Skogman-Fannie-Elms-Florence Lakes Chain Stormwater Retrofit Analysis

Prepared for the

ISANTI COUNTY SOIL AND WATER CONSERVATION DISTRICT

By

Anoka Conservation District

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Cover photo: Aerial image of (from left to right) Florence, Elms, Fannie, and Skogman Lakes. Photograph was taken in 2011.

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Executive Summary

This study provides recommendations for cost effectively improving the treatment of stormwater from areas draining to the Skogman-Fannie-Elms-Florence (SFEF) chain of lakes. The lakes chain and its surrounding subwatershed lie within the townships of Cambridge and Isanti in Isanti County and Fish Lake Township in Chisago County. A portion of the subwatershed also lies within the City of Cambridge, which is an EPA Municipal Separate Storm Sewer System (MS4) Phase II community with an approved stormwater management plan.

Improving water quality in these waterbodies is a high priority as both Fannie and Skogman Lakes have been listed as impaired due to nutrient eutrophication. Both lakes, which have been listed as impaired since 2007, witness frequent midsummer algae blooms and low clarity due to high nutrient (particularly phosphorus) concentrations. These concentrations are often above the state water quality standard for phosphorus, 40 µg/L. In addition, Florence Lake can experience winter fish kill due to low oxygen levels caused in part by the dense, nutrient-fed littoral vegetation in the lake.

This report focuses on “stormwater retrofitting” and ranking projects on cost effectiveness following a cost-benefit analysis. Stormwater retrofitting refers to adding stormwater treatment to areas which are already developed or being utilized for production. This process is investigative and creative. Stormwater retrofitting success is sometimes improperly judged by the number of projects installed or by comparing costs alone. Those approaches neglect to consider how much pollution is removed per dollar spent. In this stormwater analysis we estimated both costs and pollutant reductions and used them to calculate cost effectiveness of each possible project.

Areas that drain to the SFEF chain of lakes were delineated using available geographic information systems (GIS) watershed information, maps of stormwater conveyance features (where available), and advanced GIS terrain analysis technologies. Those areas were then divided into nine smaller stormwater drainage areas, or catchments. For each catchment, modeling of stormwater volume and pollutants was completed using water quality software for urban (WinSLAMM) and rural agrarian (ArcSWAT) landscapes. Base (without any stormwater treatment) and existing (with present day stormwater treatment) conditions were modeled. In total, under existing conditions the 7,775 acre subwatershed contributes an estimated 4,249 acre feet (ac-ft) of runoff, 1,362 pounds of phosphorus, and 371 tons of suspended solids each year to the SFEF chain of lakes.

Potential stormwater retrofits identified during this analysis were modeled to estimate reductions in volume, total phosphorus (TP), and total suspended solids (TSS). Finally, cost estimates were developed for each retrofit project, including operations and maintenance costs over the project lifetime. Projects were ranked by cost effectiveness with respect to their reduction of TP.

A variety of stormwater retrofit approaches were identified. They include:

- Maintenance of, or alterations to, existing stormwater treatment practices,
- Residential bioretention including curb-cut rain gardens and boulevard bioswales,
- Iron-enhanced sand filter (IESF) basins and retention pond benches,
- Permeable check dams,
- Lakeshore restorations,
- Filter strips on agricultural land,
- Water and sediment control basins,
- Wetland restorations, and
- New wet retention ponds.

This report provides conceptual sketches or photos of recommended stormwater retrofitting projects. The intent is to provide an understanding of the approach. If a project is selected, site-specific designs must be prepared. In addition, many of the proposed retrofits will require engineered plan sets if selected. This typically occurs after committed partnerships are formed to install the project. Committed partnerships must include willing landowners when installed on private property.

The tables on the next pages summarize 46 potential projects organized from most cost-effective to least, based on cost per pound of TP removed. If all of these practices were installed, pollutant loading to the SFEF lakes chain could be reduced by 260 lbs of TP and 136 tons of TSS. The 260 lbs-TP reduction could potentially reduce algal growth in the lake by 65 tons (assuming 1 lb phosphorus = 500 lbs algae). Reported treatment levels are dependent upon optimal site selection and sizing. More detail about each project can be found in the *Catchment Profile* pages of this report. Projects that were deemed unfeasible due to prohibitive size, number, or were too expensive to justify installation are not included in this report.

Installing all of these projects is unlikely due to funding limitations and landowner interest. Instead, it is recommended that projects be installed in order of cost-effectiveness (pounds of pollution reduced per dollar spent). Other factors, including a project's educational value, visibility, construction timing, total cost, focusing on upstream projects that benefit all lakes, or non-target pollutant reduction also affect project installation decisions and will need to be weighed by resource managers when selecting projects to pursue.

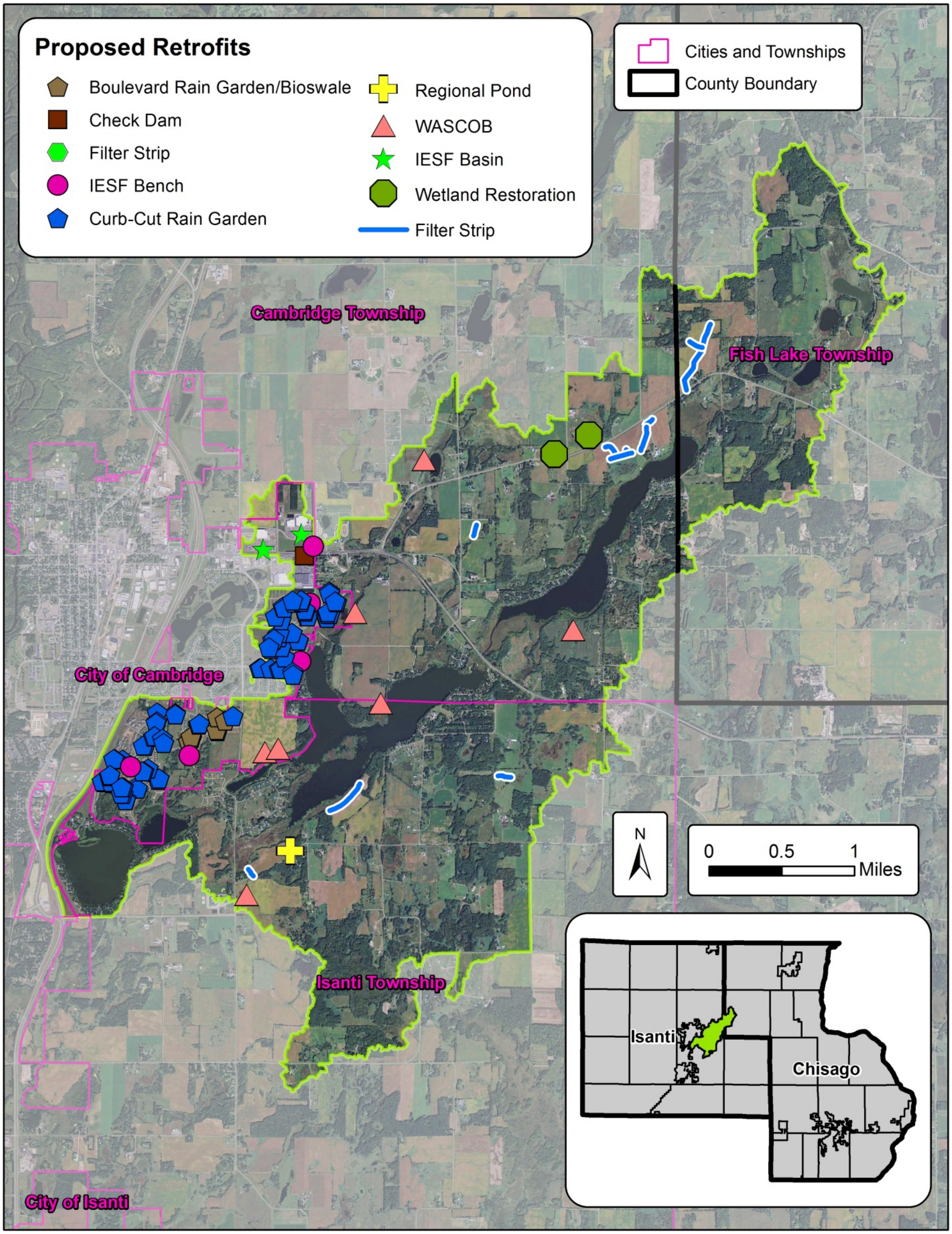


Figure 1: Proposed stormwater retrofits in the SFEF subwatershed

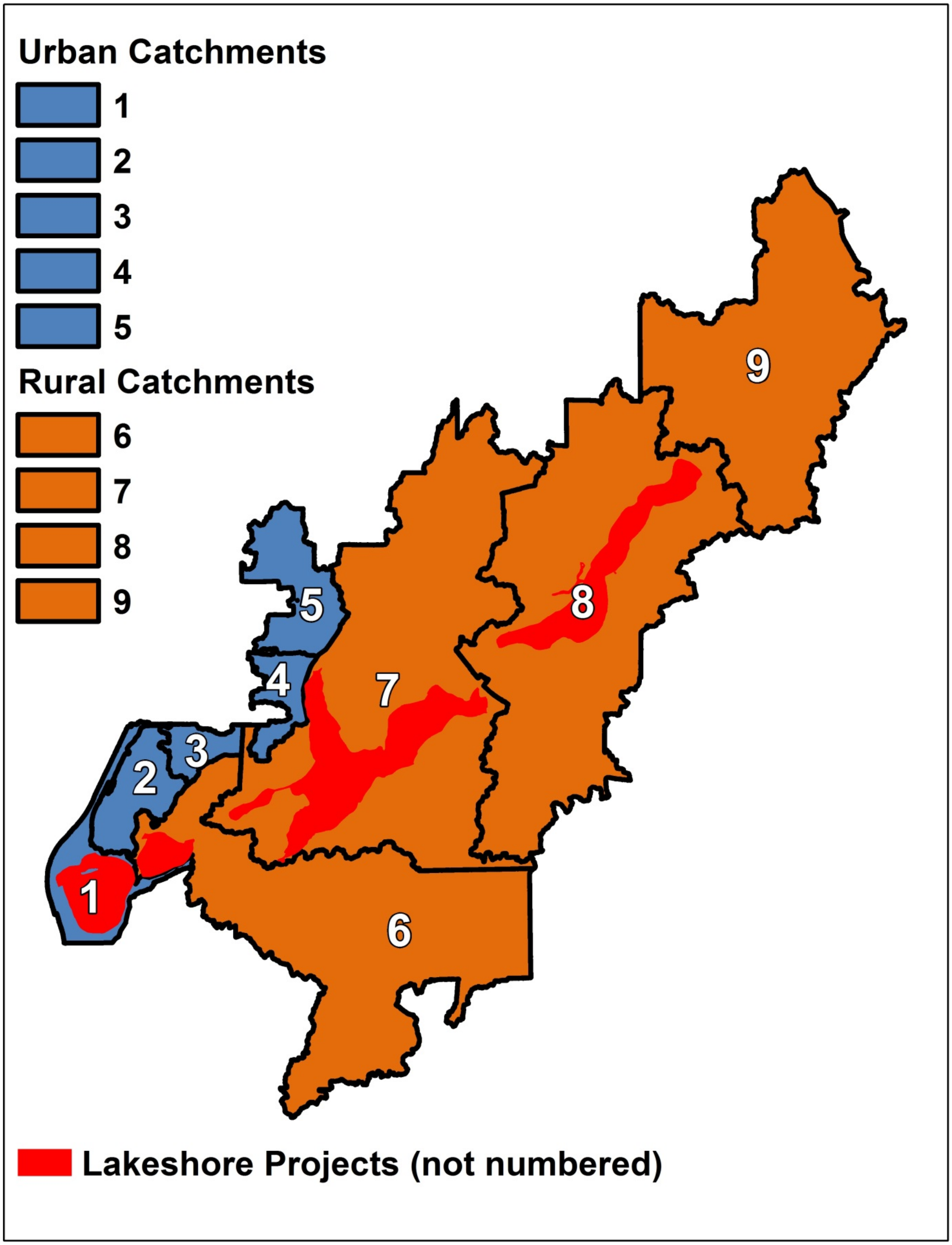


Figure 2: Areas in which projects were proposed, including urban catchments (1-5; colored blue), rural catchments (6-9; colored orange), and along lakeshore properties (colored red). Ranking table color-coding matches this figure.

Table 1: Cost-benefit of retrofits with respect to TP reduction. Projects 1-12. TSS and volume reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profile* pages.

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit ($/lb-TP/yr)[1]	TP PDR	TP Reduction w/ PDR (lb-TP/yr)	Cost-Benefit w/ PDR ($/lb-TP/yr)
1	9-A	106	Vegetated Filter Strip/Grassed Waterway	15.0-15.7	17,068-17,978	0.0	$10,910-$11,241	$961-$2,283	$100-$181	0.90	13.5-14.1	$111-$201
2	6-A	83	Vegetated Filter Strip	6.8-7.3	6,753-7,281	0.0	$10,809-$10,938	$557-$1,071	$163-$222	0.80	6.8-7.3	$204-$278
3	8-E	102	Vegetated Filter Strip/Grassed Waterway	3.4-3.5	4,805-4,896	0.0	$10,809-$10938	$557-$1,071	$318-$460	0.90	3.1-3.2	$353-$511
4	8-D	101	Vegetated Filter Strip/Grassed Waterway	3.2-3.4	4,247-4,646	0.0	$10,805-$10,924	$539-$1,016	$341-$457	0.90	2.9-3.1	$379-$508
5	7-B	90	WASCOB	3.4-4.9	5,205-8,079	0.0	$21,094-$23,938	$517-$538	$355-$457	0.90	3.1-4.4	$394-$507
6	5-C	73	IESF Bench in the Parkwood Development	7.2	0.0	0.0	$92,327	$459	$491	1.00	7.2	$491
7	6-B	84	IESF Bench for Regional Pond	25.0-50.8	0.0	0.0	$240,933-$779,983	$2,500-$10,000	$396-$647	0.80	20-40.7	$495-$809
8	7-D	92	WASCOB	2.5-3.9	3,510-6,521	0.0	$20,649-$31,138	$508-$550	$511-$614	1.00	2.5-3.9	$511-$614
9	8-A	98	Wetland Restoration	9.8-31.2	701-5,955	1.3-6.7	$260,383-$405,005	$500	$665-$1380	0.80	7.8-25.0	$532-$1,104
10	4-B	65	Catchment 4 IESF Bench	11.5-15.8	0.0	0.0	$152,605-$246,408	$1,148-$2,500	$542-$625	1.00	11.5-15.8	$542-$625
11	2-B	51	Catchment 2 IESF Pond Bench	9.8	0.0	0.0	$136,729	$918	$559	1.00	9.8	$559
12	7-G	95	Vegetated Filter Strip	2.0-2.0	2,598-2.668	0.0	$10,814-$10,883	$575-$851	$567-$694	1.00	2.0-2.0	$567-$694

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land

Urban Catchments

Rural Catchments

Lakeshore Projects

Table 2: Cost-benefit of retrofits with respect to TP reduction. Projects 13-29. TSS and volume reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profile* pages.

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit ($/lb-TP/yr)[1]	TP PDR	TP Reduction w/ PDR (lb-TP/yr)	Cost-Benefit w/ PDR ($/lb-TP/yr)
13	5-F	76	Highway 95 Pond Bench	5.0	0.0	0.0	$92,327	$459	$707	1.00	5.0	$707
14	7-E	93	WASCOB	1.8-2.5	2,268-3,496	0.0	$21,049-$27,938	$516-$538	$774-$871	1.00	1.8-2.5	$774-$871
15	8-B	99	Wetland Restoration	2.1-5.2	2,825-8,673	0.7-1.3	$38,205-$56,205	$500	$640-$1,142	0.80	1.7-4.2	$800-$1,428
16	3-C	59	Catchment 3 IESF Bench	10.7	0.0	0.0	$232,475	$2,479	$956	1.00	10.7	$956
17	7-C	91	WASCOB	0.3-2.0	278-2,560	0.0	$20,827-$32,205	$525-$558	$1,112-$4,746	1.00	0.3-2.0	$1,112-$4,746
18	5-G	78	Highway 95 Permeable Check Dams	1.0	1,347	0.0	$12,753	$730	$1,368	1.00	1.0	$1,368
T19	LR-7	117	LR-7	2.5	3,075.0	0.0	$34,805	$308	$1,540	1.00	2.5	$1,540
T19	LR-8	118	LR-8	2.5	3,075	0.0	$34,805	$308	$1,540	1.00	2.5	$1,540
T19	8-F	103	Vegetated Filter Strip/Grassed Waterway	1.5-1.6	1,108-1,165	0.0	$10,768-$10,791	$392-$484	$616-$660	0.40	0.6-0.6	$1,540-$1,650
T19	7-F	94	Vegetated Filter Strip	1.0-1.0	1,077-1,147	0.0	$10,768-$10,791	$392-$484	$930-$993	0.60	0.6-0.6	$1,550-$1,655
23	6-B	84	Regional Pond	57.8	177,212	1.2	$2,426,023	$1,200	$1,419	0.80	46.2	$1,774
24	LR-11	122	LR-11	0.9	1,125	0.0	$15,305	$113	$1,826	1.00	0.9	$1,826
25	8-C	100	WASCOB	0.6-1.0	587-1,042	0.0	$20,383-$25,005	$503-$508	$1,851-$2,537	1.00	0.6-1.0	$1,851-$2,537
26	LR-10	121	LR-10	0.8	975	0.0	$13,805	$98	$1,895	1.00	0.8	$1,895
27	2-A	49	Catchment 2 Curb-Cut Rain Gardens	0.2-0.3	25-43	0.4-0.5	$11,610	$225	$2,369-$3,356	1.00	0.2-0.3	$2,369-$3,356
28	LR-14	125	LR-14	0.9	1,170	0.0	$23,555	$390	$2,921	1.00	0.9	$2,921
29	7-A	89	WASCOB	0.3-1.0	278-1,153	0.0	$20,472-$21,538	$505-$514	$1,544-$4,632	0.50	0.2-0.5	$3,088-$9,264

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land

Table 3: Cost-benefits of retrofits with respect to TP reduction. Projects 30-46. TSS and volume reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profiles* pages

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit ($/lb-TP/yr)[1]	TP PDR	TP Reduction w/ PDR (lb-TP/yr)	Cost-Benefit w/ PDR ($/lb-TP/yr)
30	6-C	86	WASCOB	0.3-0.8	236-788	0.0	$20,383-$26,205	$503-$521	$2,409-$5,249	0.70	0.2-0.6	$3,442-$7,500
31	5-D	74	Target Parking Lot IESF Basin	1.0-1.5	252-571	0.6-1.0	$109,088-$159,243	$459-$918	$4,000-$4,150	1.00	1.0-1.5	$4,000-$4,150
32	LR-1	109	LR-1	1.4	1,740	0.0	$47,555	$570	$4,047	1.00	1.4	$4,047
33	LR-5	114	LR-5	1.2	1,530	0.0	$42,305	$765	$4,095	1.00	1.2	$4,095
34	3-A	55	Catchment 3 Curb-Cut Rain Gardens	0.0-0.2	3-34	0.1-0.3	$6,950-$15,710	$225	$5,053-$57,250	1.00	0.0-0.2	$5,053-$57,250
35	5-E	75	Fleet Farm Parking Lot IESF Basin	0.8-0.9	270-511	0.5-0.8	$109,088-$159,243	$459-$918	$5,054-$6,506	1.00	0.8-0.9	$5,054-$6,506
36	LR-9	120	LR-9	0.2	203	0.0	$7,430	$68	$5,066	1.00	0.2	$5,066
T37	LR-2	110	LR-2	0.3	390	0.0	$13,805	$195	$5,082	1.00	0.3	$5,082
T37	LR-4	113	LR-4	0.3	390	0.0	$13,805	$195	$5,082	1.00	0.3	$5,082
39	LR-3	111	LR-3	0.3	345	0.0	$12,680	$173	$5,145	1.00	0.3	$5,145
40	LR-13	124	LR-13	0.2	300	0.0	$11,555	$150	$5,440	1.00	0.2	$5,440
41	LR-6	115	LR-6	0.2	225	0.0	$9,680	$113	$6,003	1.00	0.2	$6,003
T42	4-A	63	Catchment 4 Curb-Cut Rain Gardens	0.1-0.1	7-21	0.1-0.2	$11,610	$225	$6,196-$13,425	1.00	0.0-0.1	$6,196-$13,425
T42	5-A	69	Curb-Cut Rain Gardens in the Parkwood Development	0.1-0.1	7-21	0.1-0.2	$11,610	$225	$6,196-$13,425	1.00	0.1-0.1	$6,196-$13,425
44	3-B	58	Catchment 3 Curb-Cut Boulevard Bioswales	0.0-0.1	4-14	0.0-0.1	$8,310	$225	$6,405-$32,025	1.00	0.0-0.1	$6,405-$32,025
45	5-B	71	Curb-Cut Rain Gardens in the Preserve Development	0.1-0.2	6-17	0.1-0.2	$9,730-$15,710	$225	$6,737-$10,164	1.00	0.1-0.2	$6,737-$10,164
46	LR-12	123	LR-12	0.1	150	0.0	$7,805	$75	$7,129	1.00	0.1	$7,129

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land

About this Document

This Stormwater Retrofit Analysis is a watershed management tool to help prioritize stormwater retrofit projects by performance and cost effectiveness. This process helps maximize the value of each dollar spent.

Document Organization

This document is organized into three major sections, plus references and appendices. Each section is briefly described below.

Background

This section gives the reader a brief description of the area of research, including information on lake health, water quality, and the surrounding subwatershed. The section also describes the elements used to propose and rank stormwater retrofit projects for reducing particular target pollutants.

Analytical Process

The analytical process section overviews the procedures that were followed when analyzing the watershed. It overviews the processes of retrofit scoping, desktop analysis, field investigation, modeling, cost/treatment analysis, project ranking, and project selection. Refer to *Appendix A* for a detailed description of the methods.

Analytical Elements

The analytical elements section explains a myriad of other considerations that were taken into account when developing this work product. Examples include the target pollutants and their interrelationships, project type and the implication of project selections, cultural as opposed to structural projects, and edge of field and network level benefits.

BMP Descriptions

This section details stormwater best management practices (BMPs) listed in the *Analytical Elements* section which were chosen for study in this analysis, including a description of its features, uses, and possible site considerations.

Catchment Profiles

The SFEF subwatershed was divided into project areas based on predominant land use type. These areas were further divided into catchments based on major drainage pathways. This section describes each catchment within the "urban" and "rural" areas of the Skogman-Fannie-Elms-Florence (SFEF) subwatershed. In each *Catchment Profile* the following information is provided:

Catchment Description

Within each *Catchment Profile* is a table that summarizes basic catchment information including acres, land cover, and estimated annual pollutant and volume loads. A brief description of the land cover, stormwater infrastructure, and any other important general information is also described. Existing stormwater practices are noted and their estimated effectiveness presented.

Retrofit Recommendations

The recommendation section describes the conceptual retrofit(s) that were scrutinized. It includes tables outlining the estimated pollutant removals by each, as well as costs. A map provides promising locations for each retrofit approach.

The third section of *Catchment Profiles* generally describes the state of lakeshore properties along the SFEF lakes chain and details opportunities to reduce erosion and pollutant input to the lake for shoreland owners.

Retrofit Ranking

This section ranks stormwater retrofit projects across all catchments to create a prioritized project list. The list is sorted by cost per pound of total phosphorus (TP) removed for each project over its projected life span, between 10 and 30 years. The final cost per pound treatment value includes installation and maintenance costs over the 10-30 year project life. For rural projects proposed on agricultural land, production losses have also been included.

There are many possible ways to prioritize projects, and the list provided in this report is merely a starting point. Other considerations for prioritizing installation may include:

- Non-target pollutant reductions
- Timing projects to occur with other road or utility work
- Project visibility
- Availability of funding
- Total project costs
- Educational value

Additional ranking tables for cost-effectively reducing total suspended solids (TSS) and stormwater volume loading to the SFEF lakes are listed in *Appendix C*.

References

This section identifies various sources of information synthesized to produce the protocol utilized in this analysis.

Appendices

This section provides supplemental information and/or data used during the analysis. Included in the appendices is the methods section (*Appendix A*), which outlines general procedures used when analyzing the subwatershed. This section describes the processes of retrofit scoping, desktop analysis, retrofit reconnaissance investigation, cost/treatment analysis, and project ranking. Additional project budget information is also provided for select practices in *Appendix B.*

Abbreviations

Listed below are some abbreviations used frequently throughout the text:

ArcSWAT: ArcView Extension of the Soil and Water Assessment Tool

BMP: Best Management Practice

BWSR: Board of Water and Soil Resources

DP: Dissolved Phosphorus

GIS: Geographic Information Systems

IESF: Iron-Enhanced Sand FIlter

MS4: Municipal Separate Storm Sewer System

PDR: Pollutant Delivery Ratio

PP: Particulate Phosphorus

PRC: Pollutant Reduction Calculator

SFEF: Skogman-Fannie-Elms-Florence

TP: Total Phosphorus

TSS: Total Suspended Solids

WASCOB: Water and Sediment Control Basin

WinSLAMM: Source Loading and Management Model for Windows

Background

The SFEF chain of lakes are recreational and angling lakes located east of the City of Cambridge in Isanti County. Elms and Florence are the downstream, shallow lakes with large littoral areas prone to occasional winter fish kills due low oxygen levels (likely enhanced by the abundant littoral vegetation). Fannie and Skogman lakes are the larger upstream lakes which have an overall poor water quality and experience algae blooms in summer that affect recreation.

The SFEF subwatershed, which is the land draining to the SFEF chain of lakes, covers 8,561 acres. The SFEF lakes represent 786 acres (9%) of that area. The remaining acreage is predominantly agricultural/pastoral land (48%), followed by forests (16%), other lakes/ponds and wetlands (9%), urban and rural residential lots (9%), and other assorted land uses. Residential properties are split evenly between the City of Cambridge and the outlying townships of Cambridge and Isanti in Isanti County and Fish Lake in Chisago County.

Soils in the region are generally loamy fine sands, predominantly Zimmerman, Anoka, and Hayden soils. These soils are part of the larger Anoka Sand Plain, which covers 60% of the county and is characterized by relatively little grade change and well-drained sandy soils with some isolated wetlands and other hydric regions (USDA SCS, 1958).

Water flows through the lakes chain from northeast to southwest, from Skogman Lake into Fannie, Elms, and then Florence Lake. Outflow from Florence Lake passes through a wetland east of London Drive en route to Isanti Brook. The SFEF subwatershed is part of the larger Rum River watershed, which subsequently drains south into the Mississippi River. Therefore, any improvements to these lakes would be experienced within this subwatershed as well as the Rum River and Mississippi River watersheds downstream.

Improving water quality in this subwatershed is a high priority as both Fannie and Skogman Lakes have been listed as impaired for their designated use due to nutrient eutrophication. Both lakes, which have been listed as impaired since 2007, witness frequent midsummer algae blooms and low clarity due to the high nutrient (particularly phosphorus) concentrations. These concentrations are often above the state water quality standard for phosphorus, 40 µg/L. Total Maximum Daily Load (TMDL) studies are ongoing as part of the larger Rum River Watershed Restoration and Protection (WRAP) study and will likely be completed in 2016. In addition, Elms and Florence Lake's winter fish kills are likely exacerbated by excessive nutrient inputs from their immediate watershed and inflow from Fannie and Skogman Lakes.

The importance of these lakes and stormwater treatment is reflected in the City of Cambridge's ordinances. Their rules require new construction within the watershed not increase phosphorus discharge to the lakes. The first 1" of runoff from impervious surfaces must be infiltrated or otherwise retained (alternative treatment may be used where infiltration is not feasible). New development has been accompanied with robust stormwater treatment, including many wet retention ponds and a few infiltration practices. The ability of permanently wet ponds to meet the infiltration standard, their inability to treat dissolved pollutants, and the desire to provide robust treatment in already built-out areas provides good reason to pursue stormwater retrofitting. Moreover, there is a desire to improve water quality in the lakes, not just prevent it from worsening.

The Anoka Conservation District completed this stormwater retrofit analysis for the purpose of identifying and assessing projects to improve stormwater quality in the SFEF subwatershed. Overall loading of TP, total suspended solids (TSS), and stormwater volume were determined for subdivided drainage basins within the subwatershed. Proposed retrofit treatment conditions were modeled with the ArcView extension of the Soil and Water Assessment Tool (ArcSWAT), Source Loading and Management Model for Windows (WinSLAMM), and the Board of Water and Soil Resources' Pollution Reduction Calculator (BWSR PRC) to determine each practice's capability for removing pollutants. Finally, each project was ranked based on the cost-effectiveness of the project to reduce TP loading to the SFEF lakes.

Analytical Process

This Stormwater Retrofit Analysis is a watershed management tool to identify and prioritize stormwater retrofit projects by performance and cost effectiveness. This process helps maximize the value of each dollar spent.

Scoping includes identifying the objectives and bounds of the analysis in terms of target pollutant, geography, and practices.

Desktop analysis involves the utilization of high resolution aerial photography, digital elevation data (LiDAR), soils, hydrography, parcels, stream and ditch networks, wetlands, culverts, and land use data to narrow the scope of analysis and facilitate field investigation.

Field investigation involves driving and walking through the subwatershed along every public road and parcel to observe field conditions in search of problem sites and opportunities. Problem areas include active erosion, land management practices that contribute to water quality degradation, and artificial drainage. Most problem areas present an opportunity for corrective action, including hydrologic restoration, revegetation, ponding, soil stabilization, and land management practice improvements. As part of the field investigation, an erosion inventory of the entire shoreline of the SFEF lakes was completed.

Modeling involves several methods to estimate target pollutant removals associated with potential projects. Since no single modeling methodology currently available is suited to model benefits from the variety of projects identified in this report, several methodologies had to be employed. Modeling practices are explained in *Appendix A* and include ArcSWAT, WinSLAMM, and the BWSR PRC. WinSLAMM and ArcSWAT can determine pollutant loading across the landscape and through ponds and wetlands (in the case of ArcSWAT) but are not able to determine loading from some other factors including in-lake nutrient cycling and uptake by plants and algae. These models, though, have particular utility in determining the efficacy of stormwater projects.

Cost estimating is critical for the comparison and ranking of projects, development of work plans, and pursuit of grants and other funds. Project installation costs are only one element included in cost estimates provided in this analysis. Engineering, landowner outreach, construction oversight, project administration, production loss payments for agricultural land, and long term maintenance costs were also considered. In addition to this, expected project life was incorporated into the estimate. All project costs should be verified against local experience.

Project ranking is essential to identifying which projects to pursue to achieve water quality goals. Projects were ranked by cost-effectiveness in reducing TP delivery to the SFEF lakes chain.

Project selection involves considerations other than project ranking, including but not limited to total cost, treatment train effects, social acceptability, and political feasibility.

Each of these items is explained in greater detail in Appendix A.

Analytical Elements

Many elements come into play when developing a Stormwater Retrofit Analysis. Each analysis must be customized to the target pollutant, locally acceptable practice type, local fiscal capacity, and watershed characteristics. The following sections describe how these elements were considered.

Target Pollutants

The table below describes the target pollutants and their role in water quality degradation. Projects that effectively reduce loading of multiple target pollutants can provide greater immediate and long term benefits.

Table 4: Target pollutants addressed in this report

Target Pollutant	Description
Total Phosphorus (TP)	Phosphorus is a nutrient essential to plant growth and is commonly the factor that limits the growth of plants in surface waterbodies. TP is a combination of particulate phosphorus, which is bound to sediment and organic debris, and dissolved phosphorus (DP), which is in solution and readily available for plant growth (active). Excess phosphorus contributes to eutrophication of water bodies. TP was the primary pollutant of study in this analysis and used to rank all stormwater retrofit projects by cost-effectiveness.
Total Suspended Solids (TSS)	TSS is small mineral and organic particles that can be dispersed into the water column due to turbulent mixing (MPCA website). TSS loading can create turbid and cloudy water conditions and carry with it particulate phosphorus. As such, reductions in TSS will also result in TP reductions.
Volume	Higher runoff volumes and velocities can carry greater amounts of TSS to receiving waterbodies. It can also exacerbate in-stream erosion, thereby increasing TSS loading. As such, reductions in volume will reduce TSS loading and, by extension, TP loading.

Potential Project Types

A variety of stormwater retrofit approaches were identified. The table below describes projects included in this analysis. Additional project types were considered but not included for a variety of reasons. A complete list of the considered project types is noted in *Appendix A*.

Table 5: Project types identified in the SFEF subwatershed

Project Type	Code	Description	Project Life	Modeling Method
Bioretention (including rain gardens and bioswales)	RG	Small depressions in residential landscapes designed to capture and treat runoff through infiltration and/or filtration	20	Win SLAMM
Lakeshore Restorations	LR	Stabilization of active lakeshore erosion through structural and bioengineering techniques	10	BWSR PRC
Wetland Restorations	WR	Restoration of hydrology in areas that have been drained	20	ArcSWAT
Water and Sediment Control Basins (WASCOBS)	SB	Structural practice in agricultural fields to detain runoff, settle pollutants, and stabilize swales subject to erosion	20	ArcSWAT
Vegetated Filter Strips	FS	Establishment of permanent vegetative cover along waterways or at the field's edge to slow runoff and capture sediment	20	ArcSWAT
Regional Ponds	RP	Creation of new ponds to capture and treat runoff though sedimentation	30	WinSLAMM
IESF Basins and Benches	IESF	A filtration basin or retention pond enhancement that filters stormwater through an iron-rich sand medium, thereby binding DP	30	WinSLAMM
Permeable Check Dams	CD	Permeable rock features that obstruct the flow of water through the ditch, increasing sedimentation and allow for filtration through the dam	20	WinSLAMM

Project Categories

Projects fall into one of three general categories: cultural, vegetative, and structural. Cultural practices are those that must be continued by land use managers each year in order for the benefits to persist. Vegetative practices are installed and may persist without active management or maintenance but are also easy and inexpensive to remove or denude, either intentionally or inadvertently. Structural practices are physically robust measures that also require maintenance but are difficult and expensive to remove. Thus, the resultant benefits are much less likely to be rapidly lost, barring catastrophic structural failure. The durability of a project, and therefore the persistence of benefits, is greatest for structural practices and least for cultural practices. This is not meant to imply that cultural practices should not be pursued with educational and technical assistance outreach programs, but they were not the focus of this report because of their temporal nature and difficulty to model. The table below summarizes the categories which were included in this report and why.

Table 6: Project types considered and not considered throughout this study

Project Type	Category	Included in Report	Rationale	Cost-Effectiveness
Bioretention	Structural	Yes	One of few options for built-out, residential areas	Moderate-Low
Lakeshore Restorations	Structural/ Vegetative	Yes	100% of benefits to lake	High-Low
Wetland Restorations	Structural/ Vegetative	Yes	Multiple target pollutant and habitat benefits	High-Low
WASCOBs	Structural	Yes	Socially feasible option on agricultural land that needn't remove much land from production	High-Low
Vegetated Filter Strips/Grassed Waterways	Vegetative	Yes	Included for comparative purposes, may be pursued instead of a SB but takes more land out of production	High
Regional Ponds	Structural	Yes	Neighborhood level and regional level treatment for multiple target pollutants, very durable	High-Moderate
IESF Basins and Pond Benches	Structural	Yes	Specialized method for removing DP	High-Moderate
Permeable Check Dams	Structural	Yes	Similar to IESFs in ability to remove DP	High-Moderate

Project Type	Category	Included in Report	Rationale	Cost-Effectiveness
Goose Removal	Cultural	No	Wholly cultural, can't model benefits, vegetative buffers may deter geese and provide more durable benefits	Unknown
Manure Application	Cultural	No	Wholly cultural, can't model benefits	High
Nutrient Management	Cultural	No	Wholly cultural, can't model benefits	High
Street Sweeping	Cultural	Yes	Included as a BMP currently being applied, no changes to this BMP were proposed though	High

Cost Estimates

Providing reasonable cost estimates is essential to ranking projects by cost-effectiveness, developing long term work plans, and securing funds. To capture the full cost of projects, construction costs, project design, project maintenance, promotion, and administration were included. These values are listed in detail in the tables and table footnotes within the *Catchment Profiles* section of this report.

Project promotion and administration includes local staff efforts to reach out to landowners, administer related grants, and complete necessary administrative tasks.

Design includes site surveying, drafting, engineering, and construction oversight.

Land or easement acquisition cover the cost of purchasing property or the cost of obtaining necessary utility and access easements from landowners. This was only applied to BMPs in the rural landscape.

Construction calculations are project specific and may include all or some of the following: grading, erosion control, vegetation management, structures, mobilization, traffic control, equipment, soil disposal, and rock or other materials.

Maintenance includes annual inspections and minor site remediation such as vegetation management, structural outlet repair and cleaning, and washout repair.

Location in Watershed

Network level modeling allows calculation of benefits to the receiving waterbody, not simply at the edge of field. However, due to model limitations most projects were modeled to determine their benefits at the edge of the field. The BWSR PRC and ArcSWAT are geared toward edge of field modeling in rural landscapes, whereas WinSLAMM is designed to calculate network level benefits in built-out environments. In order to translate edge of field benefits into benefits to the receiving waterbody, a pollutant delivery ratio (PDR) is used. PDRs can be highly complex calculations, including factors such as slope, distance to a water course, vegetative cover, distance to the receiving waterbody, the target pollutant, and intervening water quality treatment along the flow path. Incorporating all of these in a reproducible manner would require complex algorithms that are beyond the scope of this effort. A subjective PDR was provided as an example however. It was intuitively arrived at by a natural resource management professional utilizing maps showing the project location in the watershed, receiving waterbody, aerial photos, topography, and flow paths. Each project was assigned a factor from 0.4 to 1.0, representing the percentage of benefits that would transfer to the receiving waterbody. Local resource management professionals are encouraged to modify the PDR rankings based on their local knowledge of the landscape.

Project Selection

The combination of projects selected for pursuit could strive to achieve TP reductions in the most cost-effective manner possible. Several other factors affecting project installation decisions should be weighed by resource managers when selecting projects to pursue. These factors include but are not limited to the following:

- Total project costs
- Cumulative treatment
- Availability of funding
- Economies of scale
- Landowner willingness
- Project combinations with treatment train effects
- Non-target pollutant reductions
- Timing coordination with other projects to achieve cost savings
- Stakeholder input
- Number of parcels (landowners) involved
- Project visibility
- Educational value
- Long-term impacts on property values and public infrastructure

BMP Descriptions

BMP types proposed throughout the subwatershed are detailed in this section. This was done to provide greater detail to the reader concerning general practice guidelines and abilities as well as to reduce duplicative reporting. For each BMP type, the method of modeling, assumptions made, and cost estimate considerations are described. Additional information, including site location, size, and estimated cost and pollutant reduction potential are noted in detail in the *Catchment Profiles,* while modeling information can be found in *Appendix A*. Project types included in the following sections are:

- Bioretention
    - Curb-cut Rain Gardens
    - Boulevard Bioswales
    - Rain Leader Disconnect Rain Gardens
- Lakeshore Restorations
- New Wet Retention Ponds
- Iron-Enhanced Sand Filters
- Permeable Check Dams
- Vegetated Filter Strips/Grassed Waterways
- Water and Sediment Control Basins (WASCOBs)
- Wetland Restorations

Bioretention

Bioretention is a BMP that uses soil and vegetation to treat stormwater runoff from roads, driveways, roof tops, and other impervious surfaces. Differing levels of volume and/or pollutant reductions can be achieved depending on the type of bioretention selected.

Bioretention can function as either filtration (biofiltration) or infiltration (bioinfiltration). Biofiltration BMPs are designed with a buried perforated drain tile that allows water in the basin to discharge to the stormwater drainage system after having been filtered through the soil. Bioinfiltration BMPs have no underdrain, ensuring that all water that enters the basins will either infiltrate into the soil or be evapotranspired into the air. Bioinfiltration provides 100% retention and treatment of captured stormwater, whereas biofiltration basins provide excellent removal of particulate contaminants but limited removal of dissolved contaminants, such as DP, and stormwater volume.

The treatment efficacy of a particular bioretention project depends on many factors, including but not limited to the pollutant of concern, the quality of water entering the project, the intensity and duration of storm events, project size, position of the project in the landscape, existing downstream treatment, soil and vegetation characteristics, and project type (i.e. bioinfiltration or biofiltration). Optimally, new bioretention will capture water that would otherwise discharge into a priority waterbody untreated. Table 7 conveys the general efficacy of the two types of curb-cut rain gardens (biofiltration and bioinfiltration) in terms of the three most common pollutants, TSS, DP, particulate phosphorus (PP), and stormwater volume.

Table 7: Matrix describing curb-cut rain garden efficacy for pollutant removal based on type

Curb-cut Rain Garden Type	TSS Removal	PP Removal	DP Removal	Volume Reduction	Size of Area Treated	Site Selection and Design Notes
Bioinfiltration	High	High	High	High	High	Optimal sites are low enough in the landscape to capture most of the watershed but high enough to ensure adequate separation from the water table for treatment purposes. Higher soil infiltration rates allow for deeper basins and may eliminate the need for underdrains.
Biofiltration	High	Moderate	Low	Low	High	

Bioinfiltration projects have increased utility when looking to meet the City of Cambridge's ordinance to infiltrate or otherwise treat the first 1" of stormwater runoff from any new development site. The existing network of stormwater retention ponds are designed to treat TP and TSS but are less effective in reducing stormwater volume. This is because little infiltration occurs along the pond bottom, leaving evapotranspiration as the best route in removing water from the practice. Bioinfiltration practices placed upstream of these ponds will increase volume retention (as well as TP and TSS retention). Bioinfiltration practices are really the only cost-effective option in this urban landscape for treating stormwater volume, and should be pursued when this is a target pollutant.

The volume and pollutant removal potential of each bioretention practice was estimated using WinSLAMM. In order to calculate cost-benefit, the cost of each project had to be estimated. To fully estimate the cost of project installation, labor costs for project outreach and promotion, project design, project administration, and project maintenance over the anticipated life of the practice were considered in addition to actual construction costs. Rain gardens were modeled and priced on a per garden basis. In terms of cost, significant savings could be achieved for administration and promotion (and possibly construction costs for a large and competitive bid) if more than one garden is installed for a particular project.

Curb-cut Rain Gardens

Curb-cut rain gardens capture stormwater that is in roadside gutters and redirect it into shallow roadside basins (Figure 3: Curb-cut rain gardens before and during rainfall events). Curb-cut rain gardens can provide treatment for impervious surface runoff from one to many properties and can be located anywhere sufficient space is available. Because curb-cut rain gardens capture water that is already part of the stormwater drainage system, they are more likely to provide higher benefits. Generally, curb-cut rain gardens were proposed in areas without sufficient existing stormwater treatment (or where treatment could be enhanced) and located immediately up-gradient of a catch basin serving a large drainage area.

Figure 3: Curb-cut rain gardens before and during rainfall events

In the urban and residential catchments studied in this analysis, most existing and proposed housing developments already contain at least one stormwater retention pond. These BMPs, generally speaking, provide sufficient treatment of sediment and other particulate pollutants. Any practices proposed upstream of these ponds should primarily provide treatment for dissolved pollutants. For this reason, underdrains are not recommended for rain gardens proposed upstream of a properly-sized retention pond.

To determine garden sizing (both top area and ponding depth), three factors were explored, including contributing drainage area, possibility to install a second inlet (called a “double-cut” rain garden), and native soil characteristics. A double cut rain garden is a garden installed with two inlets, each placed on either side of a stormwater catch basin. The additional inlet allows for input from the gutter on both sides of the catch basin, increasing pollutant retention of the BMP (especially during small rainfall events). Double-cut rain gardens were often modeled with a larger top area, 350 sq-ft, to provide more storage for the increased drainage area.

Soil characteristics must be determined at a potential site to ensure ponding does not occur for more than 24-48 hours. It is recommended that a soil survey be conducted to determine the infiltration rate of native soils. For this analysis, gardens with an expected infiltration rate of less than 1” per hour were modeled with only a 6” ponding depth. For gardens with an expected infiltration rate of greater than 1” per hour, ponds were modeled with a 12” ponding depth.

Tables in the *Catchment Profiles* section describe the most cost-effective scenarios run for each project site. Variables explored include garden storage (described in each table by top area), pond depth, and native soil infiltration rate. All gardens were presumed to have pretreatment, mulch, and perennial ornamental and native plants. The useful life of the project was assumed to be 20 years and so all costs are amortized over that time period. Additional costs were included for rehabilitation of the garden after 10 years. Annual maintenance was assumed to be completed by the landowner of the property at which the rain garden could be installed.

In cases where sidewalks are present, installing a standard curb-cut rain garden (often with a 250 sq-ft top area) can be problematic. A rain garden outside of the right-of-way requires costly retrofits to the sidewalk, such as installing a trench grate across the sidewalk or burying a drain under the sidewalk. The most cost-effective option is often installing a smaller but longer garden between the sidewalk and curb, called a “curb-cut boulevard rain garden”. These practices were modeled in WinSLAMM with either a 6” or 12” ponding depth and an 80 sq-ft top area (20’ in length parallel to roadway by 4’ in width perpendicular to roadway) for a single-cut rain garden or a 120 sq-ft top area for a double-cut garden. Similar to the larger gardens, the useful life of the project was assumed to be 20 years and so all costs were amortized over that time period. Additional costs were included for rehabilitation of the garden after 10 years. Annual maintenance was assumed to be completed by the landowner of the property at which the rain garden could be installed.

Boulevard Bioswales

Another option for retrofitting a stormwater BMP within a small boulevard may be a bioswale. This practice is similar to the boulevard rain garden in its orientation and size. Bioswales typically range from 5-30’ in length, house a rich native plant community, and are installed between the existing sidewalk and roadway curb (Figure 4). Unlike rain gardens, these practices are typically much shallower (1-3” in depth) and have a curb-cut inlet and outlet. Although many rain gardens have outlets in the form of underdrains or risers, the bioswale outlet allows for a nearly continuous flow of stormwater through the practice. Although some infiltration does occur, the primary form of treatment is the settling of pollutants as stormwater flows through the dense plant community.
This practice, similar to curb-cut rain gardens, was modeled in WinSLAMM to estimate the pollutant reduction capacity for TSS, TP, and stormwater volume. Each modeled scenario included a 20’ long (parallel to roadway), 4’ wide (perpendicular to roadway), and 3” deep bioswale with infiltration rates of 0.2” per hour or 1.0” per hour depending on native soil

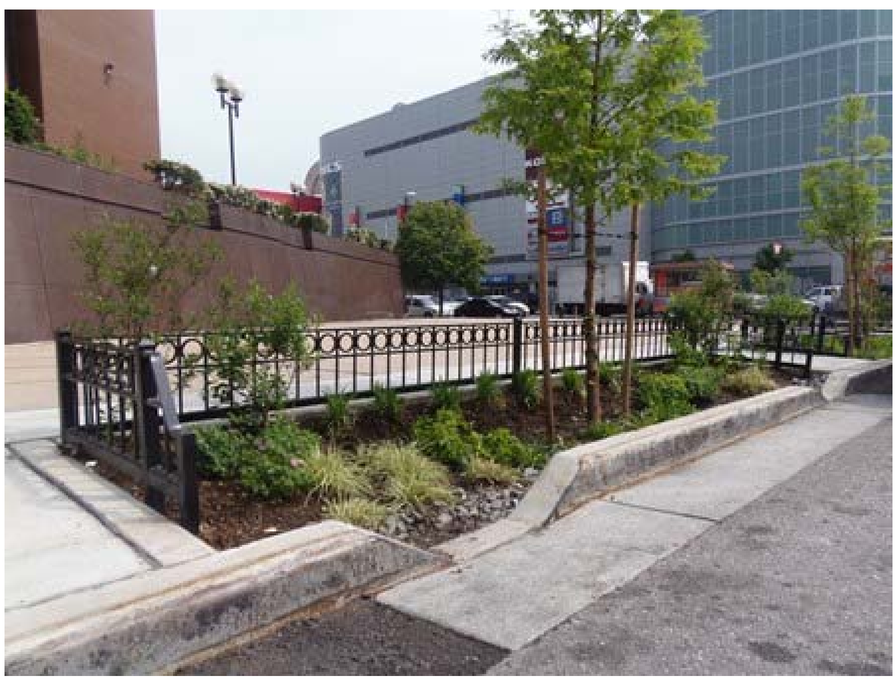


Figure 4: Right-of-way bioswale installed in New York City (NYC Environmental Protection, 2013)

characteristics. No underdrain was modeled with this practice as they are designed to be flow-through systems with limited ponding (≤ 3”).

Rain Leader Disconnect Rain Gardens

Rain leader disconnect rain gardens capture stormwater that is redirected to the garden as it discharges from gutter downspouts. Generally, they are positioned near buildings in lower areas of the property and provide treatment only for stormwater runoff generated on roof tops and upland portions of the property. Therefore, many rain leader disconnect rain gardens intercept water that would have been filtered through turf grass or other vegetation, or even infiltrated, thereby providing reduced water quality benefit relative to practices that treat runoff already in the stormwater conveyance system (e.g. curb-cut rain gardens). Table 8 conveys the general efficacy of the two types of rain leader disconnect rain gardens (biofiltration and bioinfiltration) in terms of the three most common pollutants, TSS, PP, DP, and stormwater volume.

As this practice can be installed in virtually any residential lot with gutter downspouts, benefits were estimated for a typical property in the research area. A 6” deep, 250 sq-ft garden was modeled in WinSLAMM with a contributing drainage area of 0.25 acres. The contributing drainage area consisted primarily of runoff from rooftops and landscaped areas (i.e. yards). Model results for this practice found they were not cost-effective for any of the urban catchments as they treated relatively small areas (usually only a portion of the property they’re installed upon) and required a large cluster of them to have a significant effect above existing stormwater infrastructure including stormwater retention ponds and street cleaning. No rain leader disconnect rain gardens were proposed in the *Catchment Profiles* sections of this report.

Table 8: Matrix describing rain leader disconnect rain garden efficacy for pollutant removal based on type.

Rain Leader Disconnect Rain Garden Type	TSS Removal	PP Removal	DP Removal	Volume Reduction	Size of Area Treated	Site Selection and Design Notes
Bioinfiltration	High	High	High	High	Low	Optimal sites are those where downspout discharge makes it into the stormwater drainage system, a simple downspout redirection into vegetated areas is not sufficient to treat runoff, concentrated flow occurs, and adequate treatment is absent.
Biofiltration	High	Moderate	Low	Low	Low	

Lakeshore Restorations

Lakeshore restoration involves the correction or prevention of erosion at the shoreline, often with the addition of native plants that filter runoff and offer habitat benefits. Phosphorus is carried on the eroded sediment into the waterbody, where, through a series of chemical reactions, it can become available for uptake by plants, contributing to algal blooms. The sediment can also smother fish habitat, reduce water clarity, and reduce lake depth as it fills in lower areas. For a lakeshore homeowner, stopping shoreline erosion preserves their real estate from washing away. Pursuing lakeshore stabilizations as a means of improving lake water quality is highly cost-effective since 100% of the pollutants would have made it directly into the lake.

Figure 5: Photographs during (left) and years after (right) a shoreline restoration

Lakeshore stabilization designs are site specific and need to take into account soil type, existing vegetation, slope, overland flow, wave action due to recreational activity, fetch, orientation, and landowner desires (Figure 6). Designs range from a solely vegetative treatment with no site grading, to complete slope grading and hard armoring. Costs also vary widely based on these factors as well as site access, regulatory requirements, and the length of treatment area.

For the purpose of this analysis, cost/linear foot was estimated based on erosion severity and the likely approach to stabilization efforts falling into one of two categories; 1) rock toe restoration with heavy equipment grading, or 2) BioLog with manual grading and plantings. The former was estimated at $150/linear foot and the latter was estimated at $70/linear foot. A vegetated shoreline buffer was also included for each

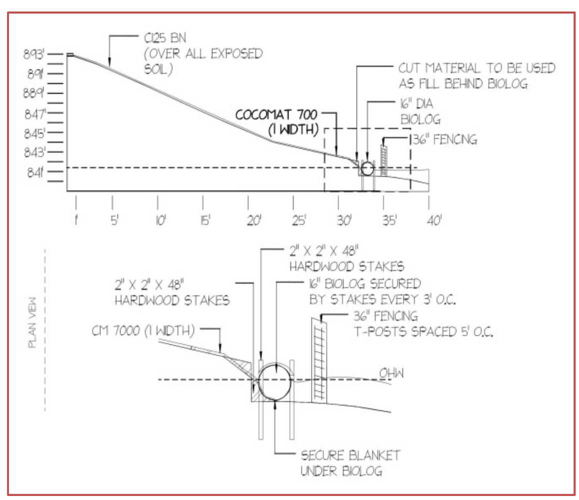


Figure 6: Typical Cross Section - Simple Design

proposed practice to help treat runoff from the shore and offer near-shore habitat (Figure 7).

An inventory of all active erosion sites was completed for the entire shoreline of Florence, Elms, Fannie, and Skogman Lakes. Instances of erosion were classified according to severity. Erosion severity determinations and soil loss estimates were calculated utilizing the Wisconsin NRCS direct volume method recession rate classifications. Methodologies are described in greater detail in *Appendix A*.

Additional variables included with the cost to install the project are promotion and administration, estimated to take 35 hours at $73/hour, project design for $1,500, and annual maintenance costing $1.50/linear-ft. Cost assumptions made to calculate the cost-benefit of each project should be verified against local experience while creating implementation plans.

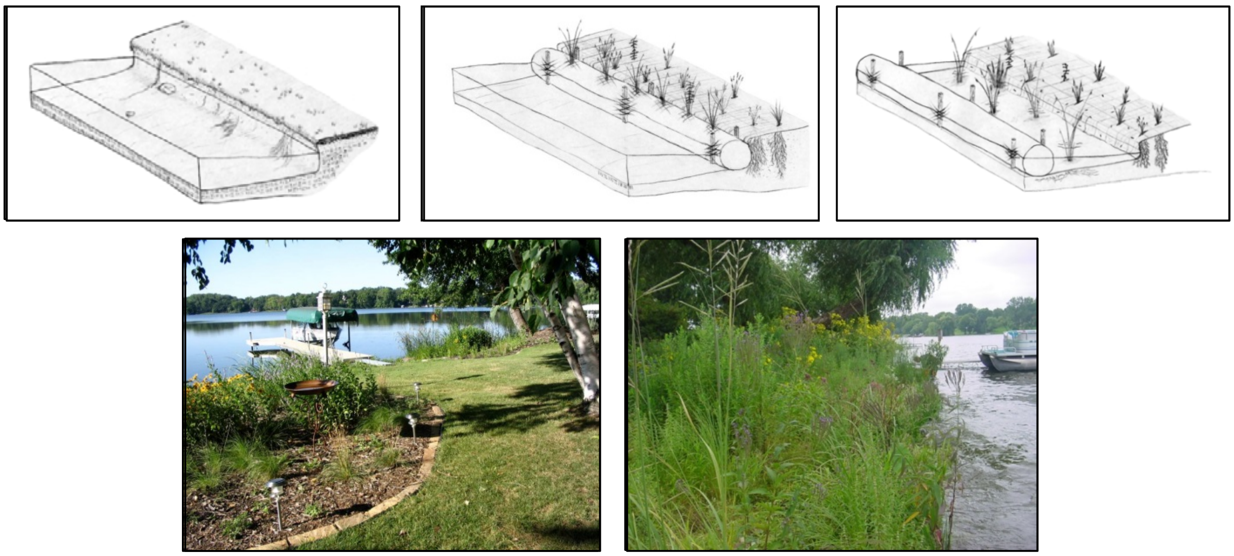


Figure 7: Conceptual images for native plant restorations

New Wet Retention Ponds

If properly designed, wet retention ponds have controlled outflows to manage discharge rates and are sized to achieve predefined water quality goals (Figure 8). Wet retention ponds treat stormwater through a variety of processes, but primarily through sedimentation. Ponds are most often designed to contain a permanent pool storage depth; it is this permanent pool of water that separates the practice from most other stormwater BMPs, including detention ponds.

Wet retention pond depth generally ranges from 3-8' deep. If ponds are less than 3' deep, winds can increase mixing through the full water depth and resuspend sediments, thereby increasing turbidity. Scour may also occur during rain events following dry periods. If more than 8' deep, thermal stratification can occur creating a layer of low dissolved oxygen near the sediment that can release bound phosphorus.

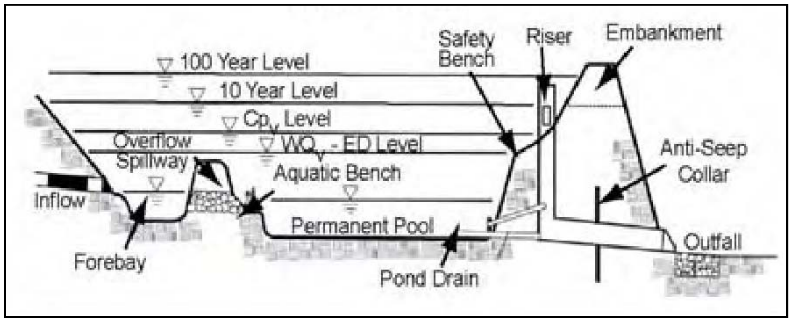


Figure 8: Schematic of a stormwater retention pond. Figure from the Urban Subwatershed Restoration Manual Series, Chapter 3: Urban Stormwater Retrofit Practices.

Above the permanent pool depth is the flood depth, which provides water quality treatment directly following storm events. Separating the permanent pool depth and the flood depth is the primary outlet control, which is often designed to control outflow rate. Configurations for the outlet control may include a V-notch or circular weir, multiple orifices, or a multiple-stage weir. Each of these can be configured within a skimmer structure or trash rack to provide additional capture of larger floating items. Above the flood depth is the emergency control structure, which is available to bypass water from the largest rainfall events, such as the 100-year precipitation event. Ponds also often include a pretreatment practice, either a forebay or sedimentation basin adjacent to the pond, or storm sewer sumps, hydrodynamic devices, or other basins further upstream from the practice.

Outside of sedimentation, other important processes occurring in ponds are nutrient assimilation and evapotranspiration by plants. The addition of shoreline plants to pond designs has increased greatly since the 1980's because of the positive effects these plants were found to have for both water quality purposes and increasing terrestrial and aquatic wildlife habitat. The ability of the pond to regulate discharge rates should also be noted. This can reduce downstream in-channel erosion, thereby decreasing TSS and TP loading from within the channel.

With the multitude of considerations for these practices, ponds must be designed by professional engineers. This report provides a rudimentary description of ponding opportunities and cost estimates for project planning purposes. In order to calculate cost-benefit, the cost of each project had to be estimated. All new stormwater ponds were assumed to involve excavation and disposal of soil, installation of inlet and outlet control structures and emergency overflow, land acquisition, erosion control, and vegetation management. Additionally, project engineering, promotion, administration, construction oversight, and long-term maintenance (including annual inspections and removal of accumulated sediment/debris from the pretreatment area) had to be considered in order to capture the true cost of the effort. Complete pond dredging is not included in the long-term maintenance cost because project life is estimated to be 30 years. Load reduction estimates for these projects are noted in the *Catchment Profiles* section.

The regional pond proposed in this analysis was designed and simulated within the water quality model ArcSWAT, which takes into account upland pollutant loading, pond bathymetry, and biochemical processes within the pond to estimate stormwater volume, TSS, and TP retention capacity. The model was run with and without the identified project and the difference in pollutant loading was calculated.

Iron-Enhanced Sand Filters

Current approaches to removing dissolved pollutant species, including phosphorus and metals, target infiltration practices such as rain gardens (without underdrains) and infiltration basins. Oftentimes poor soil infiltration rates or a high water table can make these practices impractical. Another option may be incorporating a soil amendment and underdrain to these practices to increase pollutant retention and allow for timely drainage of stormwater from the practice. One such approach that has found success in recent years was developed by the University of Minnesota and uses iron mixed with sand to create a media well-suited to binding with and retaining dissolved pollutants (Erickson and Gulliver, 2010). This technology, known as an iron-enhanced sand filter (IESF) or locally as the Minnesota Filter, has been most often applied in two distinct formats:

1) Retention pond IESF bench
2) IESF basin

Retention Pond IESF Bench

Wet retention ponds, although very effective in treating stormwater for suspended sediment and nutrients bound to sediment, have shown a limited ability at retaining dissolved species of nutrients. This is most notable for phosphorus. Median values for pollutant removal percentage by wet retention ponds are 84% for TSS and 50% for TP (MN Stormwater Manual; Minnesota Stormwater Steering Committee, 2014). For the case of phosphorus, dissolved species typically constitute 40-50% of TP in urban stream systems, but only 34% (median efficiency; Weiss et al., 2005) of DP is treated by the pond. Thus, a majority of the phosphorus escaping wet retention ponds is in dissolved form. This has important effects downstream as DP is a readily available nutrient for algal uptake in waterbodies and can be a main cause for nutrient eutrophication.

To augment DP retention in existing stormwater ponds, an IESF bench can be retrofit along the pond bank nearest the outlet. The IESF bench relies on the properties of iron to bind DP as it passes through an iron-rich medium. Depending on topographic characteristics of the installation site, IESF benches can rely on gravitational flow and natural water level fluctuation, or water pumping to hydrate the IESF. IESF benches must be designed to prevent anoxic conditions in the filter medium because such conditions will release the bound phosphorus. Because IESFs are intended to remove DP and not organic phosphorus, they are typically constructed just downstream of stormwater ponds, minimizing the amount of suspended solids that could compromise their efficacy and drastically increase maintenance. As an alternative to an IESF bench, a ferric-chloride injection system could be installed to bind DP into a flocculent, which would settle in the bottom of the new pond.

Figure 9 shows an IESF bench that is installed at an elevation slightly above the normal water level of the pond so that following a storm event the increase in depth of the pond would be first diverted to the IESF bench. The filter would have drain tile installed along the base of the trench and would outlet downstream of the current pond outlet. Large storm events that overwhelm the IESF bench’s capacity would exit the pond via the existing outlet.

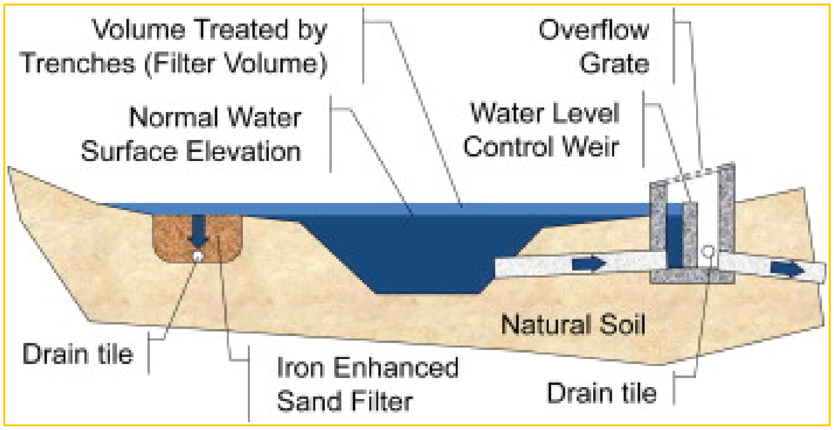


Figure 9: Iron-Enhanced Sand Filter Concept (Erickson & Gulliver, 2010)

Benefits for stormwater ponds were modeled utilizing WinSLAMM for urban catchments and ArcSWAT for rural catchments. After selecting an optimal pond configuration in terms of cost-benefit, or by using the existing pond configuration if no updates are needed, modeling for an IESF bench was also completed in WinSLAMM. WinSLAMM is able to calculate flow through constructed features such as rain gardens with underdrains, soil amendments, and controlled overflow elevations. An IESF bench works much the same way. Storm event based discharge volumes and phosphorus concentrations estimated by WinSLAMM after construction of the pond were entered into WinSLAMM as inputs into the IESF bench (baseflow, if the pond is installed in-line, was discounted as it would bypass the IESF). Various iterations of IESF benches were modeled to identify an optimal treatment level compared to construction and maintenance costs. A detailed account of the methodologies used is included in *Appendix A*. To account for the DP treated by the IESF bench, an additional 80% DP removal was assumed for each IESF bench in addition to any removal by the pond. This value is based on laboratory and field tests performed by the University of Minnesota (Erickson & Gulliver, 2010) and assumes only removal of DP species within the device. Load reduction estimates for these projects are noted in the *Catchment Profiles* sections.

In order to calculate cost-benefit, the cost of each project had to be estimated. IESF bench projects were assumed to involve some excavation and disposal of soil, land acquisition (if necessary), erosion control, and vegetation management. Additionally, project engineering, promotion, administration, construction oversight, and long-term maintenance had to be considered in order to capture the true cost of the effort. Annual maintenance costs were estimated to be $10,000 per acre of IESF based on information received from local private consulting firms.

IESF Basin

IESF basins function in much the same way filtration basins do, with stormwater entering through a curb-cut or culvert inlet, passing through a filter media, and intercepted by an underdrain positioned at the bottom of the basin. These practices are "enhanced" with the addition of an iron-rich sand media positioned around the underdrain (Figure 10). Similar to an IESF bench, the iron-sand mix within the basin increases the capacity of the practice to retain dissolved pollutant species, notably phosphorus.

These practices were modeled using the water quality model WinSLAMM. Projects were sized based on the contributing drainage area size and land use type as well as any known site constraints. Pollutant and stormwater volume removal were determined using two separate modeling iterations, both performed in WinSLAMM. First, pollutant and stormwater volume retention from within the filtration basin were determined assuming an infiltration rate of 0.2" per hour. Additional model inputs are noted in *Appendix A*. Secondly, based on laboratory experiments performed by the University of Minnesota (Erickson & Gulliver, 2010) we presumed that 80% of DP passing through the sand filter is retained prior to reaching the underdrain. Underdrain discharge and the DP concentration of water reaching the underdrain were used to determine the weight of DP in lbs retained within the media.

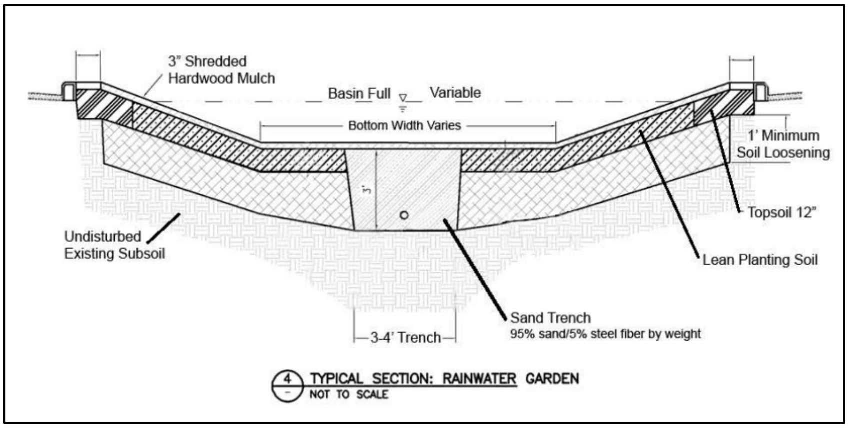


Figure 10: Typical IESF basin detail (http://www.minnesotaikes.org/Summit/Summit-2013/Maplewood%20Mall_MEK2.pdf)

In order to calculate cost-benefit, the cost of each project had to be estimated. IESF bench projects were assumed to involve some excavation and disposal of soil, land acquisition (if necessary), erosion control, and vegetation management. Additionally, project engineering, promotion, administration, construction oversight, and long-term maintenance had to be considered in order to capture the true cost of the effort. Annual maintenance costs were estimated to be $10,000 per acre of IESF based on information received from local private consulting firms.

Permeable Check Dams

Permeable check dams provide additional treatment for pollutants within ditches and grassed waterways through two processes. First, the dams act as a barrier to flow through the channel, allowing sediment and particulate pollutants to drop out of solution upstream of the dam. This promotes infiltration and evaporation of stormwater as well. Second, any water retained behind the dam can seep through a sand filter located within the rock dam. The sand, mixed with iron filings (similar to IESF benches and basins), creates an opportunity for dissolved pollutant species to be filtered out of the stormwater runoff.

Figure 11: Rock check dams in a small ditch (www.casfm.org/stormwater_committee/LID-Summary.htm)

These practices are often installed in a series, from two to a dozen practices depending on the length and slope of the ditch or waterway (Figure 11). They include an inner sand filter mixed with iron filings. The ratio of iron filings to sand should be between 5-8% by weight and these should be mixed thoroughly prior to installation. The sand-iron mix should be encased within a permeable membrane allowing for flow in and out of the filter. This filter is surrounded by rocks to promote settling and inhibit clogging of the filter.

It is recommended that these dams are installed such that the buried rock toe of the upstream dam is at the same elevation as the top of any downstream dams (Figure 12Figure 12: Check dam schematic (MPCA 2000)). This reduces the likelihood of scouring downstream of dams as water flowing over the dam intercepts ponded water rather than erodible soil. Also, the top of the most upstream dam should be installed below the outlet elevation of any pipe draining to the practice to ensure water does not back up into the upstream storm sewer infrastructure.

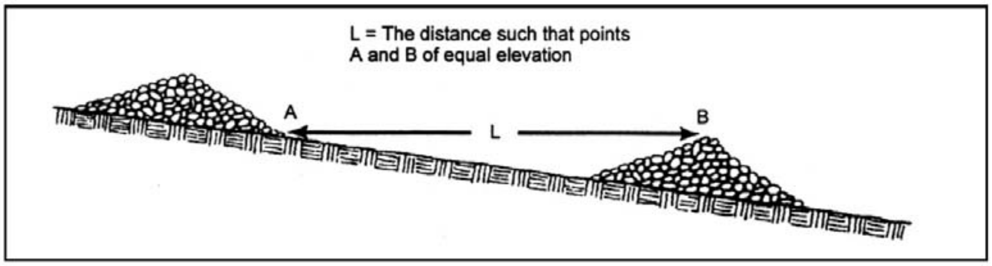


Figure 12: Check dam schematic (MPCA 2000)

The pollutant removal potential of permeable check dams was estimated using WinSLAMM. The ponding volume behind the dams was determined using LIDAR. Based on results of other IESFs, it was assumed that 80% of DP flowing through the dam was retained (Erickson & Gulliver, 2010). In order to calculate cost-benefit, the cost of each project had to be estimated. To fully estimate the cost of project installation, labor costs for project outreach, promotion, design, administration, and maintenance over the anticipated life of the practice were considered in addition to actual construction costs. Load reduction estimates for these projects are noted in the *Catchment Profiles* section.

Vegetated Filter Strips & Grassed Waterways

Vegetated filter strips are areas of vegetation planted between agricultural fields and surface waters to trap sediment, nutrients, organics and other contaminants in runoff (Figure 13). Grassed waterways function similarly but are vegetated flowages within a farm field (Figure 14). The effectiveness of filter strips and grassed waterways is well documented. Efficacy varies depending on factors such as the slope, soil type, and vegetative cover of the contributing drainage area as well as the width and vegetation type of the practice. The Agricultural BMP Handbook of Minnesota provides a thorough description of available research.

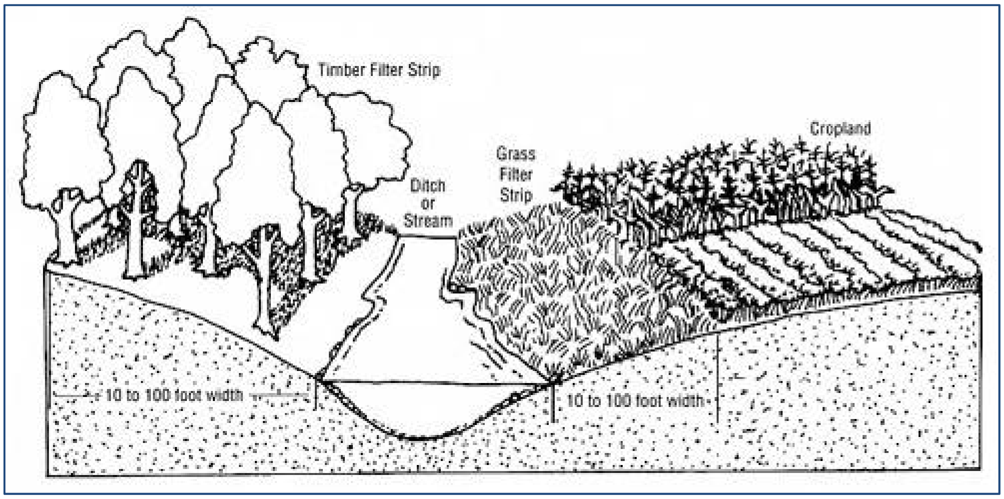


Figure 13: Filter Strip (Ohio State University Extension, web)

Filter strips and grassed waterways were only proposed in areas where active agricultural activities were occurring within 30’ of a hydraulically-connected water course. Approximately 80% of TSS is removed within the first 7.5 meters of filter strip. Dissolved constituents see much less removal and so the marginal value rapidly decreased compared to the opportunity cost of not having the land in production. This is the only non-structural practice to be presented as a proposed BMP in this analysis. While non-structural practices tend to be more cost-effective in the short term, they also tend not to remain as long on the landscape since they are easy for landowners to remove.


Figure 14: Grassed waterway (US Department of Agriculture, web)

Benefits of filter strips/grassed waterways were modeled utilizing ArcSWAT. This model combines inputs of hydrography, topography, soils, and land cover in a GIS interface and determines runoff volume and pollutant loading based on these inputs. ArcSWAT includes a filter strip tool that facilitates rapid modeling of multiple scenarios. The model was run with and without the identified project and the difference in pollutant discharge was noted. Each site was modeled with multiple vegetated filter or waterway sizes. The narrowest width that achieved the greatest relative benefit was selected to minimize land taken out of production. A detailed account of the methodologies used is included in *Appendix A*.

Because modeling was done on very small land units, water quality data were not available to calibrate the model. Model outputs are best estimates based on available data but may vary greatly from observed field conditions. Furthermore, the models predicted benefits to the adjacent water course but not necessarily benefits to the receiving waterbody. For pollutants held in suspension in the water column such as TSS, projects that are closer to the lake may be preferred to projects farther away even if the project benefits are greater for the farther projects. For dissolved pollutants such as DP or chlorides, the distance from the receiving waterbody is less critical. Ultimately, it will be the purview of watershed management professionals to select projects to pursue. To facilitate this process, maps for each project showing the location in the watershed are provided.

In order to determine cost-benefit, the cost of each project had to be estimated. To fully estimate the cost of project installation, labor costs for project outreach and promotion, project design, easement acquisition, project administration, and project maintenance over the anticipated life of the practice were considered in addition to actual installation costs. The cost of lost agricultural production was also considered. The installation costs vary depending on area of practice to be installed. The cost of design, landowner outreach, project administration, and construction oversight are comparable regardless of the project size and so those costs are held constant between projects.

Total cost for each project was calculated over 20 years assuming project design and construction oversight were $6,000, landowner outreach, and general project coordination would take 65 hours total at $73/hr. Lost production costs were valued at $800/acre/year, while filter strip establishment cost was estimated at $200/acre. Annual inspection and maintenance costs were estimated to be $300. Cost assumptions made to calculate the cost-benefit of each project should be verified against local experience while creating implementation plans.

Water and Sediment Control Basin (WASCOB)

Water and sediment control basins (WASCOBs) are designed to detain water long enough for the sediment in suspension to drop out of the water column. This is typically done by creation of an earthen embankment across a natural flowage along with an underdrain and riser to allow water to pass under the berm (Figure 15). WASCOBs should not pond more than 12" and for no more than 24 hours to ensure that crops are not overly stressed. This allows all but the berm to remain in production. There are many alternative designs including using a washed stone berm that allows water to pass through it or allowing a portion of the basin to remain ponded to gain additional water quality benefits. Other designs also include shorter berms which can allow for the berm to remain in production.

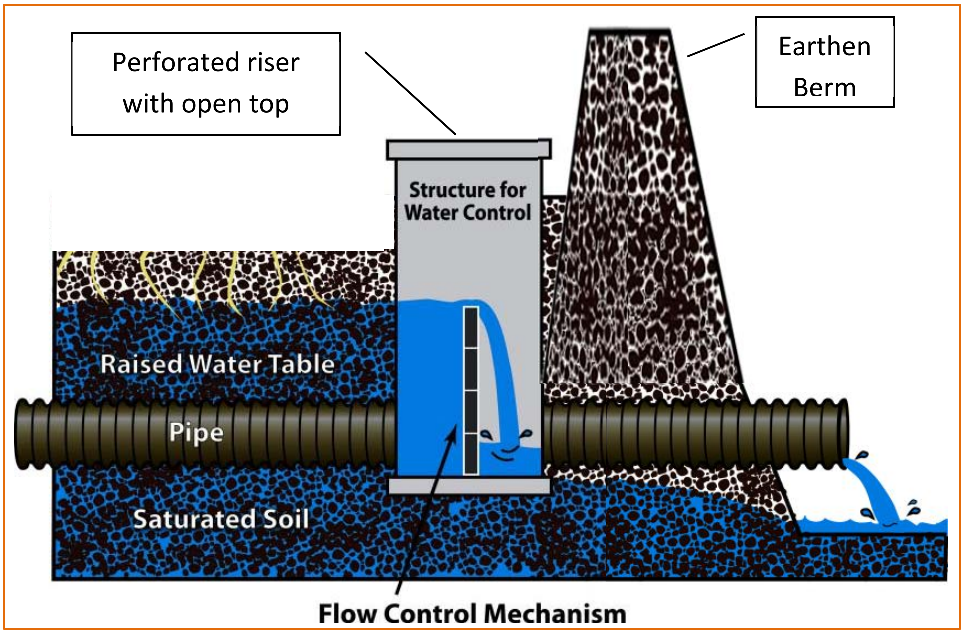


Figure 15: Water Control Attached to Drain Tile (illustration courtesy of Illinois NRCS - modified)

Benefits of WASCOBs were modeled utilizing ArcSWAT. This model combines inputs of hydrography, topography, soils, and land cover in a GIS interface and determines runoff volume and pollutant loading based on these inputs. WASCOBS were modeled as ponds to determine pollutant load reductions with volume reductions negated. The model was run with and without the identified project and the difference in pollutant discharge was noted. Each site was modeled at multiple pool depths. An average depth of 1' was selected to avoid extensive crop stress. A detailed account of the methodologies used is included in *Appendix A*. Professionally engineered designs will be necessary for all WASCOBs to ensure appropriate drainage is achieved. USDA NRCS staff may be able to provide design services.

Because modeling was done on very small land units, water quality data were not available to calibrate the model. Model outputs are best estimates based on available data but may vary greatly from observed field conditions. Furthermore, the models predicted benefits to the adjacent water course but not necessarily benefits to the receiving waterbody. For pollutants held in suspension in the water column such as TSS, projects that are closer to the lake may be preferred to projects farther away even if the project benefits are greater for the farther projects. For dissolved pollutants such as DP or chlorides, the distance from the receiving waterbody is less critical. Ultimately, it will be the purview of watershed management professionals to select projects to pursue. To facilitate this process, maps for each project showing the location in the watershed are provided.

In order to determine cost-benefit, the cost of each project had to be estimated. To fully estimate the cost of project installation, labor costs for project outreach and promotion, project design, easement acquisition, project administration, and project maintenance over the anticipated life of the practice were considered in addition to actual construction costs. Total cost for each project was calculated over 20 years assuming project design and construction oversight were $10,000, easement administration and coordination, landowner outreach, and general project coordination would take 85 hours at $73/hour, and annual inspection and maintenance costs would be $500. Structure installation is $4,000 per control structures/4000 cu-meters of storage. Earthen berms cost $40/cu-yd. installed.

All projects were assumed to use a water control structure. Although more expensive to install, they guarantee that the landowner will be able to manage water levels and ponding durations to achieve the multiple benefits of crop production and water quality improvement. The installation costs of WASCOBs vary depending on the number of structures and the size of earthen berms. The cost of design, hydraulic modeling, landowner outreach, project administration, and construction oversight are comparable regardless of the structure size and so those costs are held constant between projects. Cost assumptions made to calculate the cost-benefit of each project should be verified against local experience while creating implementation plans.

Wetland Restorations

The natural hydrologic systems throughout the study area have been altered by ditching, channelizing, impounding, tiling, and piping. Many features of the drainage system were designed to shed water from the landscape quickly to prevent property damage due to flooding and to bring marginal land into crop production. Little thought was put into how such projects would impact downstream water quality, flooding, or erosion. Furthermore, partially drained wetlands with organic soils can become large sources of phosphorus because of biochemical processes if their hydrologic regime involves the right degree and duration of water level fluctuations.

Public projects undertaken to achieve drainage goals often involve fees and/or taxes charged to landowners. Upon payment of those taxes, landowners secure long term drainage rights. These rights are described in Minnesota's Public Drainage Law (MN Stat. 103e). The foundation of this law dates back to the late 1800's. When undergoing project planning and design, it is critical not to infringe on a landowner's drainage rights by installing a project that negatively impacts off-site drainage functions.

Current water management practices put greater emphasis on downstream impacts. Contemporary water management projects encourage holding water on the landscape long enough to encourage infiltration, achieve water quality benefits such as nutrient uptake and sediment detention, and control discharge rates and time of downstream concentration to reduce downstream flooding and erosion. Restoration of the hydrologic system is advantageous because it can achieve multiple benefits. This is done by plugging ditches, breaking tile lines, installing water level control structures, and realigning drainage ways. The figures below illustrate two structure concepts frequently used to restore hydrology.

For the purpose of this analysis, field reconnaissance focused on finding opportunities to restore natural hydrology or impound water on properties where few property owners would be involved, no impacts to upstream hydrology were anticipated, and limited negative impacts to residential and agricultural land uses were likely.

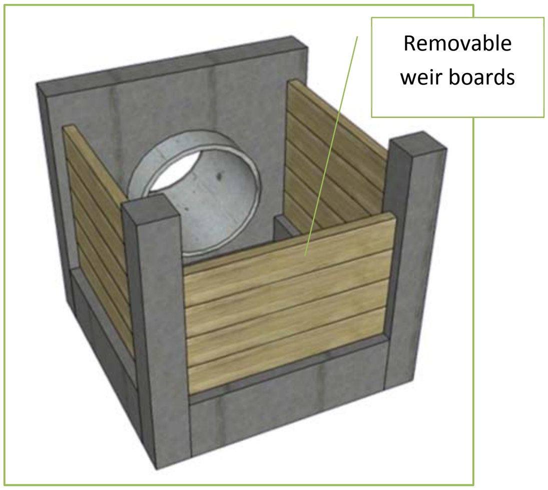


Figure 16: Box weir around a culvert

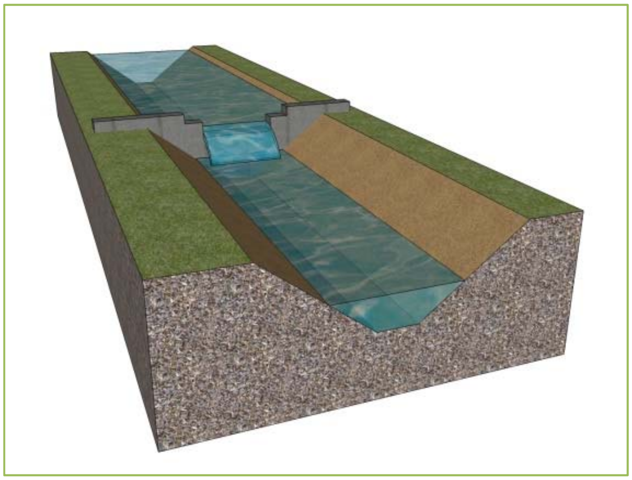


Figure 17: Channel weir

In some instances, hydrologic restoration can restore hydrology to partially drained systems without significantly expanding the size of the wetland. In other cases, hydrologic restoration will convert effectively drained wetland back into wetland. The former scenario can be classified as a hydrologic restoration, while the latter scenario can be classified as a true wetland restoration. This distinction is important for two reasons; 1) wetlands fall under the jurisdiction of several federal and state laws, and 2) there are additional private and public funding mechanisms and incentives for wetland restoration. Examples of the latter include the state wetland bank, which pays $10,000 per acre for wetland credits to offset impacts due to road projects or the private sector wetland bank, in which wetland credits typically sell for $.75-$1.25/sq-ft. Within this analysis, two cost-effective scenarios were found for restoring wetland hydrology in the SFEF subwatershed. Both projects would require a formal wetland investigation to determine whether a wetland exists on the site and what the limits of that wetland are.

If a site is determined to be a wetland, increasing ponding within that wetland can still be beneficial. Wetlands that are subject to frequent cycles of wetting and drying can become a large source of phosphorus due to complex biochemical processes. If wetland hydrology can be managed to maintain saturated conditions without drastically increasing the ponding depth, phosphorus discharge can be dramatically reduced. This can be achieved without making the wetland much larger in landscapes with steep slopes. The degree to which this is effective is highly dependent on each wetland's chemistry. Pre-project and post-project monitoring is strongly recommended to verify project success.

Benefits of wetland restoration projects were modeled utilizing ArcSWAT. This model combines inputs of hydrography, topography, soils, and land cover in a GIS interface and determines runoff volume and pollutant loading based on these inputs. The model was run with and without the identified project and the difference in pollutant discharge was noted. Each site was modeled at multiple pool restoration depths. The greatest depth that could be achieved without significantly flooding adjacent properties was selected. A detailed account of the methodologies used is included in *Appendix A*. Professionally engineered designs will be necessary for all hydrologic restoration projects to ensure drainage rights are not infringed upon.

Because modeling was done on very small land units, water quality data were not available to calibrate the model. Model outputs are best estimates based on available data but may vary greatly from observed field conditions. Furthermore, the models predicted benefits at the field edge but not necessarily benefits to the receiving waterbody. For pollutants held in suspension in the water column such as TSS, projects that are closer to the lake or main tributaries to the lake may be preferred to projects farther away even if the project benefits shows greater cost effectiveness for the farther projects. For dissolved pollutants such as DP or chlorides, the distance from the receiving waterbody is less critical. Rather than estimate the pollutant delivery ratio for each pollutant type, we focused our investigation on sites near the lakes and/or immediately adjacent to the drainage system. This approach will ensure that all identified projects have merit. Ultimately, it will be the purview of watershed management professionals to select projects to pursue. To facilitate this process, maps for each project showing the location in the watershed are provided.

In order to determine cost-benefit, the cost of each project had to be estimated. To fully estimate the cost of project installation, labor costs for project outreach and promotion, project design, easement acquisition, project administration, and project maintenance over the anticipated life of the practice were considered in addition to actual construction costs. As an example, the outlet control retrofit shown in Figure 18 cost only $8,450 to install, but design engineering, hydraulic modeling, project bidding, construction oversight, landowner outreach and education, and project reporting cost an additional $8,500.

Figure 18: Outlet Control Retrofit

Most wetland restoration projects use one of three structure types;

- box weirs (Figure 16)
- channel weirs (Figure 17)
- outlet control structure (Figure 19)

Channel weirs are used where flow is through an open ditch. Box weirs are used where flow is through a culvert. Water control structures allow landowners to dynamically manage subsurface drainage and surface ponding to achieve hydrologic goals by raising or lowering the flow mechanism. Within this analysis, both proposed projects each utilize a box weir.

To pond water, control structures must be coupled with an earthen berm unless a natural berm already exists. The installation costs of these practices vary greatly but the cost of design, hydraulic modeling, landowner outreach, project administration, and construction oversight are comparable regardless of the structure type.

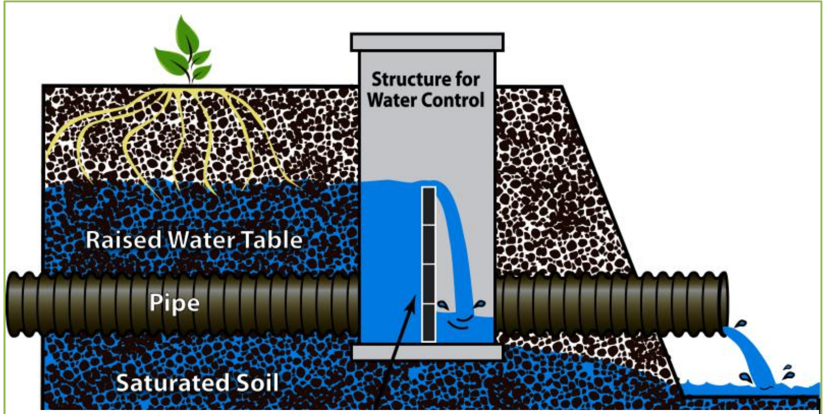


Figure 19: Water Control Attached to Drain Tile (illustration courtesy of Illinois NRCS)

Total cost for each project was calculated over 20 years assuming easement costs of $20,000/acre, project design and construction oversight of $10,000, easement administration and coordination, landowner outreach, and general project coordination taking 85 hours at $73/hr, and annual inspection and maintenance costs of $500. Structure installation is $4,000 for control structures without berms. Earthen berms cost $40/cu. yd. installed. Cost assumptions made to calculate the cost-benefit of each project should be verified against local experience while creating implementation plans.

Catchment Profiles

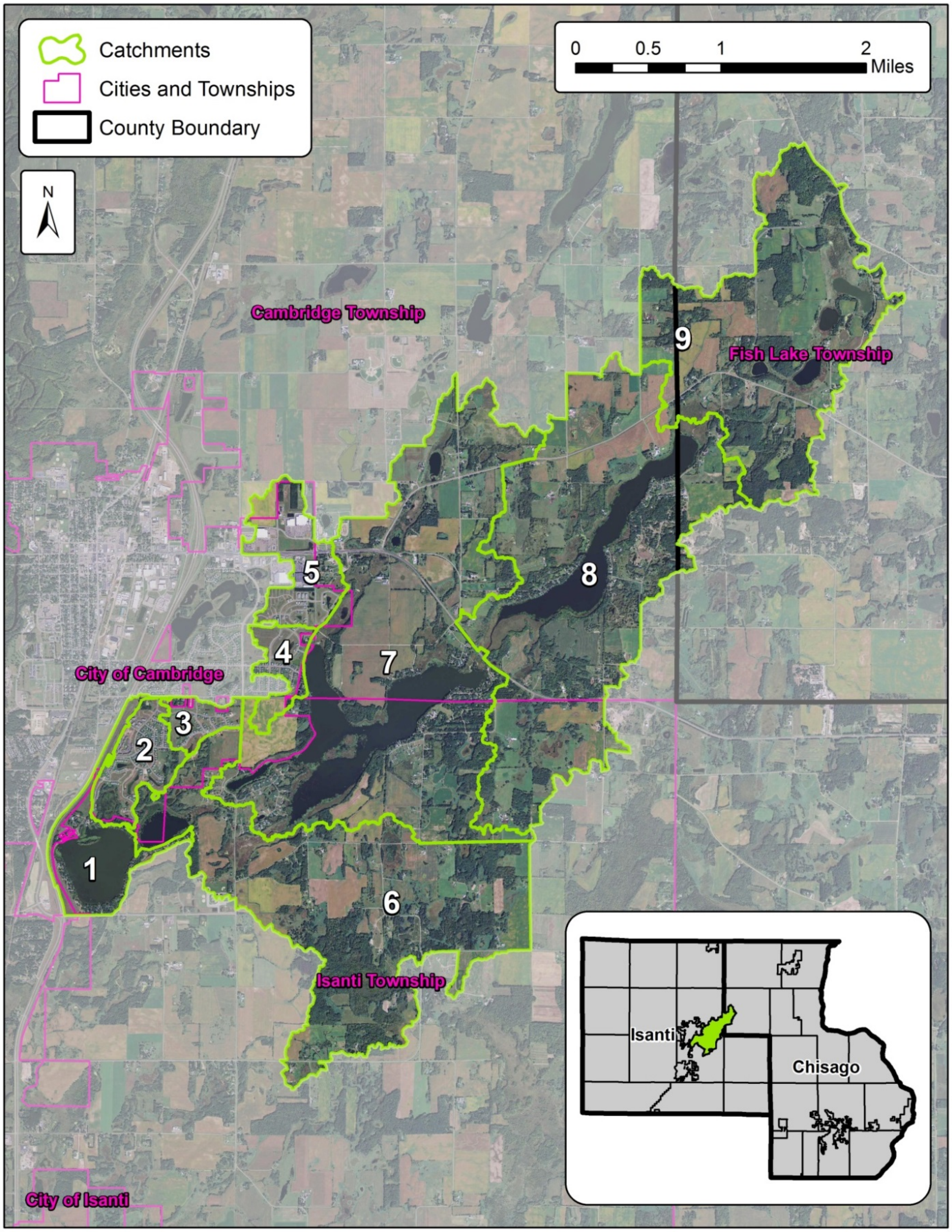
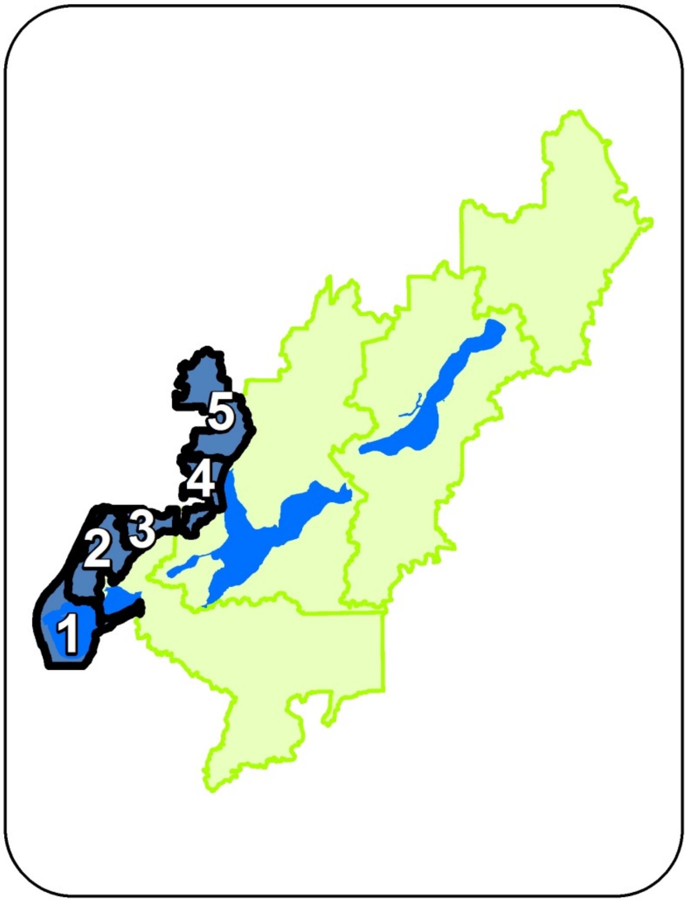


Figure 20: Map of stormwater catchments referred to in this report. Catchment Profiles on the following pages provide additional detail.

Catchment Profiles Section 1: Urban Catchments

Urban Catchments Summary	
Acres	1,088
Dominant Land Cover	Residential
TP (lbs/yr)	308
TSS (lbs/yr)	64,148
Volume (ac-ft/yr)	334



AREA SUMMARY

The urban catchments lie predominantly within the City of Cambridge, on the west side of the SFEF lakes chain. Most of the area is developed residential and commercial lots. Commercial properties are all within Catchment 5 along MN State Highway 95. Residential properties make up the majority of the developed land area, but only 29% of total area in these catchments (combined medium-density and other residential land uses). Other land use types include undeveloped land (29%), open water (28%), commercial and institutional properties (8%), and freeway (5%). Soils in this region are generally silty-sand loam, with adequate to poor drainage rates.

EXISTING TREATMENT

Treatment throughout these catchments depends greatly on available space and location within the city. Within Catchment 1, where flow paths to Florence Lake and Elms Lake are short for lakeshore and near-shore homes, little stormwater treatment is available. Conversely, for the newer developments in Catchments 2-5, a total of 28 wet retention ponds, 2 infiltration basins (dry detention ponds), and 2 grass swales treat stormwater runoff.

In addition to these structural practices, street cleaning is performed by the City of Cambridge once every four weeks across all urban catchments.

EXPECTED LAND USE CHANGES

Housing developments east of MN State Highway 65 and south of MN State Highway 95 have been platted and are expected to be completed in the coming years. Much of this construction has already begun, including the building of new single-family homes and completion of most of the stormwater infrastructure (roadway catch basins, storm sewer pipes, and wet retention ponds). These developments will greatly change the land use distribution in the urban catchments, increasing the percentage of medium-density residential area from 26.4% to 42.7%. This increase comes at the expense of undeveloped land, which will decrease by just over 16.3% in the coming years.

Land Use Type	Existing Land Use		Future Land Use	
	Acres	% of Total Area	Acres	% of Total Area
Medium-Density Residential	287.5	26.4%	464.3	42.7%
Multi-Family Residential	15.3	1.4%	15.3	1.4%
Other Residential Land Uses	19.5	1.8%	19.5	1.8%
Commercial and Institutional	84.3	7.7%	84.3	7.7%
Freeway	53.7	4.9%	53.7	4.9%
Light Industrial	3.7	0.3%	3.7	0.3%
Park	1.7	0.2%	1.7	0.2%
Undeveloped	318.5	29.3%	141.7	13.0%
Open Water	304.0	27.9%	304.0	27.9%
Total Area	1,088.2		1,088.2	

With these changes comes an increase in impervious surfaces and pollutant sources (e.g. automobiles, lawn clippings, pet waste, etc.). To better aid in future stormwater treatment planning, all proposed BMPs assume that the expected land use changes have already taken effect. This ensures that pollutant loading is not grossly underestimated for future planning and that the modeled pollutant loading to these devices over their lifetime is consistent.

Listed in the table below is a summary of annual pollutant loading to the SFEF lakes chain from urban catchments in existing and future land uses.

Pollutant Type	Existing Land Use	Future Land Use
Total Phosphorus (lbs/yr)	307.8	344.2
Total Suspended Solids (lbs/yr)	64,148	73,844
Volume (ac-ft/yr)	334.3	386.3

RETROFIT RECOMMENDATIONS

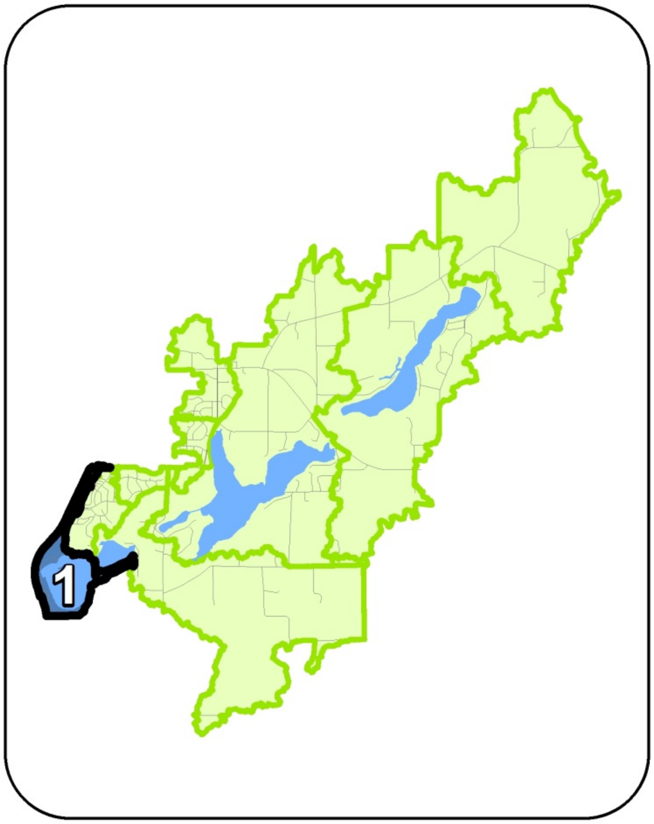
Due to the large number of wet retention ponds, no additional ponds were proposed in the urban catchments. The existing pond network is effectively treating particulate pollutants (sediment and particulate phosphorus, specifically) across all catchments where space is available for such a large practice.

To better treat dissolved forms of pollutants, which are the main pollutant source in these catchments, infiltration and filtration practices were sought. These practices can be placed upstream of existing ponds (e.g. bioretention or IESF basins), to lessen the amount of pollutants the pond must treat, or they can be installed downstream of existing ponds (e.g. IESF benches) to capture pollutants that bypass the pond

In total, 14 practice types were modeled and found not to be cost-prohibitive across the urban catchments. These practices are described within the following *Catchment Profiles* pages.

Catchment 1

Existing Catchment Summary	
Acres	282
Dominant Land Cover	Residential
TP (lbs/yr)	105.3
TSS (lbs/yr)	29,952
Volume (ac-ft/yr)	65.0



CATCHMENT DESCRIPTION

Catchment 1 is the westernmost catchment in the SFEF lakes chain. The catchment extends from the State Highway 65 corridor between 16th Ave. and 313th Ave. east across Florence Lake to the western and southern shores of Elms Lake. Land use in the catchment is primarily lakeshore residences and the State Highway.

Stormwater runoff generated within the catchment drains to either Florence Lake or Elms Lake. State Highway 65 and residences along Pine Ln., Paul's Lake Rd., 313th Ave., and London Dr. discharge into Florence Lake. Residences along 317th Ave. discharge into Elms Lake. Little stormwater infrastructure exists in the catchment, with most runoff traveling through ditches to the lakes.

EXISTING STORMWATER TREATMENT

Currently the only form of stormwater treatment is street cleaning conducted by the City of Cambridge once every four weeks.

Most of the State Highway 65 corridor is grassed open space, generating little stormwater runoff and capturing runoff from the four-lane highway in all but the largest rainfall events. This area was modeled but no retrofits were proposed as runoff along the highway is being sufficiently treated.

Based on existing land use and stormwater treatment practices, catchment-wide loading is:

	Existing Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	1			
	BMP Types	street cleaning			
	TP (lb/yr)	110.8	5.5	5%	**105.3**
	TSS (lb/yr)	32,374	2,422	7%	**29,952**
	Volume (acre-feet/yr)	65.0	0.0	0%	**65.0**

Taking into account future residential development within the region (but assuming no additional stormwater treatment), catchment-wide loading is expected to be:

	Expected Development Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	1			
	BMP Types	street cleaning			
	TP (lb/yr)	111.7	5.6	5%	**106.1**
	TSS (lb/yr)	32,649	2,452	8%	**30,197**
	Volume (acre-feet/yr)	65.5	0.0	0%	**65.5**

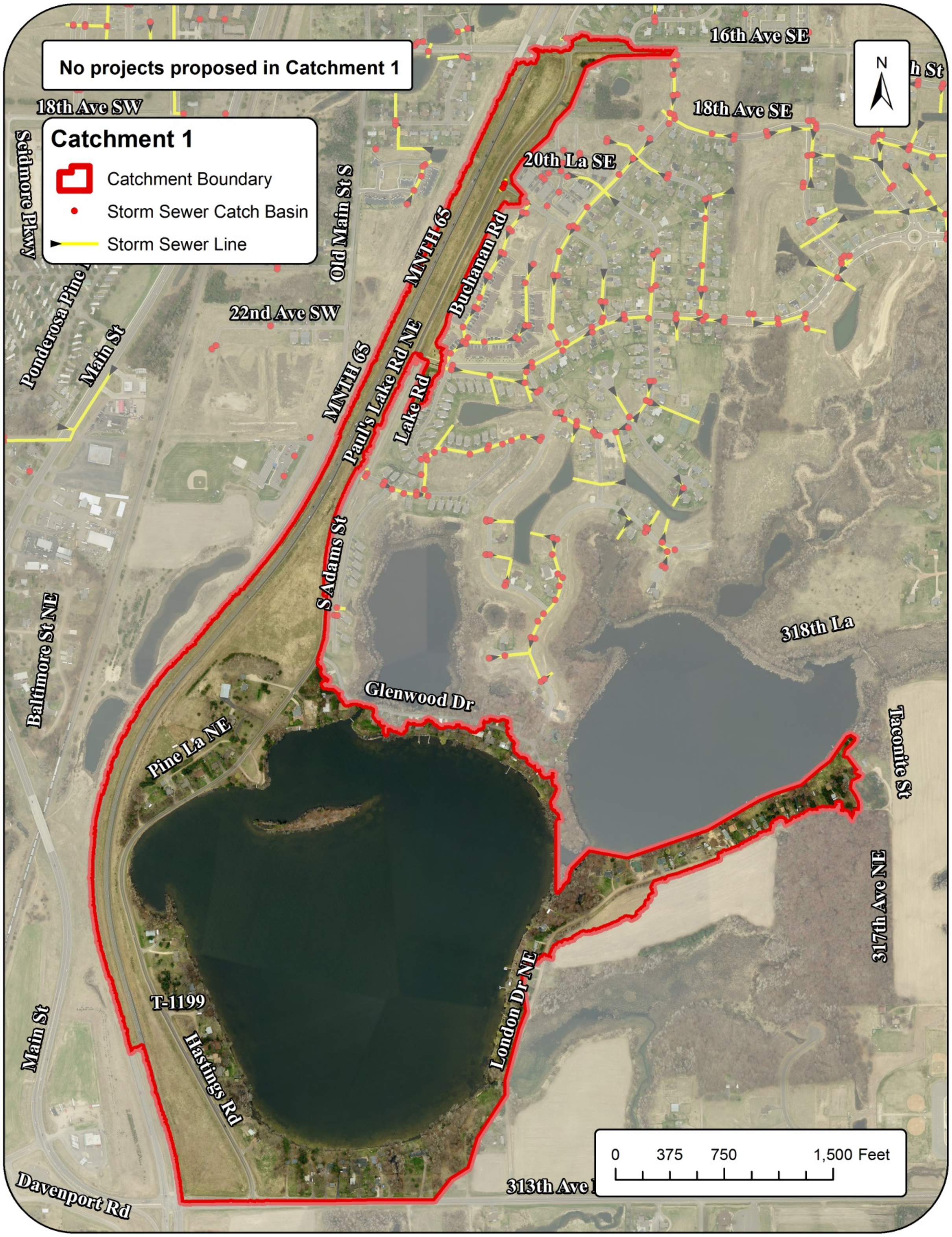
Expected development is based on the land use changes in the table below. Land use types that are expected to change are emboldened:

Land Use Type	Existing Area (acres)	Future Area (acres)
Freeway	44.7	44.7
Medium-Density Residential	**65.4**	**66.9**
Multi-Family Residential	1.0	1.0
Suburban	12.4	12.4
Park	1.7	1.7
Undeveloped	**21.3**	**19.8**
Open Water	135.2	135.2

RETROFIT RECOMMENDATIONS

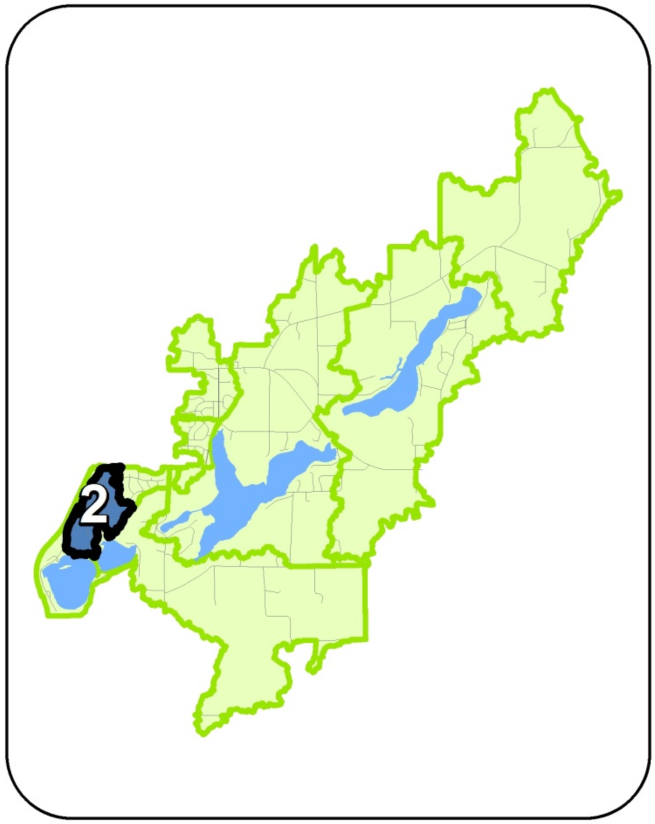
Most runoff within the catchment is generated from lakeshore lots. Lakeshore restoration projects were proposed for lots within the catchment and are described in detail in the *Catchment Profiles Section 3: Lakeshore Restorations* pages found later in this report. Besides lakeshore restorations, no other structural stormwater BMPs were proposed within Catchment 1.

RETROFIT RECOMMENDATIONS



Catchment 2

Existing Catchment Summary	
Acres	376
Dominant Land Cover	Residential
TP (lbs/yr)	54.9
TSS (lbs/yr)	6,911
Volume (ac-ft/yr)	59.9



CATCHMENT DESCRIPTION

Catchment 2 is bounded by Highway 65 to the west, 16th Ave. to the north, and Glenwood Dr. to the south. The eastern boundary snakes along Elm Lake Rd. and between developments north of Pioneer Trail.

Currently about ½ of the catchment is developed, although this is expected to increase to 77% once proposed developments are completed. Other land uses in the catchment are undeveloped open space and wetlands/open water.

EXISTING STORMWATER TREATMENT

Stormwater runoff within Catchment 2 generally follows along one of four pathways. North of 18th Ave. stormwater is directed into an infiltration basin located at Emerson Rd. and 18th Ave. This practice discharges west into another pond and subsequently into a ditch at Highway 65 and 18th Ave.

East of Bridgewater Place, and along Bridgewater Blvd. and Pioneer Trail, stormwater is conveyed via the storm sewer to a pond in Pioneer Park. This shallow (< 4 ft.) pond overflows into a wetland and then Elms Lake beyond the park.

Thirdly, west of Buchanan Pond is a small pond treating just 1.5 acres of roadway and multi-family residential runoff along Buchanan Lane.

Lastly, all other stormwater generated within the catchment flows to one or more in a series of three stormwater ponds. The first, located at 22nd Ave. and Bridgewater Blvd., overflows into another pond located between Davis St. and Elm Lake Rd. This pond overflows directly into Elms Lake. The third pond collects stormwater from east of Fillmore St. and discharges to the pond between Davis St. and Elm Lake Rd.

The last form of stormwater treatment is provided by street cleaning performed across the catchment once every four weeks.

Based on existing land use and stormwater treatment practices, catchment-wide loading is:

	Existing Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	9			
	BMP Types	street cleaning, 6 wet ponds, wetland, infiltration basin			
	TP (lb/yr)	117.6	62.7	53%	**54.9**
	TSS (lb/yr)	27,565	20,654	75%	**6,911**
	Volume (acre-feet/yr)	71.2	11.3	16%	**59.9**

Taking into account future residential development within the region (but assuming no additional stormwater treatment), catchment-wide loading is expected to be:

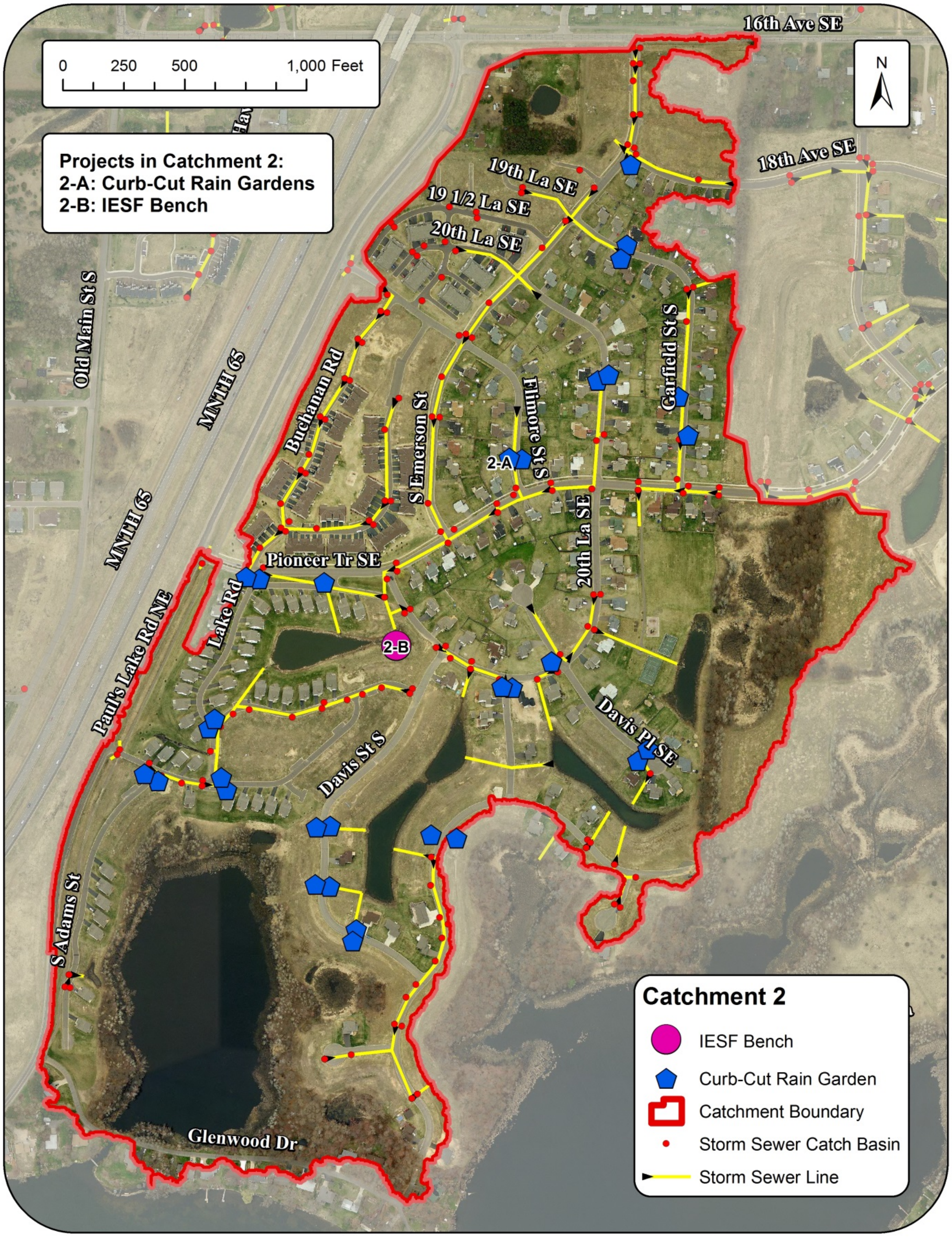
	Expected Development Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	9			
	BMP Types	street cleaning, 6 wet ponds, wetland, infiltration basin			
	TP (lb/yr)	144.3	78.6	54%	**65.7**
	TSS (lb/yr)	35,959	26,228	73%	**9,731**
	Volume (acre-feet/yr)	85.9	13.1	15%	**72.8**

Expected development is based on the land use changes in the table below:

Land Use Type	Existing Area (acres)	Future Area (acres)
Medium-Density Residential	**95.1**	**142.8**
Multi-Family Residential	10.9	10.9
Undeveloped	**71.2**	**23.5**
Open Water	198.4	198.4

All proposed retrofits in this catchment assume pollutant reduction amounts based on the expected development conditions.

RETROFIT RECOMMENDATIONS



Project ID: 2-A

Residential Curb-Cut Rain Gardens

Drainage Area – Variable
Location – Single-family residential properties throughout catchment
Property Ownership – Private
Site Specific Information – Stormwater ponds in the catchment sufficiently treat TSS and other particulate pollutants. Pollutants that can easily advect through this treatment system are in dissolved form. To remove these pollutants, curb-cut rain gardens are proposed for residential properties upstream of the ponds.

Depending on soil type, gardens are recommended to have a ponding depth of either 6” or 12”. In sandier soils where an infiltration rate of 1” per hour can be achieved, 12” gardens should be installed. These gardens, with an increased stormwater storage capacity, are the most cost-effective opportunity for treating TP in the catchment. If infiltration rates are below 1” per hour, then gardens with 6” or smaller depths should be installed to ensure ponding time is less than 48 hours.

The potential reduction for a rain garden installed in Catchment 2 is summarized in Table 9. The first column is for a garden with a 6” ponding depth. The second is for a garden with a 12” ponding depth. Notes pertaining to the expected cost of each garden can be found below the table.

Table 9: Pollutant removal potential for Project 2-A (numbers presented are for a single rain garden)

	Curb Cut Rain Garden				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**Rain Garden Depth**	6	inches	12	inches
	Top Area of Each Garden	250	sq-ft	250	sq-ft
	TP (lb/yr)	0.24	0.4%	0.34	0.5%
	TSS (lb/yr)	25	0.3%	43	0.4%
	Volume (acre-feet/yr)	0.41	0.6%	0.53	0.7%
Cost	**Administration & Promotion Costs***	$4,234		$4,234	
	Design & Construction Costs**	$7,376		$7,376	
	Total Estimated Project Cost (2014)	**$11,610**		**$11,610**	
	Annual O&M***	$225		$225	
	Cost Over 20-year Life Span	**$16,110**		**$16,110**	
Efficiency	**20-yr Average Cost/lb-TP**	**$3,356**		**$2,369**	
	20-yr Average Cost/1,000lb-TSS	**$32,220**		**$18,733**	
	20-yr Average Cost/ac-ft Vol.	**$1,965**		**$1,520**	

*(58 hours at $73/hour base cost)

**($26/sq-ft for materials and labor) + (12 hours/BMP at $73/hour for design)

***($150/year for 10-year rehabilitation) + ($75/year for routine maintenance)

Project ID: 2-B

Catchment 2 IESF Pond Bench

Drainage Area – 63.0 acres

Location – Along eastern bank of stormwater pond at Pioneer Trail and Bridgewater Blvd.

Property Ownership – Private, Bayview of Bridgewater

Site Specific Information – An IESF bench was proposed as an improvement to pond treatment. The pond currently provides treatment through retention and settling. However, the addition of an IESF will increase removal of DP as well. Up to 4,000 sq-ft is available in the space between the pond normal water level and the roadway. The bench should be positioned on the east side of the pond to accommodate an underdrain connection to the existing outlet.

Table 10: Pollutant removal potential for Project 2-B

	IESF Bench		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Number of BMPs**	1	
	Total Size of BMPs	4,000	sq-ft
	TP (lb/yr)	9.8	14.9%
	TSS (lb/yr)	0	0.0%
	Volume (acre-feet/yr)	0.0	0.0%
Cost	**Administration & Promotion Costs***	$5,475	
	Design & Construction Costs**	$131,254	
	Total Estimated Project Cost (2014)	**$136,729**	
	Annual O&M***	$918	
	Cost Over 30-year Life Span	**$164,277**	
Efficiency	**30-yr Average Cost/lb-TP**	**$559**	
	30-yr Average Cost/1,000lb-TSS	**N/A**	
	30-yr Average Cost/ac-ft Vol.	**N/A**	

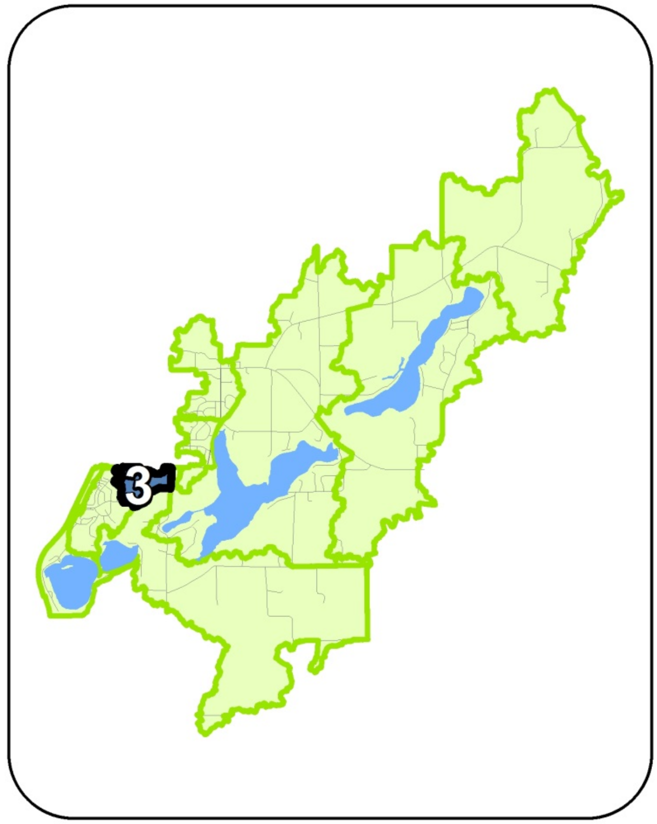
*75 hours at $73/hour

**See Appendix B for detailed cost information

***$10,000/acre for IESF Bench

Catchment 3

Existing Catchment Summary	
Acres	90
Dominant Land Cover	Residential
TP (lbs/yr)	23.8
TSS (lbs/yr)	2,030
Volume (ac-ft/yr)	26.3



CATCHMENT DESCRIPTION

This catchment lies east of Catchment 2 and between 18th Ave., Xylite St., and Pioneer Trail. Currently only 52% of the catchment are completed residential lots, although this number is expected to increase to 96% when the proposed developments are completed.

EXISTING STORMWATER TREATMENT

Although Catchment 3 is the smallest catchment in this analysis (90 acres in size) it has the second most stormwater BMPs, ten. These include eight wet retention ponds, one grass swale, and street cleaning performed once every four weeks by the City of Cambridge.

Based on existing land use and stormwater treatment practices, catchment-wide loading is:

	Existing Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	10			
	BMP Types	street cleaning, 8 wet ponds, grass swale			
	TP (lb/yr)	53.9	30.1	56%	**23.8**
	TSS (lb/yr)	12,047	10,017	83%	**2,030**
	Volume (acre-feet/yr)	30.9	4.6	15%	**26.3**

Taking into account future residential development within the region (but assuming no additional stormwater treatment), catchment-wide loading is expected to be:

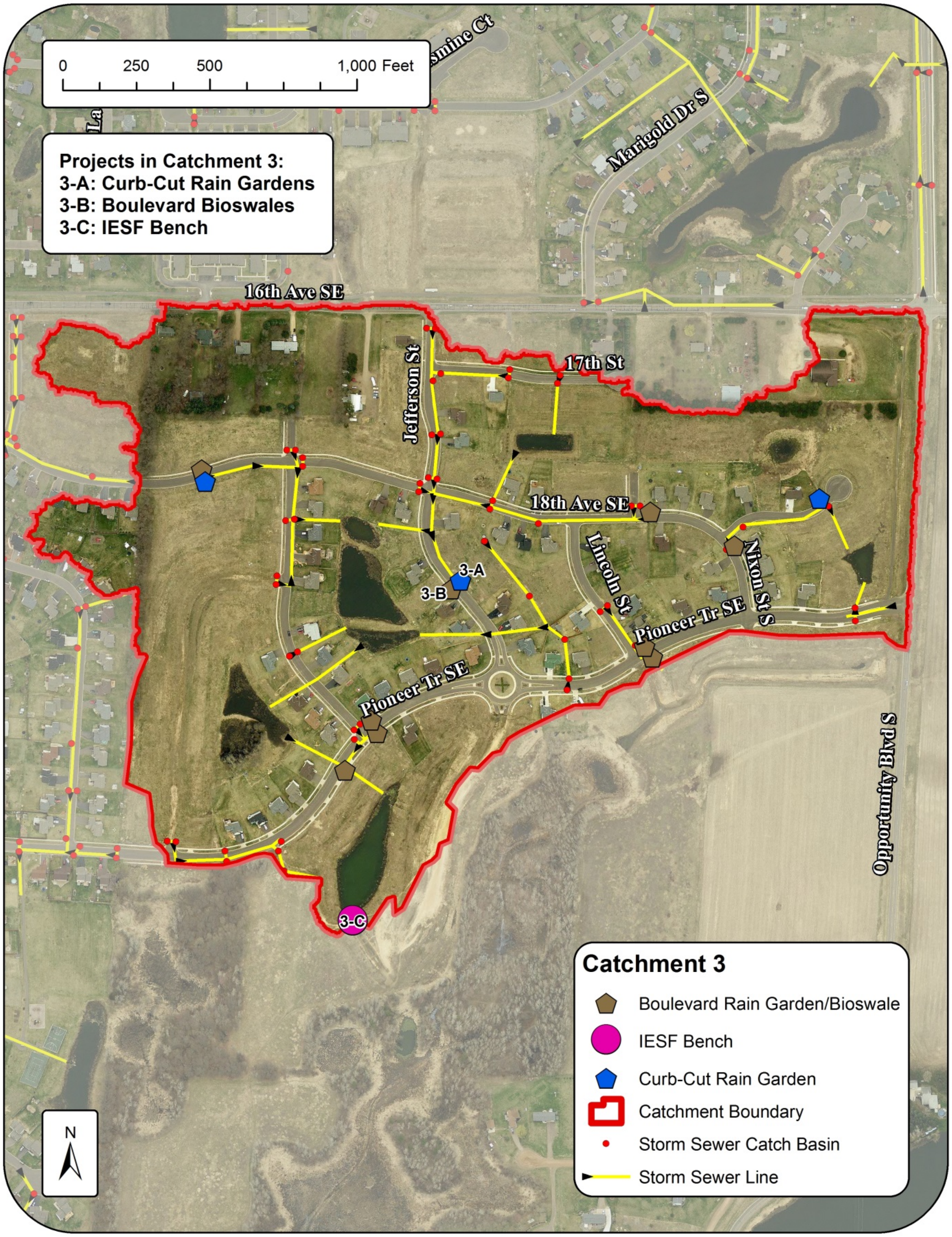
	Expected Development Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	10			
	BMP Types	street cleaning, 8 wet ponds, grass swale			
	TP (lb/yr)	76.0	45.0	59%	**31.0**
	TSS (lb/yr)	19,006	15,047	79%	**3,959**
	Volume (acre-feet/yr)	43.0	5.3	12%	**37.7**

Expected development is based on the land use changes in the table below. Land use types that are expected to change are emboldened:

Land Use Type	Existing Area (acres)	Future Area (acres)
Medium-Density Residential	**42.8**	**82.8**
Low-Density Residential	3.4	3.4
Undeveloped	**40.2**	**0.2**
Open Water	3.7	3.7

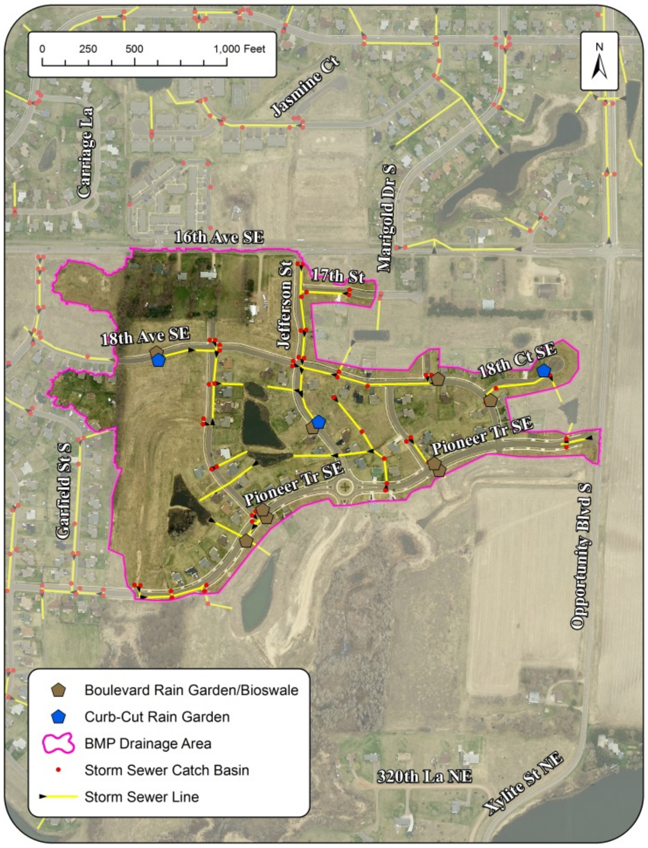
All proposed retrofits in this catchment assume pollutant reduction amounts based on the expected development conditions.

RETROFIT RECOMMENDATIONS



Project ID: 3-A

Catchment 3 Residential Curb-Cut Rain Gardens



Drainage Area – Variable
Location – Single-family residential properties throughout catchment
Property Ownership – Private
Site Specific Information – Stormwater ponds in the catchment sufficiently treat TSS and other particulate pollutants. Pollutants that can easily advect through this system are in dissolved form. To remove these pollutants, rain gardens are proposed for residential properties upstream of the ponds.

Depending on soil type, gardens are recommended to have a ponding depth of either 6" or 12". In sandier soils where an infiltration rate of 1" per hour can be achieved, 12" gardens should be installed. These gardens, with an increased stormwater storage capacity, are the most cost-effective opportunity for treating TP in the catchment. If infiltration rates are below 1" per hour, than gardens with 6" or smaller depths should be installed to ensure ponding time is less than 48 hours.

As sidewalks are prevalent throughout the catchment, both standard (installed when no sidewalk is present) and boulevard (installed between the existing sidewalk and curb) rain gardens were modeled. Standard rain gardens ranged from 250-350 sq-ft in top area. Boulevard rain gardens ranged from 80-120 sq-ft in top area.

In some cases it is more beneficial to install curb-cuts on both sides of a stormwater catch basin. This allows the garden to capture stormwater draining to the storm sewer from both sides of the street. This can often double the size of the drainage area to the garden, but can also increase the cost due to the additional inlet and associated costs with increasing area (excavation, additional mulch and plants, etc.). These scenarios were modeled with varying garden ponding depths in the following tables:

1) Table 11: A single curb-cut and 6" in ponding depth
2) Table 12: A single curb-cut and 12" in ponding depth
3) Table 13: A double curb-cut and 6" in ponding depth
4) Table 14: A double curb-cut and 12" in ponding depth

Notes pertaining to the expected cost of each garden can be found below their respective table.

Table 11: Pollutant removal potential for Project 3-A, a rain garden with a 6" ponding depth and a single curb cut

	Curb Cut Rain Garden				
	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	Rain Garden Type	Boulevard		Standard	
	Top Area of Each Garden	80	sq-ft	250	sq-ft
	TP (lb/yr)	0.01	0.0%	0.05	0.2%
	TSS (lb/yr)	3	0.1%	9	0.2%
	Volume (acre-feet/yr)	0.05	0.1%	0.09	0.2%
Cost	Administration & Promotion Costs*	$4,234		$4,234	
	Design & Construction Costs**	$2,716		$6,626	
	Total Estimated Project Cost (2014)	**$6,950**		**$10,860**	
	Annual O&M***	$225		$225	
	Cost Over 20-year Life Span	**$11,450**		**$15,360**	
Efficiency	**20-yr Average Cost/lb-TP**	**$57,250**		**$15,360**	
	20-yr Average Cost/1,000lb-TSS	**$190,833**		**$85,333**	
	20-yr Average Cost/ac-ft Vol.	**$11,450**		**$8,533**	

*(58 hours at $73/hour base cost)

**($23/sq-ft for materials and labor) + (12 hours/BMP at $73/hour for design)

***($150/year for 10-year rehabilitation) + ($75/year for routine maintenance)

Table 12: Pollutant removal potential for Project 3-A, a rain garden with a 12" ponding depth and a single curb cut

	Curb Cut Rain Garden				
	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	Rain Garden Type	Boulevard		Standard	
	Top Area of Each Garden	80	sq-ft	250	sq-ft
	TP (lb/yr)	0.05	0.2%	0.12	0.4%
	TSS (lb/yr)	9	0.2%	21	0.5%
	Volume (acre-feet/yr)	0.09	0.2%	0.18	0.5%
Cost	Administration & Promotion Costs*	$4,234		$4,234	
	Design & Construction Costs**	$2,956		$7,376	
	Total Estimated Project Cost (2014)	**$7,190**		**$11,610**	
	Annual O&M***	$225		$225	
	Cost Over 20-year Life Span	**$11,690**		**$16,110**	
Efficiency	**20-yr Average Cost/lb-TP**	**$11,690**		**$6,713**	
	20-yr Average Cost/1,000lb-TSS	**$64,944**		**$38,357**	
	20-yr Average Cost/ac-ft Vol.	**$6,494**		**$4,475**	

*(58 hours at $73/hour base cost)

**($26/sq-ft for materials and labor) + (12 hours/BMP at $73/hour for design)

***($150/year for 10-year rehabilitation) + ($75/year for routine maintenance)

Table 13 and Table 14 on the following page summarize the pollutant removal potential of a rain garden installed with two curb cuts. The most cost-effective option for treating TP in this catchment is a 12" deep standard rain garden with a top area of 350 sq-ft (Table 14). The larger size allows for greater storage capacity over the smaller sized gardens.

Table 13: Pollutant removal potential for Project 3-A, a rain garden with a 6" ponding depth and two curb cuts

	Curb Cut Rain Garden						
	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	Rain Garden Type	Boulevard		Standard		Standard	
	Top Area of Each Garden	120	sq-ft	250	sq-ft	350	sq-ft
	TP (lb/yr)	0.04	0.1%	0.06	0.2%	0.09	0.3%
	TSS (lb/yr)	4	0.1%	9	0.2%	14	0.4%
	Volume (acre-feet/yr)	0.07	0.2%	0.09	0.2%	0.16	0.4%
Cost	Administration & Promotion Costs*	$4,234		$4,234		$4,234	
	Design & Construction Costs**	$5,136		$8,126		$10,426	
	Total Estimated Project Cost (2014)	**$9,370**		**$12,360**		**$14,660**	
	Annual O&M***	$225		$225		$225	
	Cost Over 20-year Life Span	**$13,870**		**$16,860**		**$19,160**	
Efficiency	**20-yr Average Cost/lb-TP**	**$17,338**		**$14,050**		**$10,644**	
	20-yr Average Cost/1,000lb-TSS	**$173,375**		**$93,667**		**$68,429**	
	20-yr Average Cost/ac-ft Vol.	**$9,907**		**$9,367**		**$5,988**	

*(58 hours at $73/hour base cost)

**($23/sq-ft for materials and labor) + (12 hours/BMP at $73/hour for design) + ($1,500 for additional inlet)

***($150/year for 10-year rehabilitation) + ($75/year for routine maintenance)

Table 14: Pollutant removal potential for Project 3-A, a rain garden with a 12" ponding depth and two curb cuts

	Curb Cut Rain Garden						
	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	Rain Garden Type	Boulevard		Standard		Standard	
	Top Area of Each Garden	120	sq-ft	250	sq-ft	350	sq-ft
	TP (lb/yr)	0.10	0.3%	0.15	0.5%	0.20	0.6%
	TSS (lb/yr)	14	0.4%	25	0.6%	34	0.9%
	Volume (acre-feet/yr)	0.14	0.4%	0.23	0.6%	0.28	0.7%
Cost	Administration & Promotion Costs*	$4,234		$4,234		$4,234	
	Design & Construction Costs**	$5,496		$8,876		$11,476	
	Total Estimated Project Cost (2014)	**$9,730**		**$13,110**		**$15,710**	
	Annual O&M***	$225		$225		$225	
	Cost Over 20-year Life Span	**$14,230**		**$17,610**		**$20,210**	
Efficiency	**20-yr Average Cost/lb-TP**	**$7,115**		**$5,870**		**$5,053**	
	20-yr Average Cost/1,000lb-TSS	**$50,821**		**$35,220**		**$29,721**	
	20-yr Average Cost/ac-ft Vol.	**$5,082**		**$3,828**		**$3,609**	

*(58 hours at $73/hour base cost)

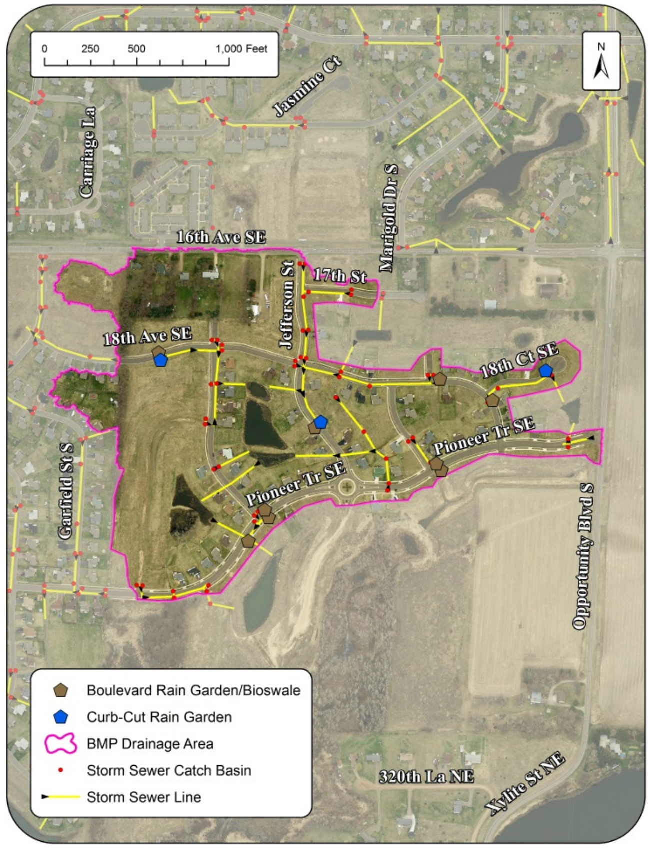
**($26/sq-ft for materials and labor) + (12 hours/BMP at $73/hour for design) + ($1,500 for additional inlet)

***($150/year for 10-year rehabilitation) + ($75/year for routine maintenance)

Practice Summary in Catchment 3: The most cost-effective option for curb-cut rain gardens in this catchment would be targeting areas with infiltration rates greater than 1" per hour where a garden with a 1' ponding depth could be installed. In addition, a double-cut garden should be pursued over a single-cut garden when *at least* 4 properties are draining to either side of the storm sewer catch basin. Please note that underdrains are not recommended as these don't allow for dissolved constituent treatment, which is the primary form of pollutants exporting this catchment.

Project ID: 3-B

Catchment 3 Curb-Cut Boulevard Bioswales (BB)



Drainage Area – Variable
Location – Single-family residential properties throughout catchment
Property Ownership – Private
Site Specific Information – These BMPs work in the same locations as the boulevard rain gardens (BRG). Table 15 summarizes the potential removal from bioswales installed in silty, more poor-drained soils (first column) and sandy, better-drained (second column) soils. All modeled bioswales assume a 3" deep swale. Within this catchment, these practices are only cost-effective when installed in sandy soils where the most infiltration of stormwater and pollutants occurs (Table 15).

Table 15: Pollutant removal potential for Project 3-B

	Boulevard Bioswale				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**Infiltration Rate of Native Soil**	0.2	inches/hr	1.0	inches/hr
	Top Area of Each Bioswale	80	sq-ft	80	sq-ft
	TP (lb/yr)	0.02	0.1%	0.10	0.3%
	TSS (lb/yr)	4	0.1%	14	0.4%
	Volume (acre-feet/yr)	0.05	0.1%	0.12	0.3%
Cost	**Administration & Promotion Costs***	$4,234		$4,234	
	Design & Construction Costs**	$4,076		$4,076	
	Total Estimated Project Cost (2014)	**$8,310**		**$8,310**	
	Annual O&M***	$225		$225	
	Cost Over 20-year Life Span	**$12,810**		**$12,810**	
Efficiency	**20-yr Average Cost/lb-TP**	**$32,025**		**$6,405**	
	20-yr Average Cost/1,000lb-TSS	**$160,125**		**$45,750**	
	20-yr Average Cost/ac-ft Vol.	**$12,810**		**$5,338**	

*(58 hours at $73/hour base cost)

**($40/sq-ft for materials and labor) + (12 hours/BMP at $73/hour for design)

***($150/year for 10-year rehabilitation) + ($75/year for routine maintenance)

Project ID: 3-C

Catchment 3 IESF Bench

Drainage Area – 90.1 acres
Location – Southern banks of the pond south of Pioneer Trail
Property Ownership – Premier Development of Cambridge
Site Specific Information – All seven upstream wet retention ponds in Catchment 3 discharge into the pond south of Pioneer Trail. This pond drains south along a small channel into a wetland and subsequently to Elms Lake. The series of ponds sufficiently treat TSS in the catchment (83% removed catchment-wide), and will continue to do so through future developments (79% catchment-wide). What could be improved is phosphorus retention, which an IESF bench would be designed to do. The proposed bench would be installed along the southwestern or southeastern bank of the pond such that the bench outlet ties into the existing drainage channel. With the large amount of undeveloped space available south of the pond a ¼ acre bench is proposed that could be installed by purchasing or attaining an easement on property south of the pond. Table 16 summarizes the pollutant removal potential of an IESF pond bench. A smaller bench would remove less pollutants overall but would likely have a similar cost-effectiveness with regards to TP removal efficiency.

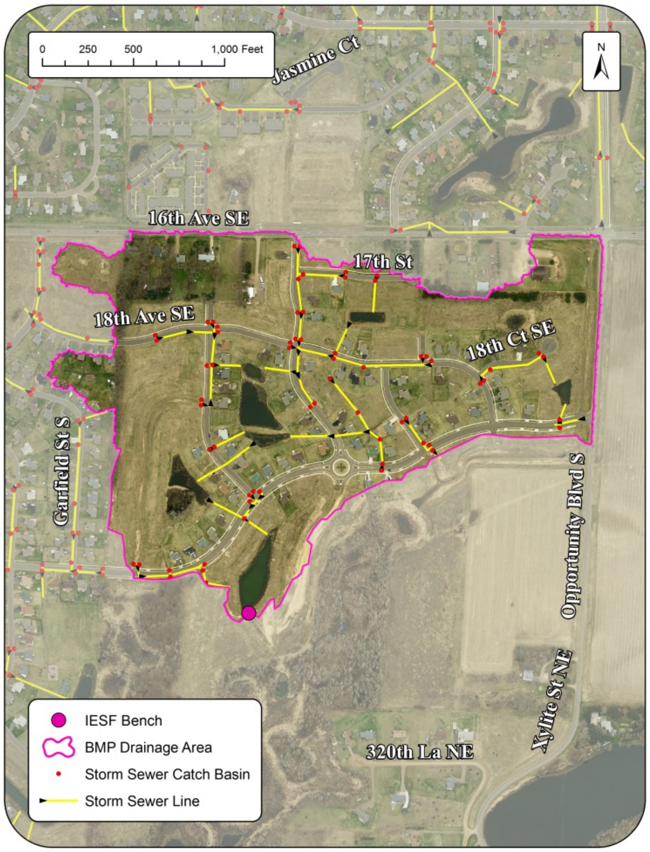


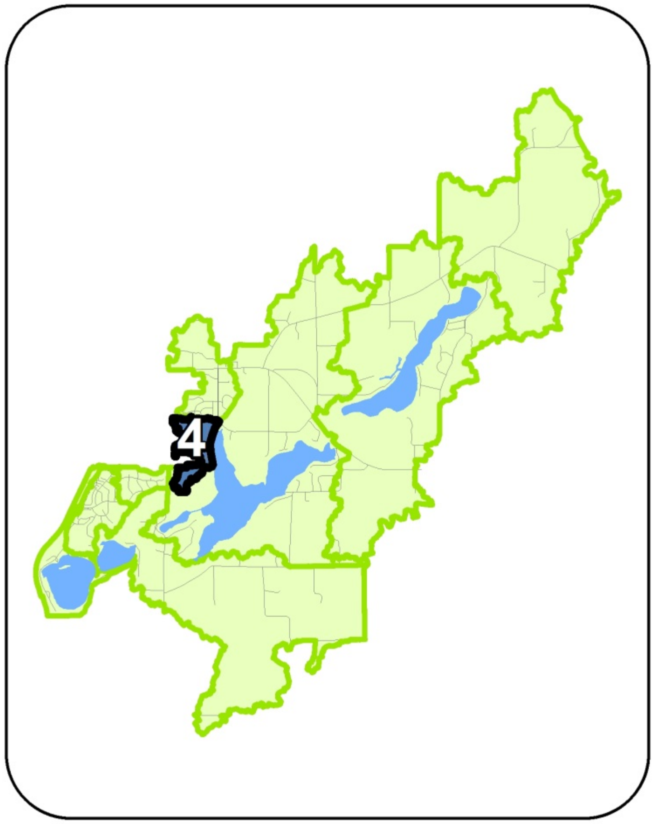
Table 16: Pollutant removal potential for Project 3-C

	IESF Bench		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Number of BMPs**	1	
	Total Size of BMPs	10,800	sq-ft
	TP (lb/yr)	10.7	34.5%
	TSS (lb/yr)	0	0.0%
	Volume (acre-feet/yr)	0.0	0.0%
Cost	**Administration & Promotion Costs***	$5,475	
	Design & Construction Costs**	$227,000	
	Total Estimated Project Cost (2014)	**$232,475**	
	Annual O&M***	$2,479	
	Cost Over 30-year Life Span	**$306,855**	
Efficiency	**30-yr Average Cost/lb-TP**	**$956**	
	30-yr Average Cost/1,000lb-TSS	**N/A**	
	30-yr Average Cost/ac-ft Vol.	**N/A**	

*75 hours at $73/hour
**See Appendix B for detailed cost information
***$10,000/acre for IESF Bench

Catchment 4

Existing Catchment Summary	
Acres	120
Dominant Land Cover	Residential
TP (lbs/yr)	34.4
TSS (lbs/yr)	3,823
Volume (ac-ft/yr)	31.7



CATCHMENT DESCRIPTION

Catchment 4 stretches from the farm field south of 16^{th} Ave. north to 8^{th} Ln. and Taft loop. The southern portion of the catchment is single-family residential lots. The northern portion is mostly undeveloped but has been platted for future development of single-family homes.

EXISTING STORMWATER TREATMENT

Most stormwater runoff generated within the catchment flows via ditching or storm sewer to at least one of three structural BMPs. Runoff from the farm field and backyards along 16^{th} Ave. and Flanders St. is conveyed via ditching to an infiltration basin located within the ditch at the intersection of 16^{th} Ave. and Flanders St.

On the northern end of the catchment, runoff generated south of 8^{th} Ln. flows to a wet retention pond within the 8^{th} Ln and 11^{th} Ave. loop. Overflow from this pond and the infiltration basin discharge into another wet retention pond located north of the intersection of Joe's Lake Rd. and Flanders St. This pond also includes a small forebay, which together discharge east directly into Fannie Lake. A small portion of the catchment east of Flanders St. receives no treatment from stormwater BMPs, discharging directly into Fannie Lake. The only form of catchment-wide treatment is street cleaning, performed once every four weeks by the City of Cambridge.

Based on existing land use and stormwater treatment practices, catchment-wide loading is:

	Existing Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	4			
	BMP Types	street cleaning, 2 wet ponds, infiltration basin			
	TP (lb/yr)	66.8	32.4	49%	**34.4**
	TSS (lb/yr)	14,457	10,634	74%	**3,823**
	Volume (acre-feet/yr)	39.0	7.3	19%	**31.7**

Taking into account future residential development within the region (but assuming no additional stormwater treatment), catchment-wide loading is expected to be:

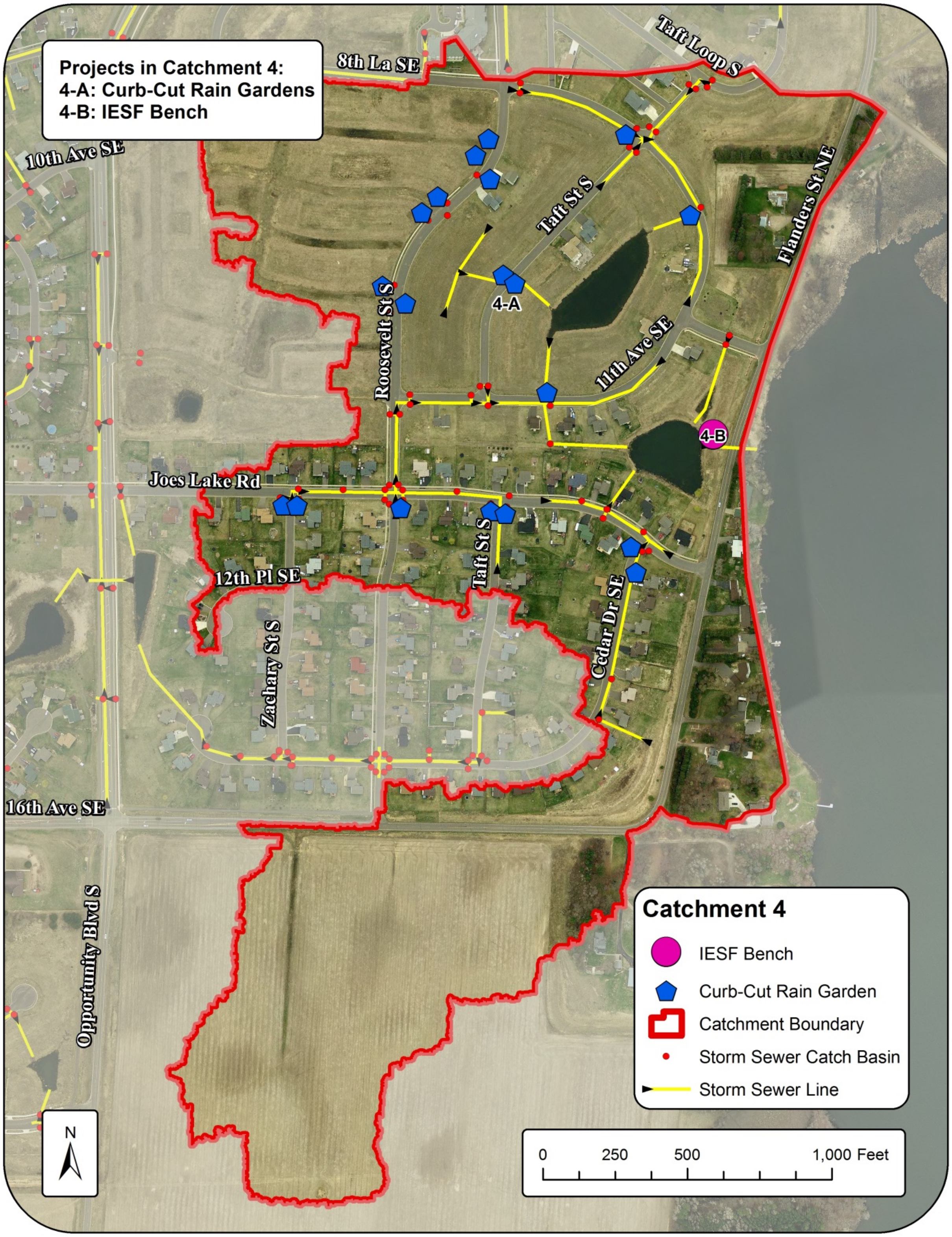
	Expected Development Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	4			
	BMP Types	street cleaning, 2 wet ponds, infiltration basin			
	TP (lb/yr)	89.8	46.2	51%	**43.6**
	TSS (lb/yr)	21,697	15,585	72%	**6,112**
	Volume (acre-feet/yr)	51.7	5.5	11%	**46.2**

Expected development is based on the land use changes in the table below. Land use types that are expected to change are emboldened:

Land Use Type	Existing Area (acres)	Future Area (acres)
Medium-Density Residential	**49.2**	**90.3**
High Rise Residential	0.4	0.4
Suburban	1.8	1.8
Undeveloped	**65.8**	**24.7**
Open Water	2.6	2.6

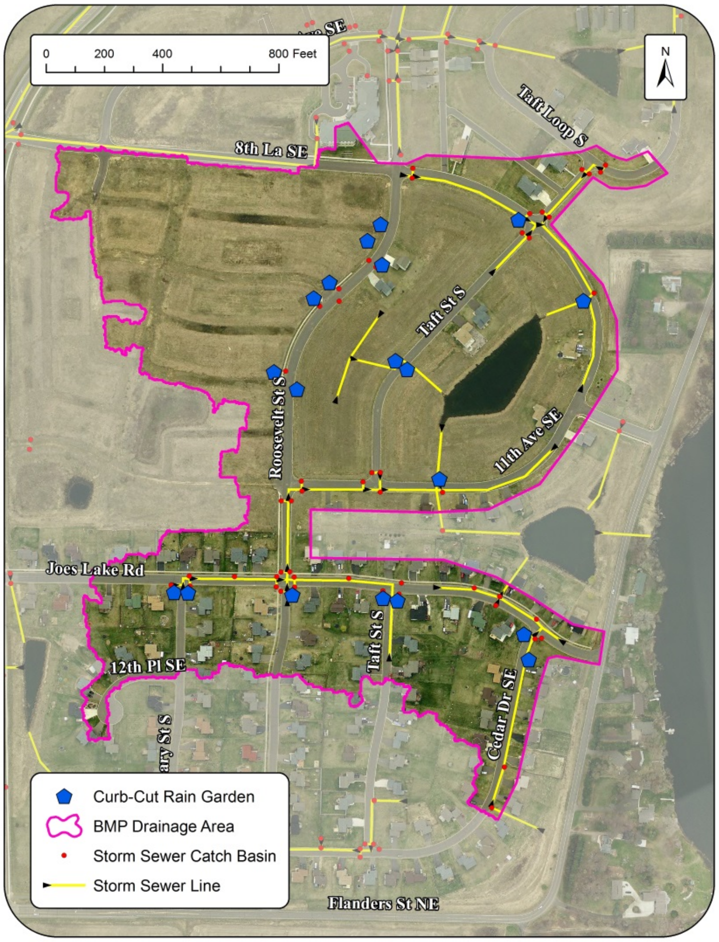
All proposed retrofits in this catchment assume pollutant reduction amounts based on the expected development conditions.

RETROFIT RECOMMENDATIONS



Project ID: 4-A

Catchment 4 Residential
Curb-Cut Rain Gardens



Drainage Area – Variable
Location – Single-family residential properties throughout catchment
Property Ownership – Private
Site Specific Information – Stormwater ponds in the catchment sufficiently treat TSS and other particulate pollutants, but may not meet the city's ordinance of infiltrating or otherwise retaining the first inch of precipitation before discharge into Fannie Lake. Pollutants that can easily advect through this system are in dissolved form. To remove these pollutants, rain gardens are proposed for residential properties upstream of the ponds.

Depending on soil type, gardens are recommended to have a ponding depth of either 6" or 12". In sandier soils where an infiltration rate of 1" per hour can be achieved, 12" gardens should be installed. These gardens, with an increased stormwater storage capacity, are the most cost-effective opportunity for treating TP in the catchment using bioretention. If infiltration rates are below 1" per hour, then gardens with 6" or smaller depths should be installed to ensure ponding time is less than 48 hours.

Rain gardens were not proposed along 11th Ave. and 8th Lane on the sides of the roadway where there were sidewalks as rain gardens in the boulevard were not as cost-effective as the standard rain gardens throughout the catchment.

Table 17 summarizes the potential removal from rain gardens with either 6" (first column) or 12" (second column) ponding depths. Notes pertaining to the expected cost of each garden can be found below their respective table.

Table 17: Pollutant removal potential for Project 4-A

	Curb Cut Rain Garden				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	Rain Garden Depth	6	inches	12	inches
	Top Area of Each Garden	250	sq-ft	250	sq-ft
	TP (lb/yr)	0.06	0.1%	0.13	0.3%
	TSS (lb/yr)	7	0.1%	21	0.3%
	Volume (acre-feet/yr)	0.09	0.2%	0.21	0.5%
Cost	Administration & Promotion Costs*	$4,234		$4,234	
	Design & Construction Costs**	$7,376		$7,376	
	Total Estimated Project Cost (2014)	**$11,610**		**$11,610**	
	Annual O&M***	$225		$225	
	Cost Over 20-year Life Span	**$16,110**		**$16,110**	
Efficiency	20-yr Average Cost/lb-TP	**$13,425**		**$6,196**	
	20-yr Average Cost/1,000lb-TSS	**$115,071**		**$38,357**	
	20-yr Average Cost/ac-ft Vol.	**$8,950**		**$3,836**	

*(58 hours at $73/hour base cost)

**($26/sq-ft for materials and labor) + (12 hours/BMP at $73/hour for design)

***($150/year for 10-year rehabilitation) + ($75/year for routine maintenance)

Project ID: 4-B

Catchment 4 IESF Bench

Drainage Area – 78.5 acres
Location – Along eastern bank of wet retention pond northwest of the Flanders St. and Joe's Lake Rd. intersection
Property Ownership – Not available in public parcel information
Site Specific Information – An IESF bench was proposed as an improvement to pond treatment. The pond currently provides treatment through retention and settling. However, the addition of an IESF bench will increase removal of DP. Space is available between the pond and Flanders St. for up to a ¼-acre (10,890 sq-ft) bench. A smaller bench was also modeled in case specific site constraints make a large bench unfeasible.

Table 18: Pollutant removal potential for Project 4-B

	IESF Bench				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	Number of BMPs	1		1	
	Total Size of BMPs	5,000	sq-ft	10,890	sq-ft
	TP (lb/yr)	11.5	26.4%	15.8	36.2%
	TSS (lb/yr)	0	0.0%	0	0.0%
	Volume (acre-feet/yr)	0.0	0.0%	0.0	0.0%
Cost	Administration & Promotion Costs*	$5,475		$5,475	
	Design & Construction Costs**	$147,130		$240,933	
	Total Estimated Project Cost (2014)	**$152,605**		**$246,408**	
	Annual O&M***	$1,148		$2,500	
	Cost Over 30-year Life Span	**$187,040**		**$296,408**	
Efficiency	30-yr Average Cost/lb-TP	**$542**		**$625**	
	30-yr Average Cost/1,000lb-TSS	**N/A**		**N/A**	
	30-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**	

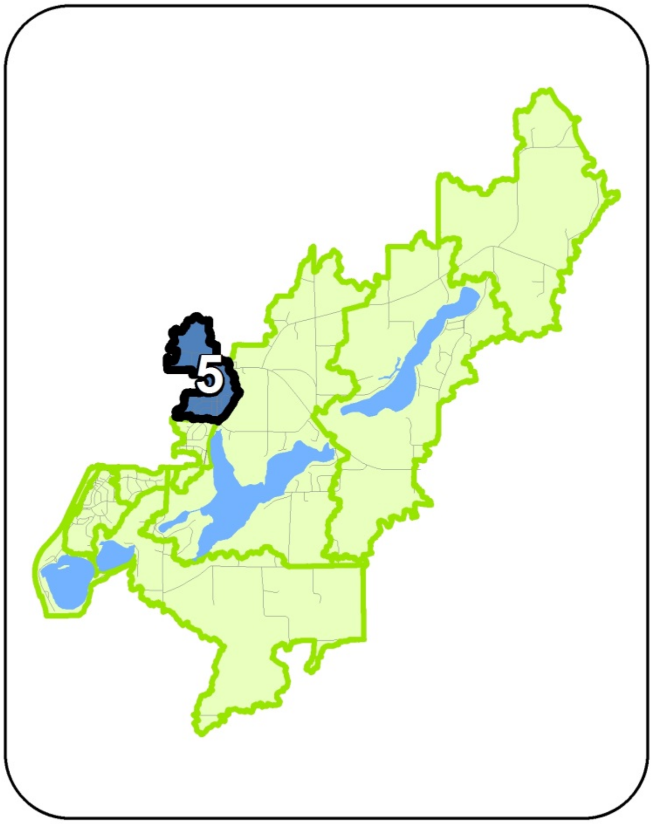
*75 hours at $73/hour

**Please see Appendix B for detailed cost information

***$10,000/acre for IESF Bench

Catchment 5

Existing Catchment Summary	
Acres	270
Dominant Land Cover	Residential
TP (lbs/yr)	89.4
TSS (lbs/yr)	21,432
Volume (ac-ft/yr)	151.4



CATCHMENT DESCRIPTION

This catchment is bisected by MN State Highway 95, with predominantly commercial properties along the highway corridor, and an assortment of other land uses away from the highway. To the north of Highway 95 are commercial properties (including Fleet Farm and Target), light industrial lots, a City of Cambridge complex, and portions of an agricultural field and open grassland. To the south of Highway 95 are additional commercial properties (notably including Menards), large residential lots along Flanders St., and unfinished residential developments.

EXISTING STORMWATER TREATMENT

Stormwater flow generated from the northern portion of the Fleet Farm property, along with runoff from the City of Cambridge complex, flow to a hydraulically connected infiltration basin and wet retention pond. These practices overflow into a 3.2 acre pond adjacent to Highway 95 northwest of its intersection with Flanders St. This pond treats runoff from all properties to its north and west within the catchment.

South of Highway 95 are eight additional wet retention ponds. Five of these ponds are in the Parkwood Development west of Flanders St. All runoff from within the development flows to at least one of these ponds. East of Flanders St. is the Cambridge-Preserve at Parkwood Subdivision, which has two ponds treating the proposed residential lots. Lastly, a wet retention pond south of Menards treats the large property to the north. This pond discharges into Parkwood Development pond system, which subsequently drains into a wetland complex upstream of Fannie Lake. The Cambridge-Preserve at Parkwood Subdivision ponds also drain into this wetland complex.

Lastly, street cleaning is performed by the City of Cambridge once every four weeks.

Based on existing land use and stormwater treatment practices, catchment-wide loading is:

	Existing Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	12			
	BMP Types	street cleaning, 10 wet ponds, infiltration basin			
	TP (lb/yr)	183.0	93.6	51%	**89.4**
	TSS (lb/yr)	64,449	43,017	67%	**21,432**
	Volume (acre-feet/yr)	172.2	20.9	12%	**151.4**

Taking into account future residential development within the region (but assuming no additional stormwater treatment), catchment-wide loading is expected to be:

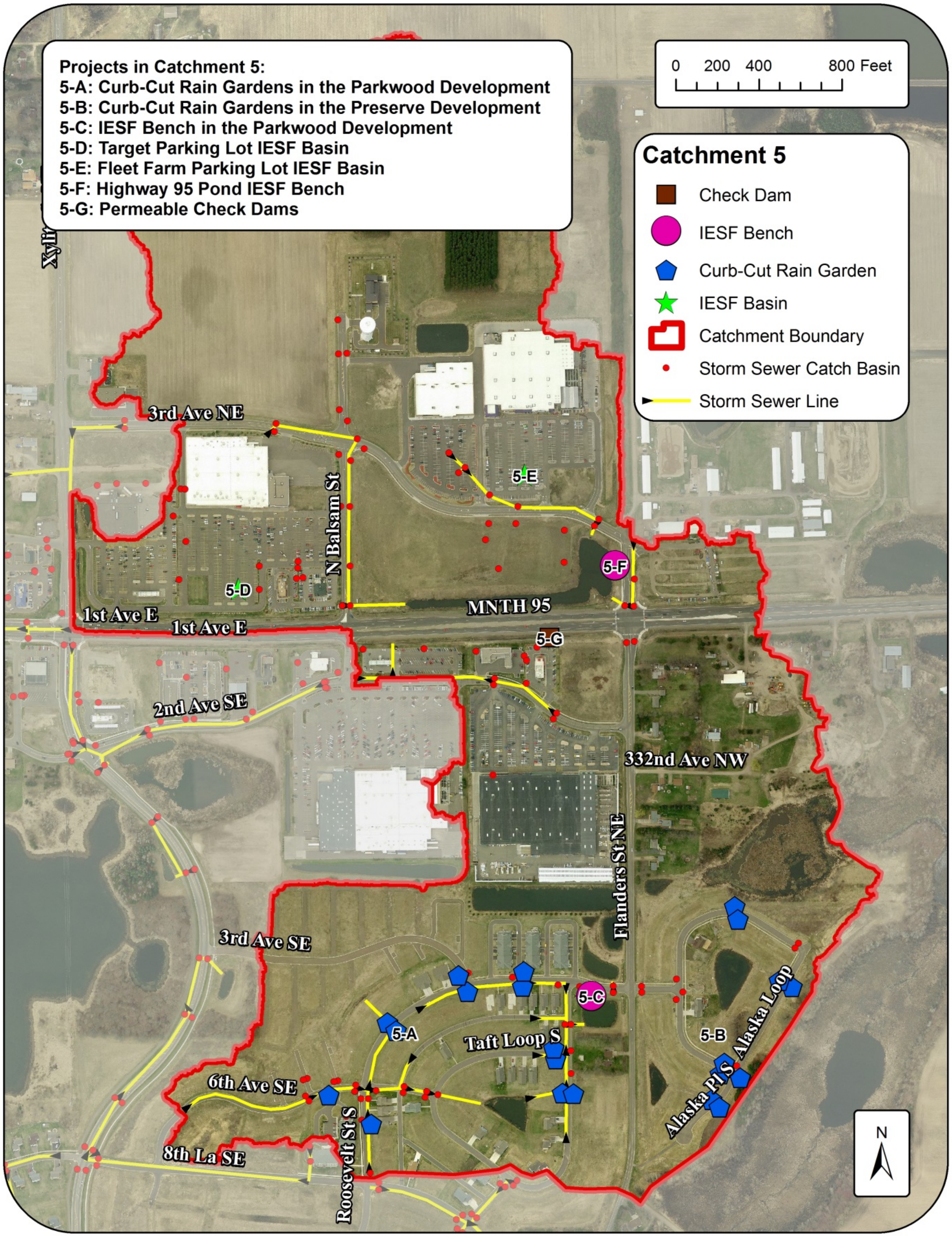
	Expected Development Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	12			
	BMP Types	street cleaning, 10 wet ponds, infiltration basin			
	TP (lb/yr)	207.2	109.4	53%	**97.8**
	TSS (lb/yr)	72,064	48,219	67%	**23,845**
	Volume (acre-feet/yr)	185.5	21.4	12%	**164.1**

Expected development is based on the land use changes in the table below. Land use types that are expected to change are emboldened:

Land Use Type	Existing Area (acres)	Future Area (acres)
Medium-Density Residential	**35.0**	**81.5**
Multi-Family Residential	3.4	3.4
High Rise Residential	1.5	1.5
Commerical	80.2	80.2
Institutional	4.1	4.1
Freeway	9.0	9.0
Light Industrial	3.7	3.7
Undeveloped	**120.0**	**73.5**
Open Water	12.9	12.9

All proposed retrofits in this catchment assume pollutant reduction amounts based on the expected development conditions.

RETROFIT RECOMMENDATIONS



Project ID: 5-A

Curb-Cut Rain Gardens in the Parkwood Development

Drainage Area – Variable
Location – Single-family residential properties throughout the development
Property Ownership – Private
Site Specific Information – A series of five stormwater ponds west of Flanders St. treat runoff from this residential development. These ponds sufficiently treat TSS and other particulate pollutants but may not meet the city's 1" rainfall infiltration standard and could use help in treating dissolved constituents. Curb-cut rain gardens are proposed to accomplish this.

Depending on soil type, gardens are recommended to have a ponding depth of either 6" or 12". In sandier soils where an infiltration rate of 1" per hour can be achieved, 12" gardens should be installed. These gardens, with an increased stormwater storage capacity, are the most cost-effective opportunity for treating TP in the catchment with bioretention (Table 19). If infiltration rates are below 1" per hour, then gardens with 6" or smaller depths should be installed to ensure ponding time is less than 48 hours.

Neither boulevard rain gardens nor boulevard bioswales were proposed for this catchment as they were not as cost-effective as standard rain gardens.

Table 19 summarizes the potential removal from rain gardens with either 6" (first column) or 12" (second column) ponding depths. Notes pertaining to the expected cost of each garden can be found below their respective table.

Table 19: Pollutant removal potential for Project 5-A

	Curb Cut Rain Garden				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**Rain Garden Depth**	6	inches	12	inches
	Top Area of Each Garden	250	sq-ft	250	sq-ft
	TP (lb/yr)	0.06	0.1%	0.13	0.3%
	TSS (lb/yr)	7	0.1%	21	0.3%
	Volume (acre-feet/yr)	0.09	0.2%	0.21	0.5%
Cost	**Administration & Promotion Costs***	$4,234		$4,234	
	Design & Construction Costs**	$7,376		$7,376	
	Total Estimated Project Cost (2014)	**$11,610**		**$11,610**	
	Annual O&M***	$225		$225	
	Cost Over 20-year Life Span	**$16,110**		**$16,110**	
Efficiency	**20-yr Average Cost/lb-TP**	**$13,425**		**$6,196**	
	20-yr Average Cost/1,000lb-TSS	**$115,071**		**$38,357**	
	20-yr Average Cost/ac-ft Vol.	**$8,950**		**$3,836**	

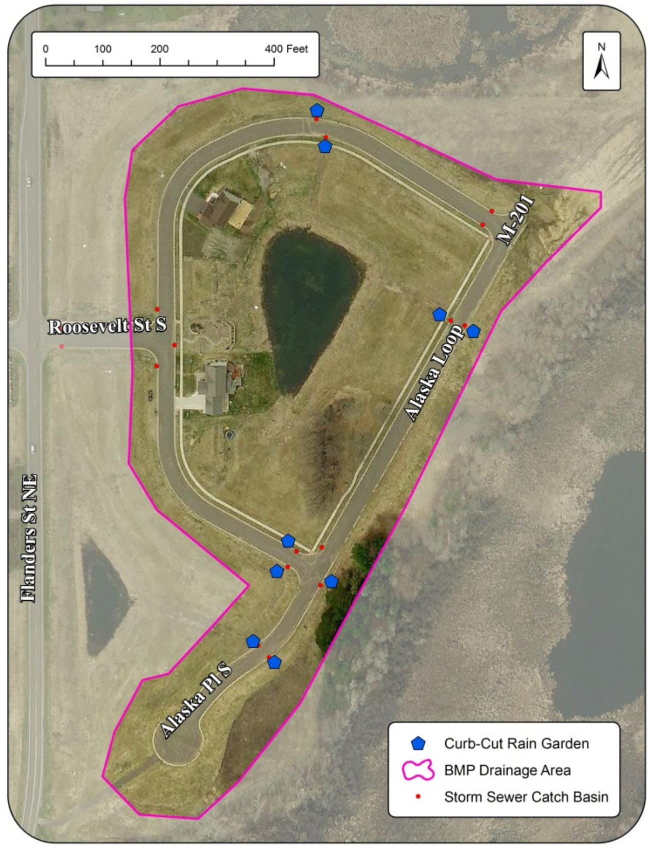
*(58 hours at $73/hour base cost)

**($26/sq-ft for materials and labor) + (12 hours/BMP at $73/hour for design)

***($150/year for 10-year rehabilitation) + ($75/year for routine maintenance)

Project ID: 5-B

Curb-Cut Rain Gardens in the Preserve Development



Drainage Area – Variable
Location – Single-family residential properties throughout catchment
Property Ownership – Private
Site Specific Information – Two stormwater ponds in this subdivision already sufficiently treat TSS and other particulate pollutants but may not meet the city's 1" rainfall infiltration standard and could use help in treating dissolved constituents. Curb-cut rain gardens could help treat these dissolved pollutants. Due to short drainage pathways in this portion of Catchment 5, these practices are only cost-effective for treating DP when drainage areas to the gardens are maximized with a double cut. In this scenario stormwater draining to a catch basin from both directions is intercepted into a single garden. For this to occur the garden must have two inlets, located along the gutter line on either side of the catch basin. Proposed gardens should only be installed in soil types with infiltration rates greater than or equal to 1" per hour. This will allow for gardens with a 12" ponding depth.

Neither single-cut boulevard rain gardens nor bioswales were proposed for this portion of Catchment 5 as they were not as cost-effective as standard rain gardens.

Table 20 summarizes the potential removal from double cut rain gardens within a boulevard (first column) or without a boulevard sized to 250 sq-ft (second column) or 350 sq-ft (third column) top area. Notes pertaining to the expected cost of each garden can be found below their respective table.

Table 20: Pollutant removal potential for Project 5-B

	Curb Cut Rain Garden						
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**Rain Garden Type**	Boulevard		Standard		Standard	
	Top Area of Each Garden	120	sq-ft	250	sq-ft	350	sq-ft
	TP (lb/yr)	0.07	0.1%	0.11	0.1%	0.15	0.2%
	TSS (lb/yr)	6	0.0%	12	0.1%	17	0.1%
	Volume (acre-feet/yr)	0.13	0.1%	0.19	0.1%	0.24	0.1%
Cost	**Administration & Promotion Costs***	$4,234		$4,234		$4,234	
	Design & Construction Costs**	$5,496		$8,876		$11,476	
	Total Estimated Project Cost (2014)	**$9,730**		**$13,110**		**$15,710**	
	Annual O&M***	$225		$225		$225	
	Cost Over 20-year Life Span	**$14,230**		**$17,610**		**$20,210**	
Efficiency	**20-yr Average Cost/lb-TP**	**$10,164**		**$8,005**		**$6,737**	
	20-yr Average Cost/1,000lb-TSS	**$118,583**		**$73,375**		**$59,441**	
	20-yr Average Cost/ac-ft Vol.	**$5,473**		**$4,634**		**$4,210**	

*(58 hours at $73/hour base cost)

**($26/sq-ft for materials and labor) + (12 hours/BMP at $73/hour for design) + ($1,500 for additional inlet)

***($150/year for 10-year rehabilitation) + ($75/year for routine maintenance)

Project ID: 5-C

IESF Bench in the Parkwood Development

Drainage Area – 27.8 acres
Location – Along northern bank of the stormwater pond at Flanders St. and Roosevelt St.
Property Ownership – State of Minnesota
Site Specific Information – To help the stormwater ponds in the Parkwood Development treat phosphorus, an IESF bench is proposed along the pond southwest of the intersection of Flanders St. and Roosevelt St. Space is available for a bench with a ponding area of 2,000 sq-ft between the pond's northern bank and Roosevelt St. The outlet from the bench should be tied to the existing overflow outlet structure east of the proposed bench's location.

Table 21: Pollutant removal potential for Project 5-C

	IESF Bench		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Number of BMPs**	1	
	Total Size of BMPs	2,000	sq-ft
	TP (lb/yr)	7.2	7.4%
	TSS (lb/yr)	0	0.0%
	Volume (acre-feet/yr)	0.0	0.0%
Cost	**Administration & Promotion Costs***	$5,475	
	Design & Construction Costs**	$86,852	
	Total Estimated Project Cost (2014)	**$92,327**	
	Annual O&M***	$459	
	Cost Over 30-year Life Span	**$106,101**	
Efficiency	**30-yr Average Cost/lb-TP**	**$491**	
	30-yr Average Cost/1,000lb-TSS	**N/A**	
	30-yr Average Cost/ac-ft Vol.	**N/A**	

*75 hours at $73/hour

**Please see Appendix B for detailed cost information

***$10,000/acre for IESF Bench

Project ID: 5-D

Target Parking Lot IESF Basin

Drainage Area – 11.0 acres
Location – Target Store parking lot
Property Ownership – Dayton Hudson Corporation
Site Specific Information – A large impervious area predominantly within the Target Store property could use additional treatment of stormwater pollutants. An IESF basin is proposed for this property, to be located in the low-traffic area of the parking lot. When determining the cost of this project, it was assumed that installation would occur during regular repaving of the parking lot. Any additional costs for resurfacing or rerouting existing stormwater infrastructure under the parking lot would need to be included. A pre-treatment chamber to remove large solids was included. Biofiltration cells were also modeled for this property but were not cost-effective due to the treatment of sediment and particulate pollutants in the large stormwater pond downstream of the property on Highway 95.

Table 22: Pollutant removal potential for Project 5-D

	Target Parking Lot IESF Basin				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**Number of BMPs**	1		1	
	Total Size of BMPs	2,000	sq-ft	4,000	sq-ft
	TP (lb/yr)	0.95	1.0%	1.48	1.5%
	TSS (lb/yr)	252	1.1%	571	2.4%
	Volume (acre-feet/yr)	0.60	0.4%	0.99	0.6%
Cost	**Administration & Promotion Costs***	$5,475		$5,475	
	Design & Construction Costs**	$103,613		$153,768	
	Total Estimated Project Cost (2014)	**$109,088**		**$159,243**	
	Annual O&M	$459		$918	
	Cost Over 30-year Life Span	**$118,271**		**$177,608**	
Efficiency	**30-yr Average Cost/lb-TP**	**$4,150**		**$4,000**	
	30-yr Average Cost/1,000lb-TSS	**$16,252**		**$10,904**	
	30-yr Average Cost/ac-ft Vol.	**$6,571**		**$5,980**	

*75 hours at $73/hour
**Please see Appendix B for detailed cost information
***$10,000/acre for IESF Basin

Project ID: 5-E

Fleet Farm Parking Lot
IESF Basin

Drainage Area – 10.8 acres
Location – Fleet Farm parking lot
Property Ownership – Kohl's Illinois, Inc. and Mill's Properties, Inc.
Site Specific Information – A portion of the Fleet Farm and Kohl's parking lots could potentially use additional treatment of stormwater runoff. An IESF basin is proposed within the Fleet Farm property, to be located in the low-traffic area of the parking lot. When determining the cost of this project, it was assumed that installation would occur during regular repaving of the parking lots. Any additional costs for resurfacing or rerouting existing stormwater infrastructure under the parking lots would need to be included. A pre-treatment chamber to remove large solids was included. Biofiltration cells were also modeled for this property but were not cost-effective due to the treatment of sediment and particulate pollutants in the large stormwater pond downstream of the property on Highway 95.

Table 23: Pollutant removal potential for Project 5-E

	Fleet Farm Parking Lot IESF Basin				
	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	Number of BMPs	1		1	
	Total Size of BMPs	2,000	sq-ft	4,000	sq-ft
	TP (lb/yr)	0.78	0.8%	0.91	0.9%
	TSS (lb/yr)	270	1.1%	511	2.1%
	Volume (acre-feet/yr)	0.51	0.3%	0.83	0.5%
Cost	Administration & Promotion Costs*	$5,475		$5,475	
	Design & Construction Costs**	$103,613		$153,768	
	Total Estimated Project Cost (2014)	**$109,088**		**$159,243**	
	Annual O&M	$459		$918	
	Cost Over 30-year Life Span	**$118,271**		**$177,608**	
Efficiency	30-yr Average Cost/lb-TP	**$5,054**		**$6,506**	
	30-yr Average Cost/1,000lb-TSS	**$15,168**		**$12,185**	
	30-yr Average Cost/ac-ft Vol.	**$7,730**		**$7,133**	

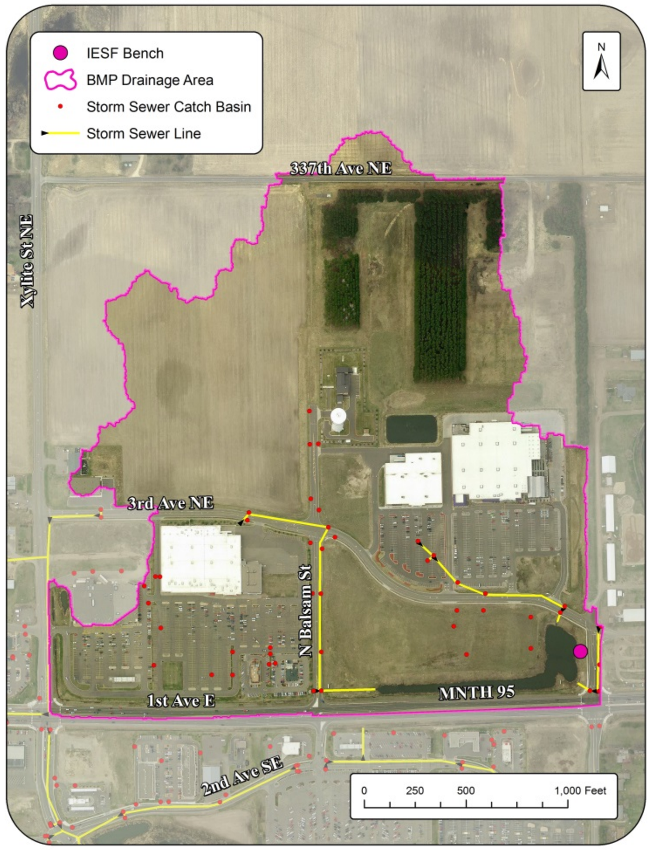
*75 hours at $73/hour

**Please see Appendix B for detailed cost information

***$10,000/acre for IESF Basin

Project ID: 5-F

Highway 95 Pond IESF Bench



Drainage Area – 126.5 acres
Location – East of Highway 95 pond and west of Flanders St.
Property Ownership – City of Cambridge
Site Specific Information –The Highway 95 pond accepts stormwater runoff from all properties north and west of the site within Catchment 5. The pond is sufficiently sized to treat particulate pollutants, including sediment and bound forms of phosphorus, but could be improved for treating dissolved constituents by adding an IESF bench. Table 24**Error! Reference source not found.** summarizes the removal potential of this practice.

Table 24: Pollutant removal potential for Project 5-F

IESF Bench			
	Cost/Removal Analysis	New Treatment	% Reduction
Treatment	Number of BMPs	1	
	Total Size of BMPs	2,000	sq-ft
	TP (lb/yr)	5.0	5.1%
	TSS (lb/yr)	0	0.0%
	Volume (acre-feet/yr)	0.0	0.0%
Cost	Administration & Promotion Costs*	$5,475	
	Design & Construction Costs**	$86,852	
	Total Estimated Project Cost (2014)	**$92,327**	
	Annual O&M***	$459	
	Cost Over 30-year Life Span	**$106,101**	
Efficiency	30-yr Average Cost/lb-TP	**$707**	
	30-yr Average Cost/1,000lb-TSS	**N/A**	
	30-yr Average Cost/ac-ft Vol.	**N/A**	

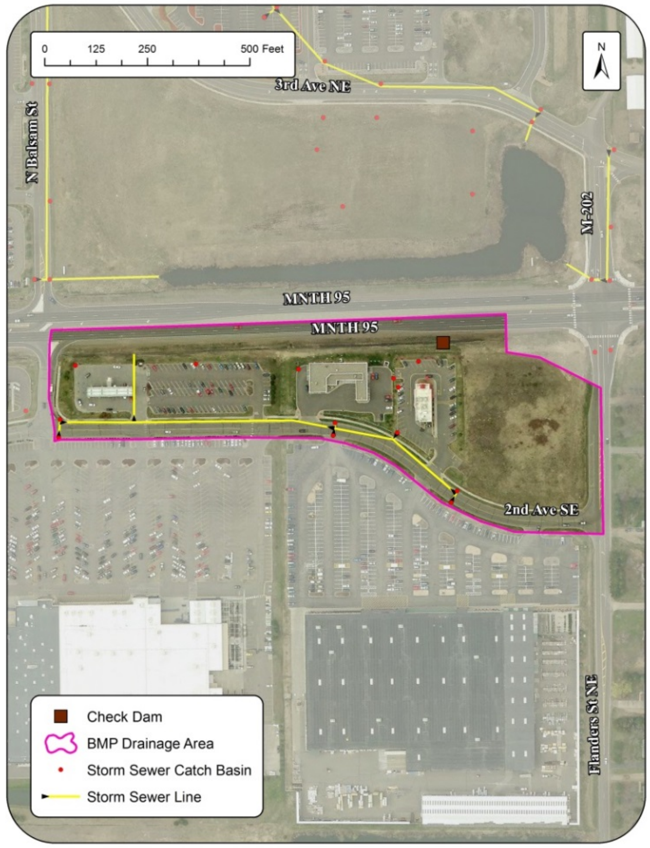
*75 hours at $73/hour

**Please see Appendix B for detailed cost information

***$10,000/acre for IESF Bench

Project ID: 5-G

Highway 95 Permeable Check Dams



Drainage Area – 10.5 acres
Location – Within the Highway 95 southern ditch between Balsam St. and Flanders St.
Property Ownership – State of Minnesota Department of Transportation
Site Specific Information – Stormwater generated on commercial properties along 2nd Ave. drains to the ditch south of Highway 95. This ditch flows east along Highway 95 and directly into a wetland north of Fannie Lake. Permeable check dams are proposed along the ditch to promote sediment and debris accumulation upstream of the dams and dissolved pollutant retention within the dams. Check dams modeled for this location were 2' high (on average), 4' long, and 20' in width to span ditch sides. Table 25 summarizes the removal potential of this practice.

Table 25: Pollutant removal potential for Project 5-G

	Permeable Check Dams		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	Number of BMPs	2	
	Total Size of BMPs	240	cu-ft
	TP (lb/yr)	1.0	1.0%
	TSS (lb/yr)	1,347	5.6%
	Volume (acre-feet/yr)	0.0	0.0%
Cost	Administration & Promotion Costs*	$2,920	
	Design & Construction Costs**	$9,833	
	Total Estimated Project Cost (2014)	**$12,753**	
	Annual O&M***	$730	
	Cost Over 20-year Life Span	**$27,353**	
Efficiency	20-yr Average Cost/lb-TP	**$1,368**	
	20-yr Average Cost/1,000lb-TSS	**$1,015**	
	20-yr Average Cost/ac-ft Vol.	**N/A**	

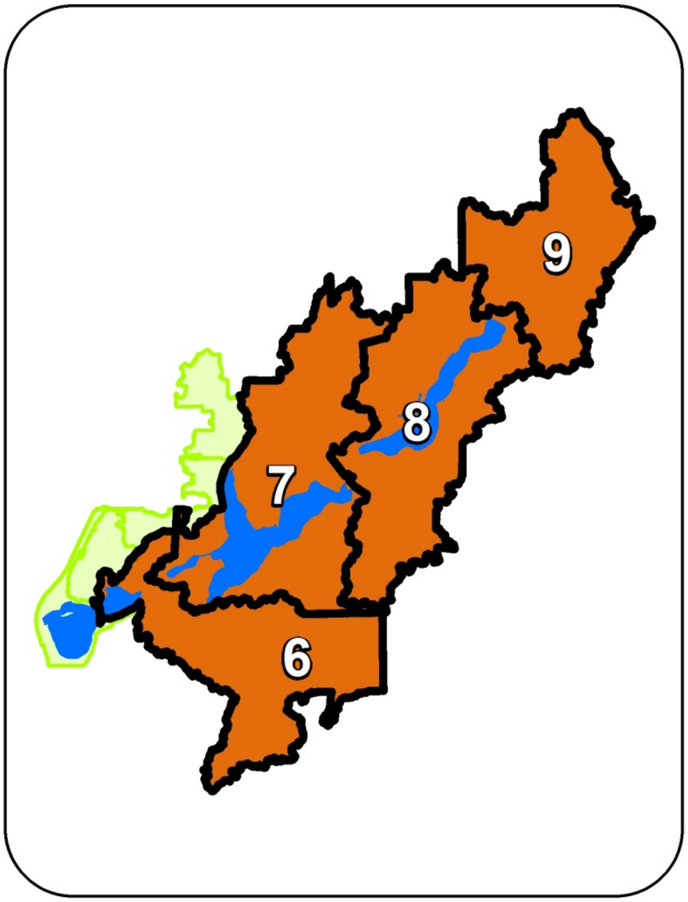
*(40 hours at $73/hour base cost)

**Please see Appendix B for detailed cost information

***(5 hours for each dam at $73/year for cleaning sediment/debris and maintenance)

Catchment Profiles Section 2: Rural Catchments

Existing Network Summary	
Acres	7,474
Dominant Land Cover	Agricultural
TP (lbs/yr)	1,054
TSS (lbs/yr)	677,463
Volume (ac-ft/yr)	3,915



AREA SUMMARY

The "rural" portions of the SFEF subwatershed include acreage draining to the lakes from within the townships of Cambridge, Isanti, and Fish Lake as well as some undeveloped and agricultural land draining to the lakes from within the City of Cambridge.

The rural catchments are predominantly agricultural, with more than half the land use either under production (mostly corn and soybeans, 32% of land area) or open to pasture and hay (23%). Other land uses in these catchments include mixed forests (18%), open water in the form of wetlands and small ponds (17%), rural residential lots (6%), and grasslands (4%). Soils are generally silty-sand loam, with average to poor drainage rates.

Annual pollutant loading to the SFEF lakes chain from rural catchments includes 1,054 lbs-TP, 339 tons-TSS, and 3,915 ac-ft of water volume (Table 26).

EXISTING TREATMENT

Generally speaking, little to no treatment is provided to stormwater runoff prior to discharge into the SFEF lakes chain. Runoff from farm fields, pasture lands, and residential lots flows directly to ditches, where it is transported quickly to either Skogman, Fannie, or Elms Lakes. In some cases, such as in Catchment 9, runoff first discharges into a small pond or wetland. Within these waterbodies sediment and PP can settle out of the water column and phosphorus can be used biologically by plants or animals. These pollutant "sinks" can act as buffers for downstream lakes or rivers by permanently trapping sediment, promoting nutrient uptake, and storing water to ensure recharge occurs at a more natural time scale (prior to artificial drainage).

Table 26: Summary of existing pollutant loading from rural catchments

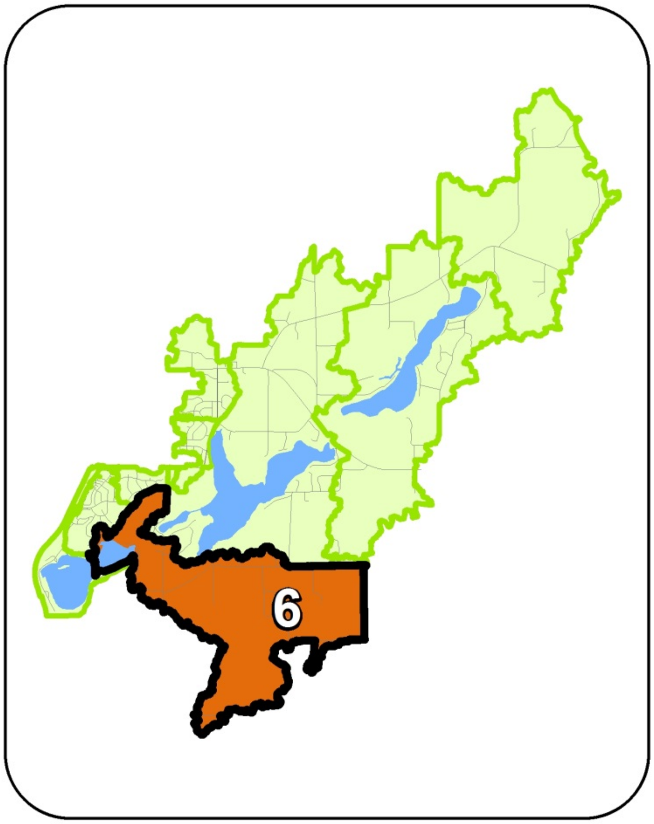
			Existing Pollutant Loading					
Catchment	Receiving Lake	Area (ac)	TP (lbs/yr)	TP (lbs/ac)	TSS (lbs/yr)	TSS (lbs/ac)	Vol. (ac-ft/yr)	Vol. (ac-ft/ac)
6	Elms	1,676	284	0.17	179,397	107	804	0.48
7	Fannie	2,287	384	0.17	240,818	105	1375	0.60
8	Skogman	2,069	255	0.12	169,790	82	1109	0.54
9	Skogman	1,442	131	0.09	87,458	61	627	0.43

RETROFIT RECOMMENDATIONS

Most structural stormwater BMPs proposed in rural landscapes try to mimic the processes which would have occurred before artificial drainage. These include wetland restorations, hydrologic restorations, WASCOBs, and regional ponds. Other BMPs, such as filter strips, try to simulate the effect riparian buffers have by trapping coarse particles as they move with overland water towards a ditch or lake. Proposed BMP sites were chosen where existing land use required additional treatment, such as on the edge of a farm field. In total, 18 BMPs were recommended across these rural catchments.

Catchment 6

Existing Catchment Summary	
Acres	1,676
Dominant Land Cover	Agricultural
TP (lbs/yr)	284.0
TSS (lbs/yr)	179,397
Volume (ac-ft/yr)	804.4



CATCHMENT DESCRIPTION

Catchment 6 encompasses all rural lands draining directly to Elms Lake. This includes farm fields (36% of catchment area), pasture lands (21%), forests (21%), open water/wetlands (13%, including Elms Lake), rural residential lots (4%) and grasslands (4%). The lands are predominantly within Isanti Township, but also include rural portions of the City of Cambridge.

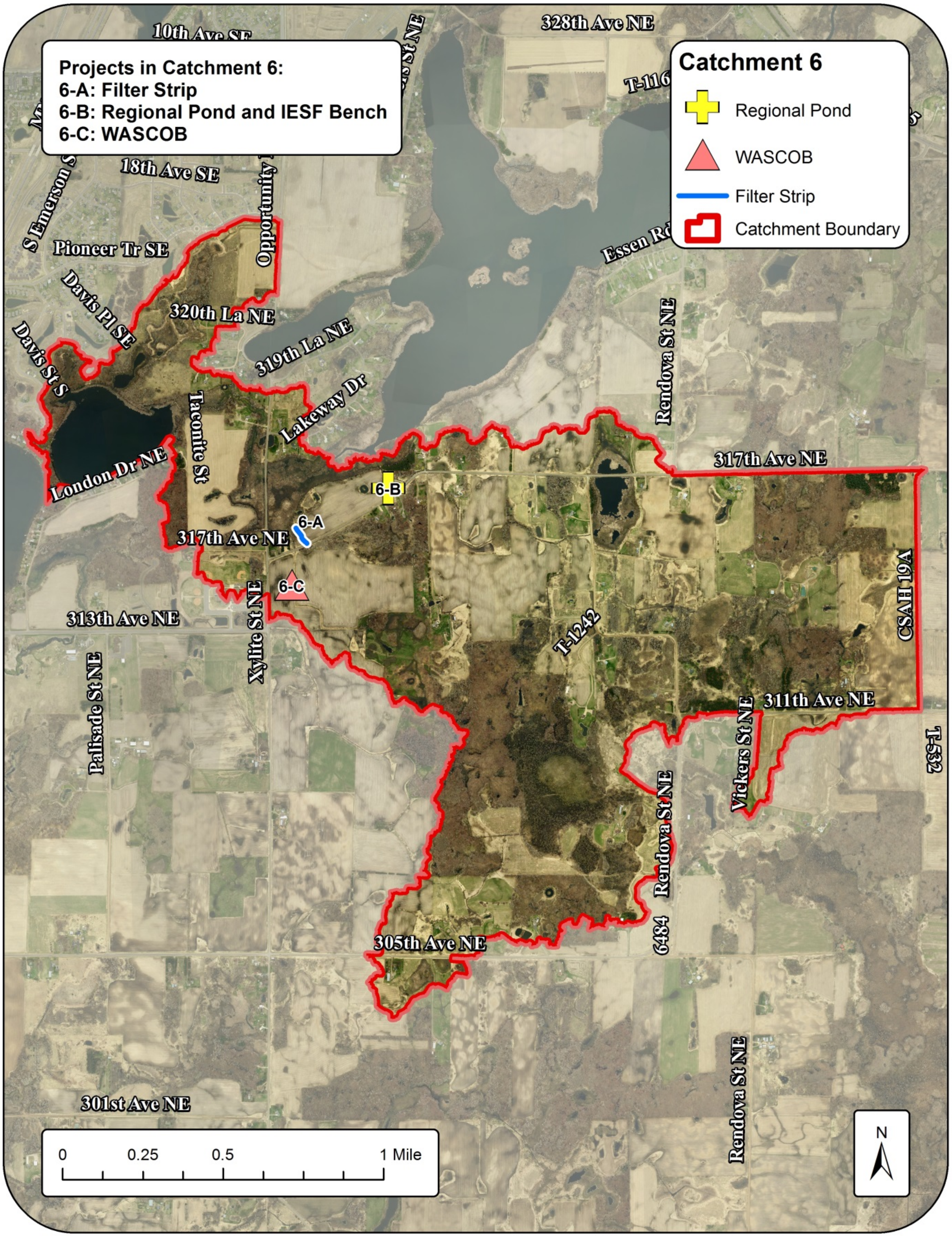
EXISTING STORMWATER TREATMENT

There are no catchment-wide stormwater treatment practices. Runoff generated on the landscape is conveyed to ditches and discharged directly into Elms Lake. There are some wetlands in-line and upstream of the ditching system that provide treatment for TSS and TP. The large wetland at 317th Ave. and Naples St. is an example of this. Wetlands and ponds were modeled in ArcSWAT with other land use, soil, and terrain conditions to determine TSS, TP, and volume loading to Elms Lake from this catchment.

Catchment-Wide Existing Conditions

	Existing Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	0			
	BMP Types	N/A			
	TP (lb/yr)	284.0	0.0	0%	**284.0**
	TSS (lb/yr)	179,397	0	0%	**179,397**
	Volume (acre-feet/yr)	804.4	0.0	0%	**804.4**

RETROFIT RECOMMENDATIONS



Project ID: 6-A

Vegetated Filter Strip

Drainage Area – 59.1 acres
Location – On or adjacent to field west of 317th Ave.
Property Ownership – Private
Site Specific Information – A large upstream drainage area and a lack of crop residue has led to rill erosion on a farm field just southeast of Elms Lake. A large, edge-of-field filter strip is recommended at the outlet of the watershed. Otherwise, a grassed waterway may also work along the blue path noted on the map to the right. Table 27 summarizes the pollutant removal potential for an edge-of field filter strip of varying widths from 10-30'.

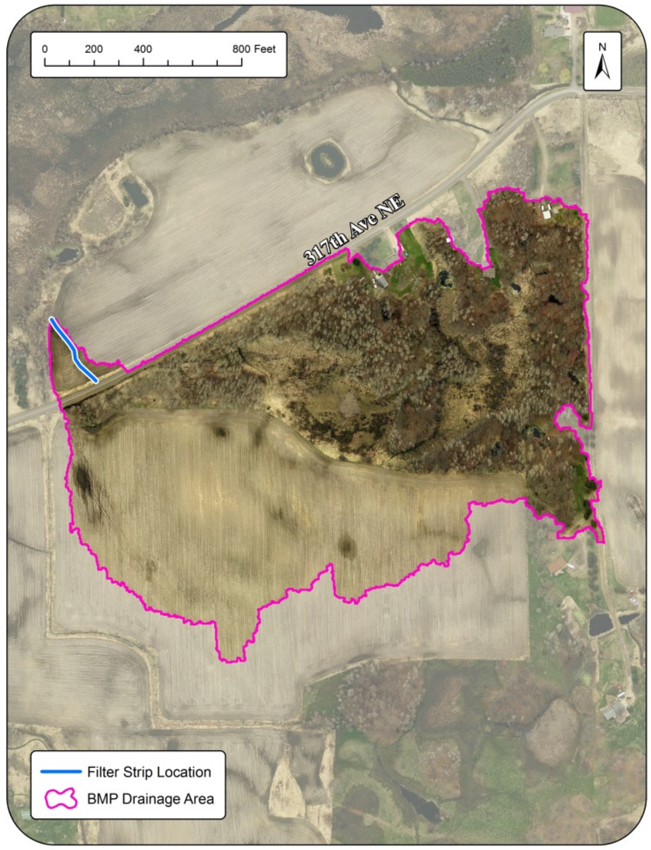


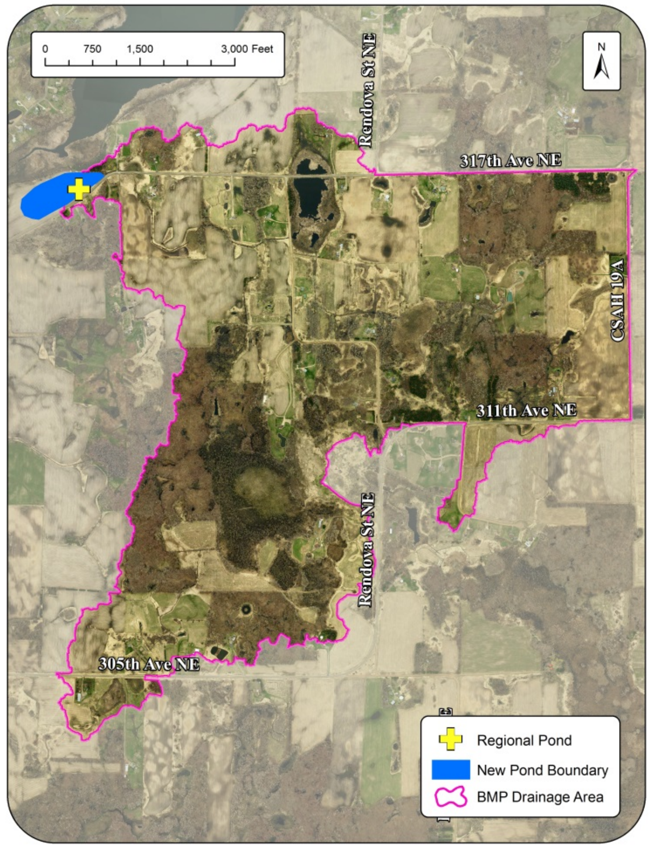
Table 27: Pollutant removal potential for Project 6-A

	Vegetated Filter Strip						
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	BMP Width	10	feet	20	feet	30	feet
	BMP Length	1,400	feet	1,400	feet	1,400	feet
	TP (lb/yr)	6.75	67.5%	7.06	70.6%	7.30	73.0%
	TSS (lb/yr)	6,753	72.7%	7,175	77.3%	7,281	78.4%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%	0.00	0.0%
Cost	Administration & Promotion Costs*		$4,745		$4,745		$4,745
	Design, Oversight, & Construction Costs**		$6,064		$6,129		$6,193
	Total Estimated Project Cost (2014)		**$10,809**		**$10,874**		**$10,938**
	Annual Production Lost***		$257		$514		$771
	Annual O&M		$300		$300		$300
	Cost Over 20-year Life Span		**$21,951**		**$27,156**		**$32,362**
Efficiency	**20-yr Average Cost/lb-TP**	**$163**		**$192**		**$222**	
	20-yr Average Cost/1,000lb-TSS	**$163**		**$189**		**$222**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**		**N/A**	

*(65 hours at $73/hour)
**($200/acre for filter strip establishment) + ($6,000 for design and construction oversight)
***($800/acre/year)

Project ID: 6-B

Regional Pond and IESF Bench



Drainage Area – 1,128 acres
Location – Between Fannie Lake and 317th Ave.
Property Ownership – Private
Site Specific Information – A new stormwater retention pond is proposed which would treat the upstream agricultural and residential land use for TSS and TP prior to it entering Fannie Lake. An 8' deep, 12 acre pond meets the MPCA permit requirement for at least 1,800 cu-ft of permanent pool storage per acre of drainage to the pond. It also removes greater than 80% of TSS but just 25% of TP from its upstream drainage area. An IESF bench was also proposed with this pond to increase TP retention. Table 28 summarizes the removal potential of the pond alone.

Table 28: Pollutant removal potential for Project 6-B, new regional pond only

	New Regional Pond		
	Cost/Removal Analysis	New Treatment	% Reduction
Treatment	Pond Depth	8	feet
	Pond Area	12.0	acres
	TP (lb/yr)	57.82	25.0%
	TSS (lb/yr)	177,212	88.9%
	Volume (acre-feet/yr)	1.20	0.2%
Cost	Administration & Promotion Costs*	$6,205	
	Design, Oversight, & Construction Costs**	$2,419,818	
	Total Estimated Project Cost (2014)	**$2,426,023**	
	Annual O&M	$1,200	
	Cost Over 30-year Life Span	**$2,462,023**	
Efficiency	20-yr Average Cost/lb-TP	**$1,419**	
	30-yr Average Cost/1,000lb-TSS	**$463**	
	30-yr Average Cost/ac-ft Vol.	**$68,390**	

*(85 hours at $73/hour)

**Please see Appendix B for detailed cost information

An IESF pond bench was modeled for various sizes ranging from 0.25-2.0 acres. Based on drainage area size, cost effectiveness of the device, and available space at the site the following IESF sizes were proposed:

Table 29: Pollutant removal potential for Project 6-B, IESF bench only

	RP1 IESF Bench						
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	Number of BMPs	1		1		1	
	Total Size of BMPs	0.25	acres	0.5	acre	1.0	acres
	TP (lb/yr)	24.96	10.8%	38.26	16.5%	50.77	21.9%
	TSS (lb/yr)	0	0.0%	0	0.0%	0	0.0%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%	0.00	0.0%
Cost	Administration & Promotion Costs*	$5,475		$5,475		$5,475	
	Easement, Design, Oversight, & Construction Costs**	$240,933		$420,617		$779,983	
	Total Estimated Project Cost (2014)	**$246,408**		**$426,092**		**$785,458**	
	Annual O&M***	$2,500		$5,000		$10,000	
	Cost Over 30-year Life Span	**$296,408**		**$526,092**		**$985,458**	
Efficiency	**30-yr Average Cost/lb-TP**	**$396**		**$458**		**$647**	
	30-yr Average Cost/1,000lb-TSS	**N/A**		**N/A**		**N/A**	
	30-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**		**N/A**	

*75 hours at $73/hour

**Please see Appendix B for detailed cost information

***$10,000/acre for IESF Bench

These scenarios retain anywhere from 11-22% of upstream TP. This bench should not be installed without some form of pretreatment, which can only sufficiently by supplied by a large pond for such a large upstream drainage area. Thus, the IESF should only be installed in tandem with the regional pond. The location for the bench should be near the pond outlet, likely along the northern or eastern bank of the pond.

Project ID: 6-C
WASCOB

Drainage Area – 5.0 acres
Location – On field east of intersection of Xylite St. and 313th Ave.
Property Ownership – Private
Site Specific Information – Two berm sizes were modeled for this location. The first, a berm which ponds water up to the 961 ft. contour, would require a 20 ft. long berm. The second, a berm which ponds water up to the 962 ft. contour, would require a 75 ft. long berm. Table 30 summarizes the removal potential of this practice.

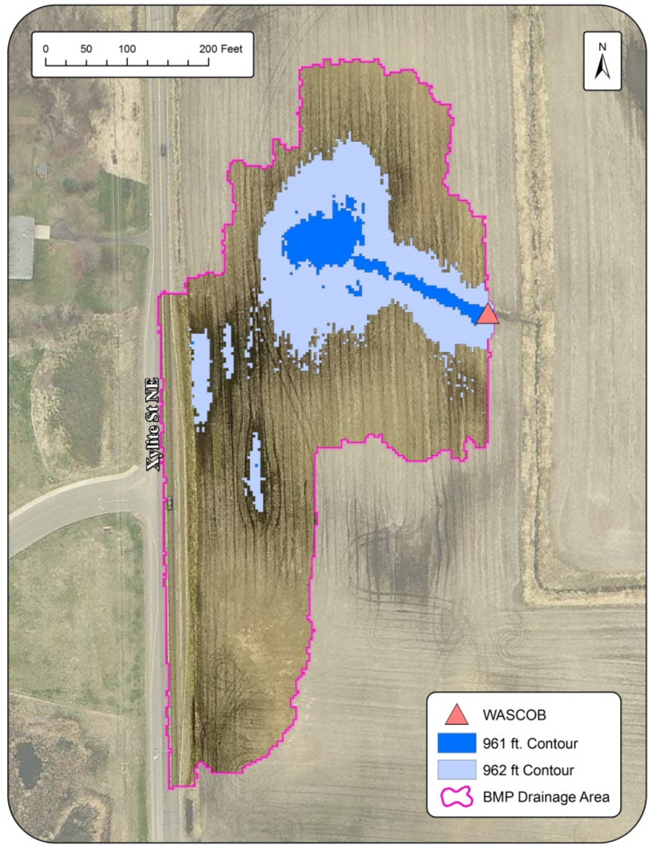


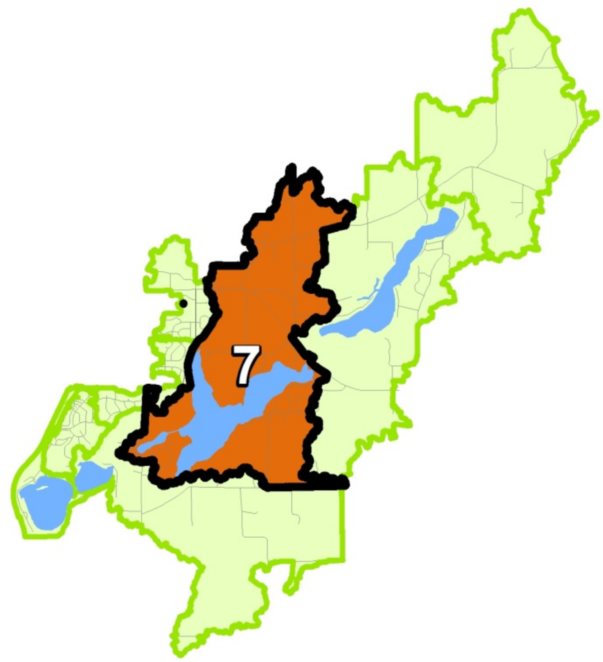
Table 30: Pollutant removal potential for Project 6-C

	Water and Sediment Control Basin				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**Pool Elevation**	961	feet	962	feet
	Pool Area	0.2	acres	1.1	acres
	TP (lb/yr)	0.29	29.0%	0.76	76.0%
	TSS (lb/yr)	236	17.3%	788	57.9%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%
Cost	**Administration & Promotion Costs***	$6,205		$6,205	
	Design, Oversight, & Construction Costs**	$14,178		$20,000	
	Total Estimated Project Cost (2014)	**$20,383**		**$26,205**	
	Annual Production Lost***	$3		$21	
	Annual O&M	$500		$500	
	Cost Over 20-year Life Span	**$30,447**		**$36,621**	
Efficiency	**20-yr Average Cost/lb-TP**	**$5,249**		**$2,409**	
	20-yr Average Cost/1,000lb-TSS	**$6,451**		**$2,324**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**	

*(85 hours at $73/hour)
**See BMP Descriptions section for detailed cost information
***($500/year)

Catchment 7

Existing Catchment Summary	
Acres	2,287
Dominant Land Cover	Agricultural
TP (lbs/yr)	383.7
TSS (lbs/yr)	240,818
Volume (ac-ft/yr)	1,374.7



CATCHMENT DESCRIPTION

Catchment 7 encompasses all rural lands draining directly to Fannie Lake. This includes farm fields (36% of catchment area), pasture lands (17%), forests (13%), open water/wetlands (24%, including Fannie Lake), rural residential lots (7%) and grasslands (3%). The lands are predominantly within Cambridge Township, but also include rural portions of the City of Cambridge. Included within the 539 acres of wetlands and open water is Fannie Lake, totaling 354 acres, and Mud Lake, totaling 20 acres.

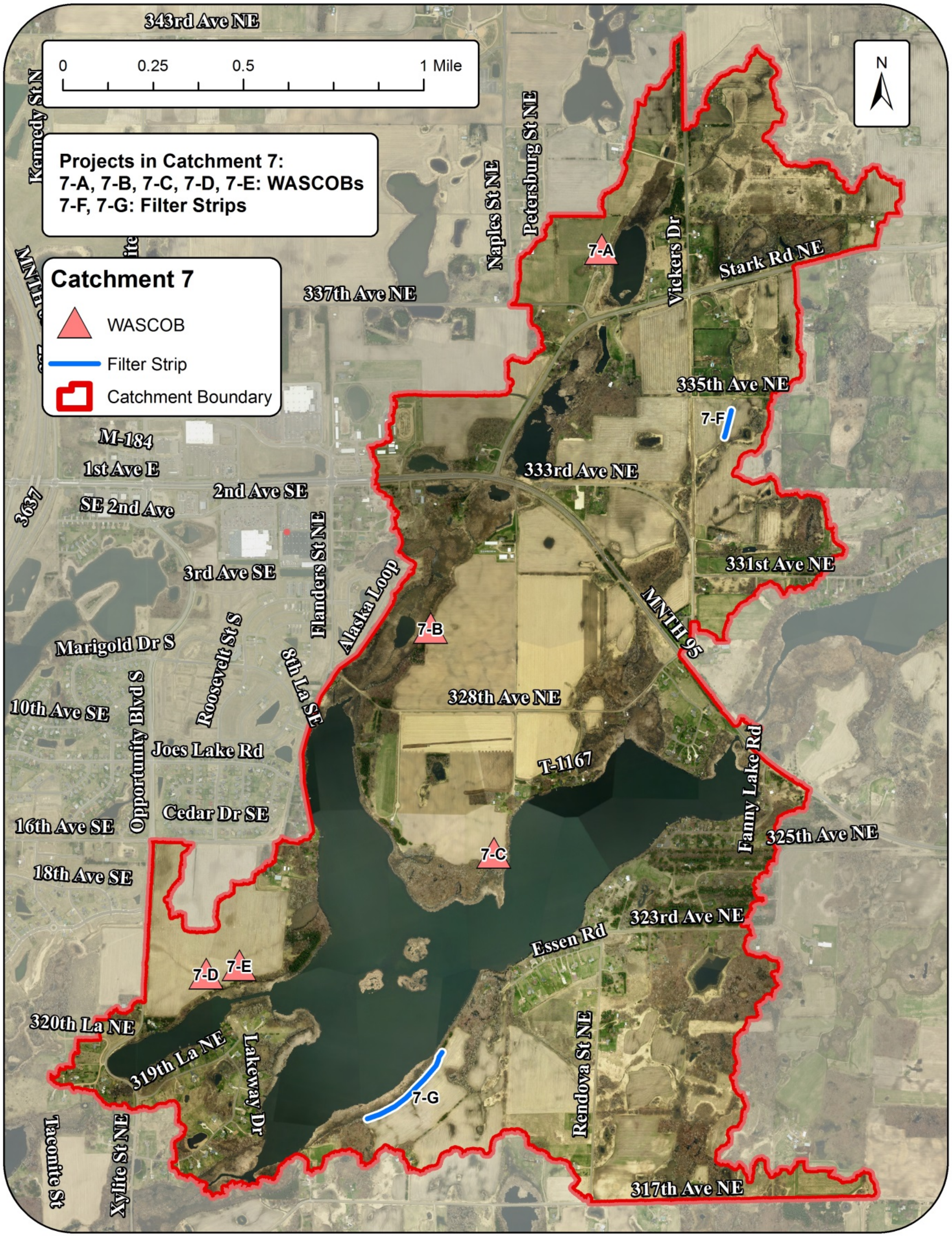
EXISTING STORMWATER TREATMENT

There are no catchment-wide stormwater treatment practices. Runoff generated on the landscape is conveyed to ditches and discharged directly into Fannie Lake. Wetland complexes in the northern portion of the catchment likely provide some form of treatment for TSS and TP. There is little opportunity for this treatment in the southern portion of the catchment, where runoff from farm fields and residential lots is discharged directly into the lake.

Catchment-Wide Existing Conditions

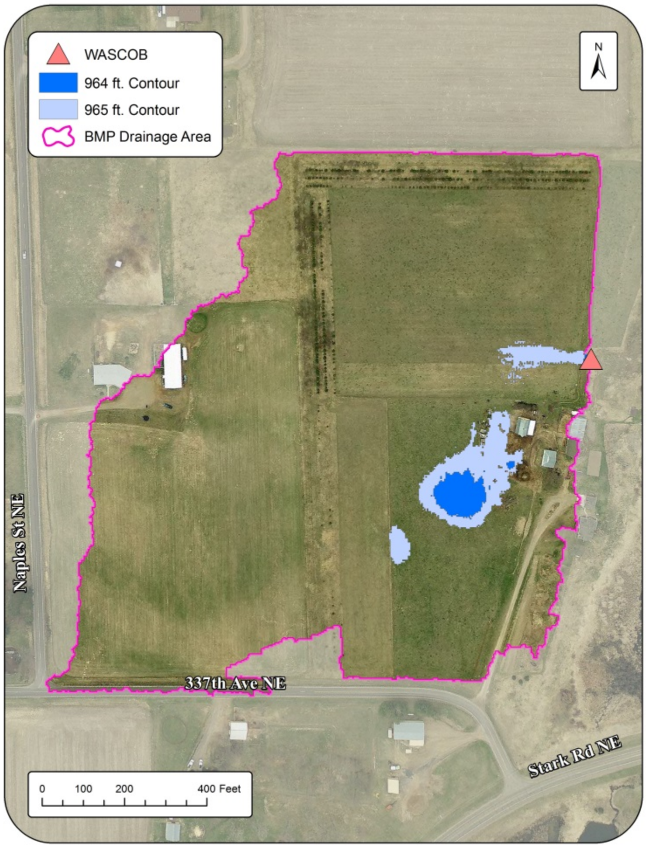
	Existing Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	0			
	BMP Types	N/A			
	TP (lb/yr)	383.7	0.0	0%	**383.7**
	TSS (lb/yr)	240,818	0	0%	**240,818**
	Volume (acre-feet/yr)	1,374.7	0.0	0%	**1374.7**

RETROFIT RECOMMENDATIONS



Project ID: 7-A

WASCOB



Drainage Area – 30.4 acres
Location – On farm field northwest of the Stark Rd. and 337th Ave. intersection
Property Ownership – Private
Site Specific Information – Two berm sizes were modeled for this location. The first, a berm which ponds water up to the 964 ft. contour, would require a 30 ft. long berm. The second, a berm which ponds water up to the 965 ft. contour, would require a 50 ft. long berm. Table 31 summarizes the removal potential of this practice.

Table 31: Pollutant removal potential for Project 7-A

	Water and Sediment Control Basin				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	Pool Elevation	964	feet	965	feet
	Pool Area	0.3	acres	1.2	acres
	TP (lb/yr)	0.33	8.9%	1.03	27.8%
	TSS (lb/yr)	278	5.5%	1,153	22.6%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%
Cost	Administration & Promotion Costs*		$6,205		$6,205
	Design, Oversight, & Construction Costs**		$14,267		$15,333
	Total Estimated Project Cost (2014)		**$20,472**		**$21,538**
	Annual Production Lost***		$5		$14
	Annual O&M		$500		$500
	Cost Over 20-year Life Span		**$30,568**		**$31,810**
Efficiency	20-yr Average Cost/lb-TP	**$4,632**		**$1,544**	
	20-yr Average Cost/1,000lb-TSS	**$5,498**		**$1,379**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**	

*(85 hours at $73/hour)
**See BMP Descriptions section for detailed cost information
***($500/year)

Project ID: 7-B

WASCOB

Drainage Area – 42.8 acres
Location – On farm field northwest of 328th Ave. and Naples St. intersection
Property Ownership – Private
Site Specific Information – Two berm sizes were modeled for this location. The first, a berm which ponds water up to the 960 ft. contour, would require a 100 ft. long berm. The second, a berm which ponds water up to the 961 ft. contour, would require a 140 ft. long berm. Table 32 summarizes the removal potential of this practice.

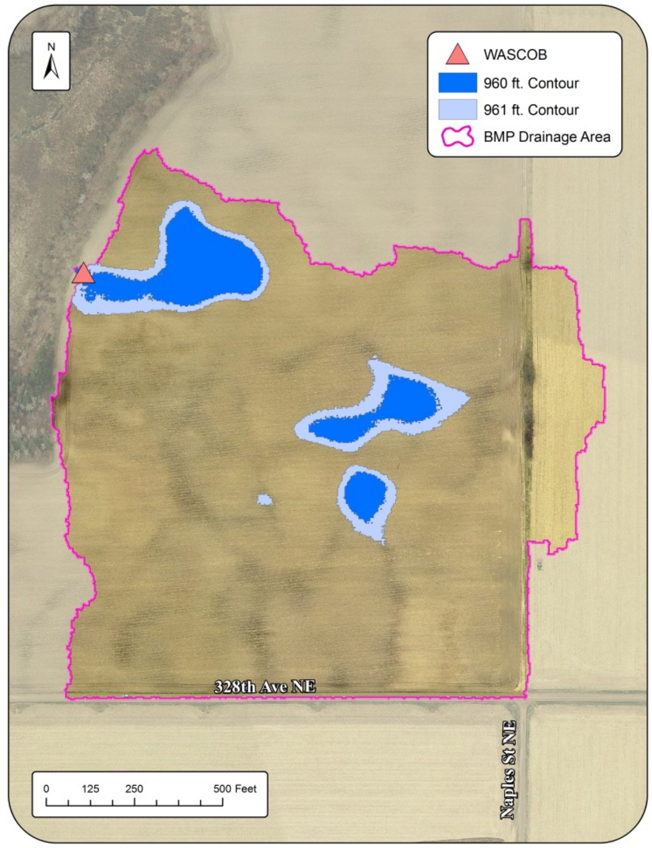


Table 32: Pollutant removal potential for Project 7-B

	Water and Sediment Control Basin				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	Pool Elevation	960	feet	961	feet
	Pool Area	2.5	acres	4.4	acres
	TP (lb/yr)	3.44	41.3%	4.89	58.8%
	TSS (lb/yr)	5,205	50.2%	8,079	77.8%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%
Cost	Administration & Promotion Costs*		$6,205		$6,205
	Design, Oversight, & Construction Costs**		$14,889		$17,733
	Total Estimated Project Cost (2014)		**$21,094**		**$23,938**
	Annual Production Lost***		$17		$38
	Annual O&M		$500		$500
	Cost Over 20-year Life Span		**$31,430**		**$34,706**
Efficiency	20-yr Average Cost/lb-TP	**$457**		**$355**	
	20-yr Average Cost/1,000lb-TSS	**$302**		**$215**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**	

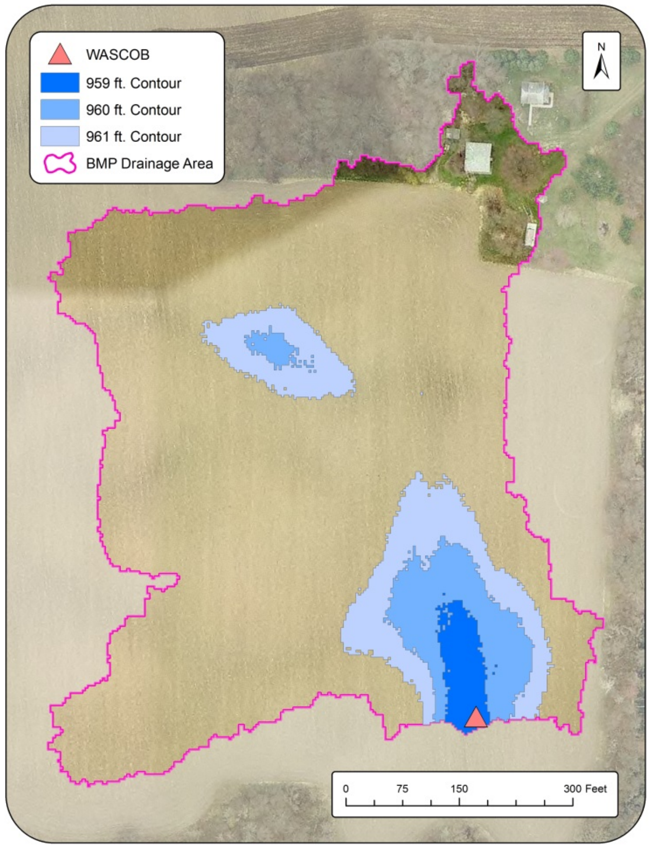
*(85 hours at $73/hour)

**See BMP Descriptions section for detailed cost information

***($500/year)

Project ID: 7-C

WASCOB



Drainage Area – 10.0 acres
Location – On farm field draining directly into Fannie Lake south of 328th Ave.
Property Ownership – Private
Site Specific Information – Three berm sizes were modeled for this location. The first, a berm which ponds water up to the 959 ft. contour, would require a 70 ft. long berm. The second, a berm which ponds water up to the 960 ft. contour, would require a 100 ft. long berm. The third berm ponds water to the 961 ft. contour and requires a 150 ft. long berm. Table 33 summarizes the removal potential of this practice.

Table 33: Pollutant removal potential for Project 7-C

	Water and Sediment Control Basin						
	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	Pool Elevation	959	feet	960	feet	961	feet
	Pool Area	0.2	acres	0.8	acres	1.7	acres
	TP (lb/yr)	0.33	8.9%	1.03	27.8%	1.95	52.7%
	TSS (lb/yr)	278	5.5%	1,153	22.6%	2,560	50.2%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%	0.00	0.0%
Cost	Administration & Promotion Costs*		$6,205		$6,205		$6,205
	Design, Oversight, & Construction Costs**		$14,622		$16,667		$26,000
	Total Estimated Project Cost (2014)		**$20,827**		**$22,872**		**$32,205**
	Annual Production Lost***		$25		$42		$58
	Annual O&M		$500		$500		$500
	Cost Over 20-year Life Span		**$31,323**		**$33,704**		**$43,357**
Efficiency	**20-yr Average Cost/lb-TP**	**$4,746**		**$1,636**		**$1,112**	
	20-yr Average Cost/1,000lb-TSS	**$5,634**		**$1,462**		**$847**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**		**N/A**	

*(85 hours at $73/hour)
**See BMP Descriptions section for detailed cost information
***($500/year)

Project ID: 7-D
WASCOB

Drainage Area – 29.9 acres
Location – Western portion of the farm field southeast of 16th Ave. and Opportunity Blvd. intersection
Property Ownership – Private
Site Specific Information – Three berm sizes were modeled for this location. The first, a berm which ponds water up to the 958 ft. contour, would require a 50 ft. long berm. The second, a berm which ponds water up to the 959 ft. contour, would require a 100 ft. long berm. The third berm ponds water to the 960 ft. contour and requires a 130 ft. long berm. Table 34 summarizes the removal potential of this practice.

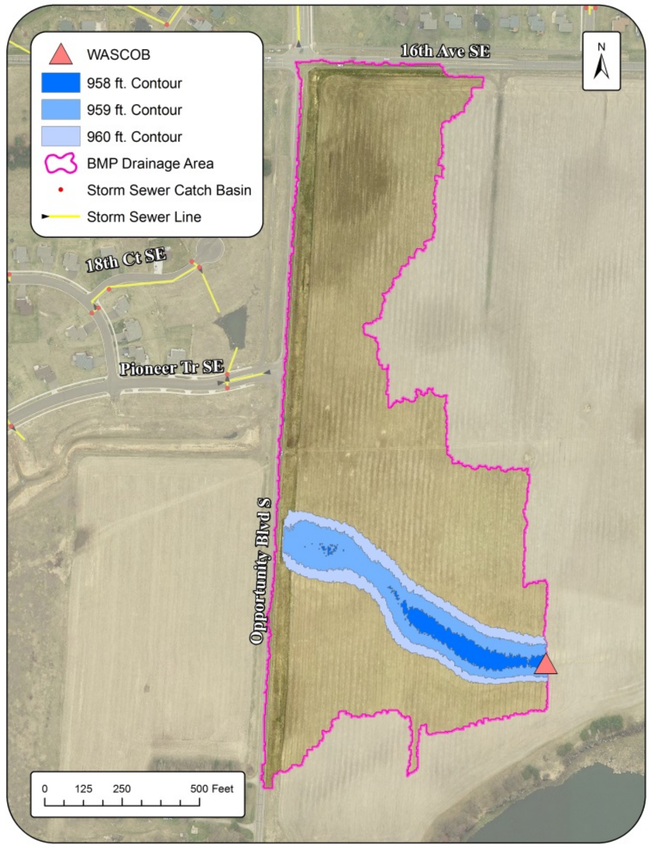


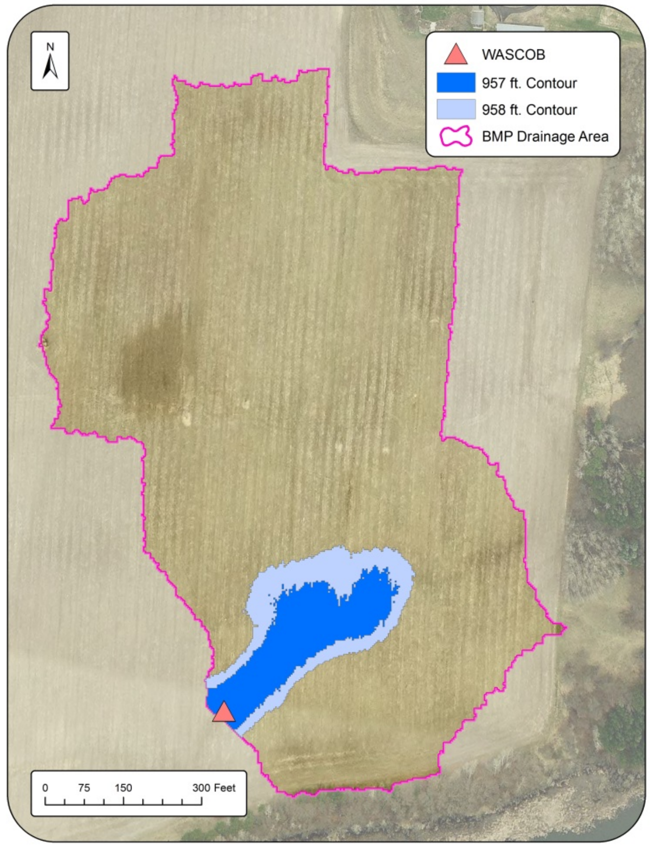
Table 34: Pollutant removal potential for Project 7-D

	Water and Sediment Control Basin						
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**Pool Elevation**	958	feet	959	feet	960	feet
	Pool Area	0.6	acres	2.5	acres	3.9	acres
	TP (lb/yr)	2.51	38.6%	3.05	46.9%	4.12	63.4%
	TSS (lb/yr)	3,510	35.1%	4,478	44.8%	6,521	65.3%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%	0.00	0.0%
Cost	**Administration & Promotion Costs***	$6,205		$6,205		$6,205	
	Design, Oversight, & Construction Costs**	$14,444		$16,667		$24,933	
	Total Estimated Project Cost (2014)	**$20,649**		**$22,872**		**$31,138**	
	Annual Production Lost***	$8		$27		$50	
	Annual O&M	$500		$500		$500	
	Cost Over 20-year Life Span	**$30,809**		**$33,416**		**$42,146**	
Efficiency	**20-yr Average Cost/lb-TP**	**$614**		**$548**		**$511**	
	20-yr Average Cost/1,000lb-TSS	**$439**		**$373**		**$323**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**		**N/A**	

*(85 hours at $73/hour)
**See BMP Descriptions section for detailed cost information
***($500/year)

Project ID: 7-E

WASCOB



Drainage Area – 19.4 acres
Location – Eastern portion of the farm field southeast of 16th Ave. and Opportunity Blvd. intersection
Property Ownership – Private
Site Specific Information – Two berm sizes were modeled for this location. The first, a berm which ponds water up to the 957 ft. contour, would require a 95 ft. long berm. The second, a berm which ponds water up to the 958 ft. contour, would require a 140 ft. long berm. Table 35 summarizes the removal potential of this practice.

Table 35: Pollutant removal potential for Project 7-E

	Water and Sediment Control Basin				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**Pool Elevation**	957	feet	958	feet
	Pool Area	1.0	acres	1.7	acres
	TP (lb/yr)	1.80	43.9%	2.50	61.0%
	TSS (lb/yr)	2,268	38.5%	3,493	59.3%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%
Cost	**Administration & Promotion Costs***	$6,205		$6,205	
	Design, Oversight, & Construction Costs**	$14,844		$21,733	
	Total Estimated Project Cost (2014)	**$21,049**		**$27,938**	
	Annual Production Lost***	$16		$38	
	Annual O&M	$500		$500	
	Cost Over 20-year Life Span	**$31,369**		**$38,706**	
Efficiency	**20-yr Average Cost/lb-TP**	**$871**		**$774**	
	20-yr Average Cost/1,000lb-TSS	**$692**		**$554**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**	

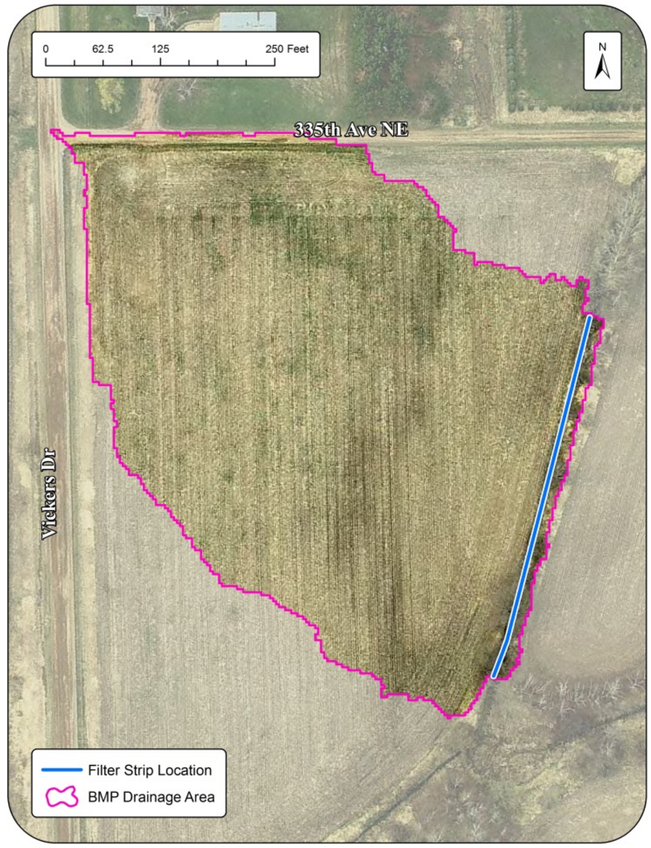
*(85 hours at $73/hour)

**See BMP Descriptions section for detailed cost information

***($500/year)

Project ID: 7-F

Vegetated Filter Strip



Drainage Area – 5.7 acres
Location – On field southeast of intersection of Vickers Dr. and 335th Ave.
Property Ownership – Private
Site Specific Information – An edge-of-field filter strip is proposed on the west side of the ditch. Table 36 summarizes the pollutant removal potential for an edge-of field filter strip of varying widths from 10-20 ft.

Table 36: Pollutant removal potential for Project 7-F

	Vegetated Filter Strip				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**BMP Width (from ditch)**	10	feet	20	feet
	BMP Length	500	feet	500	feet
	TP (lb/yr)	1.00	76.9%	1.03	79.2%
	TSS (lb/yr)	1,107	76.2%	1,147	79.0%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%
Cost	**Administration & Promotion Costs***		$4,745		$4,745
	Design, Oversight, & Construction Costs**		$6,023		$6,046
	Total Estimated Project Cost (2014)		**$10,768**		**$10,791**
	Annual Production Lost***		$92		$184
	Annual O&M		$300		$300
	Cost Over 20-year Life Span		**$18,604**		**$20,463**
Efficiency	**20-yr Average Cost/lb-TP**	**$930**		**$993**	
	20-yr Average Cost/1,000lb-TSS	**$840**		**$892**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**	

*(65 hours at $73/hour)

**($200/acre for filter strip establishment) + ($6,000 for design and construction oversight)

***($800/acre/year)

Project ID: 7-G

Vegetated Filter Strip

Drainage Area – 19.7 acres
Location – South shore of Fannie Lake west of Rendova St.
Property Ownership – Private
Site Specific Information – An edge-of-field filter strip is proposed to better treat stormwater running off farm fields south of Fannie Lake and directly into the lake. Table 37 summarizes the pollutant removal potential for increasing any existing buffer by 10-20 ft. along the 1,500 ft. shore.

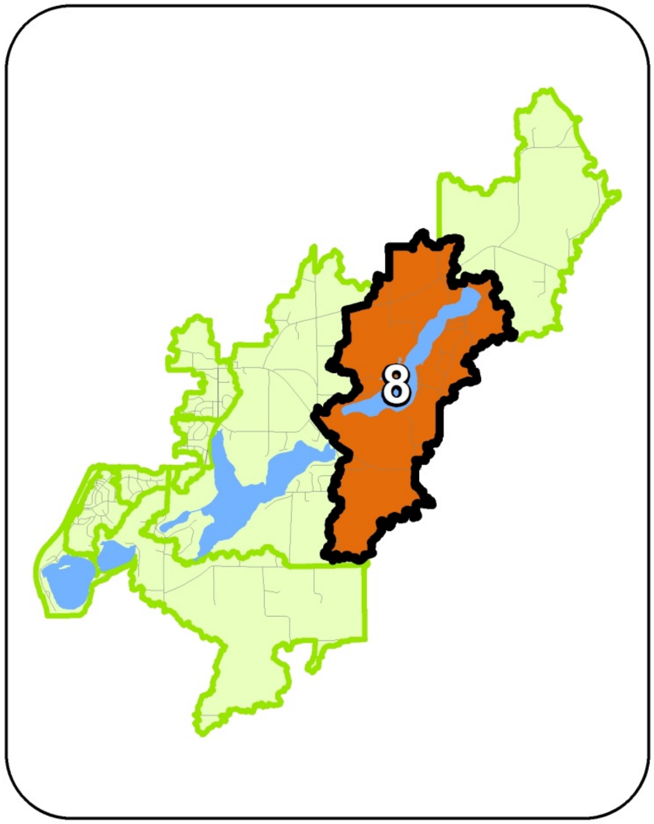
Table 37: Pollutant removal potential for Project 7-G

	Vegetated Filter Strip				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**BMP Width (from ditch)**	10	feet	20	feet
	BMP Length	1,500	feet	1,500	feet
	TP (lb/yr)	1.97	70.4%	2.01	71.8%
	TSS (lb/yr)	2,598	77.1%	2,668	79.2%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%
Cost	**Administration & Promotion Costs***	$4,745		$4,745	
	Design, Oversight, & Construction Costs**	$6,069		$6,138	
	Total Estimated Project Cost (2014)	**$10,814**		**$10,883**	
	Annual Production Lost***	$275		$551	
	Annual O&M	$300		$300	
	Cost Over 20-year Life Span	**$22,322**		**$27,900**	
Efficiency	**20-yr Average Cost/lb-TP**	**$567**		**$694**	
	20-yr Average Cost/1,000lb-TSS	**$430**		**$523**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**	

*(65 hours at $73/hour)
**($200/acre for filter strip establishment) + ($6,000 for design and construction oversight)
***($800/acre/year)

Catchment 8

Existing Network Summary	
Acres	2,069
Dominant Land Cover	Agricultural
TP (lbs/yr)	254.7
TSS (lbs/yr)	169,790
Volume (ac-ft/yr)	1,109.1



CATCHMENT DESCRIPTION

Catchment 8 spans from the agricultural fields north of Stark Rd. to 317th Ave. to the south. The eastern boundary is just over the Isanti County line. The catchment has a nearly even distribution of agricultural lands (26% of catchment area), pasture lands (26%), forests (28%), and other land uses (20%, predominantly rural residential and wetlands). The catchment straddles the boundary between Cambridge and Isanti townships, and drains completely into Skogman Lake. The 201 acres making up Skogman Lake are completely within the catchment boundaries.

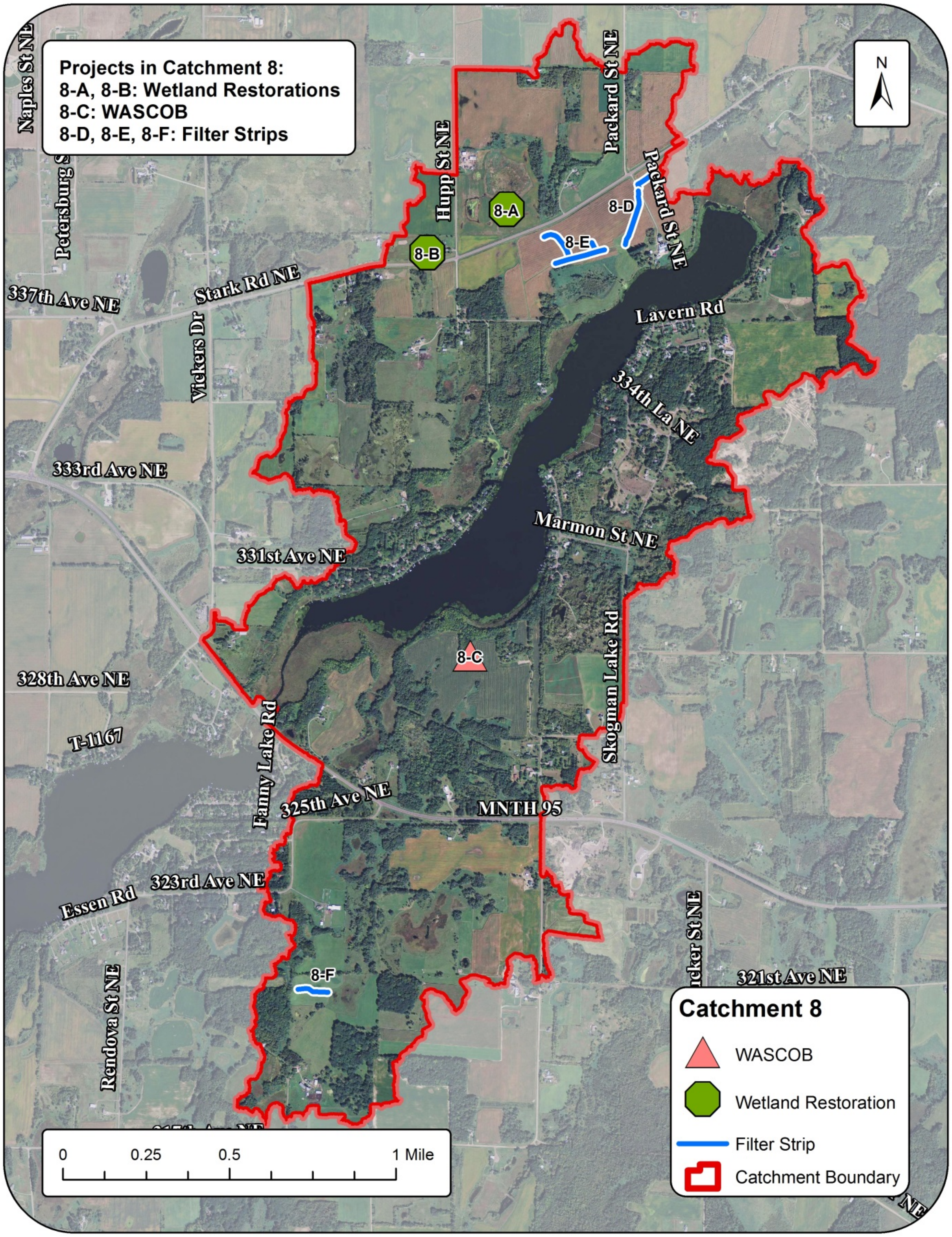
EXISTING STORMWATER TREATMENT

There are no catchment-wide stormwater treatment practices. Runoff generated on the landscape is conveyed to ditches and discharged directly into Skogman Lake. Some near-lake wetlands provide treatment for TSS and nutrients from upstream farm fields. There is also a wetland complex south of the lake straddling Highway 95. Although this wetland has likely been drained from its historical size, it still provides a buffer to the downstream lake system. These wetlands, along with others, were modeled in ArcSWAT with land use, soil, and terrain conditions to determine TSS, TP, and volume loading to Skogman Lake and downstream waterbodies from this catchment.

Catchment-Wide Existing Conditions

	Existing Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	0			
	BMP Types	N/A			
	TP (lb/yr)	254.7	0.0	0%	**254.7**
	TSS (lb/yr)	169,790	0	0%	**169,790**
	Volume (acre-feet/yr)	1,109.1	0.0	0%	**1109.1**

RETROFIT RECOMMENDATIONS



Project ID: 8-A
Wetland Restoration

Drainage Area – 196.3 acres
Location – Property northeast of Stark Road and Hupp St. intersection
Property Ownership – Private
Site Specific Information – A former wetland, which has been drained and farmed, could be restored to improve hydrology and nutrient retention. A culvert control structure is recommended along Stark Road to control discharge and provide overflow to prevent flooding the highway. Ponding to two distinct contour depths is proposed in Table 38.

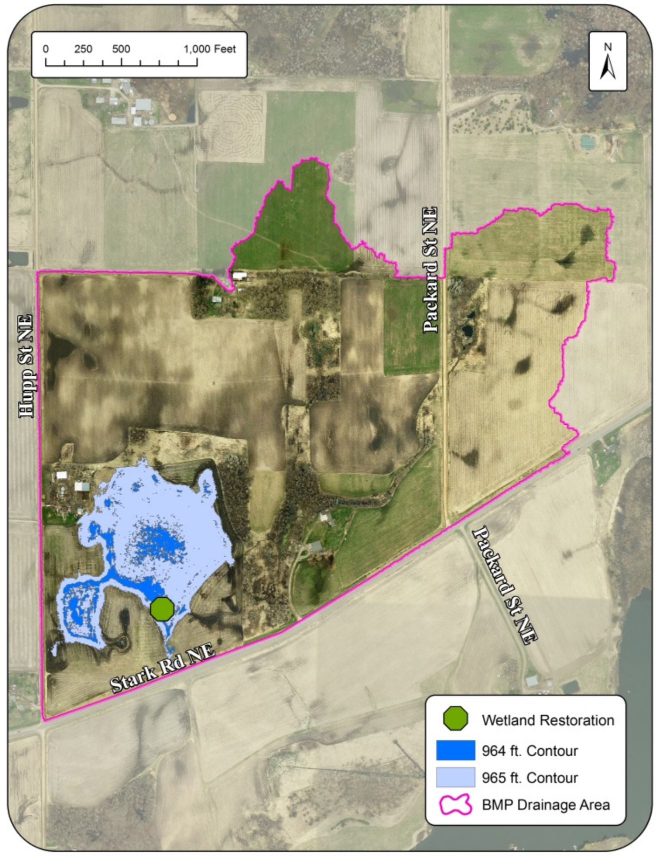


Table 38: Pollutant removal potential for Project 8-A

	Wetland Restoration				
	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	Pool Elevation	964	feet	965	feet
	Pool Area	3.7	acres	19.2	acres
	TP (lb/yr)	9.80	12.1%	31.20	38.6%
	TSS (lb/yr)	701	1.4%	5,955	11.6%
	Volume (acre-feet/yr)	1.30	1.2%	6.70	6.3%
Cost	Administration & Promotion Costs*	$6,205		$6,205	
	Design, Oversight, & Construction Costs**	$14,178		$14,800	
	Easement Cost***	$240,000		$384,000	
	Total Estimated Project Cost (2014)	**$260,383**		**$405,005**	
	Annual O&M	$500		$500	
	Cost Over 20-year Life Span	**$270,383**		**$415,005**	
Efficiency	20-yr Average Cost/lb-TP	**$1,380**		**$665**	
	20-yr Average Cost/1,000lb-TSS	**$19,286**		**$3,485**	
	20-yr Average Cost/ac-ft Vol.	**$10,399**		**$3,097**	

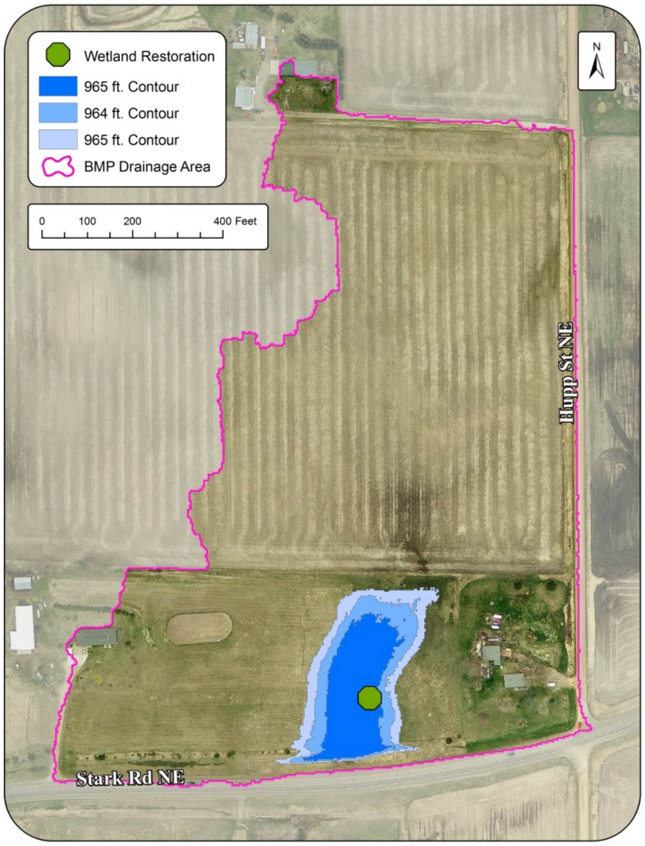
*(85 hours at $73/hour)

**See BMP Descriptions section for detailed cost information

***($20,000/acre)

Project ID: 8-B

Wetland Restoration



Drainage Area – 27.6 acres
Location – Property northwest of Stark Road and Hupp St. intersection
Property Ownership – Private
Site Specific Information – A former wetland, which has been drained and farmed, could be restored and expanded to improve hydrology and nutrient retention. A culvert control structure is recommended along Stark Road to control discharge and provide overflow to prevent flooding the highway. No earthen berm is proposed at this site. Ponding to two distinct contour depths is proposed in Table 39.

Table 39: Pollutant removal potential for Project 8-B

	Wetland Restoration						
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	Pool Elevation	963	feet	964	feet	965	feet
	Pool Area	0.9	acres	1.4	acres	1.8	acres
	TP (lb/yr)	2.11	22.9%	3.63	39.5%	5.17	56.2%
	TSS (lb/yr)	2,825	22.8%	5,568	45.0%	8,673	70.1%
	Volume (acre-feet/yr)	0.66	4.1%	1.02	6.3%	1.29	8.0%
Cost	Administration & Promotion Costs*		$6,205		$6,205		$6,205
	Design, Oversight, & Construction Costs**		$14,000		$14,000		$14,000
	Easement Cost***		$18,000		$28,000		$36,000
	Total Estimated Project Cost (2014)		**$38,205**		**$48,205**		**$56,205**
	Annual O&M		$500		$500		$500
	Cost Over 20-year Life Span		**$48,205**		**$58,205**		**$66,205**
Efficiency	20-yr Average Cost/lb-TP	**$1,142**		**$802**		**$640**	
	20-yr Average Cost/1,000lb-TSS	**$853**		**$523**		**$382**	
	20-yr Average Cost/ac-ft Vol.	**$3,652**		**$2,853**		**$2,566**	

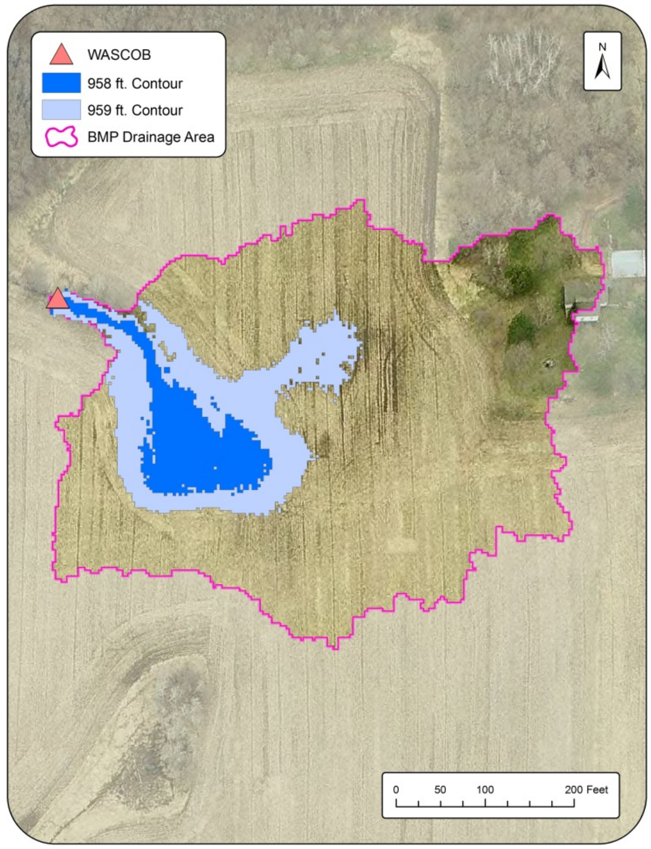
*(85 hours at $73/hour)

**See BMP Descriptions section for detailed cost information

***($20,000/acre)

Project ID: 8-C

WASCOB



Drainage Area – 19.4 acres
Location – Eastern portion of the farm field southeast of 16th Ave. and Opportunity Blvd. intersection
Property Ownership – Private
Site Specific Information – Two berm sizes were modeled for this location. The first, a berm which ponds water up to the 957 ft. contour, would require a 95 ft. long berm. The second, a berm which ponds water up to the 958 ft. contour, would require a 140 ft. long berm. Table 40 summarizes the pollutant removal potential of this practice.

Table 40: Pollutant removal potential for Project 8-C

Water and Sediment Control Basin					
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**Pool Elevation**	958	feet	959	feet
	Pool Area	0.3	acres	1.0	acres
	TP (lb/yr)	0.60	54.5%	0.95	86.4%
	TSS (lb/yr)	587	50.1%	1,042	88.9%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%
Cost	**Administration & Promotion Costs***		$6,205		$6,205
	Design, Oversight, & Construction Costs**		$14,178		$18,800
	Total Estimated Project Cost (2014)		**$20,383**		**$25,005**
	Annual Production Lost		$3		$8
	Annual O&M***		$500		$500
	Cost Over 20-year Life Span		**$30,447**		**$35,165**
Efficiency	**20-yr Average Cost/lb-TP**	**$2,537**		**$1,851**	
	20-yr Average Cost/1,000lb-TSS	**$2,593**		**$1,687**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**	

*(85 hours at $73/hour)
**See BMP Descriptions section for detailed cost information
***($500/year)

Project ID: 8-D

Vegetated Filter Strip/Grassed Waterway

Drainage Area – 16.0 acres
Location – Farm field between Stark Rd. and Skogman Lake
Property Ownership – Private
Site Specific Information – A grassed waterway is proposed to better treat stormwater runoff from farm fields north of Skogman Lake. The proposed BMP widths in Table 41 measure the width from the middle of the drainage flow path to one side (i.e. the 10 ft from ditch buffer in the table has a total width of 20 feet).

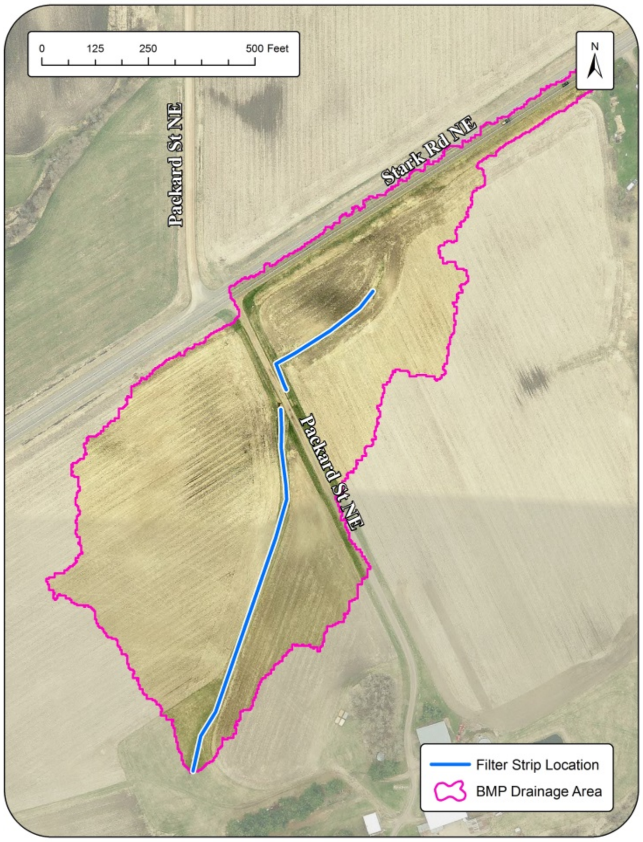


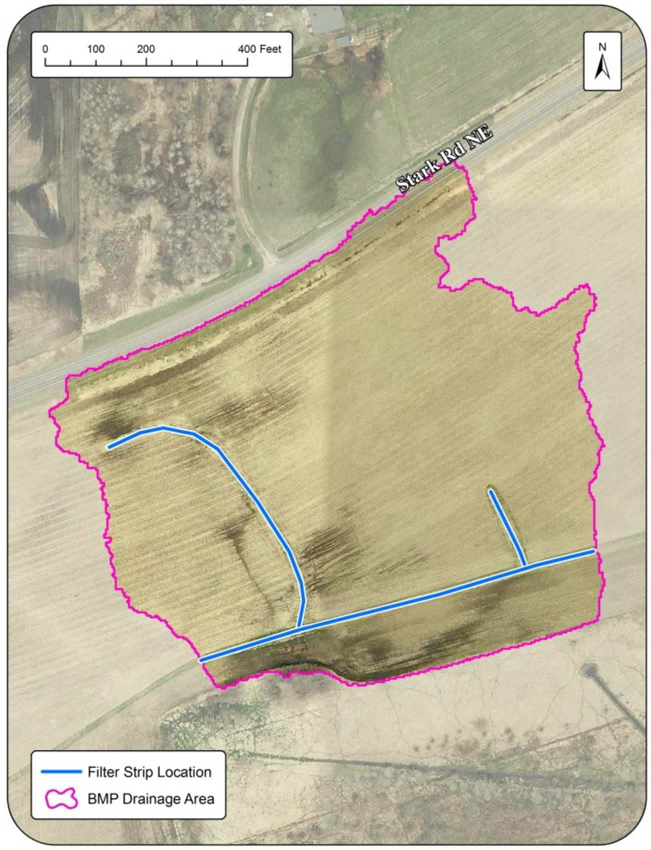
Table 41: Pollutant removal potential for Project 8-D

	Vegetated Filter Strip						
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**BMP Width (from ditch)**	10	feet	20	feet	30	feet
	BMP Length	1,300	feet	1,300	feet	1,300	feet
	TP (lb/yr)	3.16	64.5%	3.36	68.6%	3.42	69.8%
	TSS (lb/yr)	4,247	71.6%	4,532	76.4%	4,646	78.4%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%	0.00	0.0%
Cost	**Administration & Promotion Costs***	$4,745		$4,745		$4,745	
	Design, Oversight, & Construction Costs**	$6,060		$6,119		$6,179	
	Total Estimated Project Cost (2014)	**$10,805**		**$10,864**		**$10,924**	
	Annual Production Lost***	$239		$477		$716	
	Annual O&M	$300		$300		$300	
	Cost Over 20-year Life Span	**$21,579**		**$26,412**		**$31,246**	
Efficiency	**20-yr Average Cost/lb-TP**	**$341**		**$393**		**$457**	
	20-yr Average Cost/1,000lb-TSS	**$254**		**$291**		**$336**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**		**N/A**	

*(65 hours at $73/hour)
**($200/acre for filter strip establishment) + ($6,000 for design and construction oversight)
***($800/acre/year)

Project ID: 8-E

Vegetated Filter Strip/Grassed Waterway



Drainage Area – 16.8 acres
Location – Farm field between Stark Rd. and Skogman Lake
Property Ownership – Private
Site Specific Information – A grassed waterway is proposed to better treat stormwater runoff from farm fields north of Skogman Lake. The proposed waterway widths in Table 42 measure the width from the middle of the drainage flow path to one side (i.e. the 10 ft from ditch buffer in the table has a total width of 20 feet).

Table 42: Pollutant removal potential for Project 8-E

	Vegetated Filter Strip						
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	BMP Width (from ditch)	10	feet	20	feet	30	feet
	BMP Length	1,400	feet	1,400	feet	1,400	feet
	TP (lb/yr)	3.45	70.4%	3.49	71.2%	3.52	71.8%
	TSS (lb/yr)	4,805	79.2%	4,866	80.2%	4,896	80.7%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%	0.00	0.0%
Cost	Administration & Promotion Costs*	$4,745		$4,745		$4,745	
	Design, Oversight, & Construction Costs**	$6,064		$6,129		$6,193	
	Total Estimated Project Cost (2014)	**$10,809**		**$10,874**		**$10,938**	
	Annual Production Lost***	$257		$514		$771	
	Annual O&M	$300		$300		$300	
	Cost Over 20-year Life Span	**$21,951**		**$27,156**		**$32,362**	
Efficiency	20-yr Average Cost/lb-TP	**$318**		**$389**		**$460**	
	20-yr Average Cost/1,000lb-TSS	**$228**		**$279**		**$330**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**		**N/A**	

*(65 hours at $73/hour)
**($200/acre for filter strip establishment) + ($6,000 for design and construction oversight)
***($800/acre/year)

Project ID: 8-F

Vegetated Filter Strip/Grassed Waterway

Drainage Area – 10.7 acres
Location – Farm field between 323rd Ave., Rendova Ave., and 317th Ave.
Property Ownership – Private
Site Specific Information – A grassed waterway is proposed to better treat stormwater runoff to Skogman Lake. The proposed BMP widths in Table 43 measure the width of the practice from the ditch bottom.

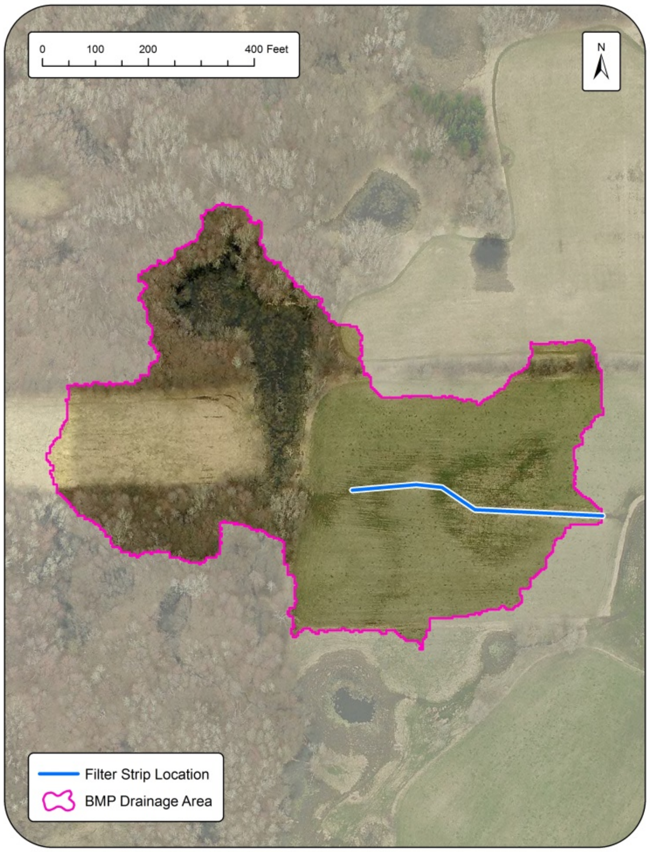


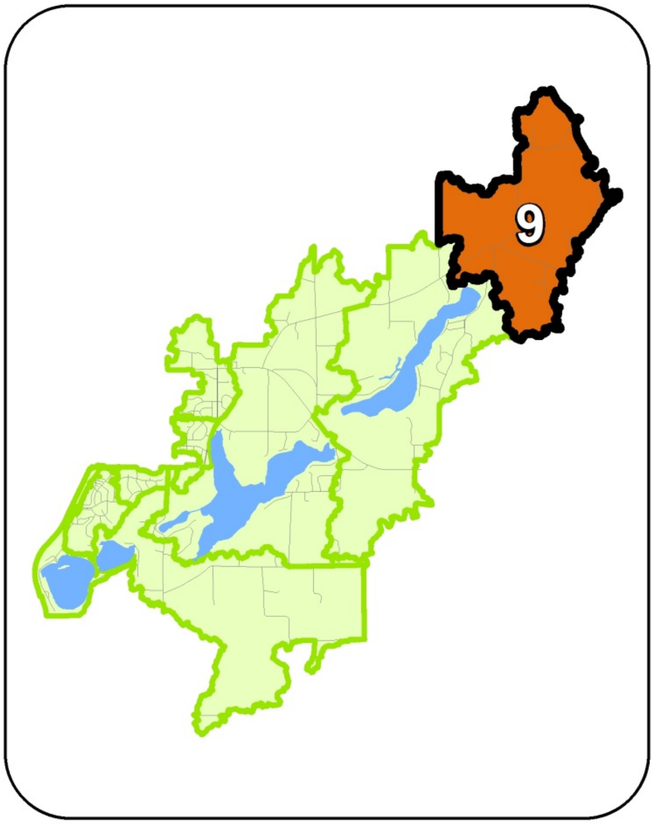
Table 43: Pollutant removal potential for Project 8-F

	Vegetated Filter Strip				
	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	BMP Width (from ditch)	10	feet	20	feet
	BMP Length	500	feet	500	feet
	TP (lb/yr)	1.51	68.6%	1.55	70.5%
	TSS (lb/yr)	1,108	74.4%	1,165	78.2%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%
Cost	Administration & Promotion Costs*	$4,745		$4,745	
	Design, Oversight, & Construction Costs**	$6,023		$6,046	
	Total Estimated Project Cost (2014)	**$10,768**		**$10,791**	
	Annual Production Lost***	$92		$184	
	Annual O&M	$300		$300	
	Cost Over 20-year Life Span	**$18,604**		**$20,463**	
Efficiency	**20-yr Average Cost/lb-TP**	**$616**		**$660**	
	20-yr Average Cost/1,000lb-TSS	**$840**		**$878**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**	

*(65 hours at $73/hour)
**($200/acre for filter strip establishment) + ($6,000 for design and construction oversight)
***($800/acre/year)

Catchment 9

Existing Network Summary	
Acres	1,442
Dominant Land Cover	Agricultural
TP (lbs/yr)	131.2
TSS (lbs/yr)	87,458
Volume (ac-ft/yr)	627.0



CATCHMENT DESCRIPTION

Catchment 9 is the most upstream catchment, draining first into Skogman Lake, and subsequently into all downstream lakes. The catchment is mostly within Fish Lake township in Chisago County, but does have a small portion of its western boundary within Cambridge Township and Isanti County.

The catchment is primarily agricultural (27% of catchment area) and pastoral (30%), but has forests (15%), open water/wetlands (17%), and other land use (11%) making up the remainder of the land area.

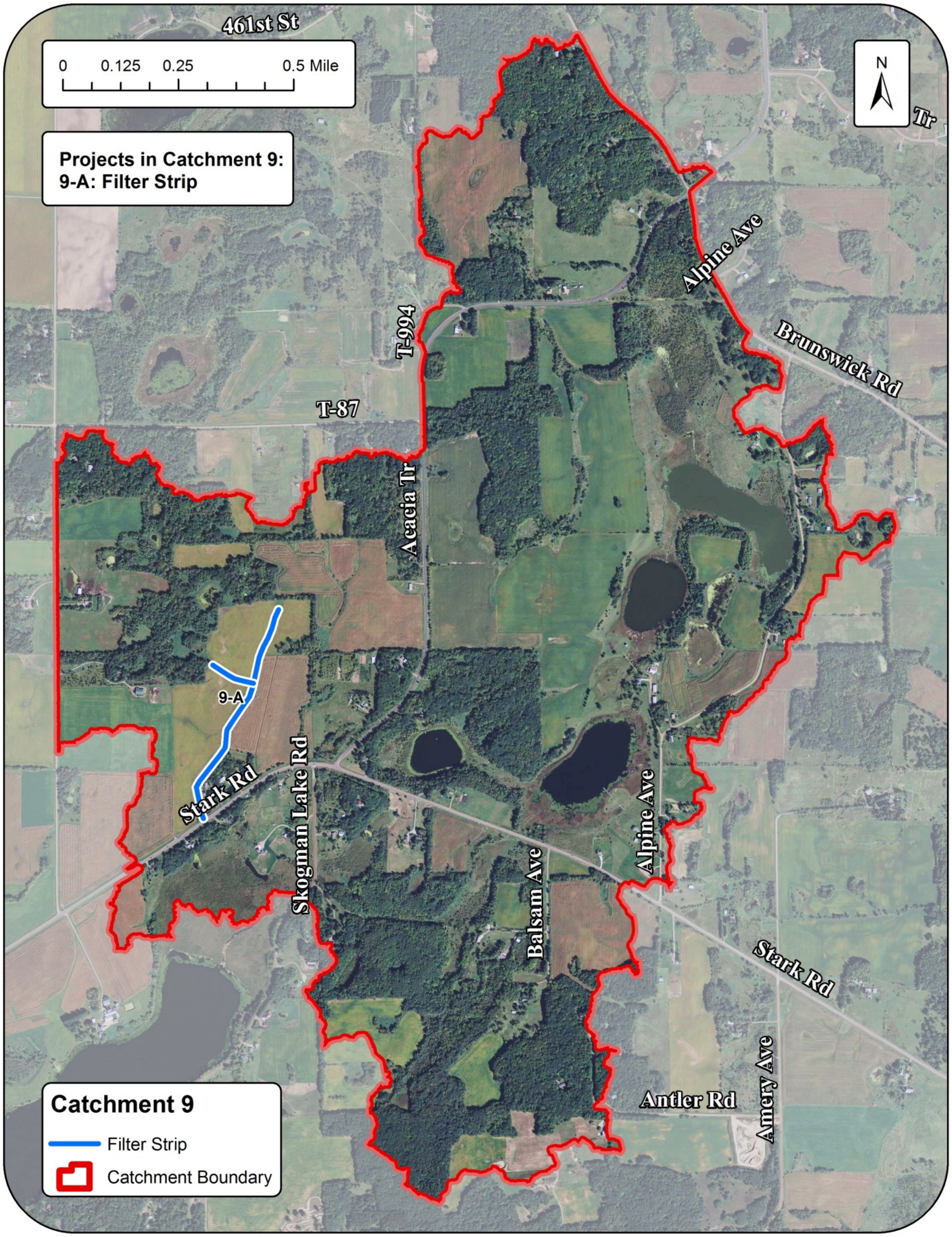
EXISTING STORMWATER TREATMENT

Stormwater runoff throughout the catchment is conveyed to Skogman Lake through three general pathways. Two of these are public ditches draining fields north of County Highway 10 and west of County Road 4. Runoff from these ditches has little opportunity to be treated before reaching Skogman Lake. The third pathway is through a set of wetlands and small lakes/ponds (including Jonason Lake). These waterbodies likely provide treatment for TSS and nutrients from the upstream farm fields and pasture lands draining to them. These waterbodies were modeled in ArcSWAT with land use, soil, and terrain conditions to determine TSS, TP, and volume loading to Skogman Lake and downstream waterbodies from this catchment.

Catchment-Wide Existing Conditions

	Existing Conditions	Base Loading	Treatment	Net Treatment %	Existing Loading
Treatment	Number of BMPs	0			
	BMP Types	N/A			
	TP (lb/yr)	131.2	0.0	0%	**131.2**
	TSS (lb/yr)	87,458	0	0%	**87,458**
	Volume (acre-feet/yr)	627.0	0.0	0%	**627.0**

RETROFIT RECOMMENDATIONS



Project ID: 9-A

Vegetated Filter Strip/Grassed Waterway

Drainage Area – 63.8 acres
Location – Farm field between Acacia Trail, Stark Rd., and Packard St.
Property Ownership – Private
Site Specific Information – A grassed waterway is proposed to better treat stormwater runoff from farm fields north of Skogman Lake. The proposed BMP widths in Table 44 measure the width from the middle of the drainage flow path to one side (i.e. the 10 ft from ditch buffer in the table has a total width of 20 feet).
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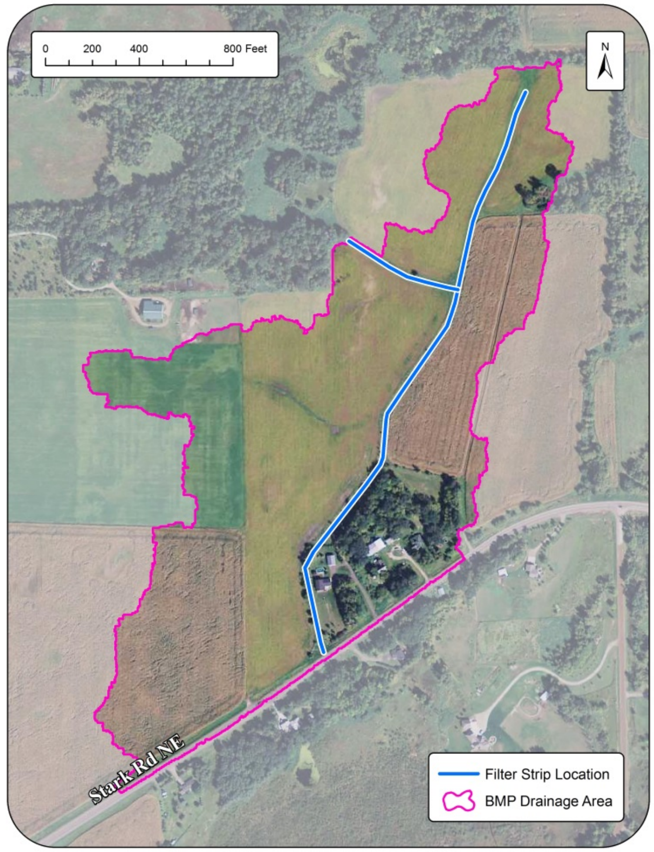


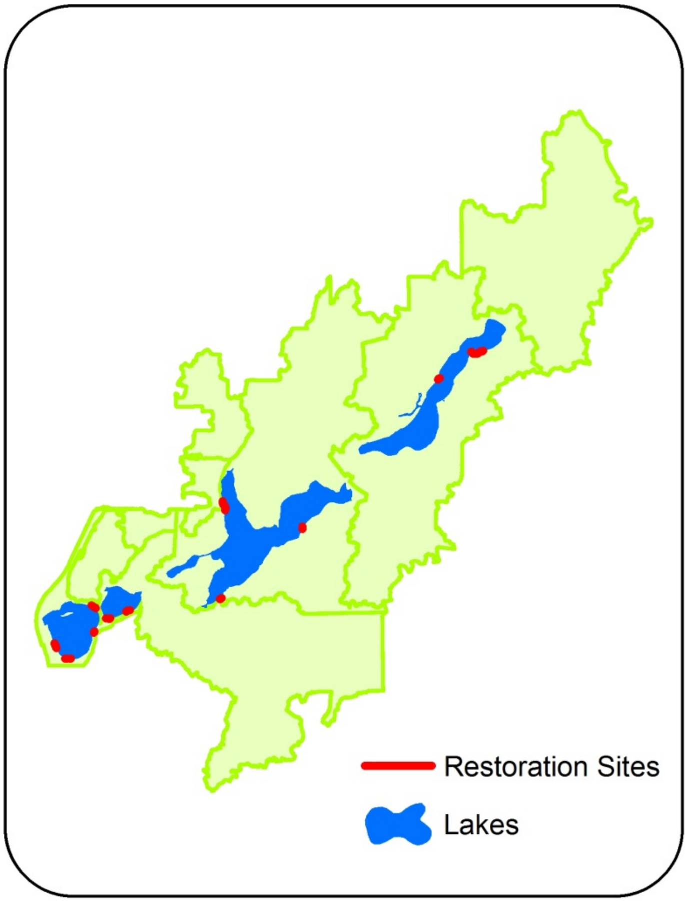
Table 44: Pollutant removal potential for Project 9-A

Vegetated Filter Strip

	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	BMP Width (from ditch)	10	feet	20	feet	30	feet
	BMP Length	3,600	feet	3,600	feet	3,600	feet
	TP (lb/yr)	15.02	67.4%	15.59	69.9%	15.70	70.4%
	TSS (lb/yr)	17,068	70.8%	17,751	73.6%	17,978	74.5%
	Volume (acre-feet/yr)	0.00	0.0%	0.00	0.0%	0.00	0.0%
Cost	Administration & Promotion Costs*		$4,745		$4,745		$4,745
	Design, Oversight, & Construction Costs**		$6,165		$6,331		$6,496
	Total Estimated Project Cost (2014)		**$10,910**		**$11,076**		**$11,241**
	Annual Production Lost***		$661		$1,322		$1,983
	Annual O&M		$300		$300		$300
	Cost Over 20-year Life Span		**$30,131**		**$43,516**		**$56,902**
Efficiency	20-yr Average Cost/lb-TP	**$100**		**$140**		**$181**	
	20-yr Average Cost/1,000lb-TSS	**$88**		**$123**		**$158**	
	20-yr Average Cost/ac-ft Vol.	**N/A**		**N/A**		**N/A**	

*(65 hours at $73/hour)
**($200/acre for filter strip establishment) + ($6,000 for design and construction oversight)
***($800/acre/year)

Catchment Profiles Section 3: Lakeshore Projects



AREA SUMMARY

Florence and Elms Lakes each lie predominantly within the City of Cambridge and Isanti Township and have seen most of their shoreline's developed by single-family residential properties. Fannie and Skogman Lakes on the other hand are split relatively evenly between small residential lots and larger, agricultural properties. Most agricultural properties have the minimum 50-ft. wide buffer for shoreland areas adjacent to MN public waters.

Shoreland areas around these lakes generally have mild (< 3%) slopes and are comparable to other lakes in the Anoka Sand Plain region. None of the lakes in the SFEF chain are overly incised, which would have made it more prone to shoreline erosion. Another source of erosion, wave action, is often enhanced by heavy recreational traffic. Each of these lakes has comparable traffic to other lakes in the region, although Fannie and Skogman Lakes are more heavily used than Elms and Florence Lakes.

EXISTING LAKE CONDITIONS

Lawns that butt up to the shore are prone to erosion, require frequent maintenance, and can be over-fertilized. Without a buffer between the lawn and lake, nutrient-rich organic matter and other dissolved pollutants have a much easier path into the waterbody. Moreover, without a buffer on the lake-side of the shore, wave action and ice jamming can erode the shore, increasing sediment and nutrient input to the lake while permanently removing expensive shoreland property.

Properties which exhibited clear evidence of erosion were flagged and analyzed to estimate the amount of annual erosion from the site and determine the strategy and cost necessary to fix it. On the following pages are 14 potential projects organized by lake. Each profile describes pertinent location information, installation type, cost, and cost-effectiveness. Please see the *BMP Descriptions* section for additional information on project site determination, installation, and cost.

Skogman Lake

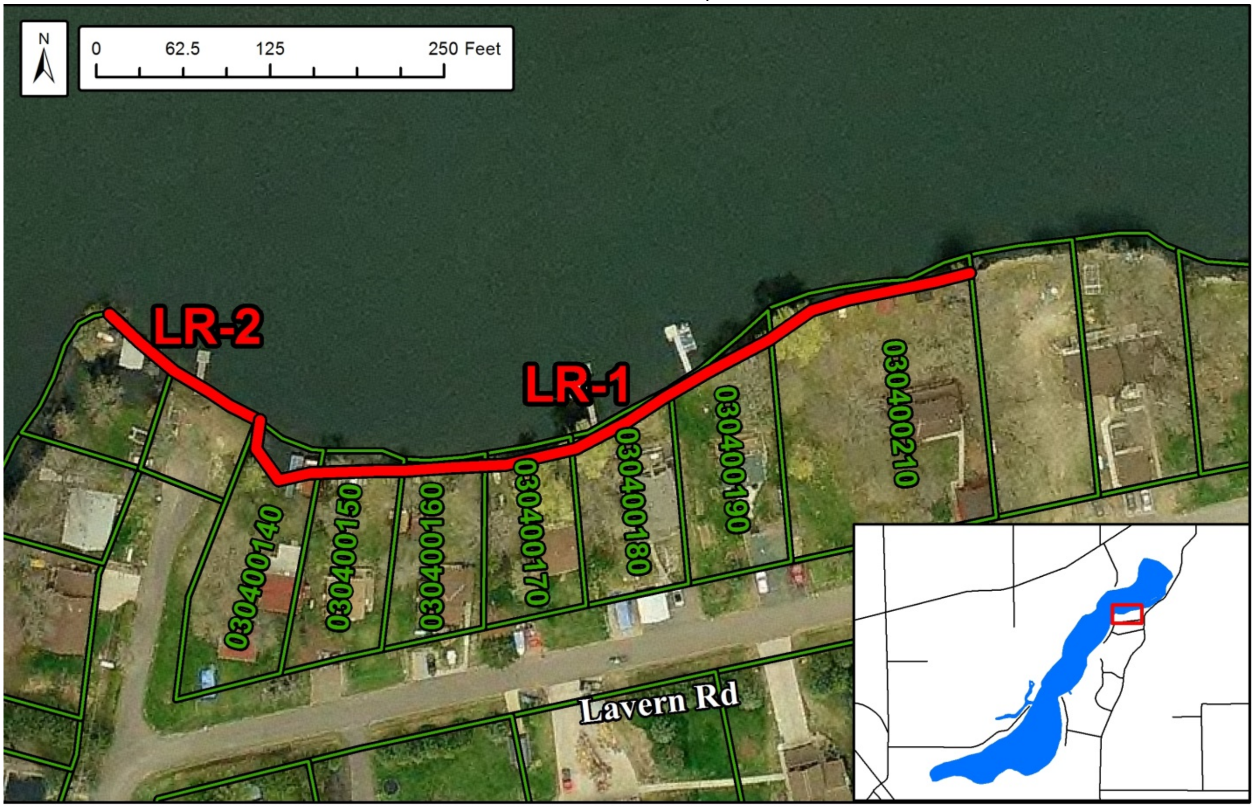
Project ID: LR-1

Receiving Waterbody – Skogman Lake
Location – Along 7 properties north of Lavern Rd.
Property Ownership – Private
Site Specific Information – A biolog restoration is recommended based on the mild eroding face seen along the shore of the properties noted below (PIN labeled for each property). In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from properties along the shore.

Table 45: Pollutant removal potential for Project LR-1

	Lakeshore Restoration		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Current Erosion Severity**	Mild	
	Length of Lakeshore to Restore	580	linear-ft
	TP (lb/yr)	1.39	100.0%
	TSS (lb/yr)	1,740	100.0%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	**Administration & Promotion Costs***	$2,555	
	Design & Construction Costs**	$45,000	
	Total Estimated Project Cost (2014)	**$47,555**	
	Annual O&M***	$870	
	Cost Over 10-year Life Span	**$56,255**	
Efficiency	**10-yr Average Cost/lb-TP**	**$4,047**	
	10-yr Average Cost/1,000lb-TSS	**$3,233**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($75/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



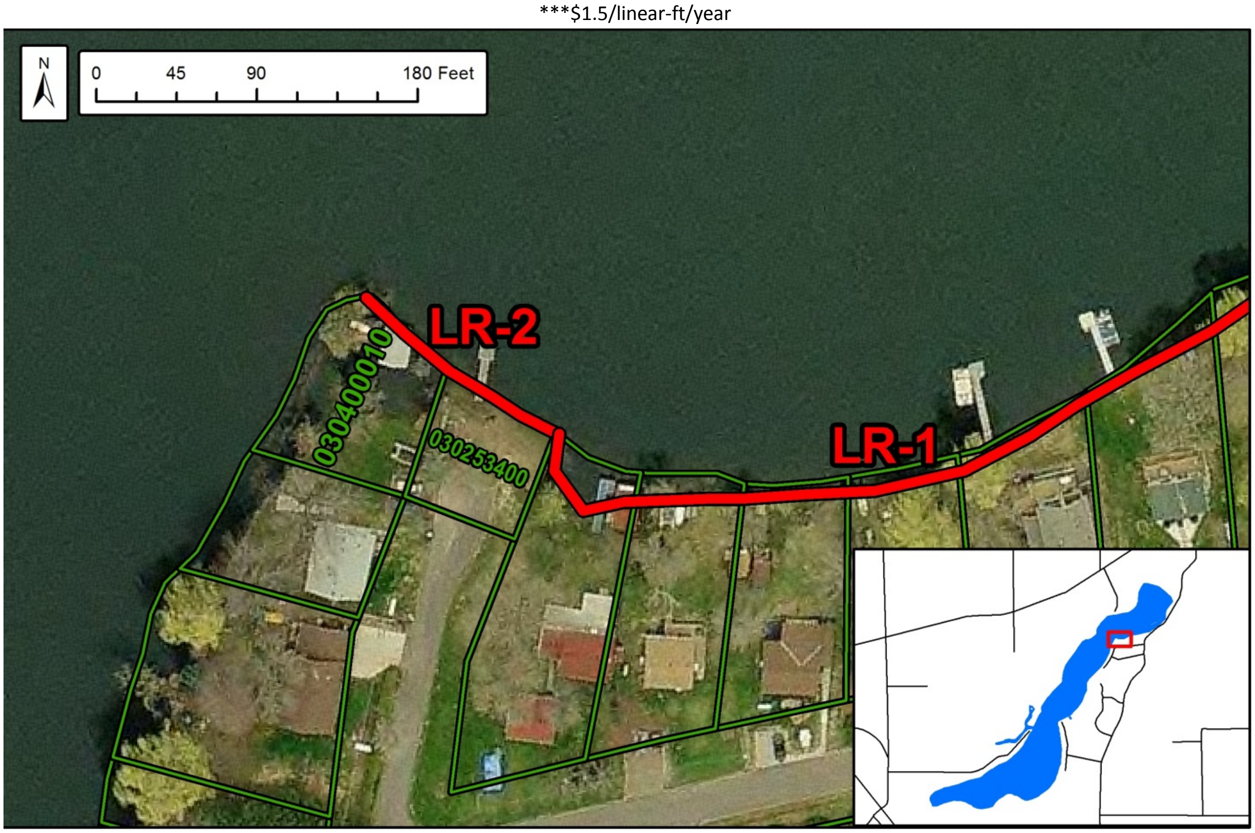
Project ID: LR-2

Receiving Waterbody – Skogman Lake
Location – Eastern shore of Skogman Lake along 2 properties north of Lavern Rd.
Property Ownership – Private
Site Specific Information – A biolog restoration is recommended based on the mild eroding face seen along the shore of the properties noted below (PIN labeled for each property). In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from properties along the shore.

Table 46: Pollutant removal potential for Project LR-2

	Lakeshore Restoration		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Current Erosion Severity**	Mild	
	Length of Lakeshore to Restore	130	linear-ft
	TP (lb/yr)	0.31	100.0%
	TSS (lb/yr)	390	100.0%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	**Administration & Promotion Costs***	$2,555	
	Design & Construction Costs**	$11,250	
	Total Estimated Project Cost (2014)	**$13,805**	
	Annual O&M***	$195	
	Cost Over 10-year Life Span	**$15,755**	
Efficiency	**10-yr Average Cost/lb-TP**	**$5,082**	
	10-yr Average Cost/1,000lb-TSS	**$4,040**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($75/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



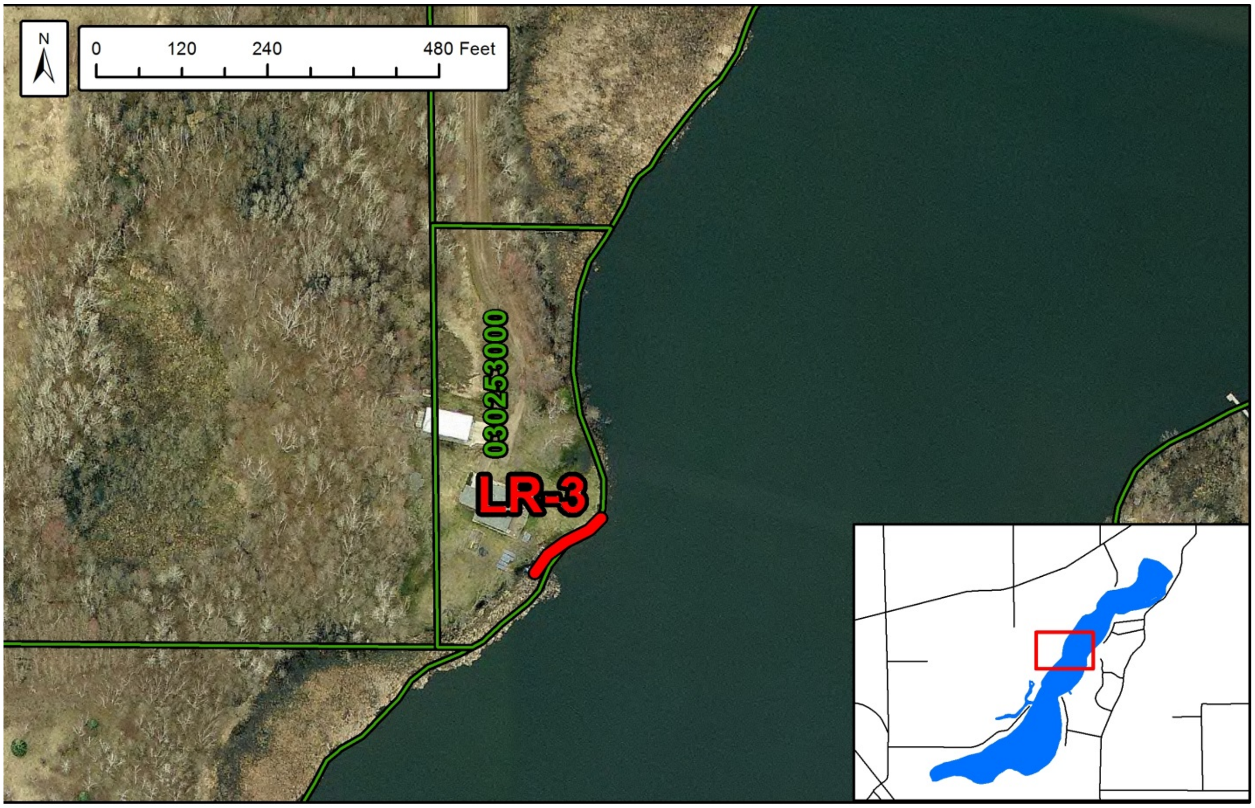
Project ID: LR-3

Receiving Waterbody – Skogman Lake
Location – Western shore of Skogman Lake south of 337th Ave.
Property Ownership – Private
Site Specific Information – A biolog restoration is recommended based on the mild eroding face seen along the shore of the property noted below (PIN labeled below). In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from the property along the shore.

Table 47: Pollutant removal potential for Project LR-3

	Lakeshore Restoration		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Current Erosion Severity**	Mild	
	Length of Lakeshore to Restore	115	linear-ft
	TP (lb/yr)	0.28	90.3%
	TSS (lb/yr)	345	88.5%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	**Administration & Promotion Costs***	$2,555	
	Design & Construction Costs**	$10,125	
	Total Estimated Project Cost (2014)	**$12,680**	
	Annual O&M***	$173	
	Cost Over 10-year Life Span	**$14,405**	
Efficiency	**10-yr Average Cost/lb-TP**	**$5,145**	
	10-yr Average Cost/1,000lb-TSS	**$4,175**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($75/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



Fannie Lake

0 750 1,500 3,000 Feet
N
3rd Ave SE
6th Ave SE
8th La SE
Taft St S
Alaska Loop
Vickers Dr
MNTH 95
Virginia Hts Dr
328th Ave NE
Joes Lake Rd
Roosevelt St S
Taft St S
Cedar Dr SE
T-1167
Fanny Lake Rd
LR-5
16th Ave SE
Opportunity Blvd S
LR-4
323rd Ave NE
Essen Rd
319th La NE
Rendova St NE
LR-6
Lakeway Dr
317th Ave NE
Rendova St NE
Vickers St NE
Fannie Lake
Restoration Sites

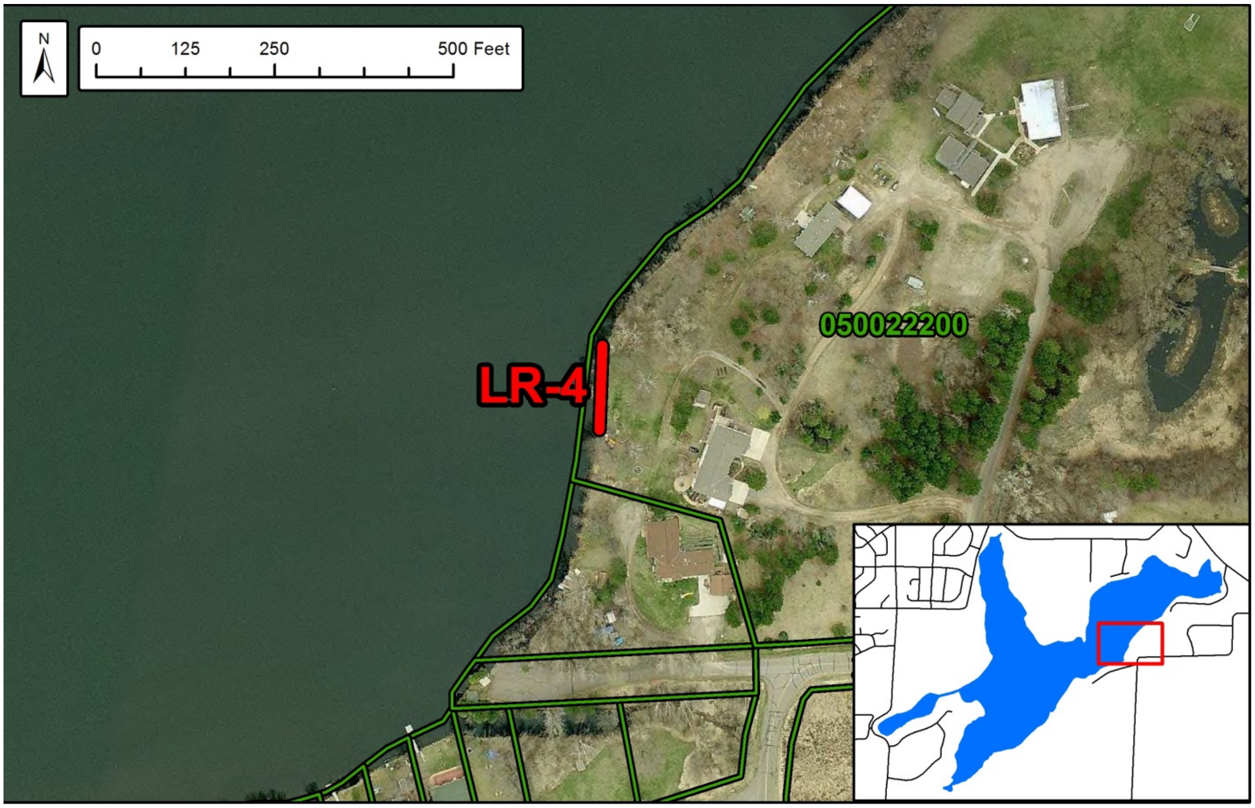
Project ID: LR-4

Receiving Waterbody – Fannie Lake
Location – Eastern shore of Fannie Lake north of 323rd Ave. and the public boat launch
Property Ownership – Private
Site Specific Information – A biolog restoration is recommended based on the mild eroding face seen along the shore of the property noted below (PIN labeled below). In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from the property along the shore.

Table 48: Pollutant removal potential for Project LR-4

	Lakeshore Restoration		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	Current Erosion Severity	Mild	
Treatment	Length of Lakeshore to Restore	130	linear-ft
Treatment	TP (lb/yr)	0.31	100.0%
Treatment	TSS (lb/yr)	390	100.0%
Treatment	Volume (acre-feet/yr)	0.00	0.0%
Cost	Administration & Promotion Costs*	$2,555	
Cost	Design & Construction Costs**	$11,250	
Cost	Total Estimated Project Cost (2014)	**$13,805**	
Cost	Annual O&M***	$195	
Cost	Cost Over 10-year Life Span	**$15,755**	
Efficiency	10-yr Average Cost/lb-TP	**$5,082**	
Efficiency	10-yr Average Cost/1,000lb-TSS	**$4,040**	
Efficiency	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($75/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



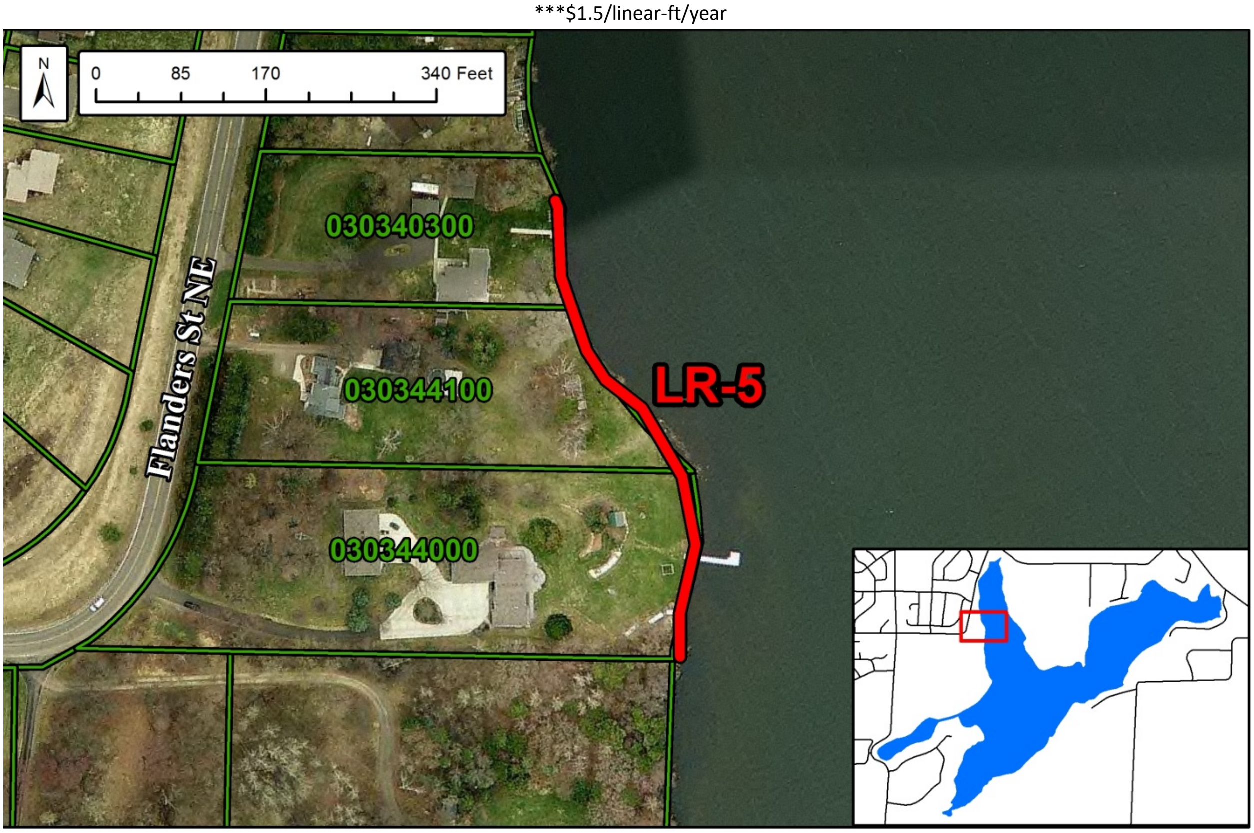
Project ID: LR-5

Receiving Waterbody – Fannie Lake
Location – Western shore of Fannie Lake east of Flanders St.
Property Ownership – Private
Site Specific Information – A biolog restoration is recommended based on the mild eroding face seen along the shore of the properties noted below (PIN labeled for each property). In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from properties along the shore.

Table 49: Pollutant removal potential for Project LR-5

	Lakeshore Restoration		
	Cost/Removal Analysis	New Treatment	% Reduction
Treatment	Current Erosion Severity	Mild	
	Length of Lakeshore to Restore	510	linear-ft
	TP (lb/yr)	1.22	393.5%
	TSS (lb/yr)	1,530	392.3%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	Administration & Promotion Costs*	$2,555	
	Design & Construction Costs**	$39,750	
	Total Estimated Project Cost (2014)	**$42,305**	
	Annual O&M***	$765	
	Cost Over 10-year Life Span	**$49,955**	
Efficiency	10-yr Average Cost/lb-TP	**$4,095**	
	10-yr Average Cost/1,000lb-TSS	**$3,265**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($75/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



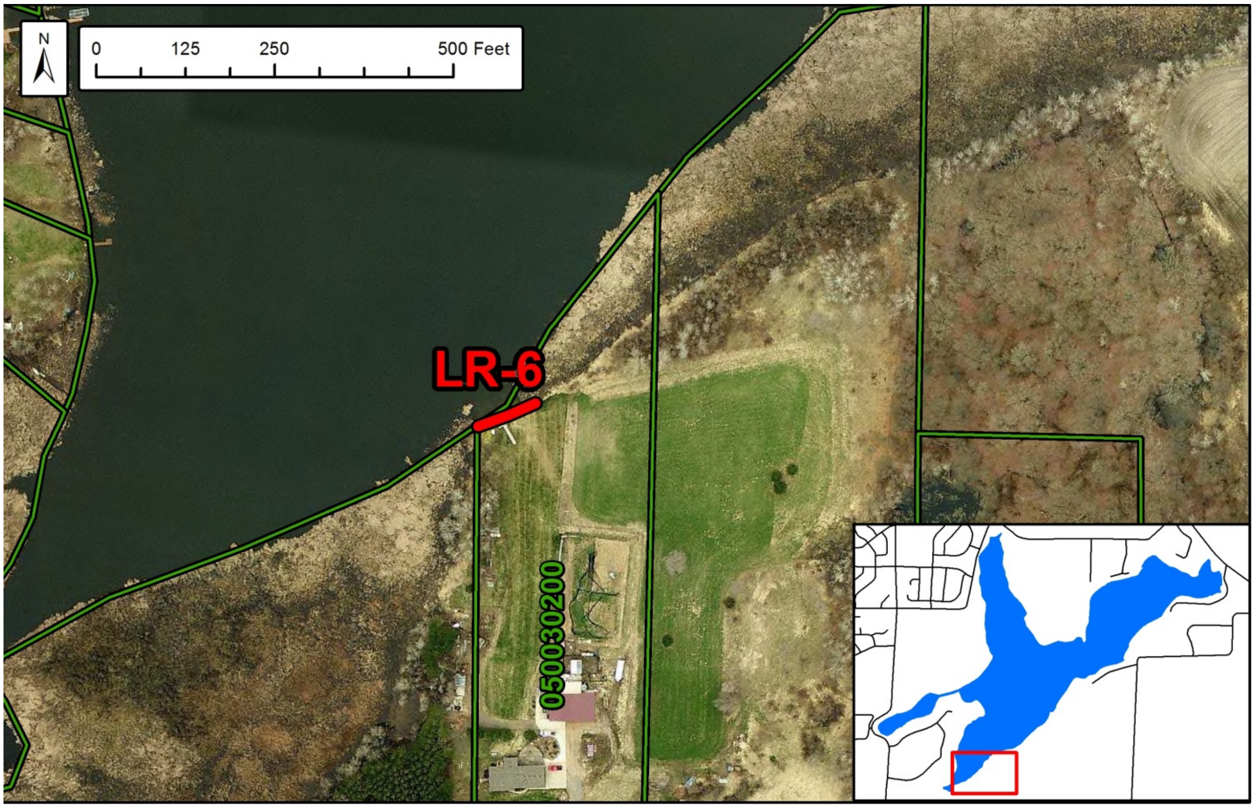
Project ID: LR-6

Receiving Waterbody – Fannie Lake
Location – Western shore of Fannie Lake east of Flanders St.
Property Ownership – Private
Site Specific Information – A biolog restoration is recommended based on the mild eroding face seen along the shore of the property noted below (PIN labeled below). In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from the property along the shore

Table 50: Pollutant removal potential for Project LR-6

	Lakeshore Restoration		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Current Erosion Severity**	Mild	
	Length of Lakeshore to Restore	75	linear-ft
	TP (lb/yr)	0.18	100.0%
	TSS (lb/yr)	225	100.0%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	**Administration & Promotion Costs***	$2,555	
	Design & Construction Costs**	$7,125	
	Total Estimated Project Cost (2014)	**$9,680**	
	Annual O&M***	$113	
	Cost Over 10-year Life Span	**$10,805**	
Efficiency	**10-yr Average Cost/lb-TP**	**$6,003**	
	10-yr Average Cost/1,000lb-TSS	**$4,802**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($75/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



Elms Lake


0
250
500
1,000 Feet
N
Garfield Pl SE
318th La
Taconite St
LR-7
London Dr NE
LR-8
Elms Lake
Restoration Sites

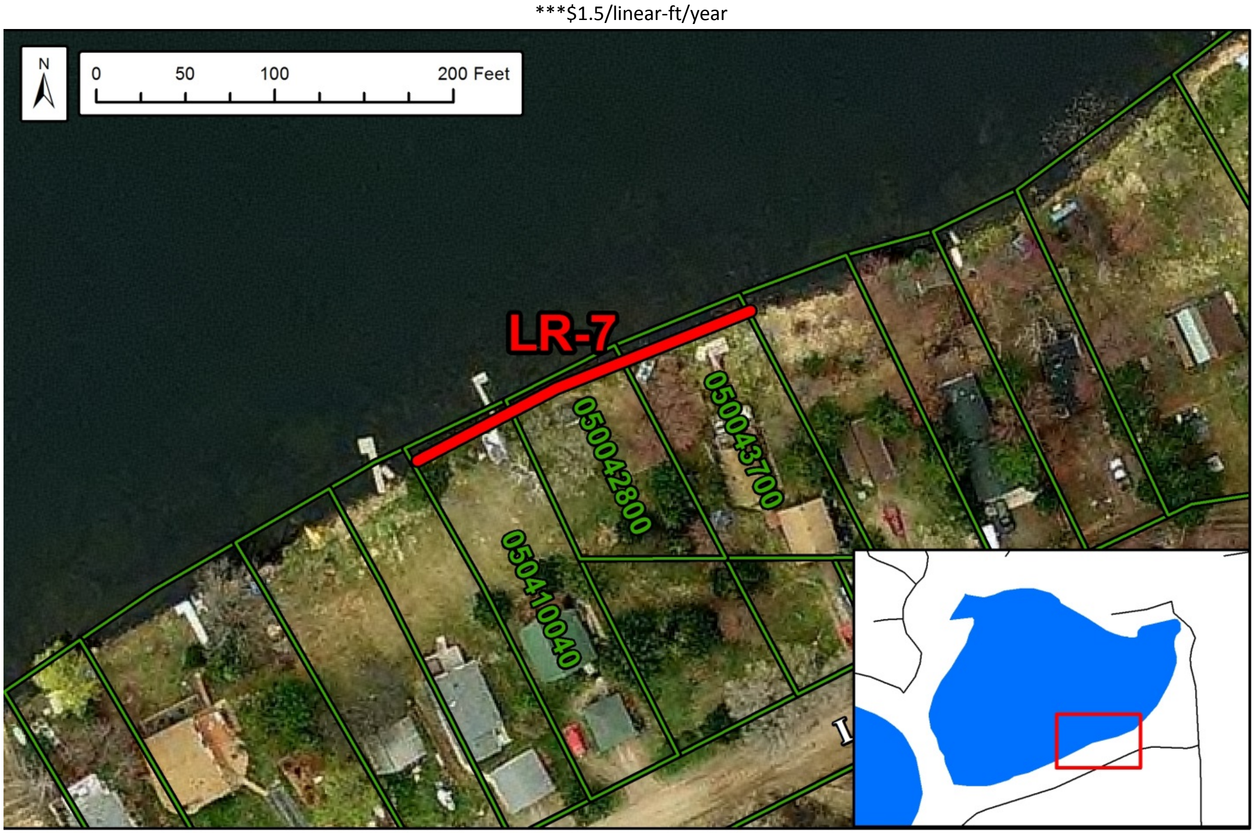
Project ID: LR-7

Receiving Waterbody – Elms Lake
Location – Southern shore of Elms Lake north of London Dr.
Property Ownership – Private
Site Specific Information – A moderately-large eroding face along the shore of the properties noted below (PIN labeled for each property) is evidence of an unstable bank. A rock toe restoration may be necessary to stabilize the bank. This may also require heavy equipment to achieve a workable grade. In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from properties along the shore.

Table 51: Pollutant removal potential for Project LR-7

	Lakeshore Restoration		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Current Erosion Severity**	Moderate	
	Length of Lakeshore to Restore	205	linear-ft
	TP (lb/yr)	2.46	1366.7%
	TSS (lb/yr)	3,075	1366.7%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	**Administration & Promotion Costs***	$2,555	
	Design & Construction Costs**	$32,250	
	Total Estimated Project Cost (2014)	**$34,805**	
	Annual O&M***	$308	
	Cost Over 10-year Life Span	**$37,880**	
Efficiency	**10-yr Average Cost/lb-TP**	**$1,540**	
	10-yr Average Cost/1,000lb-TSS	**$1,232**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($150/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



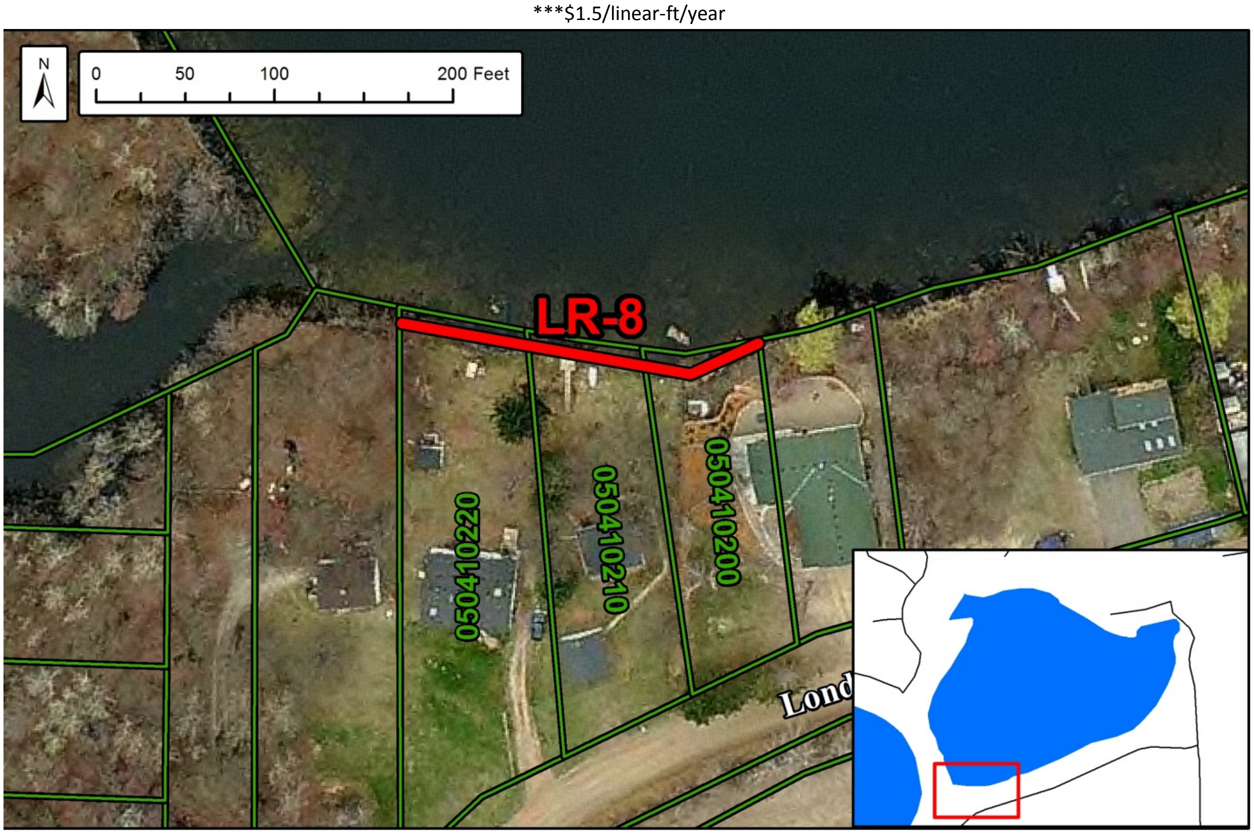
Project ID: LR-8

Receiving Waterbody – Elms Lake
Location – Southern shore of Elms Lake north of London Dr.
Property Ownership – Private
Site Specific Information – A moderately-large eroding face along the shore of the properties noted below (PIN labeled for each property) is evidence of an unstable bank. A rock toe restoration may be necessary to stabilize the bank. This may also require heavy equipment to achieve a workable grade. In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from properties along the shore.

Table 52: Pollutant removal potential for Project LR-8

Lakeshore Restoration			
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Current Erosion Severity**	Moderate	
	Length of Lakeshore to Restore	205	linear-ft
	TP (lb/yr)	2.46	1366.7%
	TSS (lb/yr)	3,075	1366.7%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	**Administration & Promotion Costs***	$2,555	
	Design & Construction Costs**	$32,250	
	Total Estimated Project Cost (2014)	**$34,805**	
	Annual O&M***	$308	
	Cost Over 10-year Life Span	**$37,880**	
Efficiency	**10-yr Average Cost/lb-TP**	**$1,540**	
	10-yr Average Cost/1,000lb-TSS	**$1,232**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($150/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



Florence Lake

Project ID: LR-9

Receiving Waterbody – Florence Lake
Location – Northeastern shore of Florence Lake southwest of Glenwood Dr. and Elm's Lake Rd. intersection
Property Ownership – Private
Site Specific Information – A biolog restoration is recommended based on the mild eroding face seen along the shore of the property noted below (PIN labeled below). In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from the property along the shore.

Table 53: Pollutant removal potential for Project LR-9

Lakeshore Restoration			
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Current Erosion Severity**	Mild	
	Length of Lakeshore to Restore	45	linear-ft
	TP (lb/yr)	0.16	100.0%
	TSS (lb/yr)	203	100.0%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	**Administration & Promotion Costs***	$2,555	
	Design & Construction Costs**	$4,875	
	Total Estimated Project Cost (2014)	**$7,430**	
	Annual O&M***	$68	
	Cost Over 10-year Life Span	**$8,105**	
Efficiency	**10-yr Average Cost/lb-TP**	**$5,066**	
	10-yr Average Cost/1,000lb-TSS	**$3,993**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($75/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year

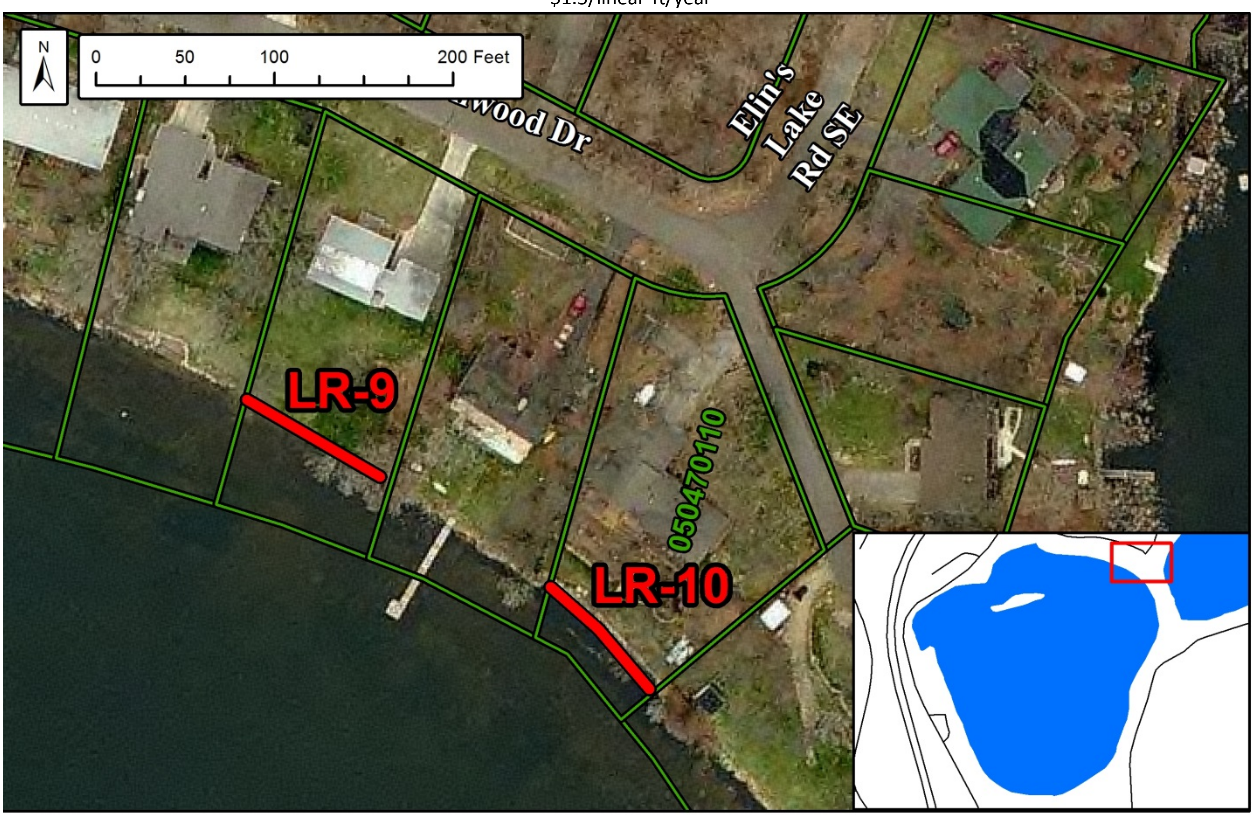
Project ID: LR-10

Receiving Waterbody – Florence Lake
Location – Northeastern shore of Florence Lake south of Glenwood Dr. and Elm's Lake Rd. intersection
Property Ownership – Private
Site Specific Information – A moderately-large eroding face along the shore of the property noted below (PIN labeled) is evidence of an unstable bank. A rock toe restoration may be necessary to stabilize the bank. This may also require heavy equipment to achieve a workable grade. In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input.

Table 54: Pollutant removal potential for Project LR-10

Lakeshore Restoration			
	Cost/Removal Analysis	New Treatment	% Reduction
Treatment	Current Erosion Severity	Moderate	
	Length of Lakeshore to Restore	65	linear-ft
	TP (lb/yr)	0.78	100.0%
	TSS (lb/yr)	975	100.0%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	Administration & Promotion Costs*	$2,555	
	Design & Construction Costs**	$11,250	
	Total Estimated Project Cost (2014)	**$13,805**	
	Annual O&M***	$98	
	Cost Over 10-year Life Span	**$14,780**	
Efficiency	10-yr Average Cost/lb-TP	**$1,895**	
	10-yr Average Cost/1,000lb-TSS	**$1,516**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($150/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



Project ID: LR-11

Receiving Waterbody – Florence Lake
Location – Eastern shore of Florence Lake west of London Dr.
Property Ownership – Private
Site Specific Information – A moderately-large eroding face along the shore of the property noted below (PIN labeled) is evidence of an unstable bank. A rock toe restoration may be necessary to stabilize the bank. This may also require heavy equipment to achieve a workable grade. In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input to the lake.

Table 55: Pollutant removal potential for Project LR-11

	Lakeshore Restoration		
	Cost/Removal Analysis	New Treatment	% Reduction
Treatment	Current Erosion Severity	Moderate	
	Length of Lakeshore to Restore	75	linear-ft
	TP (lb/yr)	0.90	100.0%
	TSS (lb/yr)	1,125	100.0%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	Administration & Promotion Costs*	$2,555	
	Design & Construction Costs**	$12,750	
	Total Estimated Project Cost (2014)	**$15,305**	
	Annual O&M***	$113	
	Cost Over 10-year Life Span	**$16,430**	
Efficiency	10-yr Average Cost/lb-TP	**$1,826**	
	10-yr Average Cost/1,000lb-TSS	**$1,460**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($150/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year

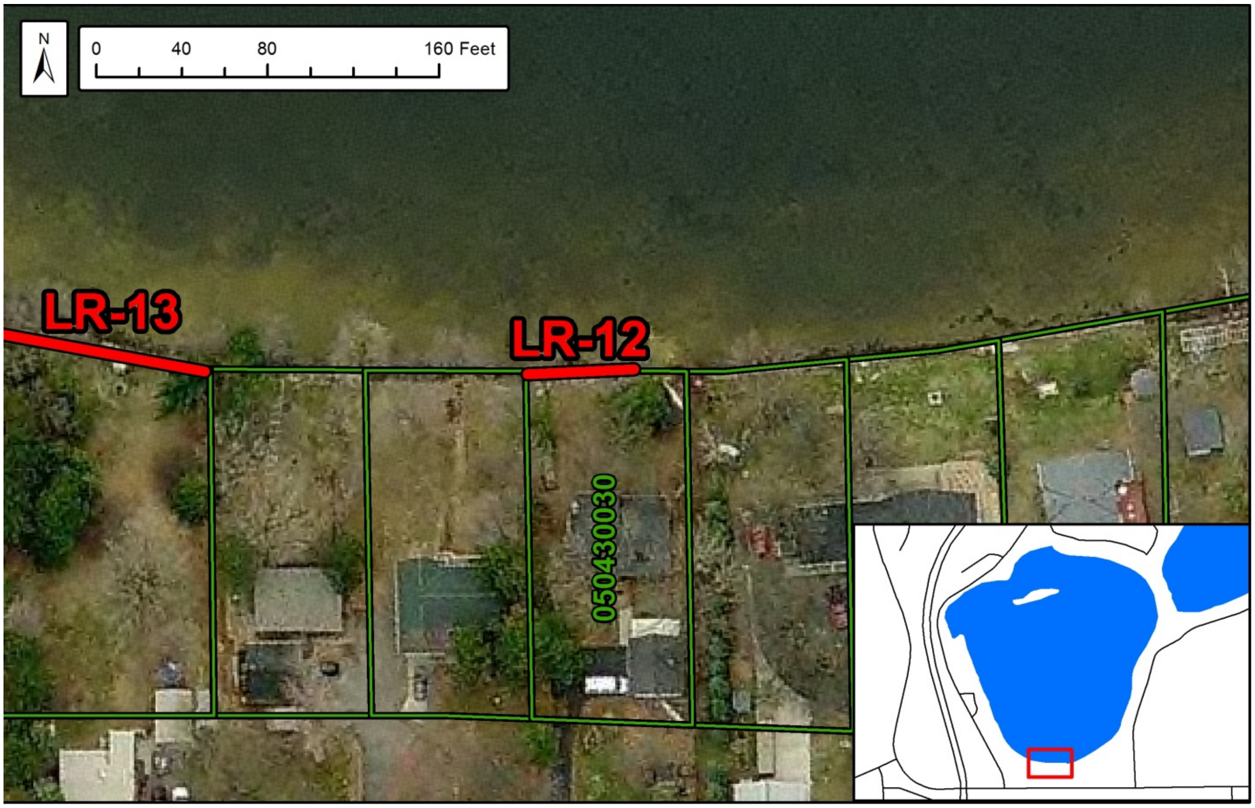
Project ID: LR-12

Receiving Waterbody – Florence Lake
Location – Southern shore of Florence Lake north of 313th Ave.
Property Ownership – Private
Site Specific Information – A biolog restoration is recommended based on the mild eroding face seen along the shore of the property noted below (PIN labeled). In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from the property along the shore.

Table 56: Pollutant removal potential for Project LR-12

	Lakeshore Restoration		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Current Erosion Severity**	Mild	
	Length of Lakeshore to Restore	50	linear-ft
	TP (lb/yr)	0.12	100.0%
	TSS (lb/yr)	150	100.0%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	**Administration & Promotion Costs***	$2,555	
	Design & Construction Costs**	$5,250	
	Total Estimated Project Cost (2014)	**$7,805**	
	Annual O&M***	$75	
	Cost Over 10-year Life Span	**$8,555**	
Efficiency	**10-yr Average Cost/lb-TP**	**$7,129**	
	10-yr Average Cost/1,000lb-TSS	**$5,703**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($75/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



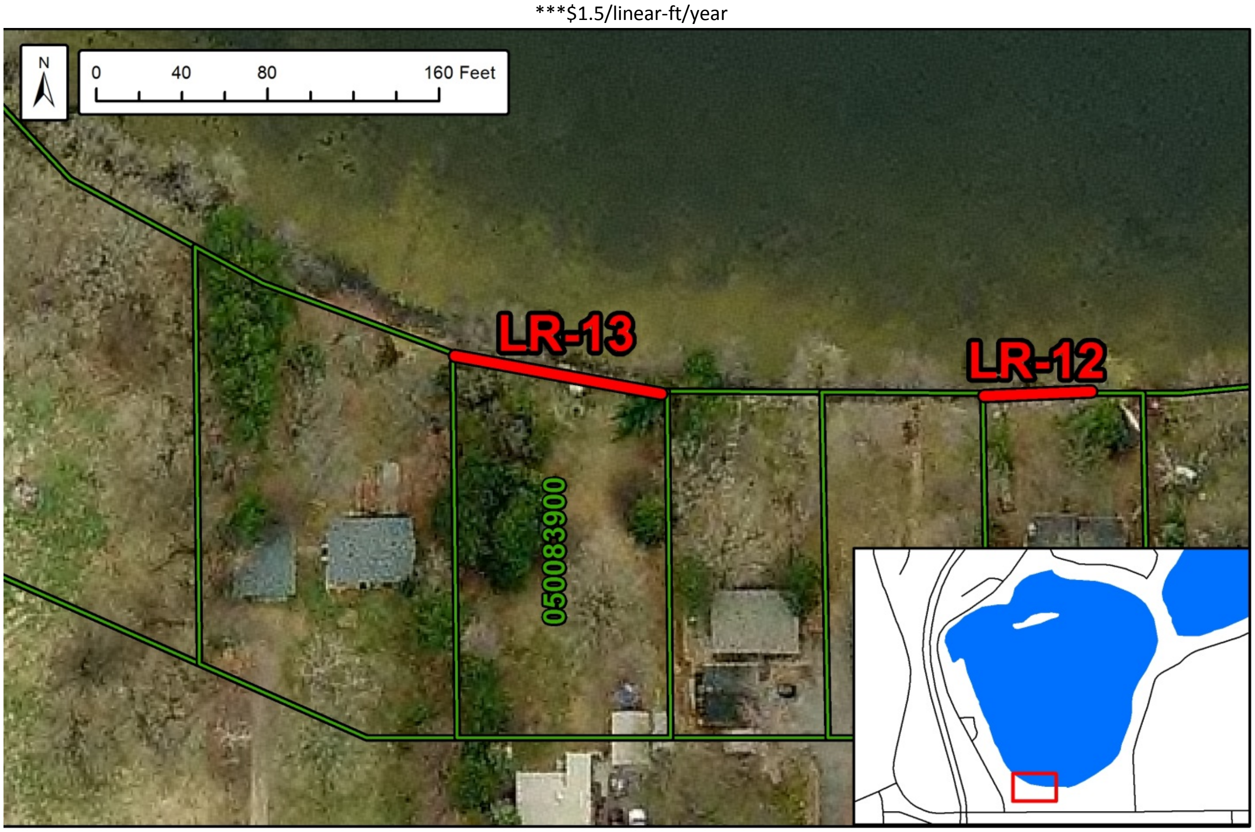
Project ID: LR-13

Receiving Waterbody – Florence Lake
Location – Southern shore of Florence Lake north of 313th Ave.
Property Ownership – Private
Site Specific Information – A biolog restoration is recommended based on the mild eroding face seen along the shore of the property noted below (PIN labeled). In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from the property along the shore.

Table 57: Pollutant removal potential for Project LR-13

	Lakeshore Restoration		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Current Erosion Severity**	Mild	
	Length of Lakeshore to Restore	100	linear-ft
	TP (lb/yr)	0.24	100.0%
	TSS (lb/yr)	300	100.0%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	**Administration & Promotion Costs***	$2,555	
	Design & Construction Costs**	$9,000	
	Total Estimated Project Cost (2014)	**$11,555**	
	Annual O&M***	$150	
	Cost Over 10-year Life Span	**$13,055**	
Efficiency	**10-yr Average Cost/lb-TP**	**$5,440**	
	10-yr Average Cost/1,000lb-TSS	**$4,352**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($75/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



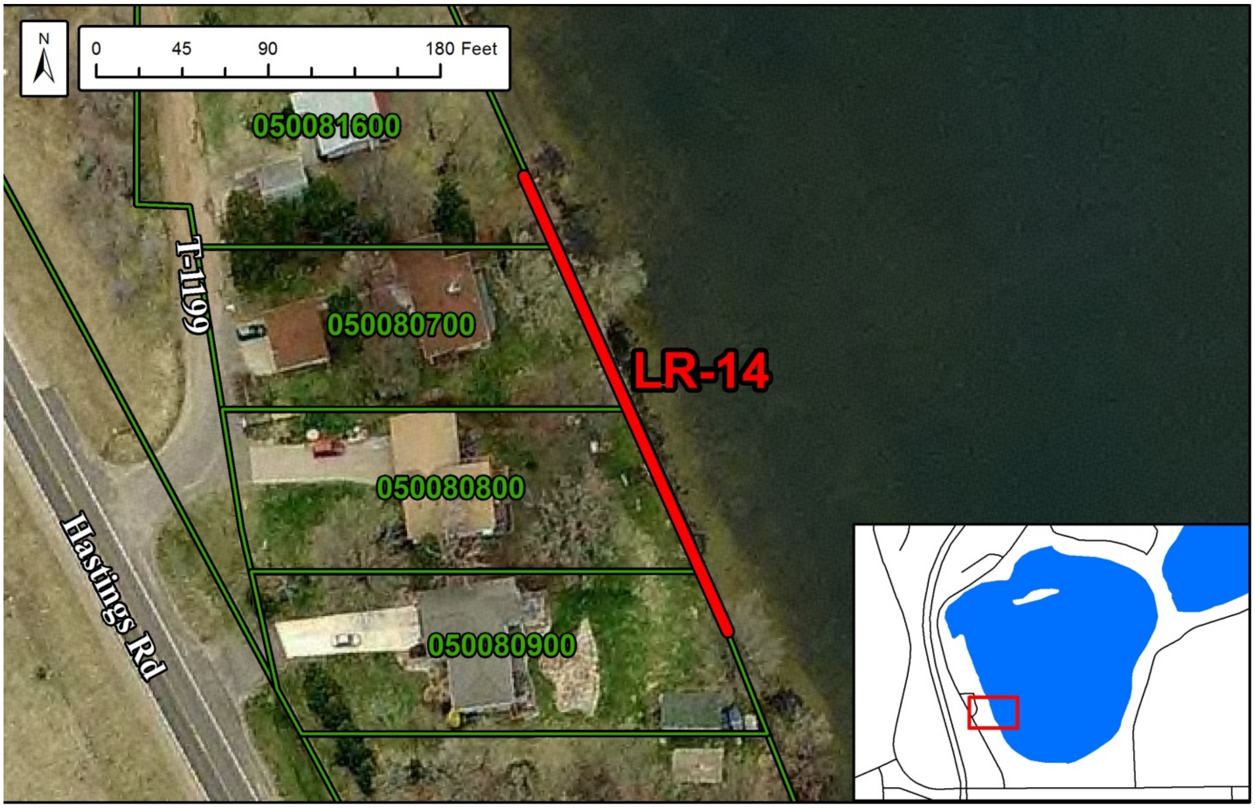
Project ID: LR-14

Receiving Waterbody – Florence Lake
Location – Western shore of Florence Lake east Hastings Rd.
Property Ownership – Private
Site Specific Information – A biolog restoration is recommended based on the mild eroding face seen along the shore of the properties noted below (PIN labeled for each property). In addition, planting native grasses along the shore and not mowing to the water's edge should decrease pollutant input from properties along the shore.

Table 58: Pollutant removal potential for Project LR-14

	Lakeshore Restoration		
	Cost/Removal Analysis	**New Treatment**	**% Reduction**
Treatment	**Current Erosion Severity**	Mild	
	Length of Lakeshore to Restore	260	linear-ft
	TP (lb/yr)	0.94	100.0%
	TSS (lb/yr)	1,170	100.0%
	Volume (acre-feet/yr)	0.00	0.0%
Cost	**Administration & Promotion Costs***	$2,555	
	Design & Construction Costs**	$21,000	
	Total Estimated Project Cost (2014)	**$23,555**	
	Annual O&M***	$390	
	Cost Over 10-year Life Span	**$27,455**	
Efficiency	**10-yr Average Cost/lb-TP**	**$2,921**	
	10-yr Average Cost/1,000lb-TSS	**$2,347**	
	10-yr Average Cost/ac-ft Vol.	**N/A**	

*(35 hours at $73/hour for promotion and administration)
**($75/linear-ft for materials and labor) + ($1,500 for design)
***$1.5/linear-ft/year



Project Ranking

The intent of this analysis is to provide the information necessary to enable local natural resource managers to successfully secure funding for the most cost-effective projects to achieve water quality goals. This analysis ranks potential projects by cost-effectiveness to facilitate project selection. There are many possible ways to prioritize projects, and the list provided in this report is merely a starting point. Local resource management professionals will be responsible to select projects to pursue. Several considerations in addition to project cost-effectiveness for prioritizing installation are included. If all identified practices were installed, significant pollution reduction could be accomplished. However, funding limitations and landowner interest will be a limiting factor in implementation. The following tables rank all modeled projects by cost-effectiveness including a TP Pollutant Delivery Ratio (PDR), explained in the *Location in Watershed* section.

Table 59: Cost-benefit of retrofits with respect to TP reduction. Projects 1-12. TSS and volume reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profile* pages.

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit (\$/lb-TP/yr)[1]	TP PDR	TP Reduction w/ PDR (lb-TP/yr)	Cost-Benefit w/ PDR (\$/lb-TP/yr)
1	9-A	115	Vegetated Filter Strip/Grassed Waterway	15.0-15.7	17,068-17,978	0.0	\$10,910-\$11,241	\$961-\$2,283	\$100-\$181	0.90	13.5-14.1	\$111-\$201
2	6-A	92	Vegetated Filter Strip	6.8-7.3	6,753-7,281	0.0	\$10,809-\$10,938	\$557-\$1,071	\$163-\$222	0.80	6.8-7.3	\$204-\$278
3	8-E	111	Vegetated Filter Strip/Grassed Waterway	3.4-3.5	4,805-4,896	0.0	\$10,809-\$10938	\$557-\$1,071	\$318-\$460	0.90	3.1-3.2	\$353-\$511
4	8-D	110	Vegetated Filter Strip/Grassed Waterway	3.2-3.4	4,247-4,646	0.0	\$10,805-\$10,924	\$539-\$1,016	\$341-\$457	0.90	2.9-3.1	\$379-\$508
5	7-B	99	WASCOB	3.4-4.9	5,205-8,079	0.0	\$21,094-\$23,938	\$517-\$538	\$355-\$457	0.90	3.1-4.4	\$394-\$507
6	5-C	83	IESF Bench in the Parkwood Development	7.2	0	0.0	\$92,327	\$459	\$491	1.00	7.2	\$491
7	6-B	93	IESF Bench for Regional Pond	25.0-50.8	0	0.0	\$240,933-\$779,983	\$2,500-\$10,000	\$396-\$647	0.80	20-40.7	\$495-\$809
8	7-D	101	WASCOB	2.5-3.9	3,510-6,521	0.0	\$20,649-\$31,138	\$508-\$550	\$511-\$614	1.00	2.5-3.9	\$511-\$614
9	8-A	107	Wetland Restoration	9.8-31.2	701-5,955	1.3-6.7	\$260,383-\$405,005	\$500	\$665-\$1380	0.80	7.8-25.0	\$532-\$1,104
10	4-B	75	Catchment 4 IESF Bench	11.5-15.8	0	0.0	\$152,605-\$246,408	\$1,148-\$2,500	\$542-\$625	1.00	11.5-15.8	\$542-\$625
11	2-B	61	Catchment 2 IESF Pond Bench	9.8	0	0.0	\$136,729	\$918	\$559	1.00	9.8	\$559
12	7-G	104	Vegetated Filter Strip	2.0-2.0	2,598-2.668	0.0	\$10,814-\$10,883	\$575-\$851	\$567-\$694	1.00	2.0-2.0	\$567-\$694

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land

Urban Catchments

Rural Catchments

Lakeshore Projects

Table 60: Cost-benefit of retrofits with respect to TP reduction. Projects 13-29. TSS and volume reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profile* pages.

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit ($/lb-TP/yr)[1]	TP PDR	TP Reduction w/ PDR (lb-TP/yr)	Cost-Benefit w/ PDR ($/lb-TP/yr)
13	5-F	86	Highway 95 Pond Bench	5.0	0	0.0	$92,327	$459	$707	1.00	5.0	$707
14	7-E	102	WASCOB	1.8-2.5	2,268-3,496	0.0	$21,049-$27,938	$516-$538	$774-$871	1.00	1.8-2.5	$774-$871
15	8-B	108	Wetland Restoration	2.1-5.2	2,825-8,673	0.7-1.3	$38,205-$56,205	$500	$640-$1,142	0.80	1.7-4.2	$800-$1,428
16	3-C	69	Catchment 3 IESF Bench	10.7	0	0.0	$232,475	$2,479	$956	1.00	10.7	$956
17	7-C	100	WASCOB	0.3-2.0	278-2,560	0.0	$20,827-$32,205	$525-$558	$1,112-$4,746	1.00	0.3-2.0	$1,112-$4,746
18	5-G	87	Highway 95 Permeable Check Dams	1.0	1,347	0.0	$12,753	$730	$1,368	1.00	1.0	$1,368
T19	LR-7	126	LR-7	2.5	3,075	0.0	$34,805	$308	$1,540	1.00	2.5	$1,540
T19	LR-8	127	LR-8	2.5	3,075	0.0	$34,805	$308	$1,540	1.00	2.5	$1,540
T19	8-F	112	Vegetated Filter Strip/Grassed Waterway	1.5-1.6	1,108-1,165	0.0	$10,768-$10,791	$392-$484	$616-$660	0.40	0.6-0.6	$1,540-$1,650
T19	7-F	103	Vegetated Filter Strip	1.0-1.0	1,077-1,147	0.0	$10,768-$10,791	$392-$484	$930-$993	0.60	0.6-0.6	$1,550-$1,655
23	6-B	93	Regional Pond	57.8	177,212	1.2	$2,426,023	$1,200	$1,419	0.80	46.2	$1,774
24	LR-11	131	LR-11	0.9	1,125	0.0	$15,305	$113	$1,826	1.00	0.9	$1,826
25	8-C	109	WASCOB	0.6-1.0	587-1,042	0.0	$20,383-$25,005	$503-$508	$1,851-$2,537	1.00	0.6-1.0	$1,851-$2,537
26	LR-10	130	LR-10	0.8	975	0.0	$13,805	$98	$1,895	1.00	0.8	$1,895
27	2-A	59	Catchment 2 Curb-Cut Rain Gardens	0.2-0.3	25-43	0.4-0.5	$11,610	$225	$2,369-$3,356	1.00	0.2-0.3	$2,369-$3,356
28	LR-14	134	LR-14	0.9	1,170	0.0	$23,555	$390	$2,921	1.00	0.9	$2,921
29	7-A	98	WASCOB	0.3-1.0	278-1,153	0.0	$20,472-$21,538	$505-$514	$1,544-$4,632	0.50	0.2-0.5	$3,088-$9,264

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land

Table 61: Cost-benefits of retrofits with respect to TP reduction. Projects 30-46. TSS and volume reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profiles* pages

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit ($/lb-TP/yr)[1]	TP PDR	TP Reduction w/ PDR (lb-TP/yr)	Cost-Benefit w/ PDR ($/lb-TP/yr)
30	6-C	95	WASCOB	0.3-0.8	236-788	0.0	$20,383-$26,205	$503-$521	$2,409-$5,249	0.70	0.2-0.6	$3,442-$7,500
31	5-D	84	Target Parking Lot IESF Basin	1.0-1.5	252-571	0.6-1.0	$109,088-$159,243	$459-$918	$4,000-$4,150	1.00	1.0-1.5	$4,000-$4,150
32	LR-1	118	LR-1	1.4	1,740	0.0	$47,555	$570	$4,047	1.00	1.4	$4,047
33	LR-5	123	LR-5	1.2	1,530	0.0	$42,305	$765	$4,095	1.00	1.2	$4,095
34	3-A	65	Catchment 3 Curb-Cut Rain Gardens	0.0-0.2	3-34	0.1-0.3	$6,950-$15,710	$225	$5,053-$57,250	1.00	0.0-0.2	$5,053-$57,250
35	5-E	85	Fleet Farm Parking Lot IESF Basin	0.8-0.9	270-511	0.5-0.8	$109,088-$159,243	$459-$918	$5,054-$6,506	1.00	0.8-0.9	$5,054-$6,506
36	LR-9	129	LR-9	0.2	203	0.0	$7,430	$68	$5,066	1.00	0.2	$5,066
T37	LR-2	119	LR-2	0.3	390	0.0	$13,805	$195	$5,082	1.00	0.3	$5,082
T37	LR-4	122	LR-4	0.3	390	0.0	$13,805	$195	$5,082	1.00	0.3	$5,082
39	LR-3	120	LR-3	0.3	345	0.0	$12,680	$173	$5,145	1.00	0.3	$5,145
40	LR-13	133	LR-13	0.2	300	0.0	$11,555	$150	$5,440	1.00	0.2	$5,440
41	LR-6	124	LR-6	0.2	225	0.0	$9,680	$113	$6,003	1.00	0.2	$6,003
T42	4-A	73	Catchment 4 Curb-Cut Rain Gardens	0.1-0.1	7-21	0.1-0.2	$11,610	$225	$6,196-$13,425	1.00	0.0-0.1	$6,196-$13,425
T42	5-A	79	Curb-Cut Rain Gardens in the Parkwood Development	0.1-0.1	7-21	0.1-0.2	$11,610	$225	$6,196-$13,425	1.00	0.1-0.1	$6,196-$13,425
44	3-B	68	Catchment 3 Curb-Cut Boulevard Bioswales	0.0-0.1	4-14	0.0-0.1	$8,310	$225	$6,405-$32,025	1.00	0.0-0.1	$6,405-$32,025
45	5-B	81	Curb-Cut Rain Gardens in the Preserve Development	0.1-0.2	6-17	0.1-0.2	$9,730-$15,710	$225	$6,737-$10,164	1.00	0.1-0.2	$6,737-$10,164
46	LR-12	132	LR-12	0.1	150	0.0	$7,805	$75	$7,129	1.00	0.1	$7,129

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land

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Appendix A – Modeling Methods

Water Quality Models

Two distinct water quality models were used in this analysis, WinSLAMM and ArcSWAT. Each was chosen based on the specialized inputs and features that provide reliable, land use-specific estimates for pollutant loading under existing and proposed conditions. Two separate models were utilized as each is more applicable to either rural or urban landscapes.

WinSLAMM is a water quality model that is well-suited to evaluate runoff in urbanized settings. This model uses an abundance of stormwater data from the Upper Midwest and elsewhere to quantify runoff volumes and pollutant loads from urban areas. It has detailed accounting of pollutant loading from various land uses, and allows the user to build a model "landscape" that reflects the actual landscape being considered.

On the other hand, the Soil and Water Assessment Tool (SWAT) is a partially physically-based and partially empirically-based watershed model applied most often to rural settings (although recent software releases have increased the usability in urban environments). This model has additional land cover and soil inputs to reflect the highly varied landscapes across agrarian and undeveloped areas.

Drainage basins were delineated using the ArcView extension of SWAT, or ArcSWAT. These basins were then aggregated into catchments to determine the dominant flow paths to the SFEF chain of lakes. Catchments predominantly within the City of Cambridge where urban residential and commercial properties represented a majority of the land use were modeled with WinSLAMM. Catchments in the Townships of Cambridge, Isanti, and Fish Lake with predominantly rural residential and agricultural properties were modeled with ArcSWAT.

Input Parameters for ArcSWAT

Stormwater runoff generated in rural catchments was estimated using ArcSWAT, which combines hydrography, topography, soils, and land cover data in a GIS interface and determines runoff volume and pollutant loading based on these inputs (Table 62). Beginning with a digital elevation model, ArcSWAT delineated basins in the SFEF subwatershed based on predefined threshold values for minimum basin size. To improve model efficiency, hydrologic response units (HRUs) were derived within each basin based on a unique combination of land cover and soil type. An area was computed for each HRU, as well as an average slope to deliver runoff directly to the basin's outlet. For example, a single 10 acre basin may be split into 20 HRUs, each with a specific land cover and soil type.

Digital elevation model (DEM) data was downloaded from the Minnesota Geospatial Information Office (MNGEO) webpage. To route overland flow under roadways and driveways, culvert locations were determined through desktop analysis and field surveys and "burned" into the landscape.

Land Cover data were provided by the US Geological Survey's National Land Cover Database (NLCD). We used the latest year in which an ArcSWAT look-up table was available: 2006. NLCD 2006 is a 16-class (in the contiguous 48 states) dataset that allowed for compromise between a large and well defined

Table 62: GIS file sources and use in ArcSWAT modeling and desktop analysis

Dataset	Source	Purpose	Notes
Digital elevation model (DEM)	Minnesota Geologic Information Office (MNGEO)	Model input of topography	Horizontal resolution: meets or exceeds 0.6 m; Vertical resolution: meets or exceeds 0.1 m
Soils	United State Department of Agriculture (USDA) and the Nature Resources Conservation Service (NRCS) - Soils Survey Geographic Database (SSURGO)	Model input, determining BMP viability, locating hydric soils	
Land cover	National Land Cover Dataset (NLCD) 2006	Model input	
Parcel data	Isanti County; Chisago County	Display homeowner information	Downloaded September 2014
Streams	Minnesota Department of Natural Resources (DNR)	Model input (flow routing), map display	Public waters inventory, watercourse delineations
Lakes and wetlands	Minnesota Department of Natural Resources (DNR)	Map display	Public waters inventory, basin delineations
Aerial photography	Pictometry	Verify land cover information, map display	Photos taken during the summer of 2011
Municipal boundary	MNGEO	Map display	
Roads	The Lawrence Group, Minnesota Department of Transportation (MNDOT), Metropolitan Council	Map display, BMP description	
Culverts	Desktop analysis of DEM, field survey	Model input, BMP siting	

dataset (e.g. Minnesota Land Cover Classification System with >600 classes) and a smaller one which reduces computational time. Because of annual changes to crop coverage, such as rotations between corn and soybeans, all tilled agricultural fields were evaluated similarly. Soils data were provided by the Anoka County Digital Soil Survey and were characterized in ArcSWAT using the Soil Survey Geographic Database (SSURGO). Precipitation data were uploaded from the Weather Generator model within ArcSWAT based on historical readings from local climatic stations.

Infiltration and surface runoff were determined within SWAT using a modified version of the SCS curve number (CN) method. Erosion and sediment yield were estimated for each HRU using the Modified Universal Soil Loss Equation (MUSLE). ArcSWAT determined phosphorus transport and transformation using a host of processes in both mineral and organic form, which were summed to determine total phosphorus load.

ArcSWAT Model Calibration

Calibration parameters were derived from the Sunrise River Watershed SWAT model (Almedinger and Ulrich, 2010) and used to calibrate the SFEF catchment models. The Sunrise River subwatershed is the next major subwatershed southeast of the SFEF subwatershed (although not hydrologically connected), and topographic and hydrologic conditions vary little across the two subwatersheds. Calibration parameters developed by Almendinger and Ulrich (2010) used in this analysis are listed in Table 63. Additional detail can be found in Appendix B of their paper.

To model the effect of reservoirs and wetlands within ArcSWAT, methodology proposed by Almedinger and Ulrich (2010) was employed to determine total ponding depth, area, and retention capacity for both TP and TSS. ArcHydro was utilized to determine the depressional storage area and volume from wetlands and lowland features in the landscape. The depressional storage within each subbasin of a catchment was aggregated across the catchment to determine an overall area and volume treated. ArcHydro is only able to recognize ponding capabilities above the existing water surface, so any permanent (and possibly seasonally permanent) ponding occurring in wetlands and ponds needs to be taken into account as well. To do this, an average 0.25 m depth was assumed across all depressions in the SFEF subwatershed. This depth seems low, but considering that many of these depressions are ephemeral ditches and backyard depressions which only retain water during and directly following storm events, this number is likely close when averaged across an entire catchment. These depressions were modeled within the landscape using the 'Pond' parameter dialog. Principal and emergency spillway area and volume were determined following empirical equations derived by Almedinger and Ulrich (2010):

$$\text{Principal Area} = 0.94 * (\text{ArcHydro Depression Area})$$

$$\text{Emergency Area} = 1.13 * (\text{ArcHydro Depression Area})$$

$$\text{Principal Volume} = 0.91 * (\text{ArcHydro Depression Volume})$$

$$\text{Emergency Volume} = 1.18 * (\text{ArcHydro Depression Volume})$$

Table 63: ArcSWAT calibration parameters for SFEF catchment models

Parameter	Description	Units	Modeled Value	Default Value
.BSN table values - general watershed attribute input data, applies to all HRUs				
SMTMP	Snow melt base temperature	^oC	-5	1
SMFMX	Melt factor for snow on June 21	mm $H_20/^oC$-day	1.5	4.5
SFTMP	Snowfall temperature	^oC	-2	1
SMFMN	Melt factor for snow on December 21	mm $H_20/^oC$-day	0.5	4.5
SNOCOVMX	Snowpack water content at which coverage is 100%	mm H_20	10	1
IPET	Potential evapotranspiration method	-	Priestly-Taylor	-
SPCON	Channel sediment transport (linear parameter)	-	0.01	0.0001
SURLAG	Surface runoff lag time	days	1	4
SPEXP	Exponent parameter for calculating sediment re-entrained in channel sediment routing	-	1.5	1
CDN	Denitrification parameter	-	0	1.4
SNDCO	Soil water denitrification point parameter	-	0.99	1.1
PSP	Phosphorus sorption coefficient	-	0.3	0.4
PHOSKD	Phosphorus soil partitioning coefficient	-	100	175
PPERCO	Phosphorus percolation coefficient	-	17.5	10
.GW table values - groundwater input data, applies to all HRUs				
GW_DELAY	Groundwater delay	days	10	30
ALPHA_BF	Baseflow alpha factor	days	0.5	0.048
RCHRG_DP	Deep aquifer percolation fraction	-	0.6	-
GWSOLP	Concentration of soluble phosphorus in groundwater	mg-P/L	0.012	0
.MGT1 table values - general watershed attribute input data, applied to select HRUs				
CN2	Initial SCS curve number for moisture condition II	-	Default - 25%	Varies
USLE_P	USLE equation support practice factor	-	0.4	1
.RTE table values - main channel input data, applied to all HRUs				
CH_N2	Manning's 'n' value for main channel	-	0.05	0.5
CH_EROD (MO1-MO12)	Channel erodibility factor for each month	-	0.001	0
CH_COV1	Channel erodibility factor	-	0.6	0
CH_COV2	Channel cover factor	-	1	0
.CROP table values - input data for the land cover/plant growth database, applied to all HRUs				
Applied to alfalfa crops:				
BIO_E	Radiation efficiency value	$(kg/ha)/(MJ/m^2)$	11	20

Parameter	Description	Units	Modeled Value	Default Value
Applied to corn crops:				
BIO_E	Radiation efficiency value	$(kg/ha)/(MJ/m^2)$	36	39
HVSTI	Harvest Index	(kg/ha)/(kg/ha)	0.4	0.5
RSDCO	Plant residue decomposition coefficient	-	0.099	0.05
Applied to corn silage crops:				
BIO_E	Radiation efficiency value	$(kg/ha)/(MJ/m^2)$	36	39
RSDCO	Plant residue decomposition coefficient	-	0.099	0.05
Applied to soybean crops:				
HVSTI	Harvest Index	(kg/ha)/(kg/ha)	0.4	0.5
WSYF	Lower limit of harvest index	-	0.1	0.01
RSDCO	Plant residue decomposition coefficient	-	0.099	0.05

In natural systems, sedimentation in waterbodies is controlled by factors including current velocity, wind speed, fetch, and shoreline vegetative coverage. Within ArcSWAT, sedimentation is controlled by an equilibrium sediment concentration, above which all sediment is presumed to fall out of suspension.

This value was derived from Almedinger and Ulrich (2010) where D is the mean depth of the pond or reservoir in meters and NSED is the equilibrium sediment concentration in mg/L.

$$\mathrm{NSED} = 100 * \mathrm{D}^{-2}$$

Phosphorus retention generated by the pond or reservoir was determined using the phosphorus settling rate. This parameter was set at 0 m/year for ponds/wetlands. Additional input parameters for the .pnd table include NDTARG = 5 days, PND_FR = 1, and PND_K = 0.2

Following calibration, the ArcSWAT model was run for a seven year period, 2004-2010, for each catchment model. The first two years of the model run were used to bring all conditions into equilibrium. Results from years 2006-2010 were analyzed to determine average annual loading of TP, TSS, and volume. Each reported value represents the 5-year average of these model runs.

Input Parameters for WinSLAMM

Volume and pollutant export from catchments with predominantly developed residential and commercial land uses were modeled with WinSLAMM. WinSLAMM is an empirically-based model using stormwater data from Upper Midwest to determine load export and BMP effectiveness. The user can simulate various stormwater treatment practices in her/her model landscape and compare results to existing (without the treatment practice) conditions. WinSLAMM uses rainfall and temperature data from a typical year, routing stormwater through the user's model for each storm.

The initial step was to create a "base" model which estimated pollutant loading from each catchment in its present-day state without taking into consideration any existing stormwater treatment. To accurately model the land uses in each catchment, we delineated each land use in each catchment using geographic information systems (specifically, ArcMap), and assigned each a WinSLAMM standard land use file. A site specific land use file was created by adjusting total acreage and accounting for local soil types. This process resulted in a model that included estimates of the acreage of each type of source area (roof, road, lawn, etc.) in each catchment.

Table 64: WinSLAMM model inputs for catchment and BMP modeling

Parameter	File/Method
Land use acreage	ArcMap
Precipitation/Temperature Data	Minneapolis 1959 – the rainfall year that best approximates a typical year.
Winter season	Included in model. Winter dates are 11-4 to 3-13.
Pollutant probability distribution	WI_GEO01.ppd
Runoff coefficient file	WI_SL06 Dec06.rsv
Particulate solids concentration file	WI_AVG01.psc
Particle residue delivery file	WI_DLV01.prr
Street delivery files	WI files for each land use.

Once the "base" model was established, an "existing conditions" model was created by incorporating any existing stormwater treatment practices in each catchment. This included street cleaning performed in the residential streets surrounding the lake as well as the constructed grass swale and weir along Front Blvd. west of the lake.

Finally, each proposed stormwater treatment practice was added to the "existing conditions" model and pollutant reductions were generated. Because neither a detailed design of each practice nor in-depth site investigation was completed, a generalized design for each practice was used. Whenever possible, site-specific parameters were included. Design parameters were modified to obtain various levels of treatment. It is worth noting that we modeled each practice individually, and the benefits of projects may not be additive, especially if serving the same area. Reported treatment levels are dependent upon optimal site selection and sizing. Also, all urban catchments modeled with WinSLAMM discharge stormwater runoff directly to the lake. Therefore, reductions from proposed BMPs directly benefit the lake.

Simulating BMPs in SWAT

Wetland Restorations

Proposed conditions, with installed BMPs, were modeled within the landscape using the 'Pond' parameter dialog (Table 65). Each proposed wetland restoration increases holding capacity of stormwater runoff, thereby increasing hydraulic residence time and promoting sedimentation. Wetland restorations assume only a change in hydrology to promote ponding to existing topography. This might occur by breaking a tile line, installing a weir, ditch block, or berming across a previously graded land bridge. Ponding area and volume was determined using the NRCS GIS Engineering tools for ArcGIS v10.0 at various elevations. These values were used as the principal spillway height in the Pond dialog (.pnd table) of ArcSWAT. Emergency spillway area and volume was determined following empirical equations derived by Almedinger and Ulrich (2010) for the Sunrise River watershed in east-central Minnesota,

$$\text{Emergency Area} = 1.13 * (\text{Principal Area})$$

$$\text{Emergency Volume} = 1.18 * (\text{Principal Volume})$$

In natural systems, sedimentation is controlled by factors including current velocity, wind speed, fetch, and vegetative coverage around the waterbody. Within ArcSWAT, sedimentation is controlled by an equilibrium sediment concentration, above which all sediment is presumed to fall out of suspension. This value was derived from Almedinger and Ulrich (2010) where D is the mean depth of the pond in meters and NSED is the equilibrium sediment concentration in mg/L.

$$\text{NSED} = 100 * \text{D}^{-2}$$

Phosphorus retention generated by the BMP was determined using the phosphorus settling rate (Table 65). The phosphorus settling rate was set at 20 m/year to bring settling values in line with reservoirs throughout east central Minnesota (Almedinger, personal communication). In some cases phosphorus retention was below the amount expected from sedimentation rates. As adsorbed phosphorus is available in nearly all types of sediment, a certain percentage of TP will be removed from the water column as sediment falls out of suspension. The mass of phosphorus bound to sediment was estimated from the Minnesota Board of Water and Soil Resources (BWSR) Pollution Reduction Estimator (PRC) for sheet and rill erosion, where P_{SED} is the phosphorus content in the sediment in lbs/acre/year and S is the sediment load in tons/acre/year.

$$P_{SED}\left(\frac{lbs}{ac - yr}\right) = 1.5999 * S^{0.7998}$$

When this value over a given time span was greater than the expected phosphorus retention based on the settling rate, phosphorus reductions were reported solely as phosphorus adsorbed to sediment.

Table 65: ArcSWAT Parameters for the 'Pond' input file (.pnd)

Parameter	Description	Units	Modeled Value[1]	Default Value	Explanation
PND_FR	Fraction of basin area draining into the pond	-	1	0	"Edge-of-field" or "end-of-pipe" BMPs were modeled as a single basin with the entire basin draining to the pond
PND_PSA	Surface area of pond when filled to principal spillway	ha	Variable	0	Determined by NRCS GIS Engineering tools
PND_PVOL	Volume of pond when filled to principal spillway	10^4 m^3	Variable	0	Determined by NRCS GIS Engineering tools
PND_ESA	Surface area of pond when filled to emergency spillway	ha	Variable	0	Emergency spillway area (ha) = 1.13 * Principal spillway area (ha)
PND_EVOL	Volume of pond when filled to emergency spillway	10^4 m^3	Variable	0	Emergency spillway volume (10^4 m^3) = 1.18 * Principal spillway volume (10^4 m^3)
PND_VOL	Initial volume of pond water	10^4 m^3	0	0	initially set at 0 but run with 2-year equilibrium time
PND_SED	Initial sediment concentration of pond water	mg/L	0	0	initially set at 0 but run with 2-year equilibrium time
PND_NSED	Equilibrium sediment concentration in pond	mg/L	Variable	0	NSED = 100 * D^{-2} ; where D = mean depth (m)
PND_K	Hydraulic conductivity through pond bottom	mm/hr	0.2	0	Conductivity for silt and clay soils
PSETL1	Phosphorus settling rate in pond during first period	m/year	20	10	Increased for shallower ponds (1-2 ft. in depth), Settling period not seasonally dependent

[1] Default values were used unless otherwise noted.

Parameter	Description	Units	Modeled Value[1]	Default Value	Explanation
PSETL2	Phosphorus settling rate in pond during second period	m/year	20	10	Settling period is year-round (not seasonally dependent)
PND_SOLP	Initial concentration of soluble P in pond	mg-P/L	0	0	initially set at 0 but run with 2-year equilibrium time
PND_ORGP	Initial concentration of organic (particulate) P in pond	mg-P/L	0	0	initially set at 0 but run with 2-year equilibrium time

Filter Strips

ArcSWAT contains a separate submodel for filter strips, which can be initiated by creating a scheduled management operations (.ops) file. This file allows for runoff within specified HRUs to flow through the filter strip prior to reaching the drainage channel. The basin was clipped to include only portions of the landscape draining to the filter strip, which allowed for all HRUs within the submodel to similarly drain to the practice. This also ensures that all land use types are included in pollutant retention calculations.

Four input parameters are available for specifying filter strip characteristics. Recommended values were provided by the *Conservation Practice Modeling Guide for SWAT and APEX*:

1) VFSI: Activates filter strip (1 = active; 0 = inactive).
2) VFSRATIO: Field area to filter strip ratio. Field area was determined from delineating the drainage basin. The proposed filter strip area was measured using ArcGIS. This area included both sides of the waterway.
3) VFSCON: Fraction of the total runoff from the entire field entering the most concentrated 10% of the filter strip (recommended value of 0.25-0.75).
4) VFSCH: Fraction of flow through the most concentrated 10% of the filter strip that is fully channelized (recommended value of 0).

Values for VFSCON and VFSCH were increased to 0.75 and 0.25, respectively, to better mimic regional characteristics of buffers in central Minnesota (Nieber et al., 2011).

Similar to all other BMPs run with ArcSWAT, the model was run for a seven year period, 2004-2010. The first two years of the model run were used to bring all conditions into equilibrium. Results from years 2006-2010 were analyzed to determine average yearly load of TP, TSS, and volume. Each reported value represents the 5-year average of these model runs.

Sediment Basins

Sediment basins are often viewed as depressions (natural or man-made) in the landscape that accept stormwater runoff for the purpose of promoting sedimentation. In this application, standing water would be present for extended periods of time. For this analysis, sediment basins were modeled as structures that slow the runoff of drainage from farm fields but do not hold water indefinitely. When tied to drain tile, these structures (which are often called Water and Sediment Control Basins (WASCOBs)) will reduce the velocity of the drainage enough for sediment to drop out of suspension while allowing for the stormwater to drain slowly from behind the berm into the tile line. ArcSWAT does not have a submodel for this type of practice. As recommended by the *Conservation Practice Modeling Guide for SWAT and APEX*, these structures can be modeled as ponds in ArcSWAT. To be comparative to WASCOBs, though, we assumed no retention of water from the structure. It was assumed all water reaching the structure would be advected downstream through the tile system. Pond parameters set within ArcSWAT are comparative to those listed in Table 65. Equilibrium sediment concentration associated with these structures is still based on ponding depth up to either the berm height or riser overflow height (depending on design).

Similar to all other BMPs run with ArcSWAT, the model was run for a seven year period, 2004-2010. The first two years of the model run were used to bring all conditions into equilibrium. Results from years 2006-2010 were analyzed to determine average yearly load of TP, TSS, and volume. Each reported value represents the 5-year average of these model runs.

New Ponds

Ponds were proposed in the landscape where sufficient drainage area could sustain a permanent pool of water (MPCA, 2014). Ponds were proposed following guidance from the Minnesota Pollution Control Agency, in which depths are equal to or less than 8-10 ft. to prohibit stratification and at least 1,800 cu-ft. of pond storage is available for each acre of drainage area. Ponds were modeled at multiple depths and areas with ArcSWAT, following similar conditions noted in the 'Wetland Restorations' section above. Similar to all other BMPs run with ArcSWAT, the model was run for a seven year period, 2004-2010. The first two years of the model run were used to bring all conditions into equilibrium. Results from years 2006-2010 were analyzed to determine average yearly load of TP, TSS, and volume. Each reported value represents the 5-year average of these model runs.

When assessing the results of these BMP models, please keep in mind that:

1) Proposed ponding for each BMP is based on current topography, which has been greatly altered over the last 150 years through clear-cutting, drainage, grading, and tilling. If the goal were to achieve restoration of an area to its natural, pre-settlement condition, it may be necessary to replicate landscape features long erased by land use by installing features such as dikes, berms, and weirs that exceed design parameters considered in this analysis. This could result in area and storage conditions that are different from those modeled in this study. The study results can at least be a guideline for restoration activities and pollutant reduction potential.

2) Unfortunately, as there is no existing monitoring data at each prospective BMP location, greater refinement of model calibration could not be performed. If definitive reduction totals are needed for each BMP, then monitoring water quality at the inlet and outlet of installed practices should be pursued where practical. These data could then be used to better calibrate the model to localized conditions and to better design subsequent BMPs.

Simulating BMPs in WinSLAMM

Bioretention Practices

Curb-Cut Rain Garden

Curb-cut rain gardens were modeled as drainage area control practices within WinSLAMM. None were modeled with underdrains, as treating dissolved constituents is a goal of these practices due to the number of stormwater retention ponds already in the landscape. Top area, bottom area, and native soil infiltration rate varied for each model run. Figure 21 describes specific input parameters for curb-cut rain gardens in the WinSLAMM model.

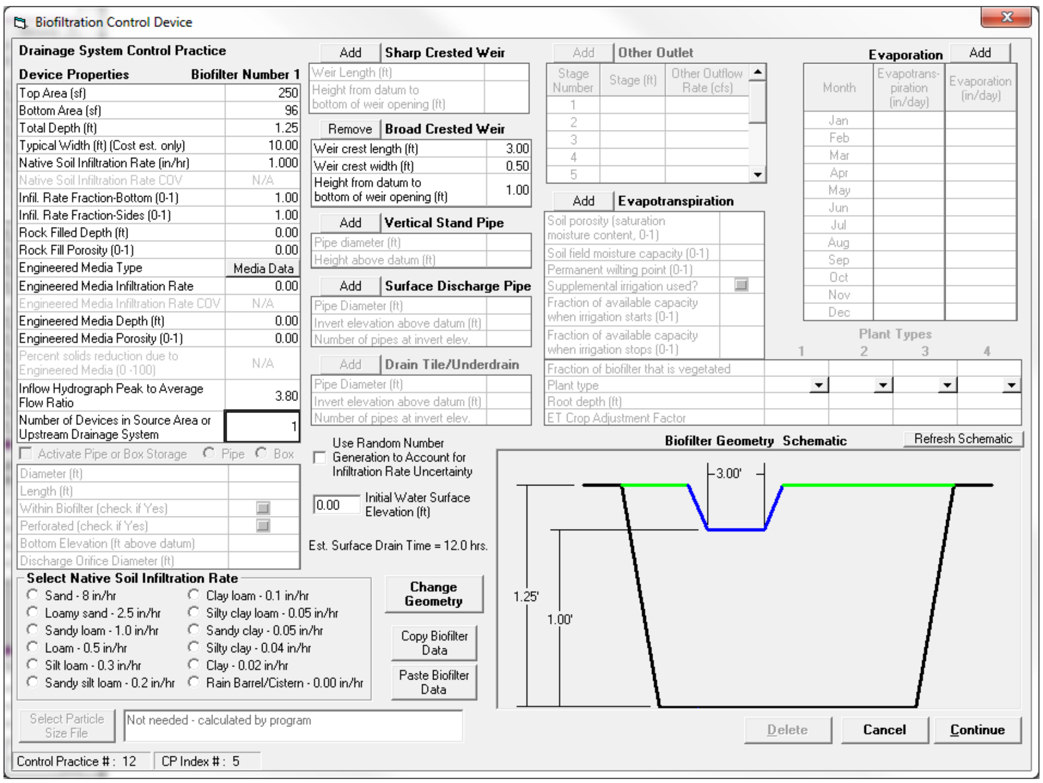

Figure 21: WinSLAMM input screen for a curb-cut rain garden

Boulevard Bioswales

Boulevard bioswales were modeled as grass swale drainage area control practices within WinSLAMM. This was done as bioswales have both an inlet and outlet, and function more like swales than a typical infiltration basin (such as a curb-cut rain garden). Input parameters for boulevard bioswales are shown in Figure 22. Swale density was determined by swale length and the drainage area to the bioswale (shown in the figure below as 0.790 acres).

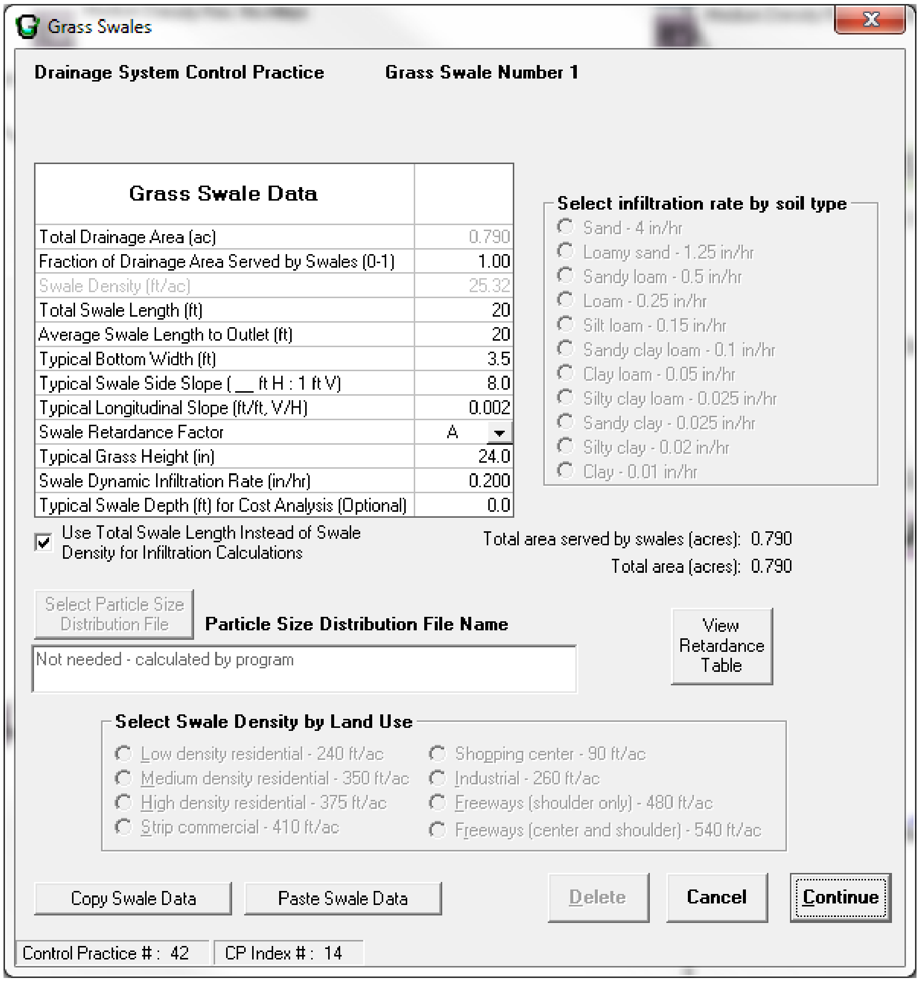

Figure 22: WinSLAMM input screen for a boulevard bioswale

IESF Basins and Benches

IESF basins were modeled as biofiltration drainage area control practices. These were sized much larger than curb-cut rain gardens as they most often treat larger and more impervious drainage areas (e.g. commercial buildings with large parking lots). Native soil infiltration rates were modeled conservatively at 0.2"/hr while the engineered media infiltration rate reflects infiltration of well-sorted sand fill, 8.0"/hr. Between the two proposed IESF basin locations in the Fleet Farm and Target parking lots, the only input values that varied were basin storage. Figure 23 lists all input values for the Target Parking lot IESF basin.

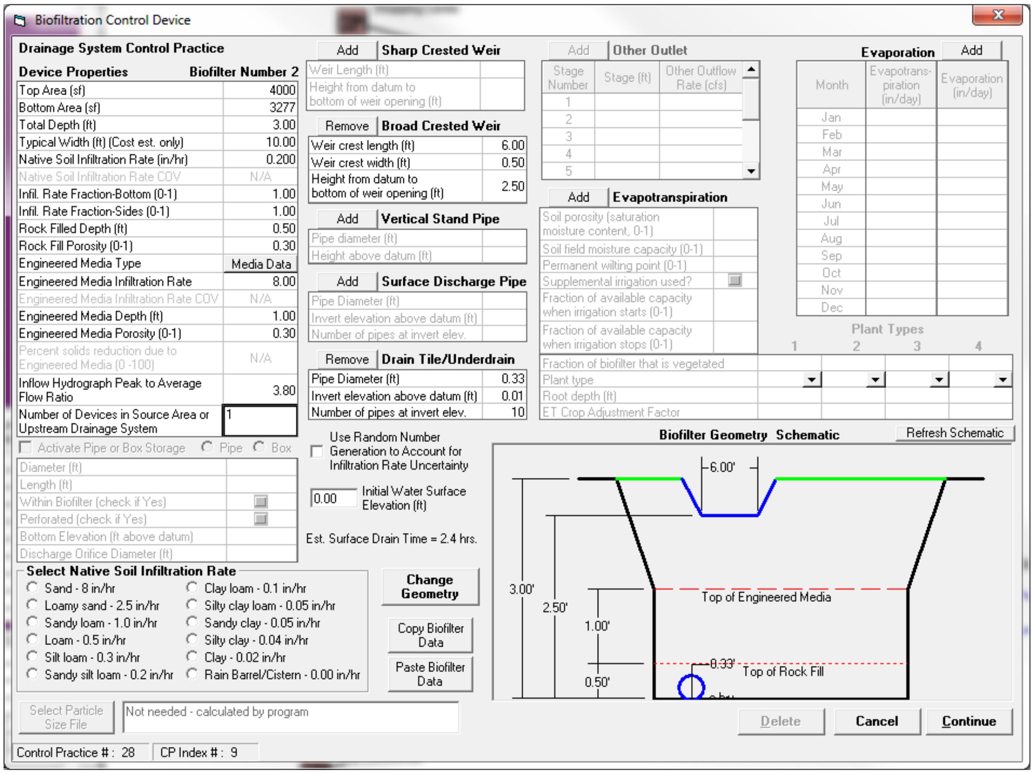

Figure 23: WinSLAMM input screen for an IESF basin

IESF benches were modeled similarly to IESF basins, as a drainage area control practice with an underdrain and sandy fill. Differences between the practices include a deeper ponding depth, larger weir, and complete lack of infiltration with the IESF bench. Infiltration was negated as it is likely a liner will be installed around the bench to ensure no water encroaches from either the pond or the underlying water table. Figure 24 lists all input values for a typical IESF bench. For the most part, only top and bottom area and the number of underdrains varied between each project.

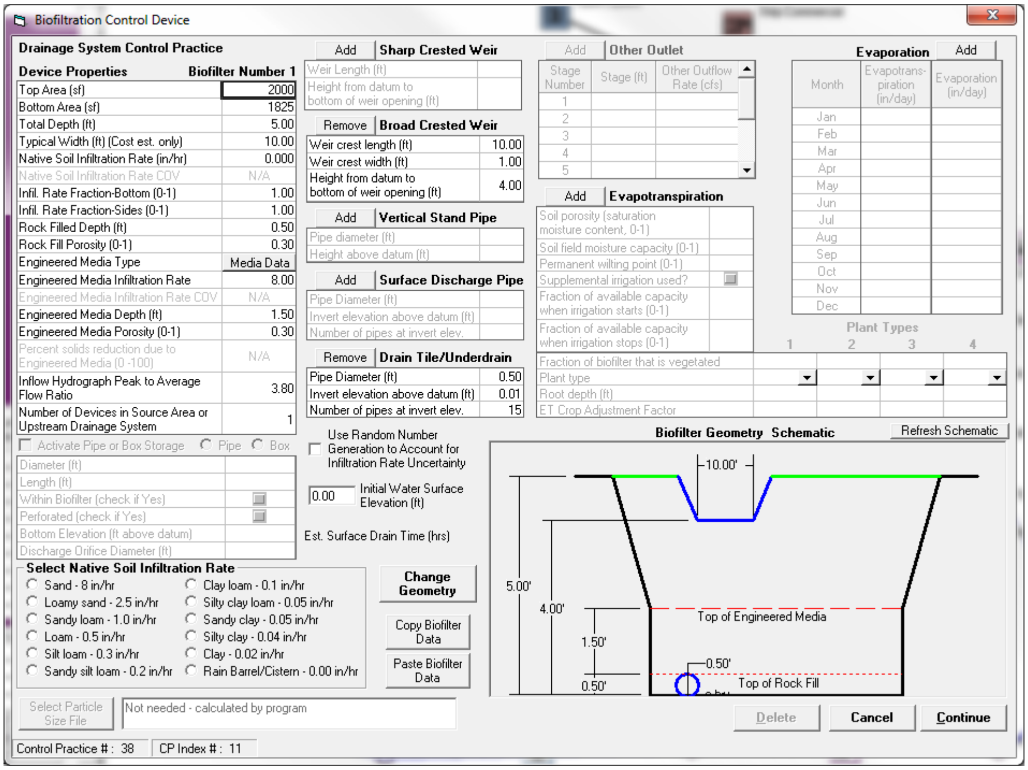

Figure 24: WinSLAMM input screen for an IESF bench

Permeable Check Dams

With this BMP there are two processes that drive pollutant retention within the practice. First, stormwater ponds behind the dam, dropping particulate pollutants out of suspension. Secondly, any water that has been impounded by the dam can either pass through the dam (and its IESF) or be evapotranspired prior to passing through the dam. To mimic these processes within WinSLAMM two different models were created, each with the same land use, soil, and existing stormwater infrastructure conditions. Within both models a biofiltration drainage area control practice was installed.

To model the effect of detaining water behind the dam, a biofiltration control practice with the same ponding storage as the check dams was modeled. This practice did not have an underdrain and assumes relatively silty soils (0.2"/hour infiltration rate; Figure 25). TSS and particulate phosphorus retention was determined from this model. For water passing through the filter, a similarly sized biofiltration control practice was modeled, but in this case was modeled with an underdrain (Figure 26). Dissolved phosphorus retention was determined from this model assuming that 80% of dissolved phosphorus flowing through the dam was retained (Erickson & Gulliver, 2010). Total phosphorus, or TP, reduction was the summation of particulate and dissolved phosphorus reductions between the two models. Volume reductions were assumed to be negligible based on comparisons with similar IESF basins and benches.

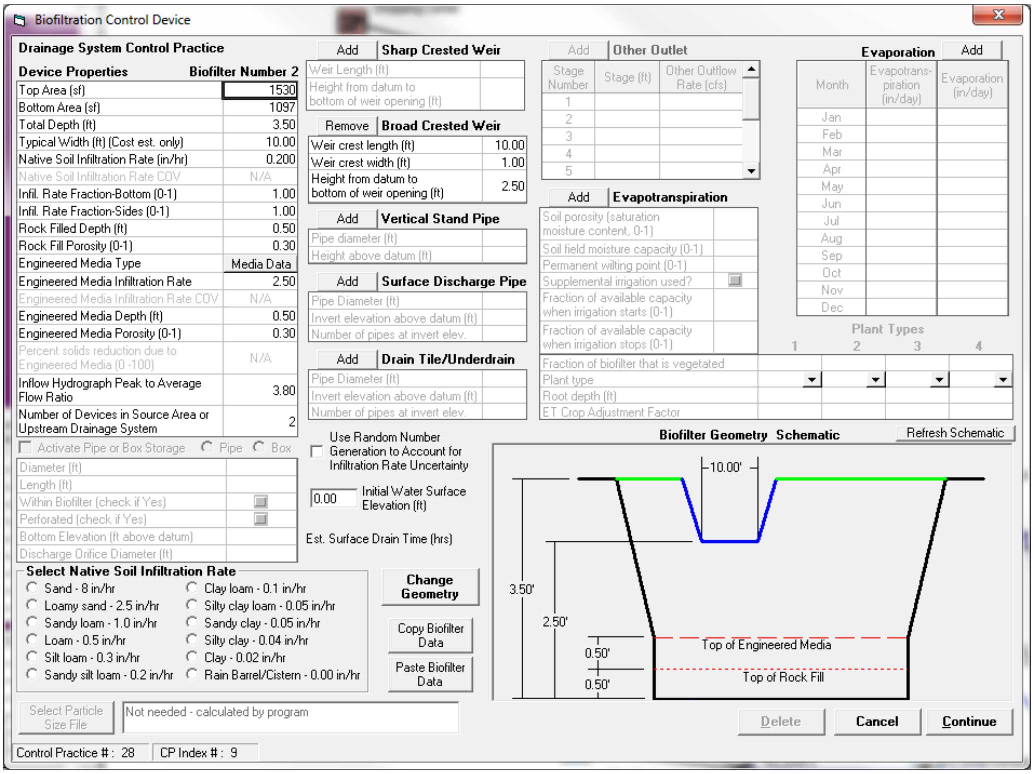

Figure 25: WinSLAMM input screen for a permeable check dam (modeled without an underdrain)

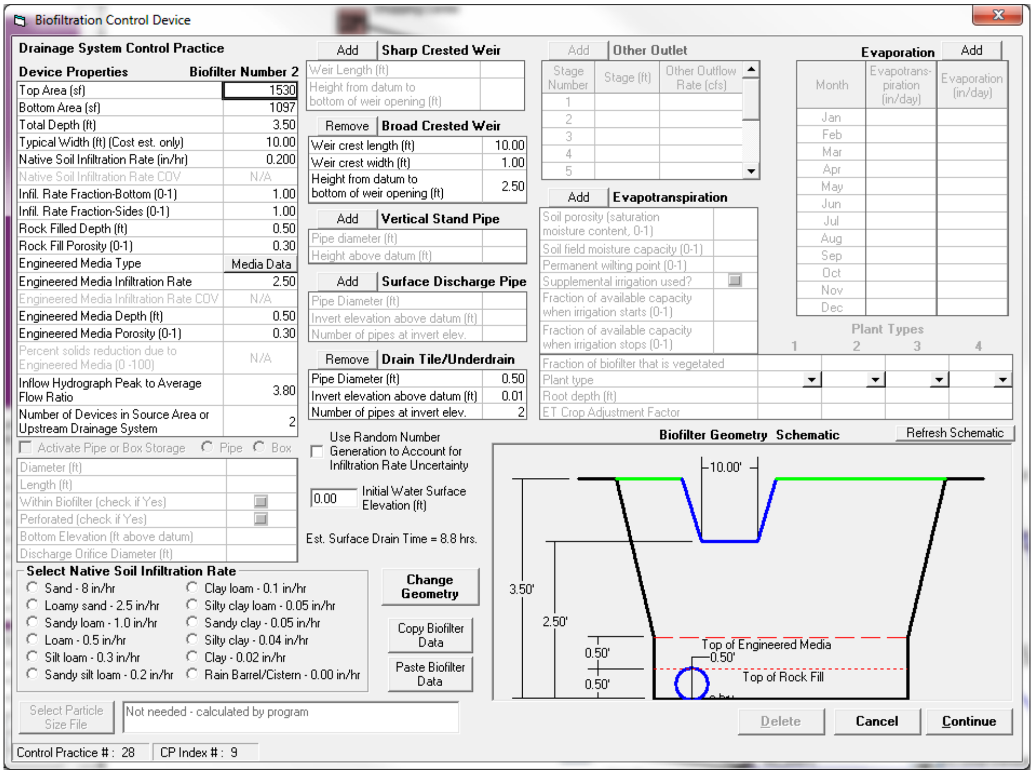

Figure 26: WinSLAMM input screen for a permeable check dam (modeled with an underdrain)

Other BMP Modeling

Lakeshore Restorations

Lakeshore restoration locations were determined following completion of an inventory of all active erosion sites along the entire shoreline of each lake in the SFEF chain. Instances of erosion were classified according to severity (Table 66). Erosion severity determinations and soil loss calculations were estimated utilizing the Wisconsin NRCS direct volume method recession rate classifications. Recession rate descriptions were altered slightly to better describe observed field conditions and are shown in the table on the following page.

Phosphorus reduction estimates were based upon the Board of Water and Soil Resources Pollution Reduction Estimator, which estimates phosphorus loading based upon a correlation between voided sediment volume and type with soil density averages and phosphorus concentrations. Soil losses associated with lakeshore restoration projects can be estimated using the equation:

$$\left(\text{Lakeshore Soil Loss } \left[\frac{\text{lbs}}{\text{yr}}\right]\right) = \left\{\begin{pmatrix}\text{Eroding}\\ \text{Face[ft]}\end{pmatrix} * \begin{pmatrix}\text{Recession}\\ \text{Rate } \left[\frac{\text{ft}}{\text{yr}}\right]\end{pmatrix} * \begin{pmatrix}\text{Shoreline}\\ \text{Length [ft]}\end{pmatrix} * \begin{pmatrix}\text{Soil Bulk}\\ \text{Density } \left[\frac{\text{lbs}}{\text{ft}^3}\right]\end{pmatrix}\right\}$$

Figure 27 on the following page describes the orientation at which the eroding face and shore length are measured. For the purpose of this analysis the following assumptions were made:

- Soils along the lakeshore were assumed to be silt, the most prevalent type in the area
- Soils had a bulk density of 100 lbs/ft^3.
- Soils had a TP concentration of 1 lb for every 1,250 lbs of sediment
- Sediment delivery rates were 100% due to the proximity to the lake

Table 66: Lakeshore recession rate classification

Severity	Lateral Recession Rate (ft/yr)	Description
Offset	<0.01	Erosion offset from the shoreline. Erosion does not appear to be entering waterbody but bank failure, bluff slumps, and/or seepage visible.
Slight	0.01-0.059	Some bare shore, but active erosion is minimal. Minor or no vegetative overhang. No exposed tree roots.
Moderate	0.06-0.29	Shore is predominantly bare, with some undercutting and vegetative overhang. Some exposed tree roots, but no slumps or slips.
Severe	0.3-0.5	Shore is bare, with vertical slope and/or severe vegetative overhang. Many exposed tree roots and some fallen trees and slumps or slips. Some changes in cultural features such as fence corners missing and realignment of roads or trails.
Very Severe	0.5+	Shore is bare, with washouts, vertical slopes, and severe vegetative overhang. Many fallen trees eroding out and changes in cultural features as above. Multiple types of erosion present.

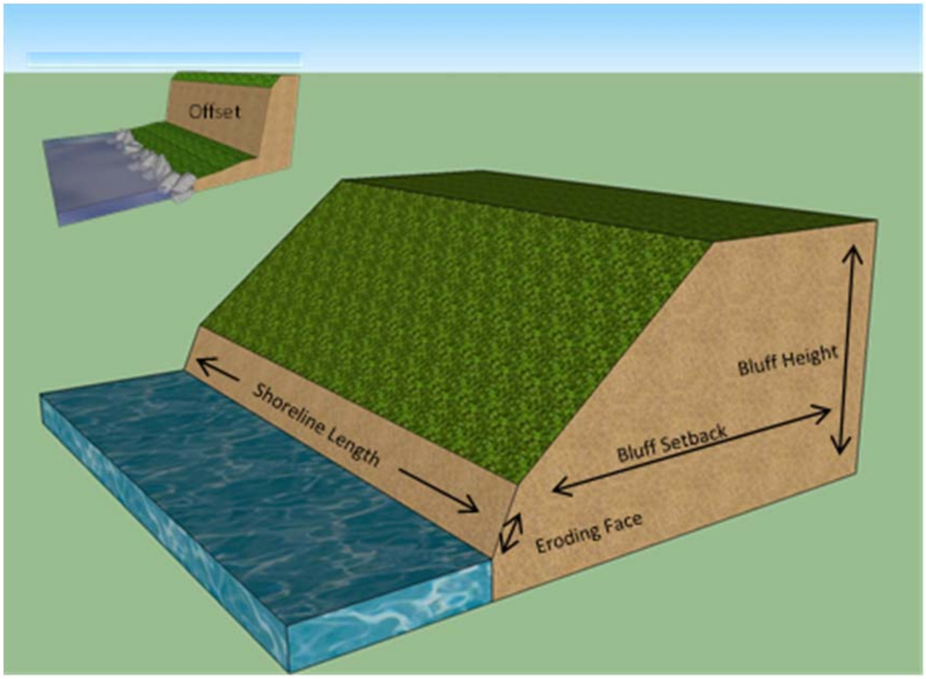

Figure 27: Schematic illustrating lakeshore erosion terms

Appendix B – Project Budget Estimates

This appendix is a compilation of tables that shows in greater detail the calculations that were made and quantities used to arrive at the cost estimates for practices where the information provided elsewhere in the document is insufficient to reconstruct the budget. This section includes cost estimates for IESF basins, IESF benches, a new retention pond, and permeable check dams.

IESF Benches

Table 67: Budget estimate for the IESF pond bench in Catchment 2

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$20,000.00	1	$20,000.00
Mobilization	each	$5,000.00	1	$5,000.00
Land Acquisition	acres	$25,000.00	0.25	$6,250.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	296	$3,703.70
IESF Materials and Installation	sq-ft	$15.00	4000	$60,000.00
Outlet Control Structure	each	$20,000.00	1	$20,000.00
			Total for Project =	$124,953.70

Table 68: Budget estimate for the IESF pond bench in Catchment 3

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$20,000.00	1	$20,000.00
Mobilization	each	$5,000.00	1	$5,000.00
Land Acquisition	acres	$0.00		$0.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	800	$10,000.00
IESF Materials and Installation	sq-ft	$15.00	10800	$162,000.00
Outlet Control Structure	each	$20,000.00	1	$20,000.00
			Total for Project =	$227,000.00

Table 69: Budget estimate for the 5,000 sq-ft IESF pond bench in Catchment 4

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$20,000.00	1	$20,000.00
Mobilization	each	$5,000.00	1	$5,000.00
Land Acquisition	acres	$25,000.00	0.5	$12,500.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	370	$4,629.63
IESF Materials and Installation	sq-ft	$15.00	5000	$75,000.00
Outlet Control Structure	each	$20,000.00	1	$20,000.00
			Total for Project =	$147,129.63

Table 70: Budget estimate for the 10,890 sq-ft IESF pond bench in Catchment 4

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$20,000.00	1	$20,000.00
Mobilization	each	$5,000.00	1	$5,000.00
Land Acquisition	acres	$25,000.00	0.5	$12,500.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	807	$10,083.33
IESF Materials and Installation	sq-ft	$15.00	10890	$163,350.00
Outlet Control Structure	each	$20,000.00	1	$20,000.00
			Total for Project =	$240,933.33

Table 71: Budget estimate for the IESF pond bench in the Parkwood Development of Catchment 5

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$20,000.00	1	$20,000.00
Mobilization	each	$5,000.00	1	$5,000.00
Land Acquisition (none - property is state-owned)				$0.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	148	$1,851.85
IESF Materials and Installation	sq-ft	$15.00	2000	$30,000.00
Outlet Control Structure	each	$20,000.00	1	$20,000.00
			Total for Project =	$86,851.85

Table 72: Budget estimate for the IESF pond bench along the Highway 95 pond in Catchment 5

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$20,000.00	1	$20,000.00
Mobilization	each	$5,000.00	1	$5,000.00
Land Acquisition (none - property is state-owned)				$0.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	148	$1,851.85
IESF Materials and Installation	sq-ft	$15.00	2000	$30,000.00
Outlet Control Structure	each	$20,000.00	1	$20,000.00
			Total for Project =	$86,851.85

Table 73: Budget estimate for a 0.25 acre IESF pond bench along the new regional pond in Catchment 6

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$20,000.00	1	$20,000.00
Mobilization	each	$5,000.00	1	$5,000.00
Land Acquisition	acres	$25,000.00	0.5	$12,500.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	807	$10,083.33
IESF Materials and Installation	sq-ft	$15.00	10890	$163,350.00
Outlet Control Structure	each	$20,000.00	1	$20,000.00
			Total for Project =	$240,933.33

Table 74: Budget estimate for a 0.50 acre IESF pond bench along the new regional pond in Catchment 6

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$20,000.00	1	$20,000.00
Mobilization	each	$5,000.00	1	$5,000.00
Land Acquisition	acres	$25,000.00	0.75	$18,750.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	1613	$20,166.67
IESF Materials and Installation	sq-ft	$15.00	21780	$326,700.00
Outlet Control Structure	each	$20,000.00	1	$20,000.00
			Total for Project =	$420,616.67

Table 75: Budget estimate for a 1.0 acre IESF pond bench along the new regional pond in Catchment 6

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$20,000.00	1	$20,000.00
Mobilization	each	$5,000.00	1	$5,000.00
Land Acquisition	acres	$25,000.00	1.25	$31,250.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	3227	$40,333.33
IESF Materials and Installation	sq-ft	$15.00	43560	$653,400.00
Outlet Control Structure	each	$20,000.00	1	$20,000.00
			Total for Project =	$779,983.33

IESF Basins

Table 76: Budget estimate for a 2,000 sq-ft Target parking lot IESF basin in Catchment 5

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$10,000.00	1	$10,000.00
Mobilization	each	$5,000.00	1	$5,000.00
Land Acquisition - practice maintained by original owner				$0.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	65	$812.50
Engineered Soil Mix (5% iron by weight)	cu-yards	$275.00	44.5	$12,237.50
On-site Soil Mixing	cu-yards	$125.00	44.5	$5,562.50
Additional Materials and Installation	sq-ft	$20.00	2000	$40,000.00
Retrofit Existing Stormwater Infrastructure	each	$20,000.00	1	$20,000.00
			Total for Project =	$103,612.50

Table 77: Budget estimate for a 4,000 sq-ft Fleet Farm parking lot IESF basin in Catchment 5

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$10,000.00	1	$10,000.00
Mobilization	each	$5,000.00	1	$5,000.00
Land Acquisition - practice maintained by original owner				$0.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	135	$1,687.50
Engineered Soil Mix (5% iron by weight)	cu-yards	$275.00	66.7	$18,342.50
On-site Soil Mixing	cu-yards	$125.00	66.7	$8,337.50
Additional Materials and Installation	sq-ft	$20.00	4000	$80,000.00
Retrofit Existing Stormwater Infrastructure	each	$20,000.00	1	$20,000.00
			Total for Project =	$153,367.50

Permeable Check Dams

The cost estimate in Table 78 assumes 2 check dams, each 2' high, 4' deep, 20' wide at top and 10' wide at base. Inner sand filter dimensions were estimated to be 1.5' high, 2' deep, and 10' wide.

Table 78: Budget estimate for permeable check dams

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$1,500.00	1	$1,500.00
Mobilization and Site Preparation	each	$3,000.00	1	$3,000.00
Land Acquisition - owned by MNDOT, would likely be maintained by city				$0.00
Engineered Soil Mix (5% iron by weight)	cu-yards	$275.00	2.3	$632.50
Rocks	cu-yards	$125.00	4.0	$500.00
Permeable Liner	per dam	$100.00	2.0	$200.00
Installation	per dam	$2,000.00	2	$4,000.00
			Total for Project =	$9,832.50

New Regional Pond

The cost estimate in Table 79 is for a pond over-excavated to 8 ft. deep covering 12 total acres. Cost estimates for the associated IESF bench can be found in Tables Table 73, Table 74, and Table 75.

Table 79: Budget estimate for the regional pond in Catchment 6

Activity	Units	Unit Price	Quantity	Unit Price
Design	each	$25,000.00	1	$25,000.00
Mobilization	each	$10,000.00	1	$10,000.00
Land Acquisition	acres	$25,000.00	13	$325,000.00
Site Preparation	each	$10,000.00	1	$10,000.00
Excavation	cu-yards	$12.50	154,880	$1,936,000.00
Top Soil	cu-yards	$30.00	3,098	$92,928.00
Revegetation	sq-ft	$0.25	43,560	$10,890.00
Outlet Control Structure	each	$10,000.00	1	$10,000.00
			Total for Project =	$2,419,818.00

Appendix C – Additional Ranking Tables

Cost-Benefit for Reducing TSS

The following tables rank all modeled projects by cost-effectiveness in reducing TSS using a Pollutant Delivery Ratio (PDR), explained in the *Location in Watershed* section. TP is the primary pollutant of concern in this subwatershed, but these rankings may be used to gain a better understanding of the additional benefits of each project.

Table 80: Cost-benefit with respect to TSS reduction. Projects 1-12. TP and volume reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profile* pages.

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit ($/1,000 lb-TSS/yr)[1]	TSS PDR	TSS Reduction w/ PDR (lb-TSS/yr)	Cost-Benefit w/ PDR ($/1,000 lb-TSS/yr)
1	9-A	106	Vegetated Filter Strip/Grassed Waterway	15.0-15.7	17,068-17,978	0.0	$10,910-$11,241	$961-$2,283	$88-$158	0.90	15,361-16,180	$98-$176
2	6-A	83	Vegetated Filter Strip	6.8-7.3	6,753-7,281	0.0	$10,809-$10,938	$557-$1,071	$163-$222	0.80	5,402-5,825	$204-$278
3	7-B	90	WASCOB	3.4-4.9	5,205-8,079	0.0	$21,094-$23,938	$517-$538	$215-$302	0.90	4,685-7,271	$239-$336
4	8-E	102	Vegetated Filter Strip/Grassed Waterway	3.4-3.5	4,805-4,896	0.0	$10,809-$10938	$557-$1,071	$228-$330	0.90	4,325-4,406	$253-$366
5	8-D	101	Vegetated Filter Strip/Grassed Waterway	3.2-3.4	4,247-4,646	0.0	$10,805-$10,924	$539-$1,016	$254-$336	0.90	3,822-4,181	$282-$373
6	7-D	92	WASCOB	2.5-3.9	3,510-6,521	0.0	$20,649-$31,138	$508-$550	$323-$439	1.00	3,510-6,521	$323-$439
7	7-G	95	Vegetated Filter Strip	2.0-2.0	2,598-2.668	0.0	$10,814-$10,883	$575-$851	$430-$523	1.00	2,598-2.668	$430-$523
8	8-B	99	Wetland Restoration	2.1-5.2	2,825-8,673	0.7-1.3	$38,205-$56,205	$500	$382-$853	0.80	2,260-6,938	$478-$1,066
9	7-E	93	WASCOB	1.8-2.5	2,268-3,496	0.0	$21,049-$27,938	$516-$538	$554-$692	1.00	2,268-3,496	$554-$692
10	6-B	84	Regional Pond	57.8	177,212	1.2	$2,426,023	$1,200	$463	0.80	141,770	$579
11	7-C	91	WASCOB	0.3-2.0	278-2,560	0.0	$20,827-$32,205	$525-$558	$847-$5,634	1.00	278-2,560	$847-$5,634
12	5-G	78	Highway 95 Permeable Check Dams	1.0	1,347	0.0	$12,753	$730	1,015	1.00	1,347	1,015

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land

Urban Catchments

Rural Catchments

Lakeshore Projects

Table 81: Cost-benefit with respect to TSS reduction. Projects 13-29. TP and volume reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profile* pages.

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit ($/1,000 lb-TSS/yr)[1]	TSS PDR	TSS Reduction w/ PDR (lb-TSS/yr)	Cost-Benefit w/ PDR ($/1,000 lb-TSS/yr)
T13	LR-7	117	LR-7	2.5	3,075	0.0	$34,805	$308	$1,232	1.00	3,075	$1,232
T13	LR-8	118	LR-8	2.5	3,075	0.0	$34,805	$308	$1,232	1.00	3,075	$1,232
15	7-F	94	Vegetated Filter Strip	1.0-1.0	1,077-1,147	0.0	$10,768-$10,791	$392-$484	$840-$892	0.60	646-688	$1,400-$1,487
16	LR-11	122	LR-11	0.9	1,125	0.0	$15,305	$113	$1,460	1.00	1,125	$1,460
17	LR-10	121	LR-10	0.8	975	0.0	$13,805	$98	$1,516	1.00	975	$1,516
18	8-C	100	WASCOB	0.6-1.0	587-1,042	0.0	$20,383-$25,005	$503-$508	$1,687-$2,593	1.00	587-1,042	$1,687-$2,593
19	8-F	103	Vegetated Filter Strip/Grassed Waterway	1.5-1.6	1,108-1,165	0.0	$10,768-$10,791	$392-$484	$840-$878	0.40	443-466	$2.100-$2,195
20	LR-14	125	LR-14	0.9	1,170	0.0	$23,555	$390	$2,347	1.00	1,170	$2,347
21	7-A	89	WASCOB	0.3-1.0	278-1,153	0.0	$20,472-$21,538	$505-$514	$1,379-$5,498	0.50	139-577	$2,758-$10,996
22	LR-1	109	LR-1	1.4	1,740	0.0	$47,555	$570	$3,233	1.00	1,740	$3,233
23	LR-5	114	LR-5	1.2	1,530	0.0	$42,305	$765	$3,265	1.00	1,530	$3,265
24	6-C	86	WASCOB	0.3-0.8	236-788	0.0	$20,383-$26,205	$503-$521	$2,324-$6,451	0.70	165-552	$3,321-$9,218
25	LR-9	120	LR-9	0.2	203	0.0	$7,430	$68	$3,993	1.00	203	$3,993
T26	LR-2	110	LR-2	0.3	390	0.0	$13,805	$195	$4,040	1.00	390	$4,040
T26	LR-4	113	LR-4	0.3	390	0.0	$13,805	$195	$4,040	1.00	390	$4,040
28	LR-3	111	LR-3	0.3	345	0.0	$12,680	$173	$4,175	1.00	345	$4,175
29	LR-13	124	LR-13	0.2	300	0.0	$11,555	$150	$4,352	1.00	300	$4,352

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land

Table 82: Cost-benefit with respect to TSS reduction. Projects 30-46. TP and volume reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profile* pages.

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit ($/1,000 lb-TSS/yr)[1]	TSS PDR	TSS Reduction w/ PDR (lb-TSS/yr)	Cost-Benefit w/ PDR ($/1,000 lb-TSS/yr)
30	8-A	98	Wetland Restoration	9.8-31.2	701-5,955	1.3-6.7	$260,383-$405,005	$500	$3,485-$19,286	0.80	561-4,764	$4,356-$24,108
31	LR-6	115	LR-6	0.2	225	0.0	$9,680	$113	$4,802	1.00	225	$4,802
32	LR-12	123	LR-12	0.1	150	0.0	$7,805	$75	$5,703	1.00	150	$5,703
33	5-D	74	Target Parking Lot IESF Basin	1.0-1.5	252-571	0.6-1.0	$109,088-$159,243	$459-$918	$10,904-$16,252	1.00	252-571	$10,904-$16,252
34	5-E	75	Fleet Farm Parking Lot IESF Basin	0.8-0.9	270-511	0.5-0.8	$109,088-$159,243	$459-$918	$12,185-$15,168	1.00	270-511	$12,185-$15,168
35	2-A	49	Catchment 2 Curb-Cut Rain Gardens	0.2-0.3	25-43	0.4-0.5	$11,610	$225	$18,733-$32,220	1.00	25-43	$18,733-$32,220
36	3-A	55	Catchment 3 Curb-Cut Rain Gardens	0.0-0.2	3-34	0.1-0.3	$6,950-$15,710	$225	$29,721-$190,833	1.00	3-34	$29,721-$190,833
T37	4-A	63	Catchment 4 Curb-Cut Rain Gardens	0.1-0.1	7-21	0.1-0.2	$11,610	$225	$38,357-$115,071	1.00	7-21	$38,357-$115,071
T37	5-A	69	Curb-Cut Rain Gardens in the Parkwood Development	0.1-0.1	7-21	0.1-0.2	$11,610	$225	$38,357-$115,071	1.00	7-21	$38,357-$115,071
39	3-B	58	Catchment 3 Curb-Cut Boulevard Bioswales	0.0-0.1	4-14	0.0-0.1	$8,310	$225	$45,750-$160,125	1.00	4-14	$45,750-$160,125
40	5-B	71	Curb-Cut Rain Gardens in the Preserve Development	0.1-0.2	6-17	0.1-0.2	$9,730-$15,710	$225	$59,441-$118,583	1.00	6-17	$59,441-$118,583
T41	2-B	51	Catchment 2 IESF Pond Bench	9.8	0.0	0.0	$136,729	$918	N/A	1.00	0	N/A
T41	3-C	59	Catchment 3 IESF Bench	10.7	0.0	0.0	$232,475	$2,479	N/A	1.00	0	N/A
T41	4-B	65	Catchment 4 IESF Bench	11.5-15.8	0.0	0.0	$152,605-$246,408	$1,148-$2,500	N/A	1.00	0	N/A
T41	5-C	73	IESF Bench in the Parkwood Development	7.2	0.0	0.0	$92,327	$459	N/A	1.00	0	N/A
T41	5-F	76	Highway 95 Pond Bench	5.0	0.0	0.0	$92,327	$459	N/A	1.00	0	N/A
T41	6-B	84	IESF Bench for Regional Pond	25.0-50.8	0.0	0.0	$240,933-$779,983	$2,500-$10,000	N/A	0.80	0	N/A

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land

Cost-Benefit for Reducing Stormwater Volume

The following tables rank all modeled projects by cost-effectiveness in reducing stormwater volume using a Pollutant Delivery Ratio (PDR), explained in the *Location in Watershed* section. TP is the primary pollutant of concern in this subwatershed, but these rankings may be used to gain a better understanding of the additional benefits of each project.

Table 83: Cost-benefit with respect to stormwater volume reduction. Projects 1-12. TP and TSS reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profile* pages.

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit ($/ac-ft/yr)[1]	Vol. PDR	Vol. Reduction w/ PDR (ac-ft/yr)	Cost-Benefit w/ PDR ($/lb-TP/yr)
1	2-A	49	Catchment 2 Curb-Cut Rain Gardens	0.2-0.3	25-43	0.4-0.5	$11,610	$225	$1,520-$1,965	1.00	0.4-0.5	$1,520-$1,965
2	8-A	98	Wetland Restoration	9.8-31.2	701-5,955	1.3-6.7	$260,383-$405,005	$500	$3,097-$10,399	0.80	561-4,764	$2,478-$8,319
3	8-B	99	Wetland Restoration	2.1-5.2	2,825-8,673	0.7-1.3	$38,205-$56,205	$500	$2,566-$3,652	0.80	2,260-6,938	$3,208-$4,565
4	3-A	55	Catchment 3 Curb-Cut Rain Gardens	0.0-0.2	3-34	0.1-0.3	$6,950-$15,710	$225	$3,609-$11450	1.00	0.1-0.3	$3,609-$11450
5	4-A	63	Catchment 4 Curb-Cut Rain Gardens	0.1-0.1	7-21	0.1-0.2	$11,610	$225	$3,836-$8,950	1.00	0.1-0.2	$3,836-$8,950
6	5-A	69	Curb-Cut Rain Gardens in the Parkwood Development	0.1-0.1	7-21	0.1-0.2	$11,610	$225	$3,836-$8,950	1.00	0.1-0.2	$3,836-$8,950
7	5-B	71	Curb-Cut Rain Gardens in the Preserve Development	0.1-0.2	6-17	0.1-0.2	$9,730-$15,710	$225	$4,210-$5,473	1.00	0.1-0.2	$4,210-$5,473
8	3-B	58	Catchment 3 Curb-Cut Boulevard Bioswales	0.0-0.1	4-14	0.0-0.1	$8,310	$225	$5,338-$12,810	1.00	0.0-0.1	$5,338-$12,810
9	5-D	74	Target Parking Lot IESF Basin	1.0-1.5	252-571	0.6-1.0	$109,088-$159,243	$459-$918	$5,980-$6,571	1.00	0.6-1.0	$5,980-$6,571
10	5-E	75	Fleet Farm Parking Lot IESF Basin	0.8-0.9	270-511	0.5-0.8	$109,088-$159,243	$459-$918	$7,133-$7,730	1.00	0.5-0.8	$7,133-$7,730
11	6-B	84	Regional Pond	57.8	177,212	1.2	$2,426,023	$1,200	$68,390	0.80	1.0	$85,488
T12	2-B	51	Catchment 2 IESF Pond Bench	9.8	0	0.0	$136,729	$918	N/A	1.00	0.0	N/A

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land

Urban Catchments

Rural Catchments

Lakeshore Projects

Table 84: Cost-benefit with respect to stormwater volume reduction. Projects 13-29. TP and TSS reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profile* pages.

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit ($/ac-ft/yr)[1]	Vol. PDR	Vol. Reduction w/ PDR (ac-ft/yr)	Cost-Benefit w/ PDR ($/lb-TP/yr)
T12	3-C	59	Catchment 3 IESF Bench	10.7	0.0	0.0	$232,475	$2,479	N/A	1.00	0.0	N/A
T12	4-B	65	Catchment 4 IESF Bench	11.5-15.8	0.0	0.0	$152,605-$246,408	$1,148-$2,500	N/A	1.00	0.0	N/A
T12	5-C	73	IESF Bench in the Parkwood Development	7.2	0.0	0.0	$92,327	$459	N/A	1.00	0.0	N/A
T12	5-F	76	Highway 95 Pond Bench	5.0	0.0	0.0	$92,327	$459	N/A	1.00	0.0	N/A
T12	5-G	78	Highway 95 Permeable Check Dams	1.0	1,347	0.0	$12,753	$730	N/A	1.00	0.0	N/A
T12	6-A	83	Vegetated Filter Strip	6.8-7.3	6,753-7,281	0.0	$10,809-$10,938	$557-$1,071	N/A	0.80	0.0	N/A
T12	6-B	84	IESF Bench for Regional Pond	25.0-50.8	0.0	0.0	$240,933-$779,983	$2,500-$10,000	N/A	0.80	0.0	N/A
T12	6-C	86	WASCOB	0.3-0.8	236-788	0.0	$20,383-$26,205	$503-$521	N/A	0.70	0.0	N/A
T12	7-A	89	WASCOB	0.3-1.0	278-1,153	0.0	$20,472-$21,538	$505-$514	N/A	0.50	0.0	N/A
T12	7-B	90	WASCOB	3.4-4.9	5,205-8,079	0.0	$21,094-$23,938	$517-$538	N/A	0.90	0.0	N/A
T12	7-C	91	WASCOB	0.3-2.0	278-2,560	0.0	$20,827-$32,205	$525-$558	N/A	1.00	0.0	N/A
T12	7-D	92	WASCOB	2.5-3.9	3,510-6,521	0.0	$20,649-$31,138	$508-$550	N/A	1.00	0.0	N/A
T12	7-E	93	WASCOB	1.8-2.5	2,268-3,496	0.0	$21,049-$27,938	$516-$538	N/A	1.00	0.0	N/A
T12	7-F	94	Vegetated Filter Strip	1.0-1.0	1,077-1,147	0.0	$10,768-$10,791	$392-$484	N/A	0.60	0.0	N/A
T12	7-G	95	Vegetated Filter Strip	2.0-2.0	2,598-2.668	0.0	$10,814-$10,883	$575-$851	N/A	1.00	0.0	N/A
T12	8-C	100	WASCOB	0.6-1.0	587-1,042	0.0	$20,383-$25,005	$503-$508	N/A	1.00	0.0	N/A
T12	8-D	101	Vegetated Filter Strip/Grassed Waterway	3.2-3.4	4,247-4,646	0.0	$10,805-$10,924	$539-$1,016	N/A	0.90	0.0	N/A

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land

Table 85: Cost-benefit with respect to stormwater volume reduction. Projects 30-46. TP and TSS reductions also shown. Projects ranked by cost-benefit with the pollutant delivery ratio (PDR; see *Location in Watershed* section for definition). For more information on each project refer to the *Catchment Profile* pages.

Project Rank	Project ID	Page Number	Retrofit Name/Type	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2014 Dollars)	Additional Annual Costs Over Project Life (2014 Dollars)[1]	Cost-Benefit ($/ac-ft/yr)[1]	Vol. PDR	Vol. Reduction w/ PDR (ac-ft/yr)	Cost-Benefit w/ PDR ($/lb-TP/yr)
T12	8-E	102	Vegetated Filter Strip/Grassed Waterway	3.4-3.5	4,805-4,896	0.0	$10,809-$10938	$557-$1,071	N/A	0.90	0.0	N/A
T12	8-F	103	Vegetated Filter Strip/Grassed Waterway	1.5-1.6	1,108-1,165	0.0	$10,768-$10,791	$392-$484	N/A	0.40	0.0	N/A
T12	9-A	106	Vegetated Filter Strip/Grassed Waterway	15.0-15.7	17,068-17,978	0.0	$10,910-$11,241	$961-$2,283	N/A	0.90	0.0	N/A
T12	LR-1	109	LR-1	1.4	1,740	0.0	$47,555	$570	N/A	1.00	0.0	N/A
T12	LR-2	110	LR-2	0.3	390	0.0	$13,805	$195	N/A	1.00	0.0	N/A
T12	LR-3	111	LR-3	0.3	345	0.0	$12,680	$173	N/A	1.00	0.0	N/A
T12	LR-4	113	LR-4	0.3	390	0.0	$13,805	$195	N/A	1.00	0.0	N/A
T12	LR-5	114	LR-5	1.2	1,530	0.0	$42,305	$765	N/A	1.00	0.0	N/A
T12	LR-6	115	LR-6	0.2	225	0.0	$9,680	$113	N/A	1.00	0.0	N/A
T12	LR-7	117	LR-7	2.5	3,075	0.0	$34,805	$308	N/A	1.00	0.0	N/A
T12	LR-8	118	LR-8	2.5	3,075	0.0	$34,805	$308	N/A	1.00	0.0	N/A
T12	LR-9	120	LR-9	0.2	203	0.0	$7,430	$68	N/A	1.00	0.0	N/A
T12	LR-10	121	LR-10	0.8	975	0.0	$13,805	$98	N/A	1.00	0.0	N/A
T12	LR-11	122	LR-11	0.9	1,125	0.0	$15,305	$113	N/A	1.00	0.0	N/A
T12	LR-12	123	LR-12	0.1	150	0.0	$7,805	$75	N/A	1.00	0.0	N/A
T12	LR-13	124	LR-13	0.2	300	0.0	$11,555	$150	N/A	1.00	0.0	N/A
T12	LR-14	125	LR-14	0.9	1,170	0.0	$23,555	$390	N/A	1.00	0.0	N/A

[1]Includes annual costs for operation and maintenance as well as any production loss payments for projects on agricultural land