Lake Waconia: Feasibility of TSS and TP Reduction Practices

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Prepared on Behalf of

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CARVER COUNTY

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**Final Report by Chloe Winterhalter, Jiaqi You, James Bolton,
Erol Gudul, and Ashley Keske**

Executive Summary

At the request of Carver County, the University of Minnesota Urban Hydrology class was tasked with determining appropriate locations to install rainwater runoff treatment practices. The area of provided by Carver County was the southern half of the Lake Waconia and its surrounding watershed.

Phosphorus loading was the primary concern addressed in this study. Lake Waconia, though not impaired, has experienced an increasing level of phosphorus loading. This is partly due to stormwater runoff from urban sources, which includes sources from industrial and residential land uses. After a storm event, water collects on impervious surfaces and washes into the storm sewer system, carrying sediment and dissolved pollutants into the lake.

We studied stormwater runoff quality using P8 Urban Catchment Model, and GIS data we were provided by Carver County was used to determine the best locations for stormwater treatment practices. We first used GIS data to find locations of low elevations, where stormwater would flow, and measured the flow area, or subwatersheds. The primary land use provided in the GIS data was used to determine the physical properties of each subwatershed, such as impervious land percentage and curve number. We then modeled each subwatershed in P8, and using precipitation and soil composition data provided by the model, measured the amount of phosphorus removed using rain gardens, ponds, and infiltration basins.

The total cost for this design would be as follows: a construction cost of $228,157 and an additional yearly maintenance cost of $46,400 after the initial five year period. This cost is for 80 residential rain gardens, an infiltration basin, and the addition of iron-enhanced sand filters around the existing wet pond.

We recommend using a combination of rain gardens, infiltration basins, and iron enhanced sand filters to reduce the phosphorus load entering Lake Waconia. The rain gardens are recommended for residential land uses, as these provide an aesthetic appeal and may be installed in residents' properties. Infiltration basins are recommended in industrial areas, where they may be installed under or around parking lots to increase infiltration in areas with a high percentage of impermeable surfaces. An iron enhanced filter is recommended to be installed around an existing stormwater detention pond to increase phosphorus removal before water is routed into existing stormwater sewers.

Introduction

Lake Waconia, located in Carver County, Minnesota, has reached phosphorous levels near the state allowable limit. This is due to stormwater runoff from both agricultural and urban sources. Land to the North of the lake has been used agriculturally, primarily for crop farming, while land to the South of the lake has been built upon to make the City of Waconia (see Figure 1). To reduce phosphorous runoff, Carver County has begun a study in the City of Waconia. This study will determine possible locations to implement stormwater treatment practices to reduce the Total Phosphorous (TP) entering the lake.

Carver County is working with the University of Minnesota to develop a plan to locate and specify infiltration or treatment practices, and estimate the TP removed from the water by each practice. This will be done by modeling the urban regions of the Lake Waconia watershed in the P8 Urban Catchment Model, a modeling software produced by William Walker Jr., PhD and Jeffrey Walker, PhD (Version 3.5; Walker, 2015). Treatment practices will be added to the current stormwater system, and a simulated storm will pass through the system as the program estimates the TP removed from the runoff produced from the storm. This removal will be compared to that without the treatment practices, to estimate the added TP removal of the practices.

Figure 1: Lake Waconia, with the City of Waconia to the South. Farmland can be seen to the North and East of the lake. *Image source: ArcMap*

Methods

Locations for treatment practices were first determined using GIS. Data was provided by Carver County of the Lake Waconia watershed, which included current stormwater manholes and pipe locations, topography and elevation data, and land use types and locations. Areas of lower elevation that were near a manhole were determined to be the best spots for treatment practices. This is because surface water was already routed to those areas, and if the treatment practices were to overflow, they would flow directly to existing stormwater infrastructure. The treatment practices would be installed upstream of the manholes, so surface runoff would first come into contact with them before flowing into the storm pipes and be directed into Lake Waconia.

Figure 2: Example image depicting information used to select treatment practice locations. The stormwater network is marked in black; contours are marked in red. The watershed, which drains towards Lake Waconia, is marked in blue. *Image source: ArcMap*

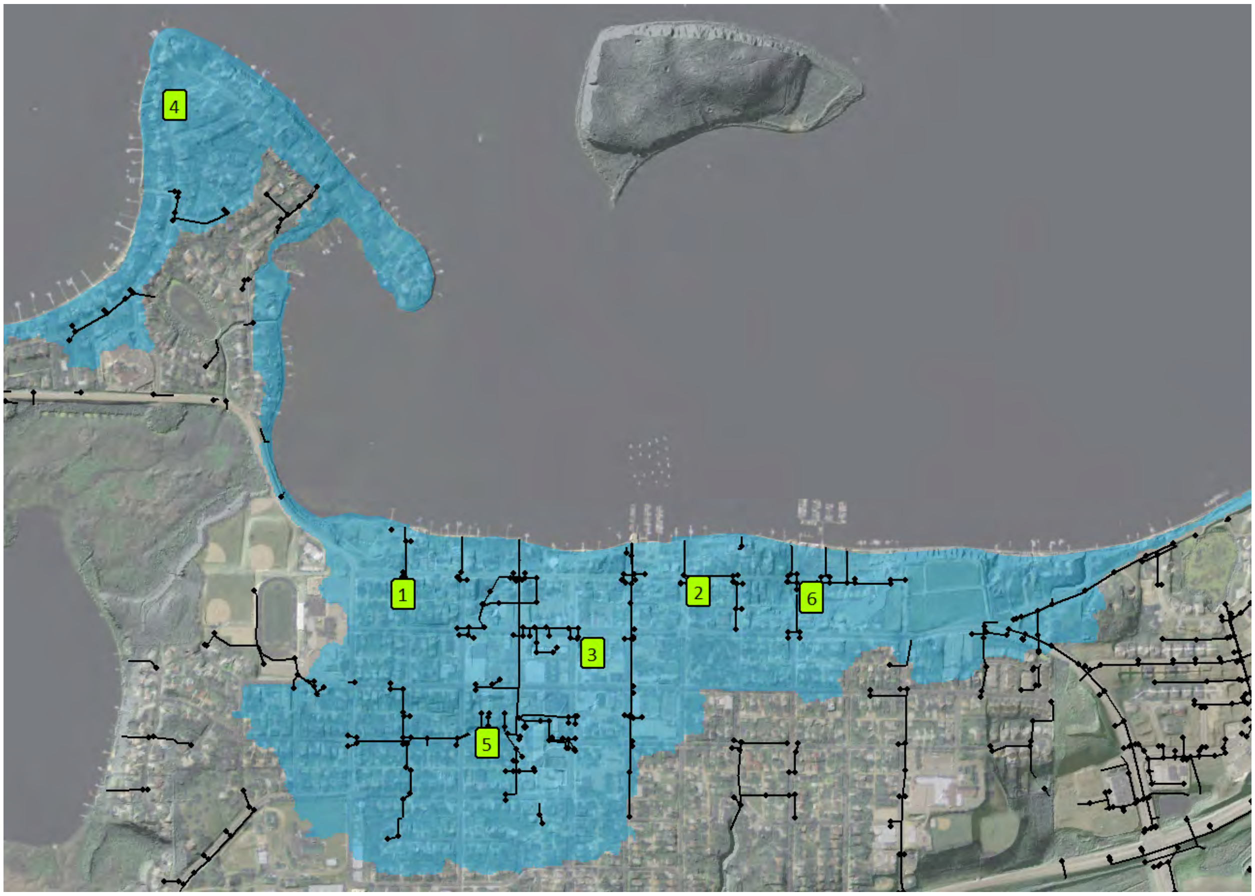

Figure 3: Estimated locations for treatment practices are marked numerically. *Image source: ArcMap*

The drainage areas of the treatment practice locations were delineated using GIS elevation data and totaled 122.6 acres. The total urban watershed was measured to be 297.8 acres, meaning the total drainage areas were found to compose 41.2% of the total urban watershed. The treatment areas were not able to account for the entire watershed because of the steep elevation changes of land, particularly close to the lakeshore. These areas are not treated in this study, and further research would be required to locate a treatment practice in those areas. The treatment locations determined were considered to have the greatest impact on the water quality of water entering Lake Waconia. The primary land use of each subwatershed studied may be found in *Table 1*.

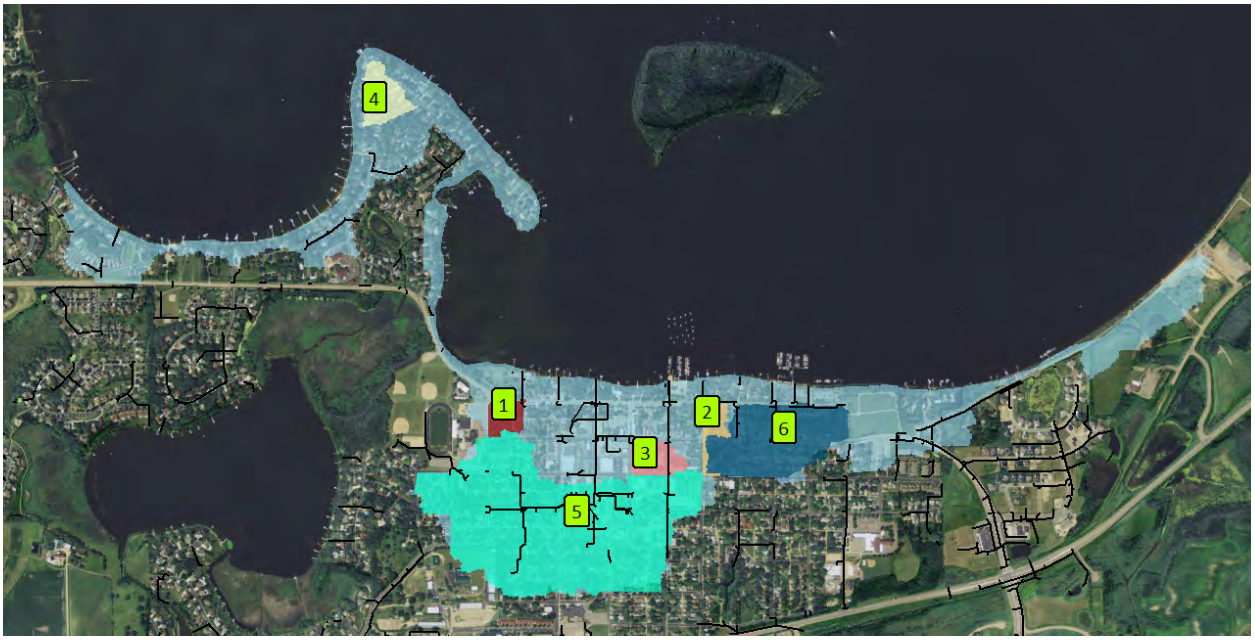

Figure 4: The area of the Lake Waconia Urban Watershed. The total urban watershed is marked in light blue. Stormwater gravity mains are marked in black. Approximate site locations are marked numerically with their appropriate subwatersheds marked in other solid colors. *Image source: ArcMap*

Site locations were estimated in ArcMap. Using a one meter by one meter digital elevation model, obtained from the Minnesota DNR website, subwatersheds pertaining to each site location were delineated. These drainage areas were determined using spatial analyst tools within the ArcGIS program. The general procedure followed the following sequence:

LiDAR DEM → Fill → Flow Direction → Flow Accumulation → Pour Points → Subwatershed Polygon

The determined areas were inspected for accuracy by observing the topographic contour lines and were found to be accurate estimations. They were highly congruent with the outer extents of the watershed as it was defined from the data provided to the University of Minnesota by Carver County.

The Lake Waconia watershed was then modeled in P8 by altering the default file provided by the program. A subwatershed was added to the model for each treatment practice. Each of these subwatersheds were assigned data according to the physical characteristics of the watershed such as area, curve number (Singh, 1982), and the directly connected impervious fraction (EPA, 2014). The values for each subwatershed are given in the *Table 1*. The individual subwatersheds were routed to Lake Waconia in the model, meaning that one subwatershed was not routed into the next and that the devices acted independently from those in different subwatersheds. This is similar to the physical subwatersheds, which are located near each other, but do not drain into one another. Each treatment practice was created using known information about them, such as infiltration rate and size. The device specs for each subwatershed are listed in *Table 2*. In the model, Lake Waconia was modeled as a pipe where all runoff from each subwatershed was concentrated, with a time of concentration of zero hours. Standing water, such as ponds, was assumed to be included in the impervious area of each subwatershed, and the percentage impervious areas (IA) were estimated using the average conditions that most applications use: 38% IA for residential area and 85% IA for commercial area (Singh, 1982). The percentage impervious areas directly connect to the storm sewer system were then calculated based on the IA of each subwatershed using the equation for commercial and medium density residential land uses (EPA, 2014). The program was run to gather both initial and final data, which included pounds of total phosphorous (TP) per year and total suspended solids (TSS) delivered to Lake Waconia each year. These values could be compared to determine how much TP was removed by each practice.

Table 1: Subwatershed Data Modeled in P8

Subwatershed Data						
Subwatershed Number	**Primary Land Use**	**Area (acres)**	**Curve Number**	**Soil Type**	**Directly Connected Impervious (%)**	**Device Modeled**
1	Residential	3.173	75	B	23	Rain Garden
2	Residential	2.742	75	B	23	Rain Garden
3	Industrial	4.713	94	C	78	Infiltration basin
4	Residential	5.981	83	C	23	Rain Garden
5	Commercial / Industrial / Residential	82.937	83	C	37	Existing Wet Pond (P8) Iron-enhanced filter
6	Residential	23.083	75	B	21	Rain Garden
Baseline	-	297.79	84	B/C	28	-

Table 2: P8 Parameters Used to Model Subwatershed Practices

P8 Parameters						
Subwatershed Number	**1**	**2**	**3**	**4**	**5**	**6**
Device Modeled	Rain Garden	Rain Garden	Infiltration basin	Rain Garden	Existing Wet Pond	Rain Garden
Bottom elevation (ft)	0	0	0	0	0	0
Total Bottom area (ac)	0.023	0.023	0.092	0.092	0.21	0.23
Permanent pool area (ac)	0.023	0.023	0.092	0.092	0.21	0.23
Permanent pool volume (ac-ft)	0.046	0.046	0.184	0.184	1.26	0.46
Flood pool area (ac)	-	-	-	-	0.21	-
Flood pool volume (ac-ft)	-	-	-	-	1.68	-
Void volume (%)	40	40	40	40	-	40
Infiltration rate (in/hr)	0.3	0.3	0.2	0.2	-	0.3

Stormwater treatment practices were unique to each subwatershed. The efficiency of each practice was compared in P8, and the most cost efficient practice was then determined for each area. Treatment practices including rain gardens, infiltration basins, wet ponds, and iron-enhanced sand filters were analyzed in P8. All infiltrated water was assumed to leave the watershed without entering Lake Waconia, and the infiltration rate of each infiltration device was determined by the hydrologic soil group. After modeling the treatment practices in P8, the total annual cost of TP removal was calculated per pound of phosphorous. This was done by determining the cost of installation of the treatment practice and comparing it to the TP removal efficiency to find the most cost effective TP removal practice.

Wet ponds improve stormwater quality by settling suspended particles. Suspended particles are a source of TP, making wet ponds an efficient removal practice by allowing suspended particles to settle (EPA, 2009). To model wet ponds in P8, the size and depth of the pond was estimated and entered into the wet pond modeling option. A wet pond currently exists in subwatershed 5.

Rain Gardens provide both infiltration and filtering of stormwater. As water enters the garden, plants growing in the garden and engineered soil remove phosphorous and filter suspended solids. Iron-enhanced rain gardens would more efficiently remove phosphorous, because as plants age and the root systems begin to die, the plants themselves may produce phosphorous (Gulliver, 2016). An iron-enhanced rain garden continues to remove phosphorous after the plants have died, though annual maintenance to the garden could prevent the addition of phosphorous. Therefore, annual maintenance is necessary to remove old or dying plants and introduce healthy, young plants. The cost of installing a 400 ft^2 rain garden is approximately $1,800 (LID Stormwater Design, 2016). The yearly maintenance costs in addition to this would be about $1,000 per year for the first two years (Gulliver, 2016). This is due to the possible need to replace plants until deep roots are established. With deep roots, the plants are hardier and can withstand extreme wet or dry conditions. After the first two years, the maintenance costs would be reduced to approximately $500 per year (Gulliver, 2016).

Iron enhanced sand filters remove phosphorus by adsorbing phosphorus to the iron particles (Erickson, 2012). Iron enhanced sand filters cannot be modeled in P8, so hand calculations were performed to determine the amount of phosphorus removed from the stormwater. The existing pond in the City of Waconia was modeled as a wet pond in P8 to calculate the current phosphorus levels. An iron enhanced filter may be installed on the perimeter of the pond. To determine the amount of TP an iron enhanced filter may remove, the total quantity of phosphorus was determined by multiplying the yearly TP removal by the percent removal. Iron enhanced filters may be assumed to remove 70% of dissolved phosphorus content when properly implemented in the field (Gulliver, 2012). It is recommended that iron enhanced sand filters contain between 5 to 8 percent iron filings (by weight). At this time, (as this is a new treatment practice) it is difficult to determine the exact cost of installation and operation of this treatment practice.

Soils were classified into hydrologic soil groups. This hydrologic soil group indicated the rate of infiltration observed for bare soil after prolonged wetting (Wetland Studies 2012). The soil groups initially presented concern as to the ability of the soil in the city to infiltrate water quickly (much of the city is indicated to have Type C soil types). However, further inspection of the Type C infiltrating layers, predominantly the KB regions in the following image, still suggested that infiltration occurs at a reasonable rate per the NRCS Custom Soil Resource Report for Carver County, Minnesota. The estimate from this report suggests that this soil (Kilkenny-Lester loams with two to six percent slopes), in its most limiting layer, has a “moderately high” capacity to infiltrate (0.20 to 0.60 in/hr hydraulic conductivity K_{sat}). The appropriate table from this report is located in the appendix. While this soil is listed as type C or D in the report, and it comprises a significant portion of the City of Waconia’s soil, this does not appear to be cause for concern. Based on the soil type for each subwatershed, the infiltration rates were determined according to the criteria of design infiltration rates of bioretention from the Minnesota Stormwater Manual (MSSC, 2005; *Table A3*).

Custom Soil Resource Report
Map—Hydrologic Soil Group (HSG)

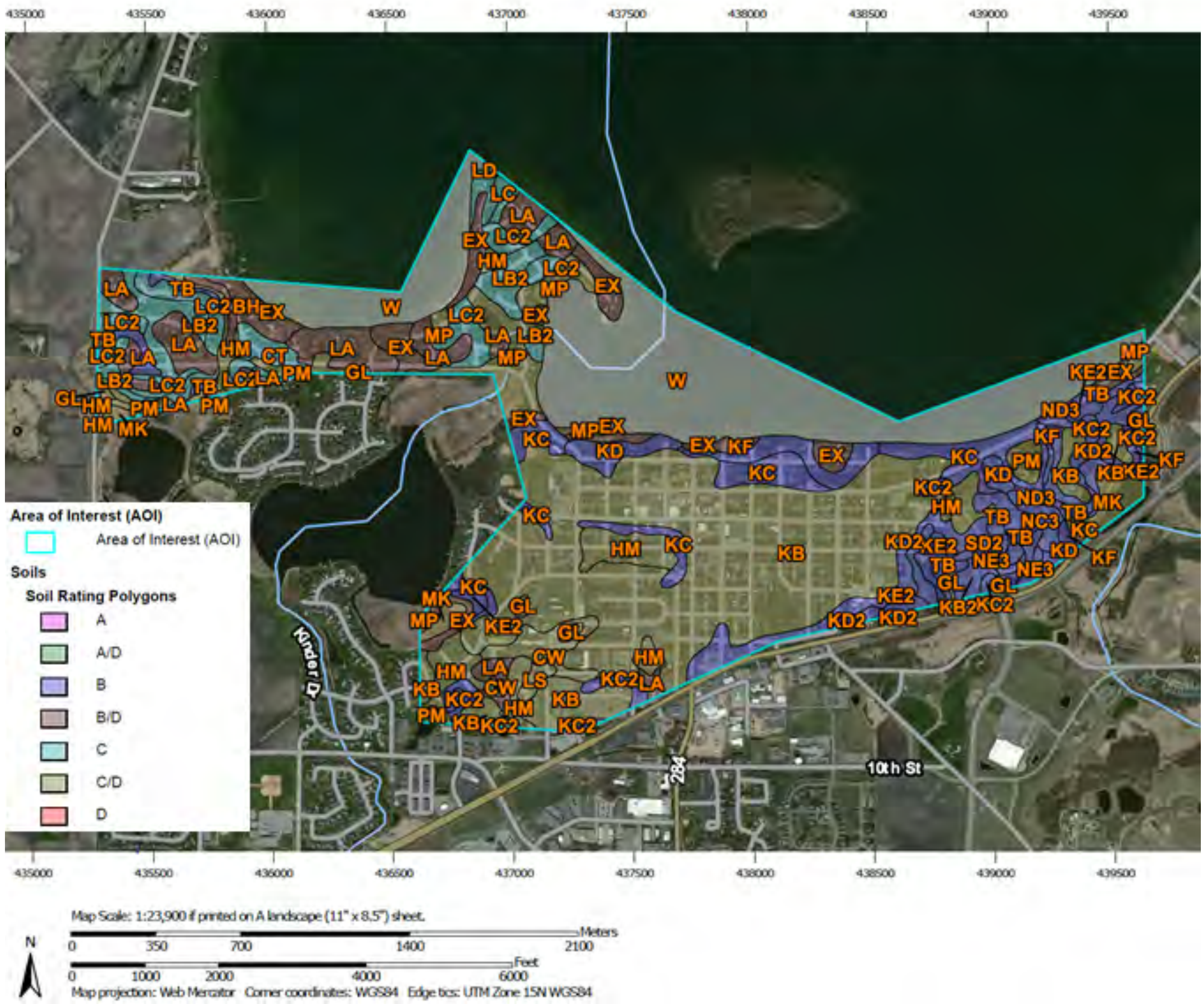

Figure 5: Soil type map for Lake Waconia urban watershed. *Source: NRCS Custom Soil Resource Report for Carver County, Minnesota*

Street sweeping was not modeled in this study due to the current presence of the practice in the city. Street sweeping data was provided by Carver County, which included pollutant removal and cost. This information may be found in Tables A1 and A2 in the Appendix. The City of Waconia's progressive policy was assumed to have a significant impact in reducing TSS and particulate phosphorus levels. A map of current street sweeping zones may also be found in the Appendix (*Figure A1*). Street sweeping was assumed to be in practice in the TP removal analysis.

Results and Discussion

Current loads of total phosphorous, loads after applying the practices, load reductions, and percentage load reductions in each subwatershed are shown in *Table 3*. Each treatment practice showed some TP reduction, and the percentage reduction of TP for most practices was 50% to 60%. Subwatershed 6 removed the highest percentage of TP, with a 57.1% load reduction, and an 8.7 pounds per year reduction.

Compared to the expected TP removal for infiltration basins (Erickson et al., 2005; *Table A4*), the rain gardens and infiltration basin in these subwatersheds worked effectively.

Table 3: Total Phosphorous Loads and Reductions By Subwatershed

TP load and reduction by watershed						
	Device Modeled	**Area of subwatershed (acres)**	**Original TP(lb/yr)**	**TP with practices (lb/yr)**	**% Reduction of TP**	**Reduction of TP (lb/yr)**
Subwatershed 1	Rain Garden	3.173	2.2	1.1	50.1	1.1
Subwatershed 2	Rain Garden	2.742	1.9	0.9	53.3	1.0
Subwatershed 3	Infiltration Basin	4.713	8.7	3.9	54.4	4.7
Subwatershed 4	Rain Garden	5.981	5	2.2	54.7	2.7
Subwatershed 5	Iron- Enhanced Sand Filter	82.937	67.4	18.9	45.6	48.5
Subwatershed 6	Rain Garden	23.083	15.3	6.3	57.1	8.7
Baseline	-	297.79	282.2	-	-	-
Sum of original TP (lb/yr)				100.5		
Sum of TP with practices (lb/yr)				33.3		
Total reduction of TP (lb/yr)				66.7		
Total % reduction of TP				66.4		
Total % reduction of TP compared to Baseline				23.6		

Subwatershed 3 was modeled as an infiltration basin, which would be applied under permeable pavement or infiltration basins near parking lots. The area of water directed into the infiltration basin is of commercial and industrial use, with a high fraction of impermeable area.

Table 4: Total Number of Rain Gardens per Subwatershed: Residential Subwatersheds Only

Recommended Number of Rain Gardens			
Subwatershed Number	Total Rain Garden Area (ac)	Total Rain Garden Area (ft^2)	Number of Recommended Rain Gardens
1	0.023	1001.88	5
2	0.023	1001.88	5
4	0.092	4007.52	20
6	0.23	10018.8	50

Residential areas in the City of Waconia were modeled with rain gardens that could be installed along the right of way. Residents living in the area that was modeled would need to provide long- term maintenance to the gardens installed on their property, and would need to agree to this. The area of the rain gardens could vary; the model specified only the total area of rain gardens. One rain garden area is typically about 200 square feet (Bannerman, 2003). This area would be divided into the total area to determine the total number of rain gardens necessary for each residential subwatershed. These results may be seen in Table 4.

Rain gardens may also be enhanced with iron filings to increase TP removal. Iron enhanced rain gardens remove an average of 88% of TP in laboratory studies (Erickson, 2012). This would create an additional cost per rain garden, and more analysis would need to be conducted to determine the cost efficiency of such a practice.

Subwatershed 5 contained a pre-existing stormwater pond. This was modeled in P8 and the results of modeling showed that the existing pond removed 24.5% of TP each year. The addition of an iron enhanced filter was manually calculated. The filter is recommended for installation around the perimeter of the pond to capture additional phosphorus, and to be composed of 5% iron filings by weight (Erickson, 2012). Table 5 shows the amount of phosphorus removed with the addition of an iron enhanced sand filter around the stormwater pond. The filters are capable of removing dissolved phosphorus, which composes 44% of the total phosphorus in the stormwater (Erickson, 2012).

Table 5: TP Removed from Stormwater with the Addition of an Iron Enhanced Sand Filter

Subwatershed 5 TP Removal			
Current TP with Existing Pond (lbs/yr)	Percent Removal with Existing Pond Per Year (%)	TP Removed with Iron Enhanced Filter (lbs/yr)	Percent Removal with Iron Enhanced Filter (%)
67.40	24.5	18.9	45.6

The most cost effective method of phosphorus removal consists of a combination of rain gardens, infiltration basins, and an iron enhanced sand filter. The final design included 80 rain gardens at a total construction cost of $228,000 a maintenance cost of $80,000 per year for the first two years, and $46,400 per year each year after. One infiltration basin located in subwatershed 3 was estimated to have a construction cost of $84,157 and an additional yearly maintenance cost of $4,800 (MPCA 2011). An iron-enhanced sand filter was added to the perimeter of the pond in subwatershed 5. As discussed previously, we are unable to estimate the cost of this treatment practice at this time.

Further Study

One area where further reduction can be accomplished is shown in figure 6. The red box displays the outlet for subwatershed 5 in addition to blue shaded area. There is a large accumulation of flow at this intersection (along W. Lake Street), further investigation into underground infiltration trenches may be needed. This would remove additional phosphorous before it enters the lake at approximately 80-90% removal (Erickson et al, 2011). More research is recommend for this practice and testing soil specific samples in this location to determine how well this practice will perform.

Figure 6: The area designated for further research into underground infiltration trenches at the intersection of W Lake St and N Vine St. Stormwater gravity mains are marked in purple. Approximate site location is shown in the red box with the appropriate subwatersheds marked in other solid colors. *Image source: ArcMap*

Conclusion

Infiltration practices are recommended for installation in the City of Waconia. Rain gardens are recommended for installation in the residential districts. The total area of rain gardens should equal the modeled area, but each rain garden may be of different size according to the site and the desires of the private landowner. Rain gardens may also be installed with 5% iron filings to create an iron enhanced garden, which may have a greater removal efficiency than a non-enhanced garden. However, this will create an additional cost to the project and more data may be needed to determine the cost efficiency of iron enhancement. Infiltration basins are recommended in the industrial subwatershed, which may consist of the installation of permeable pavement where parking lots are currently located, or infiltration trenches surrounding the parking lot, and in parking lot islands. The pond in subwatershed 5 may have increased TP removal efficiency if an iron enhanced sand filter is installed along the pond perimeter. This is recommended as a cost efficient TP removal practice. The addition of infiltration practices will reduce the amount of phosphorus entering Lake Waconia from urban sources.

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Appendix A

Table A1: Existing Street Sweeping Costs and Efficiency. Data provided by Carver County

Summary of Sweeping Events by Month

Month	# Planned Sweeping Events	Monthly Totals: Wet solids, lb	Dry solids, lb	Nitrogen, lb	Phosphorus, lb	Cost, $	Sweep Time, hr
January	0	0	0	0	0	$ -	0.0
February	0	0	0	0	0	$0.00	0.0
March	3	59198	46179	65	26	$1,403.00	87.8
April	9	78085	60621	206	37	$3,404.00	213.1
May	8	41166	32082	169	25	$3,036.00	190.1
June	9	42493	34727	192	26	$3,749.00	234.7
July	7	26979	20755	93	13	$2,714.00	169.9
August	8	37460	28748	181	20	$3,197.00	200.2
September	3	8219	6385	56	5	$828.00	51.8
October	9	72504	40664	483	53	$3,335.00	208.8
November	7	44814	26221	171	26	$3,174.00	198.7
December	0	0	0	0	0	$ -	0.0
Annual	63	410918	296384	1617.5	230.4	$ 24,840.00	

Table A2: Predicted Street Sweeping Pollutant Removal By Region. Data provided by Carver County.

Summary by Route

TOTAL $ 27,094.00

Route	Predicted Annual: Wet solids, lb	Dry solids, lb	Nitrogen, lb	Phosphorus, lb	Cost, $
Sub-Totals	**462608.7**	**316890.0**	**1692.3**	**241.4**	**$ 27,094.00**
Business	41769.1	28747.7	121.2	21.2	$ 3,220.00
Downtown	135165.1	89106.7	670.0	72.1	$ 4,784.00
Lake	101601.1	67298.0	399.6	54.3	$ 5,083.00
Natural Lake	9706.1	7541.2	28.0	5.6	$ 966.00
Residential Outlet 1	93410.6	67090.4	220.9	46.1	$ 7,084.00
Residential Outlet 2	46829.8	31838.6	117.4	22.3	$ 3,703.00
Rietz Lake	34126.9	25267.4	135.3	19.8	$ 2,254.00

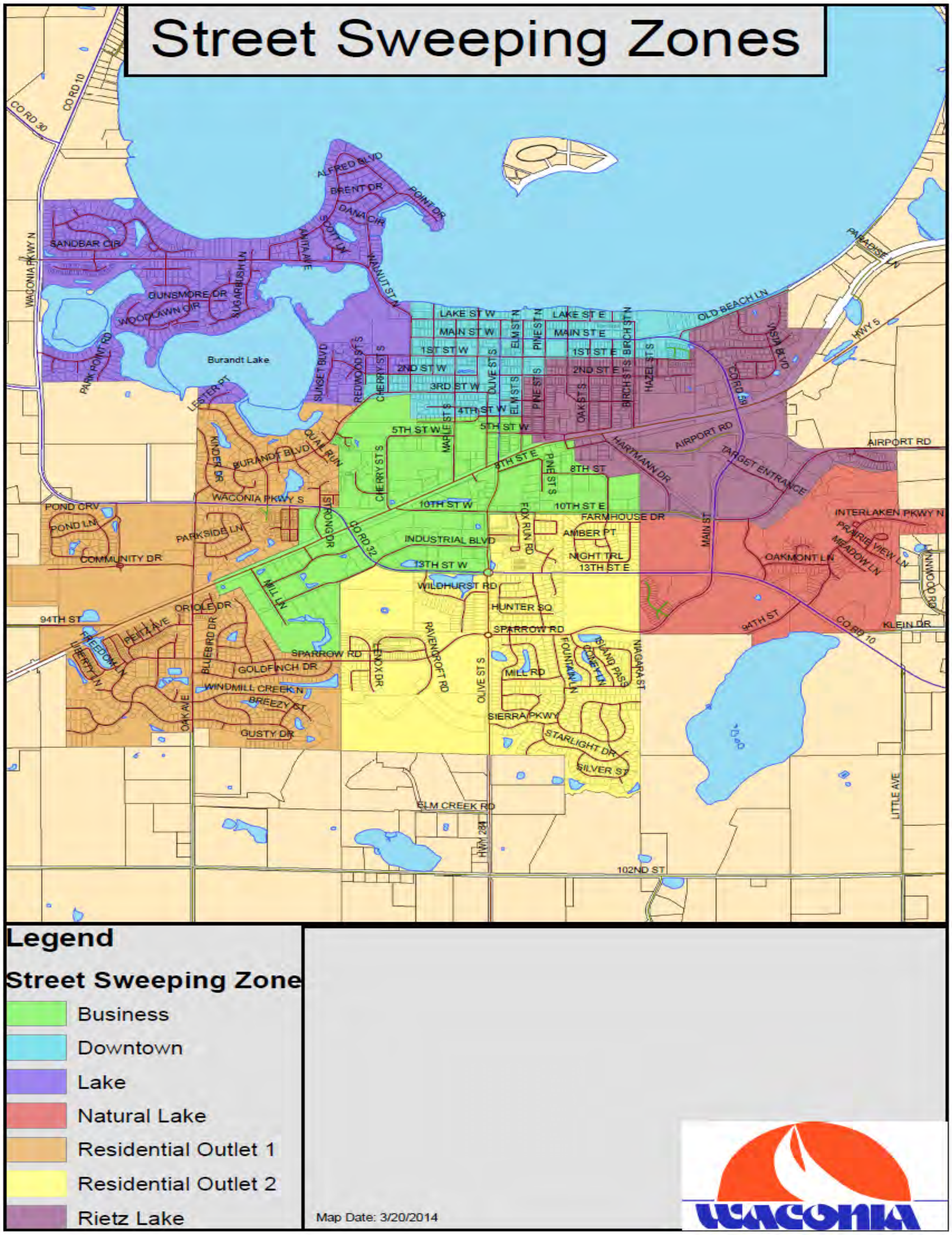


Figure A1: Map of Street Sweeping Zones

Table A3: Expected phosphorous removal for different types of treatment devices.

TYPE	Typical Phosphorus Removal (%)[1]	Median Removal Efficiency (%)			No. of Observations (respectively)
		Total	Dissolved	Ortho-	
Dry Detention Basin	15 - 45				
Wet/Retention Basins	30 - 65	46[3]	34[3]		44, 20
Constructed Wetlands	15 - 45	46[2]	23[2]	28[2]	37, 12, 7
Infiltration Basins	50 - 80	65[3]			5
Infiltration Trenches/Dry Wells	15 - 45				
Porous Pavements	30 - 65				
Grassed Swales	15 - 45				
Vegetated Filter Strips	50 - 80	15[3]	11[3]		18, 8
Surface Sand Filters	50 - 80	45[3]	-31[3]		15, 2
Other Media Filters	< 30				

Table 2. Expected phosphorus removal.

Sources: [1]modified from USEPA (1993), [2]Strecker (1992), [3]Brown and Schueler (1997)

Appendix AS

Standard AS 1: 2014 Study of the Water Quality of 169 Metropolitan Area Lakes

Waconia Lake (10–0059) *Carver County Environmental Services*

Volunteer: Carver County staff

Lake Waconia is located near the city of Waconia (Carver County). The lake is considered a Priority Lake by the Metropolitan Council for its high regional recreational value. The lake is one of the largest bodies of water in the region with a surface area of approximately 3,000 acres. It has mean and maximum depths of 4.0 m and 11.3 m (13 ft and 47 ft), respectively.

The MPCA listed the lake as impaired with respect to aquatic consumption (mercury in fish tissue) in 1998. The MN DNR designated the lake as being infested with Eurasian water milfoil (*Myriophyllum spicatum*) in 2007 and zebra mussels (*Dreissena polymorpha*) in 2014.

On each sampling day surface samples were collected for laboratory analysis of total phosphorus (TP), total Kjeldahl nitrogen (TKN), and chlorophyll including chlorophyll-a (CLA). Secchi transparency was measured during each site visit. Depth profiles of dissolved oxygen and temperature were also made. The resulting surface data are summarized in tables and figures on the following pages. For depth profile data, please refer to the MCES's EIMS system at http://es.metc.state.mn.us/eims/.

2014 summer (May - September) data summary

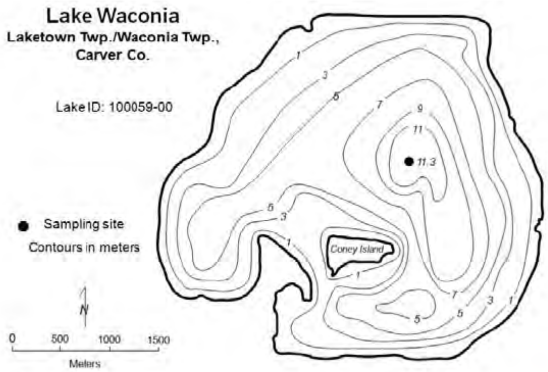
Parameter	Mean	Minimum	Maximum	Grade
TP (µg/l)	38	19	87	C
CLA (µg/l))	23	2.5	91	C
Secchi (m)	2.1	1.0	4.2	C
TKN (mg/l)	1.05	0.79	1.40	
			Lake Grade	C

The lake received a lake grade of C this year, which is consistent with its historical database. The lake grades fluctuate from year to year, but generally the lake receives either a B or C lake grade.

During each monitoring visit, the volunteer's opinions of the lake's physical condition and recreational suitability were ranked on a 1-to-5 scale. These user perception rankings are shown on the following page.

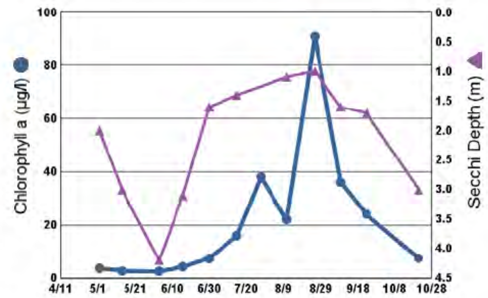
The Fisheries Section of the Minnesota Department of Natural Resources (MDNR) has conducted a fisheries survey on the lake. Information on the survey can be obtained through the MDNR Fisheries Section by calling (651) 259-5831 or by downloading the information off the Internet at http://www.dnr.state.mn.us/lakefind/.

If you notice any errors in the lake's data or physical information, or are aware of any additional or missing information, please contact Brian Johnson of the Metropolitan Council at (651) 602-8743 or brian.johnson@metc.state.mn.us.

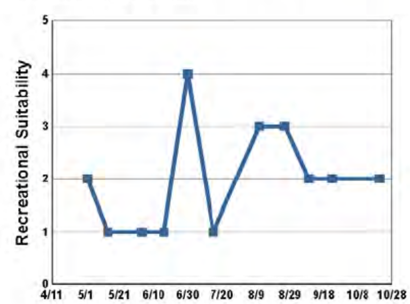


2014 Data

Date	SURF TEMP (°C)	SURF DO (mg/L)	CLA (µg/l)	SURF TP (µg/l)	Secchi (m)	PC	RS
5/2/14	6.3	11.8	3.6		2.0	2	2
5/14/14	11.7		2.6		3.0	2	1
6/3/14	20.7	10.8	2.5	20	4.2	1	1
6/16/14	19.6	9.9	4.2	19	3.1	1	1
6/30/14	23.1	8.1	7.3	33	1.6	3	4
7/15/14	21.9	7.7	16.0	30	1.4	2	1
7/28/14	23.6	10.3	38.0	40			
8/11/14	24.0	8.2	22.0	28	1.1	3	3
8/26/14	25.6		91.0	87	1.0	2	3
9/9/14	21.2	7.4	36.0	45	1.6	2	2
9/23/14	18.0	7.3	24.0	39	1.7	2	2
10/21/14	11.6	10.4	7.4	54	3.0	2	2



1 = Crystal Clear
2 = Some Algae Present
3 = Definite Algal Presence
4 = High Algal Color
5 = Severe Algal Bloom



1 = Beautiful
2 = Minor Aesthetic Problem
3 = Swimming Impaired
4 = No Swimming; Boating OK
5 = No Aesthetics Possible

Lake Water Quality Grades Based on Summertime Averages

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
TP	C	B				B						
CLA	C	B				B					C	
Secchi	C	C	C	C	D	C	C	C	D	C	C	C
Lake Grade	**C**	**B**				**B**						

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
TP			A	A	B	B	C	C	C	C	B	C
CLA			A	B	B	B	B	B	B	B	B	B
Secchi	C	C	A	B	C	C	C	C	C	B	B	C
Lake Grade			**A**	**B**	**B**	**B**	**C**	**C**	**C**	**B**	**B**	**C**

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
TP	B	B	C	C	C	C	C	C	C	B	C
CLA	B	B	C	B	C	A	C	C	B	B	C
Secchi	C	A	B	C	B	A	C	B	B	B	C
Lake Grade	**B**	**B**	**C**	**C**	**C**	**B**	**C**	**C**	**B**	**B**	**C**

Source: Metropolitan Council, EPA STORET, and/or MPCA EQuIS database(s)

Figure AS1: Part One of Description of Kilkenny-Lester loams from NRCS Custom Soil Report

KB—Kilkenny-Lester loams, 2 to 6 percent slopes

Map Unit Setting

National map unit symbol: f9j1
Elevation: 700 to 1,600 feet
Mean annual precipitation: 23 to 35 inches
Mean annual air temperature: 43 to 50 degrees F
Frost-free period: 155 to 200 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Kilkenny and similar soils: 60 percent
Lester and similar soils: 40 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Kilkenny

Setting

Landform: Moraines
Landform position (two-dimensional): Backslope
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Till

Typical profile

Ap - 0 to 11 inches: loam
Bt - 11 to 35 inches: clay loam
2Bk,2C - 35 to 80 inches: loam

Properties and qualities

Slope: 2 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Moderately well drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.60 in/hr)
Depth to water table: About 20 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum in profile: 20 percent
Gypsum, maximum in profile: 1 percent
Available water storage in profile: High (about 10.5 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: C/D

Figure AS2: Part 2 of Description of Kilkenny-Lester loams from NRCS Custom Soil Report

Description of Lester

Setting

Landform: Moraines
Landform position (two-dimensional): Backslope
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Till

Typical profile

Ap - 0 to 8 inches: loam
Bt - 8 to 35 inches: clay loam
BC - 35 to 40 inches: clay loam
C - 40 to 60 inches: loam

Properties and qualities

Slope: 2 to 5 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 2.00 in/hr)
Depth to water table: About 43 to 47 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum in profile: 20 percent
Gypsum, maximum in profile: 1 percent
Available water storage in profile: High (about 10.5 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: B

Figure AS3: Runoff Curve Numbers for selected land uses and soil types (Singh, 1982).

Table 3. Runoff Curve Numbers for Selected Agricultural, Suburban, and Urban Land Use
(Antecedent moisture condition II, and $I_a = 0.2S$)

Land Use Description		Hydrologic soil group A	B	C	D
Cultivated land[1]: without conservation treatment		72	81	88	91
: with conservation treatment		62	71	78	81
Pasture or range land: poor condition		68	79	86	89
good condition		39	61	74	80
Meadow: good condition		-30	58	71	78
Woods or forest land: thin stand, poor cover, no mulch		45	66	77	83
: good cover[2]		25	55	70	77
Open spaces, lawns, parks, golf courses, cemeteries, etc.					
good condition: grass cover on 75% or more of the area		39	61	74	80
fair condition: grass cover on 50% to 75% of the area		49	69	79	84
Commercial and business areas (85% impervious)		89	92	94	95
Industrial districts (72% impervious)		81	88	91	93
Residential[3]					
Average lot size	Average % impervious[4]				
1/8 acres or less	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, driveways, etc.[5]		98	98	98	98
Streets and roads:					
paved with curbs and storm sewers[5]		98	98	98	98
gravel		76	85	89	91
dirt		72	82	87	89

For a more detailed description of agricultural land use curve numbers refer to National Engineering Handbook, Section 4, Hydrology, Chapter 9, Aug. 1972.

[2]Good cover is protected from grazing and litter and brush cover soil.

[3]Curve numbers are computed assuming the runoff from the house and driveway is directed towards the street with a minimum of roof water directed to lawns where additional infiltration could occur.

The remaining impervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

In some warmer climates of the country a curve number of 95 may be used, (from Technical Release-55, Engineering Division, SCS, USDA)

Table AS 1: Design Infiltration Rates for each hydrologic soil group (MPCA, Minnesota Stormwater Manual website)

Hydrologic soil group	Infiltration rate (inches/hour)	Soil textures	Corresponding Unified Soil Classification
A	1.63[a]	gravel sandy gravel silty gravels	GW - well-graded gravels, sandy gravels GP - gap-graded or uniform gravels, sandy gravels GM - silty gravels, silty sandy gravels SW - well-graded gravelly sands
	0.8	sand loamy sand sandy loam	SP - gap-graded or uniform sands, gravelly sands
B	0.45		SM - silty sands, silty gravelly sands
	0.3	loam, silt loam	MH - micaceous silts, diatomaceous silts, volcanic ash
C	0.2	Sandy clay loam	ML - silts, very fine sands, silty or clayey fine sands
D	0.06	clay loam silty clay loam sandy clay silty clay clay	GC - clayey gravels, clayey sandy gravels SC - clayey sands, clayey gravelly sands CL - low plasticity clays, sandy or silty clays OL - organic silts and clays of low plasticity CH - highly plastic clays and sandy clays OH - organic silts and clays of high plasticity

Standard AS 2: UCOWR Stormwater Treatment Practices Maintenance Guide (Erickson, 2005)

Table 5. Percentage of respondents who indicated the listed factors for most frequently reducing performance in stormwater treatment practices.

		Percentages								
Stormwater Treatment Practice Type	**Number of Responses**	**Sediment Buildup**	**Litter & Debris**	**Pipe Clogging**	**Invasive Vegetation**	**Groundwater Level**	**Bank Erosion**	**Oil Spill**	**Structural Problems**	**Mechanical Problems**
Surface Sand or Soil Filter	10	50	30	10	0	0	0	10	0	0
Undeground Filtration Devices	8	50	25	13	0	13	0	0	0	0
Infiltration Basins or Trenches	39	36	21	10	5	13	5	3	5	3
Permeable Pavements	9	67	11	11	0	0	0	11	0	0
Wet Ponds	90	26	19	21	10	7	11	0	7	0
Dry Ponds	49	24	31	18	16	2	8	0	0	0
Underground Sedimentation Devices	19	58	21	11	0	5	0	0	5	0
Rain Gardens	27	33	22	7	26	7	0	4	0	0
Constructed Wetlands	37	24	19	14	22	8	11	0	3	0
Filter Strips or Swales	19	21	26	5	26	5	11	0	5	0

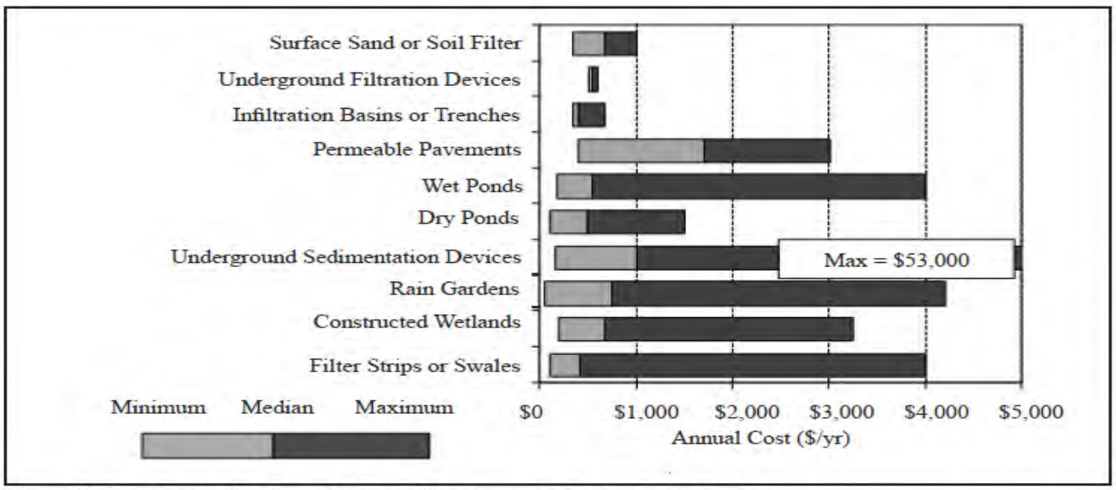


Figure 2. Annual cost of sediment removal for stormwater treatment practices.

practices. As shown in Figure 3, the annual predicted maintenance cost is roughly eight percent of total construction costs for wet ponds that cost $10,000 (2005 dollars) to construct. Therefore, maintenance cost for these stormwater treatment practices will roughly equal total construction cost after 12 years (in constant dollars). Similarly, for wet ponds that cost $100,000 (2005 dollars) to construct, annual maintenance cost is roughly four percent and will roughly equal total construction cost for these