-29%
Lead	27-34%
Zinc	17-21%
Phosphorous	0-5%
TKN	10-15%
Chromium	23%
Nickel	10-20%
PAHs	20-65%
Arsenic	14-17%

Building the SWMM Model

In order to assess the BMPs in the Crane Lake watershed more accurately, a SWMM model was built using GIS data made available from a previous study (SFTP site). This data included storm sewer information, subwatershed delineation, elevation contour data, and flow path information. Using watershed and flow path information, five land areas (subcatchments) were established to make up the Crane Lake Watershed, specified as Ridgedale, South, Residential, North East, and North West in the model (Results, Figure 1).

When creating the SWMM model, each of these subcatchments had various parameters that needed to be defined. These parameters included areas of each subcatchment, as well as the average slope of the area to determine time of concentration. GIS software was used to determine both of these parameters, as well as to determine land type. The percent slope of each subcatchment was calculated two ways because the slope varied substantially within each subcatchment, which made it difficult to determine one single flow path. First, the percent slope was calculated based on the longest direct flow path within the subcatchment using the elevation at the beginning and end points of this path. Second, the percent slope was calculated based on the highest and lowest elevation points in each area, while the water followed the natural slope of the land. The average of these two values was used in the model for each subcatchment (Appendix, Table 1).

$$\%\,Slope = \frac{High\ Elev - Low\ Elev}{Length\ of\ Flow\ Path}$$

With the subcatchments defined, it was then necessary to define the pollutant parameters. Land uses were defined as "Commercial," "Residential," or “Roads.” The primary pollutants of concern for the analysis were defined as Total Suspended Solids (TSS), Total Phosphorous (TP), and Total Nitrogen (TN). For each land use, pollutant loads were calculated based on the amount of impervious surfaces. Using the Land Use editor, it was possible to incorporate street sweeping as a BMP by manipulating the frequency of sweeping as well as its efficiency of removing various pollutants. The only land use that was made available for street sweeping was “Roads”. The total length of roads in each subcatchment was measured using GIS software, and the total road area was estimated by multiplying road length in each subcatchment by an average width of 24 feet (Results, Figure 2). The benefit of sweeping commercial parking lots was also explored. The percentage of commercial area that is used for parking was estimated from aerial images, and the required number of passes by a street sweeping machine was estimated for each lot by approximating sweeper paths of 10 feet in width.

In order for the first street sweeping event to remove a meaningful amount of pollutants, the initial buildup of pollutants was calculated. A period of five months was used to form the initial buildup, corresponding to the length of a winter in Minnesota. To calculate the initial buildup, first the water quality volume (WQV) was calculated for each subcatchment, then the maximum pollutant load (PLOAD) for each primary pollutant was calculated using the EPA’s default equation within SWMM. Finally the initial buildup was interpolated from the exponential buildup function within SWMM corresponding to five months (representing a Minnesota winter) of a one-year maximum load attainment. These parameters were calculated as below:

$$VolRunoff(\frac{ac * ft}{yr}) = (P * P_j * R_{vu} * A_u)/12$$

P = precipitation (1.25 in)
P_j = ratio of storms producing runoff (.9)
R_{vu} = Runoff Coefficient (0.9095)
A_u = Area of Impervious (acres)

$$PLOAD_{max}(\frac{lb}{ac * yr}) = \frac{Vol * C_u * 2.72}{A_u}$$

C_u = Event Mean Concentration for Pollutant (TSS=140 mg/L; TP=0.28 mg/L; TN=1.5 mg/L)

$$Initial\ Buildup\left(\frac{lb}{ac}\right) = PLOAD_{max} * (1 - e^\wedge - (150 * 0.015))$$

150 = time (days) of buildup prior to sweeping
0.015 = rate constant for the exponential buildup function meeting a 365-day maximum buildup

SWMM Simulations of Pollutant Loads

Using the SWMM Model of the Crane Lake Watershed, simulations were run for a one-year period for different combinations of treatment practices contained within the watershed: street-sweeping with multiple frequencies and rain gardens of varying size. For each simulation, a single 1.25 inch 24-hour SCS distribution rainfall event occurred on October 15, corresponding with the end of the expected Minnesota street sweeping season. When included in the simulation, street sweeping was initiated on April 1 of the year of the rain event and was performed on a specified regular interval until the day of the rain event. This timeline assumes one rain event of 1.25 inches during the non-Winter season in Minnesota for the sake of simplicity. The same timeline was used in order to differentiate between the effectiveness of different street sweeping frequencies. It allows smaller rain events to occur prior to the simulated event, but assumes that sediment will accumulate on roadways without being washed away by previous events. The pollutant removals from runoff (pounds of TSS, TP, and TN) and runoff volume reduced were recorded for each simulation. The cost of street sweeping in each simulation was estimated using the approach of Kalinosky et al (2012), which is based on the average cost of $19 per curb-mile of street sweeping. Each simulation as a whole was given a cost effectiveness rating which could be compared to all simulations.

When rain gardens were included in the simulations, they were installed for either: All Subcatchments or Residential Subcatchments ("South," "Residential," and "North East" are included in the Residential category because they have more than 50% residential land use). The impact of rain gardens was either 2.5% or 5% of the impervious area within each subcatchment corresponding to the treatment of 50% of all impervious area and 90% of all impervious area, respectively. For the three largest subcatchments, multiple rain gardens were implemented to achieve the listed total land allocation. The differences in washoff quantities for each pollutant between a baseline simulation with no stormwater treatment and the simulation with the rain gardens were recorded. Thus, an estimate of total removal could be obtained. The cost to build and maintain rain gardens used in these simulations was estimated using equations developed by the EPA. These simulations were also given a cost effectiveness rating. In some simulations, rain gardens were combined with street sweeping to explore multiple treatment options in the same subcatchments. For these simulations, total removal is recorded and total cost is calculated to develop an overall cost effectiveness rating for each simulation.

In addition, some BMPs that could not easily be simulated in SWMM were compared using their expected pollutant removal rates and average costs. Those BMPs include dry detention ponds, wet detention ponds, and inline treatment devices. Their potential impact in the Crane Lake Watershed were not simulated in SWMM, but expected removals were calculated based on documented removal rates and the hydrologic characteristics of the Crane Lake Watershed. The SWMM simulation with no street sweeping or rain gardens ("No Treatment") provided a reference for existing pollutant loads and runoff volume from which expected results could be compared with the simulated results of sweeping and rain gardens. For each SWMM simulation and Comparison simulation, several costs were calculated: An "Up-Front Cost" that includes the purchase of a street sweeper and/or construction cost of building a

BMP; an “Operations and Maintenance Cost” that includes fuel, labor, and BMP maintenance costs; and a “10-year Average Cost” that includes the up-front cost for each simulation and 10 years of ongoing operations and maintenance. These cost calculations for each simulation are included in the Appendix. From these calculations, a cost-effectiveness for each simulation allows pollutant removal to be valued between treatment strategies.

An overview of the completed simulations is listed in the table below:

Table 1: Description of the Simulations run for the Crane Lake Watershed. Simulations 1-18 were performed in the SWMM Model, while Simulations A-C were calculated by hand using expected BMP pollutant removal rates and the runoff characteristics within the SWMM model.

Simulation	Description and Location of BMPs	Sweeping Interval (Days)	BMP Area (% of Impervious)
1	No Treatment	-	-
2	Sweeping All Roads	365	-
3	Sweeping All Roads	60	-
4	Sweeping All Roads	30	-
5	Sweeping All Roads	15	-
6	Sweeping All Roads	7	-
7	Sweeping All Roads	3.5	-
8	Sweeping All Roads & Commercial Parking	30	-
9	Sweeping All Roads & Commercial Parking	15	-
10	Sweeping All Roads & Commercial Parking	7	-
11	Rain gardens in All Subcatchments	-	2.5%
12	Rain gardens in All Subcatchments	-	5%
13	Rain gardens in Residential Subcatchments	-	2.5%
14	Rain gardens in Residential Subcatchments	-	5%
15	Rain gardens in All Subcatchments & Sweeping All Roads	30	2.5%
16	Rain gardens in All Subcatchments & Sweeping All Roads	30	5%
17	Rain gardens in All Subcatchments & Sweeping All Roads	7	5%
18	Rain gardens in All Subcatchments & Sweeping All Roads & Commercial Parking	30	5%

A	Dry Detention Pond at Ridgedale	-	2.5%
B	Wet Detention Pond at Ridgedale	-	2.5%
C	Inline Treatment Devices at NE, NW	-	-

Results

Table 2: Pollutant Removal Observed in SWMM Simulations (1-18) and Estimates of Pollutant Removal for Stormwater BMPs in the Crane Lake Watershed (A-C).

Sim.	Description and Location of BMPs	Sweeping Interval (Days)	BMP Area (% of Imperv)	Pollutants Removed Phosphorus (lbs)	Total Solids (lbs)	Nitrogen (lbs)	Runoff Reduced (Gallons)
1	No Treatment	-	-	0	0	0	0
2	Sweeping All Roads	365	-	0.43	253	1.84	0
3	Sweeping All Roads	60	-	1.45	821	6.6	0
4	Sweeping All Roads	30	-	1.85	1010	8.79	0
5	Sweeping All Roads	15	-	2.32	1223	11.49	0
6	Sweeping All Roads	7	-	2.6	1339	13.31	0
7	Sweeping All Roads	3.5	-	2.75	1395	14.33	0
8	Sweeping All Roads & Commercial Parking	30	-	4.78	2534	23.22	0
9	Sweeping All Roads & Commercial Parking	15	-	5.64	2921	28.38	0
10	Sweeping All Roads & Commercial Parking	7	-	6.07	3089	31.22	0
11	Rain gardens in All Subcatchments	-	2.50%	4.01	2009	21.2	2,078,000
12	Rain gardens in All Subcatchments	-	5.00%	7.07	3542	37.35	3,620,000
13	Rain gardens in Residential Subcatchments	-	2.50%	0.6	301	3.22	352,000
14	Rain gardens in Residential Subcatchments	-	5.00%	1.08	545	5.82	631,000
15	Rain gardens in All Subcatchments & Sweeping All Roads	30	2.50%	4.09	2054	21.51	2,078,000
16	Rain gardens in All Subcatchments & Sweeping All Roads	30	5%	7.09	3550	37.4	3,620,000
17	Rain gardens in All Subcatchments & Sweeping All Roads	7	5%	7.15	3585	37.64	3,620,000
18	Rain gardens in All Subcatchments & Sweeping All Roads & Commercial Parking	30	5%	7.43	3745	38.95	3,620,000
A	Dry Detention Pond at Ridgedale	-	2.50%	1.33	2140	11.46	2,980,000
B	Wet Detention Pond at Ridgedale	-	2.50%	3.37	2350	11.46	2,980,000
C	Inline Treatment Devices at NE, NW	-	-	0.01	20	0.13	80,000

Table 3: Estimated Total Up-front Costs, Operations/Maintenance Costs, and 10-year Average Costs of using Street Sweeping and BMPs to Remove Pollutants for Each SWMM Simulation and Non-Simulated BMPs in the Crane Lake Watershed. 10-year Avg Cost assumes up-front costs of purchasing a street sweeper and constructing BMPs and 10 years of expected operating and maintenance costs for each simulation.

Sim.	Description and Location of BMPs	Sweeping Interval (Days)	BMP Area (% of Imperv)	Up-front Cost ($)	Op/Maint Cost ($/year)	10-yr Avg Cost ($/year)
1	No Treatment	-	-	0	0	0
2	Sweeping All Roads	365	-	200,000	380	20,380
3	Sweeping All Roads	60	-	200,000	1,520	21,520
4	Sweeping All Roads	30	-	200,000	2,660	22,660
5	Sweeping All Roads	15	-	200,000	4,940	24,940
6	Sweeping All Roads	7	-	200,000	9,880	29,880
7	Sweeping All Roads	3.5	-	200,000	19,760	39,760
8	Sweeping All Roads & Commercial Parking	30	-	200,000	11,305	31,305
9	Sweeping All Roads & Commercial Parking	15	-	200,000	20,995	40,995
10	Sweeping All Roads & Commercial Parking	7	-	200,000	41,990	61,990
11	Rain gardens in All Subcatchments	-	2.5%	1,783,088	89,154	267,463
12	Rain gardens in All Subcatchments	-	5%	3,190,747	159,537	478,612
13	Rain gardens in Residential Subcatchments	-	2.5%	127,487	6,374	19,123
14	Rain gardens in Residential Subcatchments	-	5%	255,034	12,752	38,255
15	Rain gardens in All Subcatchments & Sweeping All Roads	30	2.5%	1,983,088	91,814	290,123
16	Rain gardens in All Subcatchments & Sweeping All Roads	30	5%	3,390,747	162,197	501,272
17	Rain gardens in All Subcatchments & Sweeping All Roads	7	5%	3,390,747	169,417	508,492
18	Rain gardens in All Subcatchments & Sweeping All Roads & Commercial Parking	30	5%	3,390,747	170,842	509,917
A	Dry Detention Pond at Ridgedale	-	2.5%	242,482	2,425	26,673
B	Wet Detention Pond at Ridgedale	-	2.5%	234,354	2,344	25,779
C	Inline Treatment Devices at NE, NW	-	-	5,600	280	840

Table 4: Comparative Cost Effectiveness of Removing Pollutants for SWMM Simulation and Non-Simulated BMPs in the Crane Lake Watershed. The cost per pound of pollutant or gallon of runoff is based on the 10-year Average Cost shown in Table 3.

Sim.	Description and Location of BMPs	Sweeping Interval (Days)	BMP Area (% of Imperv)	Pollutants Phosphorus ($/lb)	Pollutants Total Solids ($/lb)	Pollutants Nitrogen ($/lb)	Runoff Reduced ($/gal)
1	No Treatment	-	-	0	0	0	0
2	Sweeping All Roads	365	-	47,395	80.45	11,076	0
3	Sweeping All Roads	60	-	14,841	26.22	3,261	0
4	Sweeping All Roads	30	-	12,249	22.45	2,578	0
5	Sweeping All Roads	15	-	10,750	20.40	2,171	0
6	Sweeping All Roads	7	-	11,492	22.32	2,245	0
7	Sweeping All Roads	3.5	-	14,458	28.49	2,775	0
8	Sweeping All Roads & Commercial Parking	30	-	6,549	12.35	1,348	0
9	Sweeping All Roads & Commercial Parking	15	-	7,269	14.03	1,445	0
10	Sweeping All Roads & Commercial Parking	7	-	10,213	20.07	1,986	0
11	Rain gardens in All Subcatchments	-	2.5%	66,699	133.15	12,616	0.13
12	Rain gardens in All Subcatchments	-	5%	67,696	135.13	12,814	0.13
13	Rain gardens in Residential Subcatchments	-	2.5%	31,872	63.53	5,939	0.05
14	Rain gardens in Residential Subcatchments	-	5%	35,421	70.17	6,573	0.06
15	Rain gardens in All Subcatchments & Sweeping All Roads	30	2.5%	70,935	141.25	13,488	0.14
16	Rain gardens in All Subcatchments & Sweeping All Roads	30	5%	70,701	141.19	13,403	0.14
17	Rain gardens in All Subcatchments & Sweeping All Roads	7	5%	71,118	141.85	13,509	0.14
18	Rain gardens in All Subcatchments & Sweeping All Roads & Comm Parking	30	5%	68,629	136.16	13,092	0.14
A	Dry Detention Pond at Ridgedale	-	2.5%	20,055	12.46	2,327	0.01
B	Wet Detention Pond at Ridgedale	-	2.5%	7,650	10.97	2,249	0.01
C	Inline Treatment Devices at NE, NW	-	-	84,000	42.90	6,462	0.01

Figure 1: Crane Lake Subcatchments

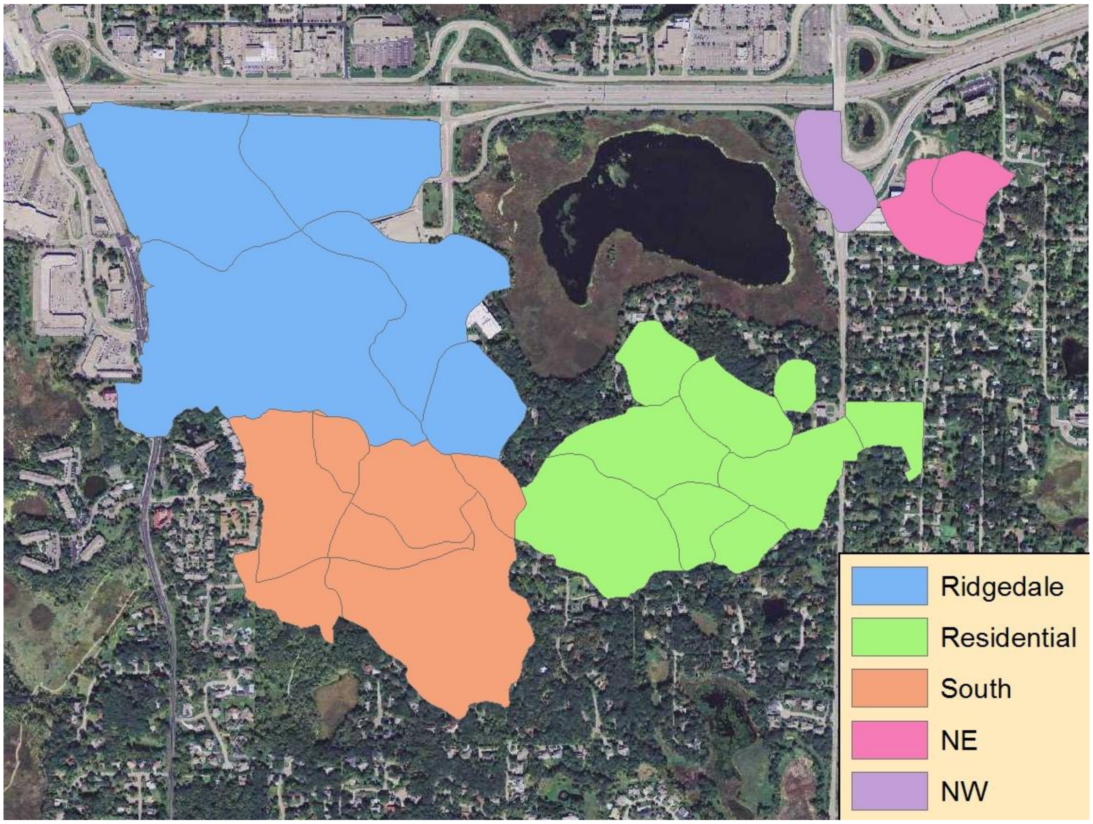
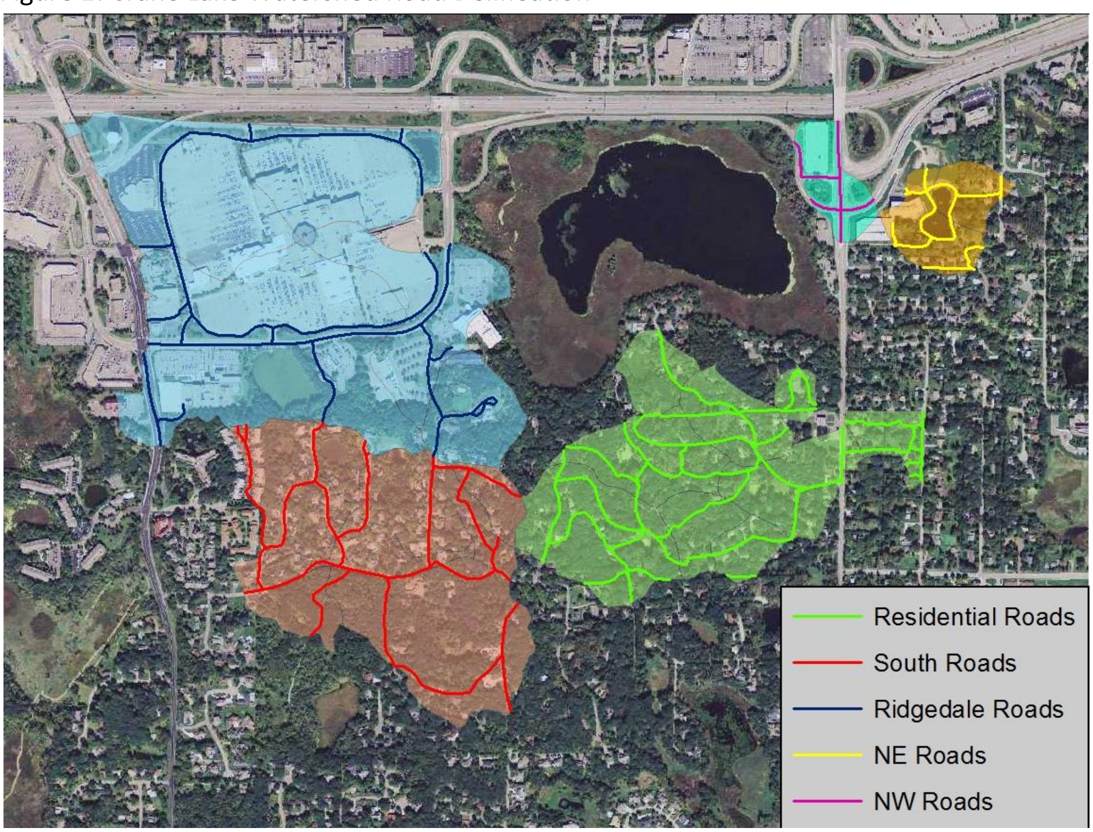


Figure 2: Crane Lake Watershed Road Delineation



Discussion

The results of the SWMM simulations helped determine approximately how much TSS, phosphorous, and nitrogen were removed from street sweeping and installing rain gardens. The amount of each pollutant removed increased steadily with an increase in sweeping frequency, but the increase in removal with respect to frequency was not linear. As sweeping is performed more times prior to the rain event, the average removal of pollutants per sweep decreases. While the rate of return of sweeping decreases, the operating cost of sweeping increases linearly with sweeping frequency. On the basis of cost, the highest return of pollutant removal occurs when sweeping is performed bimonthly (every 15 days). When the swept area expanded to include commercial parking, the amount of removal increased dramatically (between 230% and 250% increase for equivalent sweeping frequencies). Unfortunately, sweeping the entire commercial area within the Crane Lake Watershed is not an insignificant operation; the area that can be sweeped at Ridgedale alone is over three times the curb-mileage of the entire watershed, estimated at 65 curb-miles. While this would take at least a full day for one sweeper, the cost effectiveness of this approach is greater than that of sweeping the streets only. In fact, sweeping all roads and all commercial parking on a monthly routine is the most cost-effective pollutant removal strategy of all simulations run in SWMM.

Rain gardens treating 90% of the impervious area remove more phosphorus, total solids, and nitrogen than any extent of street sweeping, but their relatively higher cost makes them a less cost-effective strategy than sweeping. Rain gardens treating 50% of the impervious area remove more pollutants than standard street sweeping, but not as much as sweeping roads and commercial parking areas. Rain gardens treating 50% of impervious areas are more cost effective than rain gardens treating 90%. In addition, rain gardens implemented only in residential areas are more cost-effective than rain gardens implemented in both residential and commercial areas. The amount of impervious area in a commercial area such as Ridgedale is enormous compared to residential areas, and rain gardens in commercial areas must be very large to account for that runoff. While this cost-comparison favors only residential rain gardens, adding rain gardens in commercial areas increases pollutant removal by 650%. This comparison indicates the importance of treating the runoff from Ridgedale, but it also indicates the high cost that Ridgedale treatment necessitates. Rain gardens could be quite elegant solutions in the heavily-forested residential areas south of Crane Lake assuming the residents would be willing to have the devices occupy lawn space. Unfortunately, if they are relied on to treat all of the runoff, their relative high cost of construction and required maintenance make them a much less viable economic option.

Not surprisingly, combining street sweeping with the implementation of rain gardens increases pollutant removal over either option alone. Simulations 15-18 reveal the data for combining treatment strategies. These simulations provide the most benefit, but the cost-effectiveness for each combined simulation is very low. As sweeping and rain gardens are linked in each simulation, the effect of each individual BMP is decreased. That is, the cumulative effect is less than the sum of the individual components. Nevertheless, the combination (“treatment train”) of sweeping and rain gardens provides a level of removal not achievable by frequent sweeping or widespread rain gardens. Removing pollutants at multiple stages in the watershed can be very effective.

Although detention ponds and inline ditch treatment devices were not run in the SWMM model, their expected impacts and relevant costs were explored based on the SWMM model parameters. Since detention ponds require a larger area, an area in the eastern section of the Ridgedale subcatchment would be one of the best places to put a pond. Considering the high cost of building detention ponds, addressing runoff concerns from Ridgedale would be the best use of those funds. Should the City of Minnetonka be able to reduce the amount of parking at Ridgedale, a detention pond would be a very reasonable way to treat the runoff. A prohibitively large number of rain gardens would be needed to treat the same amount of runoff that would be satisfied by one wet detention pond. Since phosphorus is the limiting nutrient in lakes and streams, a wet detention pond would be preferred near the mall since it removes phosphorus at a greater rate than dry ponds. Detention ponds (dry or wet) do not compete well with street sweeping in terms of up-front costs in this analysis of the Crane Lake Watershed, but if a 10-year life cycle is considered they may be a less demanding solution. Their minimal maintenance makes them competitive with street sweeping in the long run.

Inline treatment was also less cost-effective than sweeping, and those devices have limited applicability in the watershed outside of the Hopkins Crossroad region east of Crane Lake. Since residential streets press right against private property, they are not realistic solutions in those areas. The inline treatment devices are likely not large enough to handle runoff from the vast imperviousness of the Ridgedale campus.

Based on the cost effectiveness of each combination of BMPs reported in Table 3, we recommend increasing the frequency of street sweeping. The current practice of sweeping once in the spring seems to be a missed opportunity. At an average cost of around $20 per curb-mile, the cost to sweep every road in the Crane Lake Watershed is less than $400. By sweeping every month or even twice a month, a much greater amount of pollutants can be removed. Knowing that the City of Minnetonka already has a high-efficiency vacuum street sweeper, sweeping more frequently is the most cost-effective strategy for removing particulate phosphorus, nitrogen, and total sediments. If the City must purchase a new high-efficiency sweeper, the cost to purchase a typical machine costs between $150,000 and $250,000 (Finley, 1996; Minton et al, 1998), or slightly less than the amount it takes to construct a detention pond to treat the runoff from the Ridgedale campus. The average cost used in this analysis includes equipment maintenance, fuel, and wages for operators, but it does not include equipment purchase cost. With an expected life of 8-10 years, purchasing new equipment would add approximately $20,000 per year to the total cost of street sweeping. This added expense would reduce the attractiveness of street sweeping, making the construction of a wet detention pond a more cost-effective option.

For the Crane Lake Watershed, which consistently meets water quality goals for a Level III water body, the City of Minnetonka may not desire to implement rain gardens or detention ponds to further reduce pollutant loads. Increasing the frequency of street sweeping to a monthly or bimonthly interval would remove enough sediment, phosphorus, and nitrogen to ensure that Crane Lake doesn't degrade in the near future. The greatest threat to Crane Lake's water quality is the runoff pollutants coming from the Ridgedale campus. We explored the cost of sweeping the parking lots, which would be the equivalent of approximately 65 curb-miles. This would promise to be an all-day task for one machine (at an estimated cost of approximately $1200 per sweep), but would reduce an enormous amount of particles that would go straight into Crane Lake. While sweeping the Ridgedale campus is an option, we believe sticking with an effective wet detention pond is likely the most practical solution to handle Ridgedale runoff.

We endorse street sweeping due to its cost effectiveness and the current satisfactory condition of Crane Lake's water quality. However, the overall effectiveness of sweeping is less than that of rain gardens or detention ponds. Street sweeping does not reduce the total volume runoff or the peak discharge of a rain event. Traditional end-of-pipe BMPs have runoff reduction benefits (see Table 2) that make their use more financially competitive. Detention ponds, for example, reduce runoff at the cost of one cent per gallon. For this reason, a wet detention pond on the Ridgedale campus is highly recommended.

If the City of Minnetonka desires to dramatically improve the water quality of Crane Lake, we strongly recommend implementing additional BMPs that remove finer particles and dissolved pollutants. Dissolved phosphorus and nitrogen account for almost half of all stormwater pollutants, and there are relatively new chemical and biological treatments that have proven effective at removing close to 80% of all pollutants (Erickson, 2013). By including vegetation in rain gardens and including a small percentage of compost in infiltration soil, the amount of dissolved phosphorus, nitrogen, and metals removed can significantly increase (Lucas & Greenway, 2011; Morgan et al, 2011). Another option that could be explored is enhancing filtration media with 5% iron filings, which have been shown to remove more than 80% of influent phosphorus (Erickson et al, 2012). Additional research should focus on these technologies to reduce the pollutants originating from Ridgedale, especially phosphorus.

Appendix

Table 1: Subcatchment Percent Slope Calculations

Subcatchment	% Slope	% Slope	Average % Slope
Ridgedale	1.24	0.62	0.93
South	1.24	1.77	1.51
Residential	1.12	2.68	1.9
North East	1.1	1.53	1.32
North West	2.27	1.12	1.7
	(based on longest flow path)	(based on highest and lowest elevations)	(What was inputted into SWMM)

Table 2: Street Sweeping Cost Calculations for Each Simulation

Sim.	Description and Location of BMPs	Sweeping Interval (Days)	BMP Area (% of Imperv)	**Sweeping Capital ($/Sweeper)**	**Street Sweeping Operation**			
					Curb-miles	$/mile	# of sweeps	**Operation Cost**
1	No Treatment	-	-	**0**	-	-	-	**0**
2	Sweeping All Roads	365	-	**200,000**	20	19	1	**380**
3	Sweeping All Roads	60	-	**200,000**	20	19	4	**1,520**
4	Sweeping All Roads	30	-	**200,000**	20	19	7	**2,660**
5	Sweeping All Roads	15	-	**200,000**	20	19	13	**4,940**
6	Sweeping All Roads	7	-	**200,000**	20	19	26	**9,880**
7	Sweeping All Roads	3.5	-	**200,000**	20	19	52	**19,760**
8	Sweeping All Roads & Commercial Parking	30	-	**200,000**	85	19	7	**11,305**
9	Sweeping All Roads & Commercial Parking	15	-	**200,000**	85	19	13	**20,995**
10	Sweeping All Roads & Commercial Parking	7	-	**200,000**	85	19	26	**41,990**
11	Rain gardens in All Subcatchments	-	2.50%	**-**	-	-	-	**0**
12	Rain gardens in All Subcatchments	-	5.00%	**-**	-	-	-	**0**
13	Rain gardens in Residential Subcatchments	-	2.50%	**-**	-	-	-	**0**
14	Rain gardens in Residential Subcatchments	-	5.00%	**-**	-	-	-	**0**
15	Rain gardens in All Subcatchments & Sweeping All Roads	30	2.50%	**200,000**	20	19	7	**2,660**
16	Rain gardens in All Subcatchments & Sweeping All Roads	30	5%	**200,000**	20	19	7	**2,660**
17	Rain gardens in All Subcatchments & Sweeping All Roads	7	5%	**200,000**	20	19	26	**9,880**
18	Rain gardens in All Subcatchments & Sweeping All Roads & Commercial Parking	30	5%	**200,000**	85	19	7	**11,305**
A	Dry Detention Pond at Ridgedale	-	2.50%	**-**	-	-	-	**0**
B	Wet Detention Pond at Ridgedale	-	2.50%	**-**	-	-	-	**0**
C	Inline Treatment Devices at NE, NW	-	-	**-**	-	-	-	**0**

Table 3: BMP Cost Calculations for Each Simulation (BMP costs were calculated from the volume-based equations listed under the description for each BMP in the Methods Section)

Sim.	Description and Location of BMPs	Sweeping Interval (Days)	BMP Area (% of Imperv)	BMP Construction Costs: BMP Volume (ft3)	BMP Construction Costs: Inline (# of Devices)	BMP Construction Costs: **Construction Cost ($)**	**BMP Maintenance ($/year)**
1	No Treatment	-	-	-	-	**0**	**0**
2	Sweeping All Roads	365	-	-	-	**0**	**0**
3	Sweeping All Roads	60	-	-	-	**0**	**0**
4	Sweeping All Roads	30	-	-	-	**0**	**0**
5	Sweeping All Roads	15	-	-	-	**0**	**0**
6	Sweeping All Roads	7	-	-	-	**0**	**0**
7	Sweeping All Roads	3.5	-	-	-	**0**	**0**
8	Sweeping All Roads & Commercial Parking	30	-	-	-	**0**	**0**
9	Sweeping All Roads & Commercial Parking	15	-	-	-	**0**	**0**
10	Sweeping All Roads & Commercial Parking	7	-	-	-	**0**	**0**
11	Rain gardens in All Subcatchments	-	2.5%	276,868	-	**1,783,088**	**89,154**
12	Rain gardens in All Subcatchments	-	5%	498,362	-	**3,190,747**	**159,537**
13	Rain gardens in Residential Subcatchments	-	2.5%	19,275	-	**127,487**	**6,374**
14	Rain gardens in Residential Subcatchments	-	5%	38,830	-	**255,034**	**12,752**
15	Rain gardens in All Subcatchments & Sweeping All Roads	30	2.5%	276,868	-	**1,783,088**	**89,154**
16	Rain gardens in All Subcatchments & Sweeping All Roads	30	5%	498,362	-	**3,190,747**	**159,537**
17	Rain gardens in All Subcatchments & Sweeping All Roads	7	5%	498,362	-	**3,190,747**	**159,537**
18	Rain gardens in All Subcatchments & Sweeping All Roads & Commercial Parking	30	5%	498,362	-	**3,190,747**	**159,537**
A	Dry Detention Pond at Ridgedale	-	2.5%	442,988	-	**242,482**	**2,425**
B	Wet Detention Pond at Ridgedale	-	2.5%	442,988	-	**234,354**	**2,344**
C	Inline Treatment Devices at NE, NW	-	-	-	8	**5,600**	**280**

References

- *SFTP Site*. N.d. Resilient Communities Project. City of Minnetonka.
- *Maintaining Detention Ponds*. N.d. SEMSWA Offices, Englewood, Colorado.
- "Dry Detention Ponds." *EPA*. N.p., 24 May 2006. Web. <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse>.
    - Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for Chesapeake Research Consortium. Edgewater, MD. Center for Watershed Protection. Ellicott City, MD.
- "Wet Ponds." *EPA - Stormwater Menu of BMPs*. N.p., 21 Aug. 2012. Web. <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results>.
- King County Department of Transportation. 2011. *In-Line Ditch Stormwater Treatment BMP Program Final Report.* Stormwater Management Implementation Grant Program.
- Selbig WR, Bannerman RT. 2007. *Evaluation of street sweeping as a stormwater-quality-management tool in three residential basins in madison, WI*. US Geological Survey: Report nr 2007-5156.
- Rochfort Q, Exall K, P'ng J, Shi V, Stevanovic-Briatico V, Kok S, Marsalek J. 2009. *Street sweeping as a method of source control for urban stormwater pollution.* Water Qual Res J Can: 44(1):48-58.
- Waschbusch RJ, Selbig WR, Bannerman RT. 1999. *Sources of phosphorus in stormwater and street dirt from two urban residential basins in Madison, Wisconsin, 1994-95*. Madison, WI: U.S. Dept. of the Interior, U.S. Geological Survey ; Branch of Information Services [distributor]: Report nr WRi no.99-4021.
- Minton GR, Lief B, Sutherland RC. 1998. *High efficiency sweeping or clean a street, save a salmon!* Stormwater Treatment Northwest Newsletter: 4(4).
- Tetra Tech in association with Pacific Water Resources, Inc. 2001. *Quantifying the impact of catch basin cleaning and street sweeping on storm water quality for a great lakes tributary: A pilot study.* Upper Grand River Watershed Alliance: Report nr LA:P\1451001\01.
- Barr Engineering Co. 2012. *2011 Surface Water Quality Study for the City of Minnetonka.*
- "Bioretention." *LID Urban Design Tools - Bioretention*. Low Impact Development Center, Inc., 2007. Web. <http://www.lid-stormwater.net/bio_costs.htm>.

- Finley, S. 1996. Sweeping Works. *Pavement Maintenance and Reconstruction*. October/November. pp. 16 and 17.
- Kalinosky, Paula, Baker, Lawrence, Hobbie, Sarah, & Chris Buyarski. 2012. *Quantifying Nutrient Load Recovery through Targeted, Intensive Street Sweeping.* University of Minnesota: Water Resources Conference, October 17, 2012.
- Erickson, A.J., Gulliver, J.S., and P.T. Weiss. 2012. *Capturing Dissolved Phosphorus with Enhanced Sand Filtration*. Water Research (In Review).
- Erickson, Andy. 2013. *Advanced Stormwater Treatment: Dissolved Pollutants*. University of Minnesota, Civil Engineering Department: Class Presentation, April 22, 2013.
- Lucas, W.C. and Greenway, M. 2011. *Phosphorus Retention by Bioretention Mesocosms Using Media Formulated for Phosphorus Sorption: Response to Accelerated Loads*. Journal of Irrigation and Drainage Engineering. ASCE, 137(3): 144-153.
- Morgan, J.G., Paus, K.A., Hozalski, R.M., & J.S. Gulliver. 2011. *Sorption and Release of Dissolved Pollutants Via Bioretention Media*. Project Report 559, St. Anthony Falls Laboratory, University of Minnesota, Minneapolis, MN.