# Lake Orono

# Stormwater Subwatershed Assessment

*Stormwater pond, City of Elk River (Photo: Sherburne SWCD, 2016)*

## Prepared by:

*Sherburne Soil & Water Conservation District*

CLEAN WATER LAND & LEGACY AMENDMENT

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# Executive Summary

A completed Total Maximum Daily Load (TMDL) study on the Mississippi River – St. Cloud Watershed has specified for significant phosphorus loading reductions in the watershed (a 51% reduction from current levels) to Lake Orono, located in the City of Elk River, Minnesota. While the vast majority of these reductions are recommended to come from upstream rural areas, urban stormwater reductions are specified as well for many of the cities and towns within the watershed. Three municipalities discharging to the lower Elk River including the Town of Big Lake, City of Big Lake, and City of Elk River, must split a 50% reduction in their stormwater phosphorus loading in order to meet TMDL allocation goals.

The City of Elk River initiated a study in 2015 in cooperation with Sherburne Soil and Water Conservation District (SWCD) and WSB & Associates to examine the city's stormwater contribution. The partnership's goals were to identify priority contributing areas, determine applicable Best Management Practices for these areas, and to examine potential cost effective stormwater treatments to move forward with. The study resulted in several potential options.

This project examined primarily stormwater retrofit options within the City of Elk River's west service area (Lake Orono drainage area). This area was surveyed through desktop analysis and field observations to determine drainage areas, catchment basins and ultimate contributing areas. Catchments determined to drain internally or away from Lake Orono were identified and removed from consideration, as the primary goal of this study was to examine contributing areas to the lake. Further, projects deemed completely unfeasible due to prohibitive conditions (size, expense, etc.) were not investigated as potential options in this study. Within the contributing areas that remained, potential projects were identified through project partner discussions, desktop mapping and field investigations. Two Priority Management Areas (PMAs) were identified and efforts were focused to address the stormwater contributions from these basins.

Pollutant modeling of existing conditions and potential pollutant reductions via implemented BMPs were individually modeled through the use of two modeling software programs, the P8 Urban Catchment Model (Program for Predicting Polluting Particle Passage thru Pits, Puddles and Ponds, version 3.5, Walker and Walker 2015) and the Source Loading and Management Model for Windows (WinSLAMM, PV & Associates, 2016). These programs operate in a similar fashion in that they utilize existing, calibrated stormwater data to quantify runoff volumes and pollutant loads from an urban landscape. The user is able to customize land use variables based upon the modeled area of interest, and use real precipitation data and soil conditions to increase the accuracy of the model. Despite the high level of accuracy these models are able to project, the results are not calibrated to existing on the ground conditions within the City of Elk River. Therefore, the models are used in this report as estimates and therefore a guidance tool for informed decision making on potential stormwater retrofit projects.

Costs associated with project design, administrative duties, construction, and operation and maintenance were estimated based upon the best available information. Cost data were assumed over a 30-year lifespan and compared against the model benefits (pollutant reduction) to rank projects according to a cost-benefit variable (cost-effectiveness). Although the highest ranked projects in this analysis should be considered for potential retrofit projects, it is acknowledged that other variables must be considered before implementation. Considerations for funding limitations, landowner interest, educational opportunity / visibility, construction timing or other factors must be weighed by the City of Elk River and the Sherburne SWCD prior to determining which retrofit projects to pursue.

Table 1 and Table 2 displays the findings of this study, including the applicable potential stormwater retrofit options within PMA 1 and PMA 2 along with the BMP types, their pollutant reduction potential, overall cost and cost effectiveness. Table 1 lists each potential project in order of cost-effectiveness with respect to phosphorus, the pollutant of highest concern and in which Lake Orono is listed as being impaired for. Table 2 displays the BMP list sorted with respect to total suspended solids, another pollutant of concern. The most cost effective options are listed first, while lesser cost-effective options fall lower on the list.

In order to meet water quality objectives, including reducing phosphorus to meet TMDL nutrient allocation criteria, implementation of multiple projects may be warranted. These projects, installed and working in a series, will increase the level of water treatment as well as increase the longevity of downstream BMPs. More information on each treatment type is located within the catchment profiles of this report.

**Table 1. Ranked BMP summary from an assessment of West Elk River / Lake Orono stormwater.** List includes BMP size options for two Priority Management Areas (PMA's) to address urban stormwater runoff. Table sorted by 30-year cost / lb. removal of total phosphorus.

| Project Rank | Priority Management Area | Sub Catchment | Project ID | BMP Type | BMP Size (sq-ft) | Volume Reduction (rain gardens= cu-ft/yr) (others = ac-ft/yr) | TP Reduction (lbs/yr) | TSS Reduction (lbs/yr) | Project Cost | Estimated 30-yr O & M | 30-yr Cost / 1,000 lb TSS | 30-yr Cost / lb TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | - | SSD-1 | SubSurface Detention Basin | 3,610 | 881 | 7.90 | 5249.0 | $130,347 | $860 | $992 | $659 |
| 2 | 2 | - | IESF-6 | Iron-Enhanced Sand Filter | 9,365 | 2,736 | 42.30 | 5218.0 | $392,289 | $27,134 | $7,706 | $951 |
| 3 | 2 | - | IESF-5 | Iron-Enhanced Sand Filter | 6,316 | 2,290 | 35.20 | 4383.0 | $310,487 | $24,546 | $7,962 | $991 |
| 4 | 2 | - | IESF-4 | Iron-Enhanced Sand Filter | 4,262 | 1,841 | 28.20 | 3538.0 | $255,224 | $22,803 | $8,850 | $1,110 |
| 5 | 2 | - | IESF-3 | Iron-Enhanced Sand Filter | 2,722 | 1,385 | 29.72 | 2701.0 | $213,903 | $21,496 | $10,598 | $1,357 |
| 6 | 1 | 1 | RG-1 | Curb-cut Raingarden | 250 | 17,200 | 0.53 | 242.5 | $15,844 | $450 | $4,034 | $1,852 |
| 7 | 2 | - | IESF-2 | Iron-Enhanced Sand Filter | 1,546 | 922 | 19.86 | 1854.0 | $182,329 | $20,498 | $14,334 | $1,885 |
| 8 | 1 | 2 | RG-7 | Curb-cut Raingarden | 250 | 16,885 | 0.52 | 238.0 | $15,844 | $450 | $4,110 | $1,886 |
| 9 | 1 | 4 | RG-13 | Curb-cut Raingarden | 250 | 16,763 | 0.51 | 236.3 | $15,844 | $450 | $4,139 | $1,900 |
| 10 | 1 | 5 | RG-12 | Curb-cut Raingarden | 250 | 15,692 | 0.48 | 220.8 | $15,844 | $450 | $4,430 | $2,032 |
| 11 | 1 | 2 | RG-6 | Curb-cut Raingarden | 250 | 14,905 | 0.46 | 208.9 | $15,844 | $450 | $4,682 | $2,147 |
| 12 | 1 | 1 | RG-3 | Curb-cut Raingarden | 250 | 14,388 | 0.44 | 201.2 | $15,844 | $450 | $12,068 | $2,229 |
| 13 | 1 | 1 | RG-4 | Curb-cut Raingarden | 250 | 14,209 | 0.43 | 198.6 | $15,844 | $450 | $4,926 | $2,258 |
| 14 | 1 | 3 | RG-10 | Curb-cut Raingarden | 250 | 12,844 | 0.39 | 178.9 | $15,844 | $450 | $5,467 | $2,504 |
| 15 | 1 | 4 | RG-14 | Curb-cut Raingarden | 250 | 11,094 | 0.34 | 153.8 | $15,844 | $450 | $6,361 | $2,910 |
| 16 | 1 | 3 | RG-9 | Curb-cut Raingarden | 250 | 10,484 | 0.32 | 145.1 | $15,844 | $450 | $6,743 | $3,083 |
| 17 | 1 | 4 | RG-11 | Curb-cut Raingarden | 250 | 9,036 | 0.27 | 124.4 | $15,844 | $450 | $7,860 | $3,591 |
| 18 | 2 | - | IESF-1 | Iron-Enhanced Sand Filter | 980 | 466 | 7.10 | 994.0 | $167,140 | $20,017 | $25,743 | $3,604 |
| 19 | 1 | 3 | RG-5 | Curb-cut Raingarden | 250 | 7,053 | 0.21 | 95.9 | $15,844 | $450 | $10,195 | $4,637 |
| 20 | 1 | 3 | RG-2 | Curb-cut Raingarden | 250 | 6,060 | 0.18 | 82.2 | $15,844 | $450 | $20,710 | $5,423 |
| 21 | 1 | 2 | RG-8 | Curb-cut Raingarden | 250 | 5,472 | 0.16 | 74.0 | $15,844 | $450 | $13,210 | $6,020 |

**Table 2. Ranked BMP summary from an assessment of West Elk River / Lake Orono stormwater.** List includes BMP size options for two Priority Management Areas (PMA's) to address urban stormwater runoff. Table sorted by 30-year cost / 1,000 lb. removal of total suspended solids.

| Project Rank | Priority Management Area | Sub Catchment | Project ID | BMP Type | BMP Size (sq-ft) | Volume Reduction (rain gardens= cu-ft/yr) (others = ac-ft/yr) | TP Reduction (lbs/yr) | TSS Reduction (lbs/yr) | Project Cost | Estimated 30-yr O & M | 30-yr Cost / 1,000 lb TSS | 30-yr Cost / lb TP |
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# Introduction

Lake Orono is a shallow, approximately 260 acre lake located within the City of Elk River in Sherburne County, Minnesota. The lake was included on the State of Minnesota's 303(d) Impaired Waterbodies List in 2008; impairments include excessive nutrients, biological indicators of eutrophication and mercury in fish tissue. The Elk River, which drains into Lake Orono at its northwest end, was also listed in 2008 as being impaired for mercury and *Escherichia coli*, a fecal coliform bacteria.

In recent years, numerous studies have been completed on the larger Mississippi River – St. Cloud Watershed (MR-SC watershed) as well as the Elk River Watershed. A Total Maximum Daily Load (TMDL) study as well as a Watershed Restoration and Protection Strategy (WRAPS) process were completed in 2014 and 2015, respectively, for the MR-SC watershed. The TMDL study called for drastic reductions in phosphorus loading throughout the watershed; this totals a 51% overall reduction from an estimated 98,562 lbs. per year. In order for Lake Orono to meet its phosphorus goal of 60 µg/L (state shallow lake standard), a full reduction to a load of 50,815 lbs. is necessary (MPCA, 2015).

Reductions are necessary from both urban and rural areas of the watershed. Lake Orono has three Municipal Separate Storm Sewer Systems (MS4's) within its watershed that are required to reduce their nutrient loading by 50% to a total of 468.11 lbs/year. The City of Elk River demonstrated interest in working towards reductions and in 2015 joined with the Sherburne SWCD to examine potential strategies. The partnership decided to complete this assessment on the west Elk River urban service area (Figure 1). A portion of this service area drains to Lake Orono, while remaining segments discharge to the Elk River downstream of the Lake Orono dam or to the Mississippi River.

The City of Elk River and Sherburne SWCD enlisted the assistance of WSB & Associates, Inc. to complete a portion of the study. This stormwater management team defined objectives for the project as follows:

- Examine areas of stormwater input, using computer software to estimate potential pollutant (total phosphorus, TP and total suspended sediment, TSS) load to Lake Orono.
- Identify site-specific Best Management Practices (BMPs) that would assist in stormwater remediation.
- Create a listing of potential stormwater retrofit options and rank these according to cost-effectiveness.

Being that urban environments are typically quite developed to begin with, addressing sources of stormwater pollution can be quite difficult due to having to work around existing infrastructure. Pollution mitigation must address stormwater under the limitations of property ownership, local zoning regulations, United States Army Corps of Engineers (USACOE) priority navigable waterways regulations, State of Minnesota waterway regulations, as well as the physical hydrologic and structural situations at each site. Thus, stormwater management is often addressed through structure retrofitting, making use of current infrastructure and existing regulatory guidelines. The process of stormwater retrofitting can be quite difficult in some respects, but also lends itself to being innovative and adaptable in order to reach project goals under confining or limiting situations.

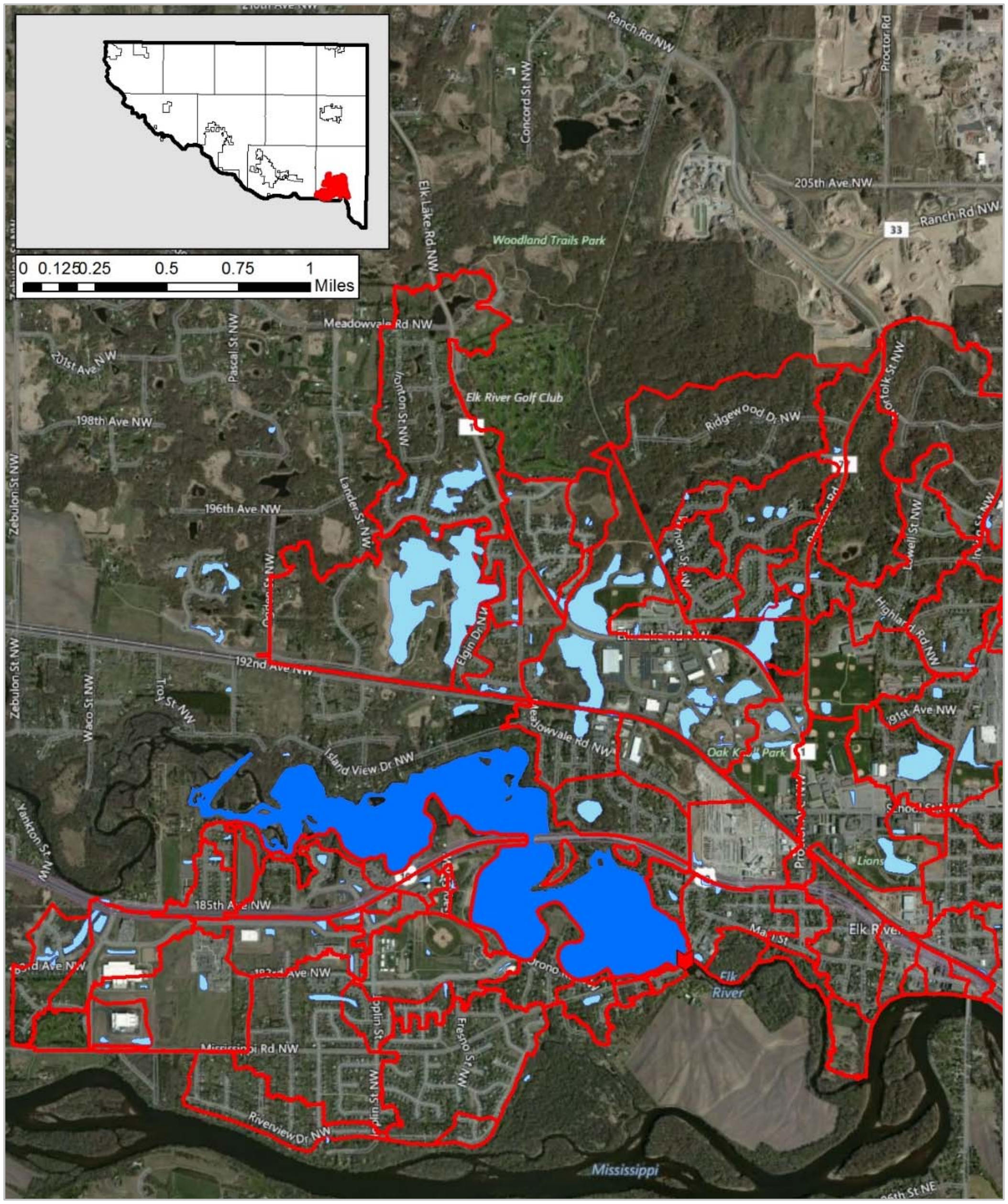



**Figure 1: City of Elk River (west) stormwater service area**. Map includes City of Elk River pipesheds which were delineated for modeling purposes.

In addition to working towards the goals set forth for the City of Elk River by the aforementioned 2015 TMDL study, this project is consistent with the goals and priorities set forth in the Sherburne County Water Plan (2007, amended 2012). The water plan lists three priority concerns, of which the first two are directly related to this project ("*Impaired and degraded lakes and streams in the Elk River Watershed*" and "*Increasing urban and residential land use replacing agriculture, forest and open space creates a concern about water quantity and quality due to increased impervious areas*"). The Elk River Watershed drains 613 square miles of land across four counties and includes 70% of Sherburne County. As previously mentioned the Elk River empties into Lake Orono before finally spilling into the Mississippi River another 1.1 miles downstream. And the City of Elk River, the largest city in Sherburne County, includes a high degree of development as well as impervious surface. The goals set forth by the plan to address the priority concerns include reducing pollutant loads to impaired waterbodies as well as mitigating stormwater impacts through stormwater retrofitting, local controls and ordinances, and innovative practices.

The support for this project is evident through the priorities set forth by both the City of Elk River and Sherburne County Water Plan. The City of Elk River recently (March 2015) updated the Stormwater Management Ordinance Sections 75-501 through 78-506. These amendments were updated to comply with Minnesota Pollution Control Agency (MPCA) general permit as a small Municipal Separate Storm Sewer System (MS4) operator. The updates included Minimal Impact Design Standards (MIDS) and 1.1" of runoff from all new impervious surfaces. The city has not had any applicants propose to use alternatives because of on-site restrictions. The city is fortunate to have soils that are conducive to infiltration practices and numerous proposed projects have been able to exceed water quality requirements. In June 2016, the City of Elk River received the Blue Star Award certification for Excellence in Community Stormwater management, an honor received by only 22 Minnesota communities. City staff continues to make improvements to the stormwater program to maintain and improve water quality throughout the city.

Further, the Lake Orono Improvement Association (LOIA) has voiced much support for this study and for continued water quality improvement projects through the formation of a Lake Orono Water Quality Committee (LOWQC). This committee is focused upon improving the condition of the lake and includes members of the City of Elk River and Sherburne SWCD on its panel.

# Project Scoping and Methods

The purpose of a sub-watershed assessment is to identify and prioritize potential stormwater retrofit projects by performance (pollution mitigation) and by cost-effectiveness. The process described in the pages that follow was modified from the Center for Watershed Protection's Urban Stormwater Retrofit Practices, Manuals 2 and 3 (Schueler & Kitchell, 2005 and Schueler et al. 2007). The designs of BMPs included in this document are largely accepted stormwater BMPs; practices that would work well from a retrofit standpoint and make use of Sherburne County's well-drained soils were selected where possible.

## *Project Scoping*

The first step in the process is watershed / catchment scoping. This process begins with a meeting including local stormwater managers and other partners, here, City of Elk River staff, Sherburne SWCD staff and WSB & Associates (contracted to complete a portion of the work). The stormwater team met to review preparatory materials for field visits and further analyses. During the meeting, existing stormwater plans were examined along with drainage patterns of the nearby subwatershed, maps depicting aerial imagery and existing pipeshed delineations. Accurate GIS data assisted the team greatly; the datasets included city pond and stormwater layers, 2-foot topography, surface hydrology, and soils data. It was during these meetings that the purpose and objectives of the study were developed. It was determined that the study would focus on phosphorus (primarily) and suspended solids reductions to Lake Orono.

## *Desktop Analysis*

The purpose of the desktop analysis was to identify a list of potential project catchments and BMP placement locations. Following the desktop analysis, field visits would be made to verify aerial photography conditions and to further refine the list of potential locations to a list of viable locations. Figure 2 displays the City of Elk River urban service area / Lake Orono stormwater drainage area. Several additional GIS layers were used for the desktop analysis and are displayed here, such as the flow direction and stormwater pipesheds. Finally, local knowledge of the existing stormwater infrastructure and conditions was discussed. These tools were used to classify all stormwater pipesheds in the west City of Elk River urban service area into the following categories:

- *<u>At Capacity</u>* – indicates that ample stormwater ponds, infiltration basins, wetlands, or other stormwater BMP structures are present in that pipeshed or that no suitable conditions exist for further stormwater BMP implementation.
- *<u>Isolated</u>* – this designation means that the pipeshed is largely internally draining, with overflow mechanisms in place for large rain events.
- *<u>Municipal</u>* – A single pipeshed that contains numerous municipal buildings and parks is slated for development work in 2017-2018. Plans have been put into place to address stormwater runoff.
- *<u>Non-contributing</u>* – these pipesheds drain water away from Lake Orono into the Elk River downstream of the dam or into the Mississippi River
- *<u>Potential</u>* – indicates pipesheds where restoration work could be considered

The team determined several criteria which was used to guide selection:

- Drainage areas under consideration would lead to the Elk River upstream of the Lake Orono dam
- Potential BMP sites must have at minimum 1-acre of drainage area
- Potential BMP sites must have direct drainage to them with no need of additional, or significant, conveyance modifications
- Potential BMP sites must not be located within known contaminated soil locations
- Site preference will be given in the following order:
    - Retrofit of existing ponds or wetlands to include water quality benefits
    - Creation of new regional, or neighborhood-scale, storage and treatment at ditch daylighting locations. Preference given to locations on publically-owned lands and in the lower watershed
    - Retrofit new BMPs within public spaces and neighborhoods

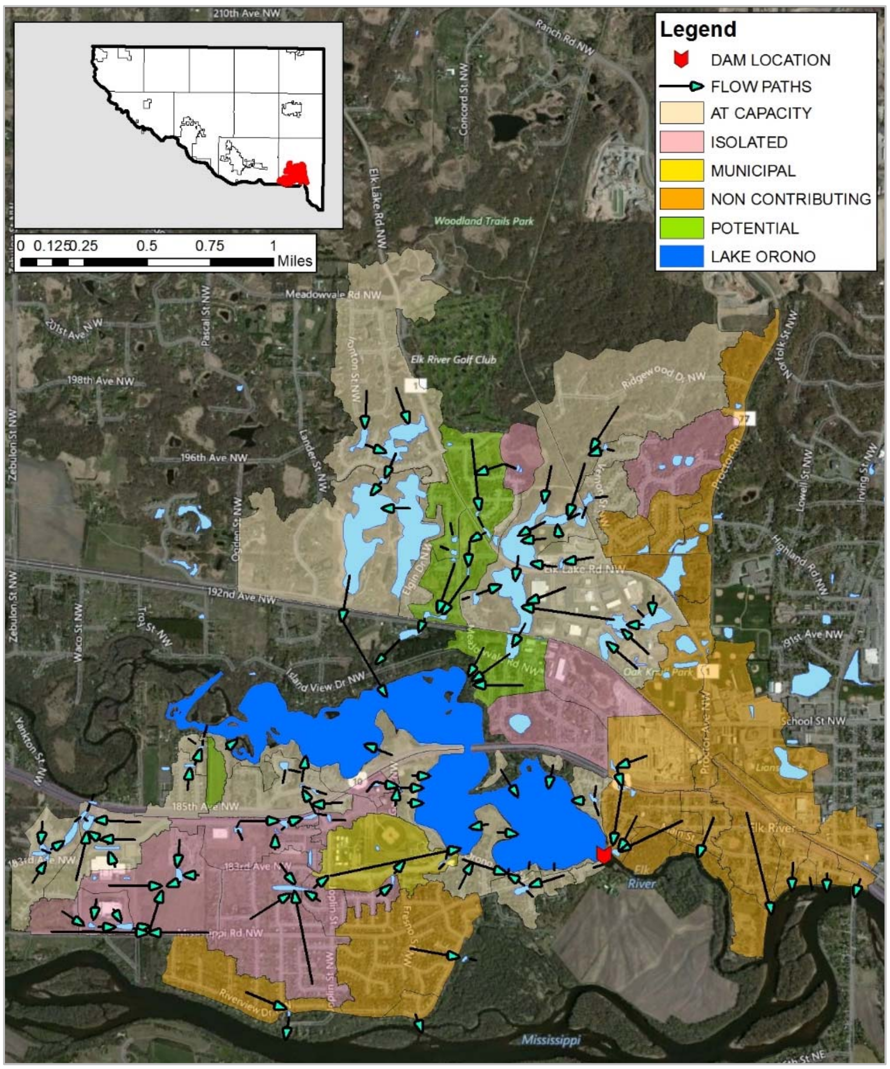



**Figure 2: Lake Orono stormwater contributing area**. Map includes water flow paths and pipesheds with stormwater retrofit potential identified.

Upon initial inspection of the available desktop materials, information and data gaps were consolidated for each potential site. This information included identification of land ownership, needs for field inspections, potential restoration / mitigation strategies for each site, etc. When information was consolidated, the stormwater team identified two contributing Priority Management Areas (PMAs). Areas eliminated from field reconnaissance and BMP modeling work included *At Capacity* areas, *Isolated* areas, the single *Municipal* area, and *Non-Contributing* areas. It was found that many areas currently have some sort of treatment or are non-contributing. This eliminated much of the drainage areas southwest and east-south east of Lake Orono for continued investigation in this study. A third *Potential* location identified on Figure 2 consists of a small agricultural field that is located between Lake Orono and Hwy 10. Since this field is less than one acre, has little slope, is in an agricultural setting and employs several agricultural BMPs, it was not considered in this urban stormwater analysis.

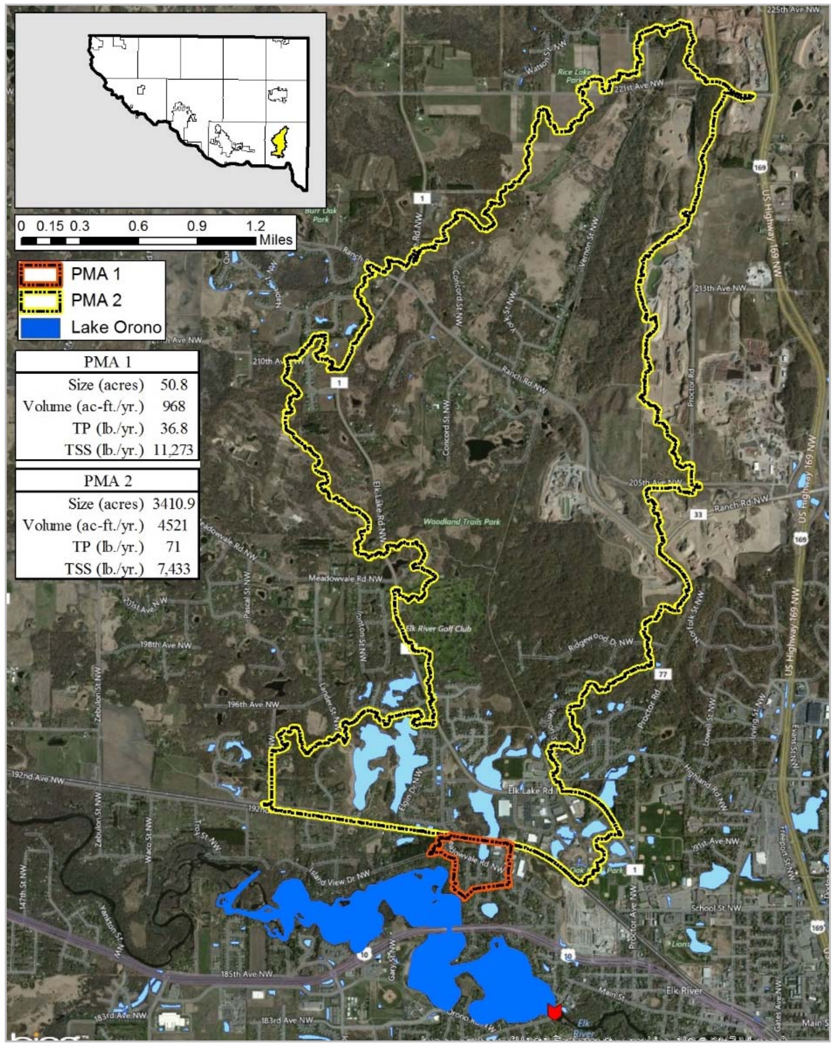



**Figure 3: Lake Orono stormwater contributing area**. Map includes water flow paths and pipesheds with stormwater retrofit potential identified, as well as P8 modeled existing water load conditions.

The two PMAs defined by the stormwater team fit well with the pre-determined objectives that the team had defined; both PMAs were directly contributing to Lake Orono, consisted of drainage areas larger than 1 acre, BMPs could be placed within the areas with minimal or no conveyance augmentation, and no known contaminated soils existed in these areas (Figure 3). While PMA 2 consists of a single pipeshed, PMA 1 was expanded to consider upstream draining areas. The directly contributing streams from PMA 1 and PMA 2 were sampled in 2016 to quantify the water quality (results included in Appendix A).

### *Field Reconnaissance*

Following the desktop research and discussion, potential sites were visited within the Lake Orono stormwater subwatershed. Actual visits to the locations assisted the stormwater management team in further defining catchment and sub-catchment boundaries, understanding structural limitations and determining BMP suitability. Detailed notes were collected at each site. Initial investigations took place in early 2016, primarily to confirm the catchment conditions as outlined within Figure 2. Additional fieldwork at this time assisted the team in identifying the PMAs along with potential BMP projects within those areas. Sherburne SWCD made a return visit to PMA 1 to better define BMP locations in December 2016 and prepare for additional modeling exercises.

Potential BMPs for each site would be determined from a list that includes extended detention, infiltration basins, iron-enhanced sand filtration, vegetated swales, bioretention, permeable pavement and sediment / chemical treatment systems. Each site would be assessed separately, as site-specific conditions vary incredibly. Hydrologic, hydraulic and land use data would be a crucial part of the BMP suitability investigation at each site. Factors that were accounted for included local soil types, hydraulic conductivity, infiltration rates, depth to ground water or bedrock, site structure, site slope, Drinking Water Supply Management Areas, wetlands, and floodplain locations. With this information in hand, computer modeling of the existing conditions and BMP reductions could be started.

### *BMP Modeling*

Modeling of the iron-enhanced sand filter bench and sub-surface sedimentation and filtration system was completed by WSB & Associates (WSB, 2016) through the use of the P8 Urban Catchment Model. Once the catchment area was determined, the P8 program calculated initial existing conditions, which were determined based upon the desktop analysis and field reconnaissance exercises.

The modeling process begins with a determination of existing conditions, often termed a “base” model. The base model depicts conditions in the stormwater catchment as they are currently – water volumes, pollutant loads, land use, etc. The models used in this study, P8 and WinSLAMM, are customized in order to accommodate a variety of conditions found in an urban environment. Prior to model setup, stormwater catchments were delineated using geographic information systems (GIS) that included topography and stormwater routing data. Additional tools, such as hillshade data layers and visual field observations were used when applicable. Catchments were further subdivided into sub-catchments for specific BMP modeling purposes. Land use data was configured into the stormwater models through a standard land use data file (WinSLAMM), which approximates the areas of sidewalks, lawns, rooftops, streets, etc. based upon the type of landscape that is entered. For the City of Elk River catchments, a “medium density residential” setting was used as it is the best fitting category given the conditions of the city’s west service area. Soils data was integrated into the models where appropriate.

Following the creation of a model depicting base conditions, the model was improved to estimate “existing conditions”. The primary addition in this exercise was the inclusion of the City of Elk River’s street sweeping practices. The city currently conducts spring sweeping to collect sand used during the winter as well as other debris that has accumulated. The spring sweepings are disposed of at a landfill due some contained contaminates (i.e. metals and fuel organics). During the summer months, the streets are swept following road seal coating, wind storms and special events such as parades. During the fall season, areas that produce heavy leaf deposits are swept up to five or six times where other areas that do not produce heavy leaf deposits may only be swept once. Sweeping efforts are tracked in the city's asset management system. Although the extra sweeping efforts result in a greater removal of stormwater pollutants, sweeping was modeled as only occurring twice annually to ensure estimates for pollutant removal were not overestimated. Following inclusion of street sweeping into the stormwater models, the base model was updated to approximate the conditions within the City of Elk River west service area prior to further BMP establishment.

The types of stormwater retrofits modeled within this report are typical stormwater BMPs that are used commonly within Minnesota. For each BMP type, the general method of modeling, assumptions made and rationale for cost estimates are included in the text that follows.

## *BMP Selection*

### Bioretention

Bioretention is a practice that utilizes the natural filtering capacity of soil and vegetation to treat stormwater runoff. The amount of stormwater treatment achieved can vary based upon the type of bioretention selected and the characteristics of the bioretention device, in addition to the initial water chemistry, the intensity and duration of storm events, size of the bioretention device, size of the BMP's catchment area, etc.

Initial field observations were made to determine site suitability for bioretention devices, including consideration of drainage areas, proximity to storm drains for overflow, estimates on space suitability and location of obstacles (utility boxes, driveways, etc.). However, following a recommendation of a bioretention device and landowner approval, site specific investigations would be required to ensure final suitability in terms of proper soil infiltration and other factors.


**Figure 4: Sherburne county curb-cut rain garden**.

Bioretention devices may either function in terms of filtration or *<u>in</u>*filtration. Filtration designs have a buried perforated drain tile which allows water to discharge to stormwater drainage systems following filtration through the bioretention device. On the other hand, infiltration designs do not incorporate an underdrain and rely upon soil infiltration or evapotranspiration to pass water along. Infiltration designs were selected for this study in order to take advantage of Sherburne County's well drained sandy soils, which allow for exceptional infiltration. However, bioretention options were placed in areas where overfill (due to heavy storm events) could escape through a curb-cut back onto the street. For this reason, bioretention designs in this study were all situated upstream of existing stormwater drains.

Curb-cut rain gardens (Figure 4) were the primary bioretention designs examined for this project. With this design, water transported along roadside gutters are directed into shallow roadside basins. These designs can provide treatment from one to numerous properties located upstream, as well as the draining roads and sidewalks. Curb-cut rain gardens may be proposed as either filtration or infiltration devices, but as previously mentioned all curb-cut designs in this project were proposed to utilize infiltration

Modeling of curb-cut rain gardens was completed by Sherburne SWCD using WinSLAMM software, version 10.1. Each rain garden was assumed to be 250 $ft^2$ in size with ½ foot in ponding depth. Infiltration rates were estimated at 1.2 inches per hour (Minnesota Stormwater Manual rates for NRCS A-type soils). As this modeling exercise involved evaluation of a single catchment, calculations for routing through multiple catchments and stormwater treatment practices was not necessary. WinSLAMM's standard land use files were used in the modeling procedure for a medium density residential area. The Minneapolis 1959 precipitation file was modeled to estimate flow duration during the year, with winter season dates set from November 4 through March 13. WinSLAMM's base files for pollutant probability distribution, runoff coefficients, particulate solids concentration and particle reside delivery were utilized.

All rain gardens were presumed to include mulch and native plants. Though not related to curb-cut bioretention cell performance, *Rain Guardian*™ forebays were included in the design cost structure for each bioretention cell inlet point as they are helpful in collecting silt and leaf litter prior to settling into the bioretention cells. This component thus reduces maintenance costs and improves cell lifespan. The lifespan of the curb-cut rain gardens were assumed to be 30 years. For cost purposes, rehabilitation of the gardens were assumed in years 10 and 20 with annual maintenance assumed to be completed by the property landowner.

### Sub-surface sedimentation and filtration system

A sub-surface detention system involves the capture and detention of stormwater from an existing stormwater network. As the name suggests, the system is located underground. It consists of a multi-chamber unit that is designed to settle out suspended solids from stormwater and allow for filtration into nearby soils. These systems may allow for entry through manhole or other access points, or may contain other maintenance (sediment removal) mechanisms such as opportunities for vacuum removal of sediments. Overflow safeguards are typically integrated in order to allow for excess water, occurring during particularly large rain events, to flow out of the unit when capacity is met.

Sub-surface sedimentation and filtration systems range greatly in size and overall function. However, the general concept is that water is settled in a ponding region so that suspended sediments may settle out. Water is then given an opportunity to filtrate into the soil. When water levels reach a critical level, an outlet allows for water to seep through so that the unit does not reach capacity. Figure 5 displays a side profile of a typical sub-surface sedimentation and filtration system.

For costing purposes, it was assumed that sub-surface sedimentation and filtration systems were built to be 3,610 sq-ft. in size. Capital costs (engineering, planning, geotechnical investigation, materials and mobilization) as well as maintenance activities were included on a 30 year basis. Maintenance factors included frequent inspections, debris removal and media maintenance while infrequent maintenance included time to unclog drains. A medium level of maintenance was assumed for this study with national average frequencies and labor assuming City staff resources are used. Finally, a 20% contingency was added to the overall cost.

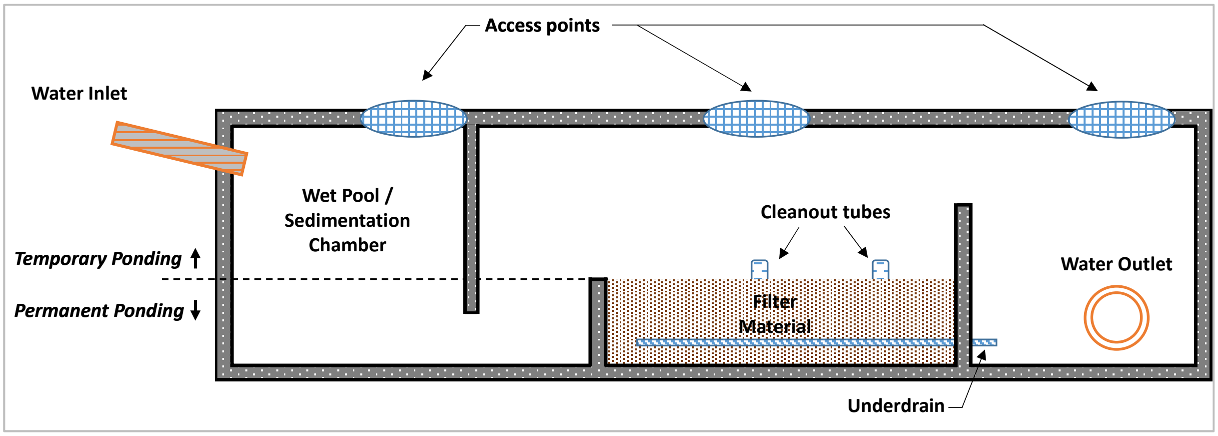



**Figure 5: Sub-surface sedimentation and filtration system schematic, side profile**.

## Iron-enhanced Sand Filter Pond Bench

A modification that may be made to a wet pond in order to improve stormwater treatment is the addition of an iron and sand filter. While wet ponds efficiently removed suspended sediments and particles from stormwater, often dissolved pollutants go untreated. In particular, dissolved phosphorus is not thoroughly addressed from a wet pond. In some circumstances, dissolved phosphorus may constitute 45% up to as much as 95% of a total phosphorus measurement in stormwater (Erickson et al 2012). Phosphorus in a dissolved form is of particular concern from a water quality standpoint as it is readily available for algal uptake in waterbodies, whereas phosphorus in the particulate form must be broken down before algae can utilize it.

Iron-enhanced sand filters can be retrofit into existing stormwater pond structures, typically near the outlet point (Figure 6). The design is based on a concept from researchers at the University of Minnesota St. Anthony Falls Laboratory, Minnesota. A mixture of raw iron filings and fine filter aggregate sand are used to increase treatment capacity. The sand acts as a filter, while the iron filings binds dissolved phosphorus through a chemical reaction (surface sorption to iron oxide, otherwise known as "rust") and removes it from the water. Mixing of these two elements is critical in order to create as many "binding sites" as possible. Poorly mixed iron can also bind to itself, reducing water permeability. These filter benches often rely on gravitational flow or natural water level fluctuation in order to pass the stormwater through the iron/sand medium. It is of great importance that the filter benches are designed to prevent anoxic conditions within the filter medium; such conditions will release the bound phosphorus. Additionally, proper maintenance is required in order to address accumulating algae or duckweed in the pond, which can impact performance. Routine maintenance to scrape and remove aquatic vegetation, remove grey much from the top 1-3 inches, break up sand media, and break up large clumps of iron shaving is recommended (Erickson et. al 2015).

The BMP has a lifespan of roughly 30 years, depending upon a number of factors including water flow and phosphorus concentrations. As time goes on, the iron filings bind more and more phosphorus and binding potential is lessened as most "binding sites" are used up. Eventually, removing and replenishing the iron-sand media is required.

For costing purposes, it was assumed that excavation/dredging of existing ponds was required as well as disposal of soil to a suitable locations. For this study, a suitable disposal location exists and it is assumed that the soil was free of excessive contaminants and would meet requirements for non-landfill disposal (Brandon Wisner, City of Elk River, personal communication). Costs were broken into capital and maintenance categories. Capital costs include engineering, planning, geotechnical investigation, materials and mobilization, while maintenance costs include annual routine inspection, reporting and information management, vegetation and inlet management) for this BMP. Corrective and infrequent maintenance costs (tilling of soil, unclogging drains, replacing mulch or plants, etc.) were included as well. The design of the structure included ¾ of the bench to include iron-enhanced sand at a depth of two feet. Several size scenarios were modeled for proposed locations. A medium level of maintenance was assumed for this study with national average frequencies and labor assuming City staff resources are used. Finally, a 20% contingency was added to the overall cost.

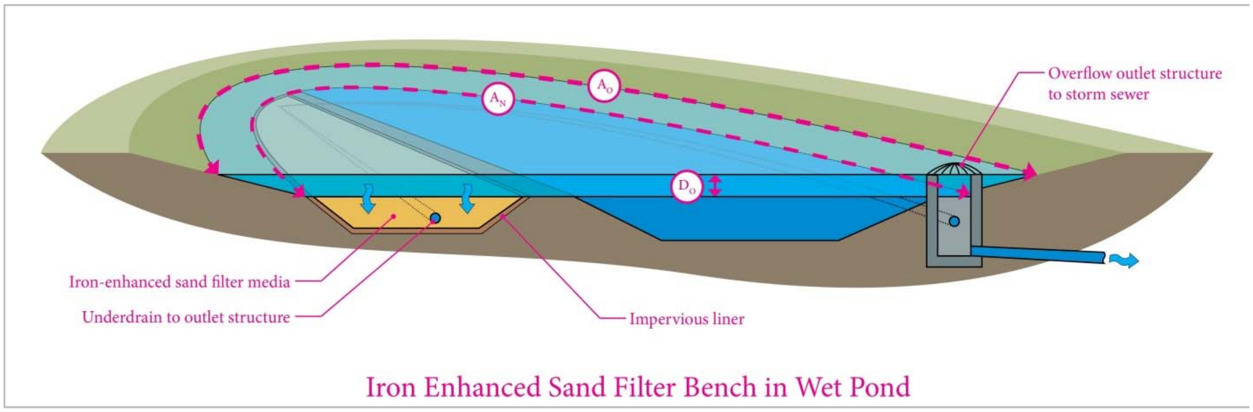



**Figure 6: Iron enhanced sand filter bench schematic.** Photo provided by Minnesota Pollution Control Agency.

## *Cost Valuation*

Cost estimating is an important aspect of the sub-watershed assessment protocol; it allows for a comparison of similar potential water quality projects to determine which ones have the greatest impact for the least amount of financial investment. For this exercise, 2016 dollars were used and sourced from several locations. The *Water Environment Research Foundation's BMP and LID Whole Life Cost Model*, Version 2.0 (Moeller and Pomeroy, 2009) was utilized for cost analysis on iron enriched sand filters and the subsurface detention basin scenarios, while costs for biofiltration (curb-cut rain gardens) were obtained from the Center for Watershed Protection's Urban Subwatershed Restoration Manual

In an effort to gain an understanding of a cost–benefit ratio, modeled annual total phosphorus reductions were coupled with BMP costs. Each strategy was evaluated on a 30-year cost term, with components separated between capital and maintenance costs. Capital costs may be defined as initial planning and engineering, materials, mobilization, etc. Maintenance costs refer to ongoing inspections, vegetation and inlet management, and necessary reporting. To determine relative cost-benefit ratio, average annual TP removal was divided by the 30-year costs. Prior to public implementation, other factors such as feasibility of implementation, price ceilings, impact on water quality goals, and opportunities to engage or display to the public were assessed in addition to the cost-benefit analysis results.

### *Tributary Monitoring*

During summer 2015, during initial discussions held on the project, the stormwater management team decided that flow and nutrient monitoring of the tributaries would provide additional data as to the nature of the tributaries and load modeling estimates. Grab samples and intermittent flow data were collected at several locations starting in summer 2015 and continuing into 2016. Unfortunately, the streams were found to be quite “flashy” and run very intermittently during the monitored time period. Samples paired with flow data were collected occasionally, but flow-based event samples were difficult to collect. No extended data analysis is included within this report, however sample data is included within Appendix A. Sampling will continue into 2017 in order to gain a better understanding of the tributaries and their nutrient loads.

# Priority Management Area Profiles

## *Priority Management Area 1*

Priority Management Area 1 is a medium density residential neighborhood along the north-east side of Lake Orono. The neighborhood has some slopes of moderate grade (2-3%) as well as a stormwater drain network that outfalls directly to Lake Orono. Stormwater from north of Meadowvale Rd NW flows through a >2 acre wetland pond before discharging into a stormwater drain. The drain runs under Albany St, then turns west at 189th Ave NW before it discharges to the lake. Stormwater sewers are incorporated along much of 189th Ave NW to add contributing stormwater to the system. Surface runoff paths south of Meadowvale Rd NW are thus limited to small catchments which drain to the storm sewer system. This area was examined for incorporation of curb-cut bioretention cells. Field investigations determined potential locations which included primary sites, considered both feasible and ideal, and secondary sites which were considered feasible but not the most effective locations due to one or more limiting factors. These secondary sites were noted, but were note modeled for pollutant-reduction calculations (Figure 7).


| Subcatchment | Acres | Volume (cu-ft/yr) | TP (lb/yr) | TSS (lb/yr) |
|---|---|---|---|---|
| SC-1 | 4.4 | 76,890 | 2.26 | 1,027.8 |
| SC-2 | 3.49 | 60,987 | 1.79 | 815.2 |
| SC-4 | 3.18 | 55,570 | 1.63 | 742.9 |
| SC-3 | 2.61 | 45,610 | 1.34 | 609.7 |
| SC-5 | 1.52 | 26,562 | 0.78 | 355.1 |

**Figure 7: Priority Management Area 1, proposed area for bioretention cells.** Map indicates the delineated PMA, delineated subcatchment areas, subcatchment existing loading conditions (sorted highest to lowest), storm sewer routing and proposed primary and secondary bioretention locations.

# PMA 1 – Sub-Catchment 1

| Existing Catchment Summary | |
|---|---|
| **Acres** | 4.40 |
| **Location** | Albany and Zumbro Streets, between 189th Ave and Meadowvale Rd. |
| **Ownership** | Private |
| **Dominant Land Cover** | Med. Density Residential |
| **Volume (cu-ft./yr.)** | 76,890 |
| **TP (lb./yr.)** | 2.26 |
| **TSS (lb./yr.)** | 1,110.4 |


This is the largest of sub-catchments within PMA1. Stormwater runoff collects and travels over moderate slopes towards several manholes and through the City of Elk River's storm sewer network into Lake Orono. Besides street sweeping, no current treatment exists

***Treatment Calculations and Cost Analysis***

| | *Curb Cut Raingarden* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Cost / Removal Analysis* | **New Treatment** | **Percent Reduction** | **New Treatment** | **Percent Reduction** | **New Treatment** | **Percent Reduction** |
| *Treatment* | **Number of BMPs** | 1 | - | 2 | - | 3 | - |
| | **Total Size (sq-ft)** | 250 | - | 500 | - | 750 | - |
| | **Volume (cu-ft/yr)** | 17,200 | 52.6 | 31,588 | 41.1 | 45,797 | 59.6 |
| | **TP (lb/yr)** | 0.53 | 21.6 | 0.97 | 39.5 | 1.40 | 57.2 |
| | **TSS (lb/yr)** | 243 | 21.8 | 444 | 40.0 | 642 | 57.8 |
| *Cost* | **Administration & Promotion** | $8,468 | | $9,344 | | $10,220 | |
| | **Design & Construction** | $7,376 | | $14,752 | | $22,128 | |
| | **Total Initial Costs** | $15,844 | | $24,096 | | $32,348 | |
| | **30-year Oper. & Maint (yr)** | $450 | | $450 | | $450 | |
| *Efficency* | **30-yr Cost/lb-TP** | $1,852 | | $1,761 | | $1,734 | |
| | **30-yr Cost/1,000lb-TSS** | $4,034 | | $3,839 | | $3,781 | |

# PMA 1 – Sub-Catchment 2

| Existing Catchment Summary | |
|---|---|
| **Acres** | 3.49 |
| **Location** | Boston St., parts of 189th Ave and Meadowvale Rd. |
| **Ownership** | Private |
| **Dominant Land Cover** | Med. Density Residential |
| **Volume (cu-ft./yr.)** | 60,987 |
| **TP (lb./yr.)** | 1.79 |
| **TSS (lb./yr.)** | 815.2 |

Currently, stormwater runoff from residential lots flows to several manholes and through the City of Elk River's storm sewer network into Lake Orono. Besides street sweeping, no current treatment exists


### *Treatment Calculations and Cost Analysis*

| | *Cost / Removal Analysis* | New Treatment | Percent Reduction | New Treatment | Percent Reduction | New Treatment | Percent Reduction |
|---|---|---|---|---|---|---|---|
| | | ***Curb Cut Raingarden*** | | | | | |
| *Treatment* | **Number of BMPs** | 1 | - | 2 | - | 3 | - |
| | **Total Size (sq-ft)** | 250 | - | 500 | - | 750 | - |
| | **Volume (cu-ft/yr)** | 14,905 | 24.4 | 31,790 | 52.1 | 37,262 | 61.1 |
| | **TP (lb/yr)** | 0.46 | 25.4 | 0.97 | 54.4 | 1.14 | 63.4 |
| | **TSS (lb/yr)** | 209 | 25.6 | 447 | 54.8 | 521 | 63.9 |
| *Cost* | **Administration & Promotion** | $8,468 | | $9,344 | | $10,220 | |
| | **Design & Construction** | $7,376 | | $14,752 | | $22,128 | |
| | **Total Initial Costs** | $15,844 | | $24,096 | | $32,348 | |
| | **30-year Oper. & Maint (yr)** | $450 | | $450 | | $450 | |
| *Efficency* | **30-yr Cost/lb-TP** | $2,147 | | $1,748 | | $2,136 | |
| | **30-yr Cost/1,000lb-TSS** | $4,682 | | $3,811 | | $4,661 | |

# PMA 1 – Sub-Catchment 3

| Existing Catchment Summary | |
|---|---|
| **Acres** | 2.61 |
| **Location** | Albany and Boston Streets, between 189th and 188th Ave. |
| **Ownership** | Private |
| **Dominant Land Cover** | Med. Density Residential |
| **Volume (cu-ft./yr.)** | 45,610 |
| **TP (lb./yr.)** | 1.34 |
| **TSS (lb./yr.)** | 609.7 |


This sub-catchment includes some of the steepest slopes in the neighborhood. Stormwater runoff from this area runs untreated through the city storm sewer drains, directly into Lake Orono. Street sweeping is the only BMP currently utilized here.

### *Treatment Calculations and Cost Analysis*

| | | Curb Cut Raingarden | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***Cost / Removal Analysis*** | **New Treatment** | **Percent Reduction** | **New Treatment** | **Percent Reduction** | **New Treatment** | **Percent Reduction** | **New Treatment** | **Percent Reduction** |
| *Treatment* | **Number of BMPs** | 1 | - | 2 | - | 3 | - | 4 | - |
| | **Total Size (sq-ft)** | 250 | - | 500 | - | 750 | - | 1,000 | - |
| | **Volume (cu-ft/yr)** | 6,060 | 13.3 | 13,113 | 28.8 | 23,597 | 51.7 | 36,441 | 79.9 |
| | **TP (lb/yr)** | 0.18 | 13.5 | 0.39 | 29.2 | 0.71 | 52.9 | 1.10 | 82.0 |
| | **TSS (lb/yr)** | 82 | 13.5 | 178 | 29.2 | 323 | 53.0 | 502 | 82.4 |
| *Cost* | **Administration & Promotion** | $8,468 | | $9,344 | | $10,220 | | $11,096 | |
| | **Design & Construction** | $7,376 | | $14,752 | | $22,128 | | $29,504 | |
| | **Total Initial Costs** | $15,844 | | $24,096 | | $32,348 | | $40,600 | |
| | **30-year Oper. & Maint (yr)** | $450 | | $450 | | $450 | | $450 | |
| *Efficency* | **30-yr Cost/lb-TP** | $5,423 | | $4,353 | | $3,427 | | $2,869 | |
| | **30-yr Cost/1,000lb-TSS** | $11,894 | | $9,559 | | $7,512 | | $6,280 | |

# PMA 1 – Sub-Catchment 4

| Existing Catchment Summary | |
|---|---|
| **Acres** | 3.18 |
| **Location** | 188th Ave, along with Concord and Boston St south of 189th Ave. |
| **Ownership** | Private |
| **Dominant Land Cover** | Med. Density Residential |
| **Volume (cu-ft./yr.)** | 55,570 |
| **TP (lb./yr.)** | 1.63 |
| **TSS (lb./yr.)** | 742.9 |


Also with relatively steeply sloping streets and residential yards, this sub-catchment routes stormwater directly through the City of Elk River's storm sewer network into Lake Orono. Besides street sweeping, no current treatment exists.

***Treatment Calculations and Cost Analysis***

| | *Curb Cut Raingarden* | | | | | | |
|---|---|---|---|---|---|---|---|
| | ***Cost / Removal Analysis*** | **New Treatment** | **Percent Reduction** | **New Treatment** | **Percent Reduction** | **New Treatment** | **Percent Reduction** |
| ***Treatment*** | **Number of BMPs** | 1 | - | 2 | - | 3 | - |
| | **Total Size (sq-ft)** | 250 | - | 500 | - | 750 | - |
| | **Volume (cu-ft/yr)** | 9,036 | 16.3 | 25,799 | 46.4 | 36,893 | 66.4 |
| | **TP (lb/yr)** | 0.27 | 16.7 | 0.79 | 48.2 | 1.12 | 68.8 |
| | **TSS (lb/yr)** | 124 | 16.8 | 361 | 48.6 | 515 | 69.3 |
| ***Cost*** | **Administration & Promotion** | $8,468 | | $9,344 | | $10,220 | |
| | **Design & Construction** | $7,376 | | $14,752 | | $22,128 | |
| | **Total Initial Costs** | $15,844 | | $24,096 | | $32,348 | |
| | **30-year Oper. & Maint (yr)** | $450 | | $450 | | $450 | |
| ***Efficency*** | **30-yr Cost/lb-TP** | $3,591 | | $2,164 | | $2,162 | |
| | **30-yr Cost/1,000lb-TSS** | $7,860 | | $4,721 | | $4,719 | |

# PMA 1 – Sub-Catchment 5

| Existing Catchment Summary | |
|---|---|
| **Acres** | 1.52 |
| **Location** | Concord St. south of Meadowvale Rd. |
| **Ownership** | Private |
| **Dominant Land Cover** | Med. Density Residential |
| **Volume (cu-ft./yr.)** | 26,562 |
| **TP (lb./yr.)** | 0.78 |
| **TSS (lb./yr.)** | 355.1 |

Currently, stormwater runoff from residential lots flows to several manholes and through the City of Elk River's storm sewer network into Lake Orono. Besides street sweeping, no current treatment exists


***Treatment Calculations and Cost Analysis***

| *Curb Cut Raingarden* | | | |
|---|---|---|---|
| | *Cost/Removal Analysis* | **New Treatment** | **Percent Reduction** |
| *Treatment* | **Number of BMPs** | 1 | - |
| | **Total Size (sq-ft)** | 250 | - |
| | **Volume (cu-ft/yr)** | 15,692 | 59.1 |
| | **TP (lb/yr)** | 0.48 | 61.7 |
| | **TSS (lb/yr)** | 221 | 62.2 |
| *Cost* | **Administration & Promotion** | $8,468 | |
| | **Design & Construction** | $7,376 | |
| | **Total Initial Costs** | $15,844 | |
| | **30-year Oper. & Maint (yr)** | $450 | |
| *Efficency* | **30-yr Cost/lb-TP** | $2,032 | |
| | **30-yr Cost/1,000lb-TSS** | $4,430 | |

# PMA 1 – Entire Catchment

| Existing Catchment Summary | |
|---|---|
| **Acres** | 50.80 |
| **Location** | NE corner of Lake Orono, north and south of Meadowvale Rd. |
| **Ownership** | Private, with some City property |
| **Dominant Land Cover** | Med. Density Residential and Commercial |
| **Volume (ac-ft./yr.)** | 968 |
| **TP (lb./yr.)** | 36.8 |
| **TSS (lb./yr.)** | 11,273 |


North of Meadowvale Rd, stormwater is directed to an engineered pond for initial treatment. Overflow from the pond spills south through the city stormwater sewer system. The residential area south of Meadowvale Rd. drains to this same sewer network which eventually drains to Lake Orono. Current BMPs in PMA 1 include the stormwater pond (believed to be in good working order) and street sweeping (2x annually).

***Treatment Calculations and Cost Analysis***

| ***Sub-Surface Detention Basin*** | | | |
|---|---|---|---|
| | ***Cost/Removal Analysis*** | **New Treatment** | **Percent Reduction** |
| ***Treatment*** | **Number of BMPs** | 1 | - |
| | **Total Size (sq-ft)** | 3,610 | - |
| | **Volume (cu-ft/yr)** | 881 | 9.0 |
| | **TP (lb/yr)** | 7.90 | 21.5 |
| | **TSS (lb/yr)** | 5,249 | 46.6 |
| ***Cost*** | **Administration & Promotion** | $41,832 | |
| | **Design & Construction** | $88,515 | |
| | **Total Initial Costs** | $130,347 | |
| | **30-year Oper. & Maint (yr)** | $860 | |
| ***Efficency*** | **30-yr Cost/lb-TP** | $659 | |
| | **30-yr Cost/1,000lb-TSS** | $992 | |

# Priority Management Area Profiles

## *Priority Management Area 2*

Priority Management Area 2 includes several pipesheds in north of Lake Orono and a portion occurs outside of the City of Elk River stormwater service area. The area drains industrial areas, residential, parks, a golf course, and some agricultural land through a primary and several secondary ditch-ways. Despite this area being treated through a series of upstream stormwater ponds, it was examined in this analysis for potential for additional remediation. End-of-pipe potential projects were examined primarily, and a city owned pond located just north of Lake Orono was concentrated upon for potential end-of-pipe remediation. Though end-of-pipe projects were focused upon in PMA 2 for this report, at the time of this writing a secondary upstream wetland remediation project is being investigated as part of a separate project. Additional efforts located upstream would of course enhance the effectiveness and longevity of projects proposed in this report.

The city owned stormwater pond was designed sometime in the 1940's and has not been dredged since. Field investigations during fall 2016 indicated an average of 2-3 feet of depth, with the inlet area containing coarse sand deposits and organic material dominating the downstream end of the pond. A county ditch runs through a culvert under 192$^{nd}$ Ave and carries water from the 3,400 acre watershed through it. During the fall 2016 field investigation, significant erosion of the banks of this inlet were noted. Though the stormwater pond is held through an easement by the City of Elk River, the surrounding property is owned and operated by a local greenhouse business. The property owner has expressed willingness to work collaboratively to restore the pond, address stormwater quality, and remediate the erosion issues at the inlet.

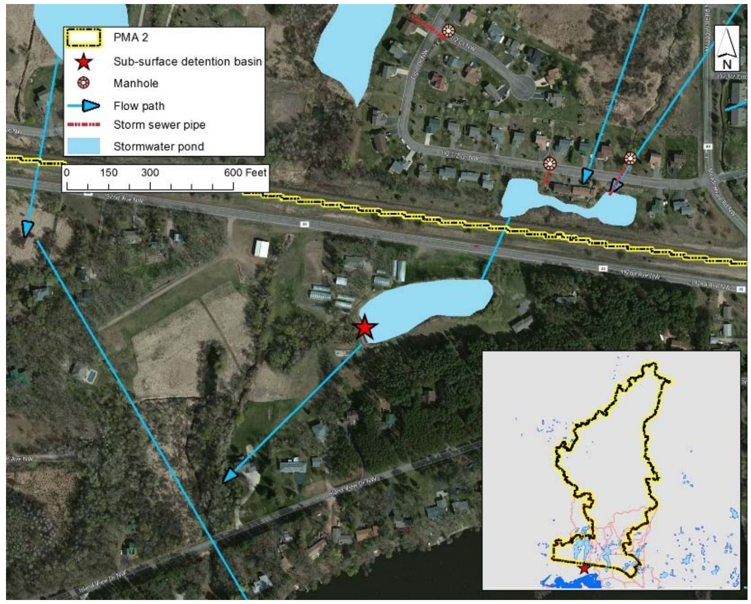
This site was examined for a potential iron-enhanced sand filter. Various size options were modeled through P8 software to determine pollutant reduction potential as well as cost-benefit. The City of Elk River would provide the resources to properly clean and maintain the sand filter if it was implemented.

**Figure 8 (above left). PMA 2 stormwater pond inlet**. PMA 2 drains to this pond and in 2016 a high degree of erosion was noted.

**Figure 9 (above-right). PMA 2 stormwater pond**. Pond currently treats PMA 2 to a minimal degree and could be restored through dredging and implementation of a stormwater BMP.

# PMA 2 – Entire Catchment

| Existing Catchment Summary | |
|---|---|
| **Acres** | 3,410.9 |
| **Location** | North of 192nd Ave to Rice Lake Park (221st Ave). |
| **Ownership** | Mix of private and publicly owned |
| **Dominant Land Cover** | Residential, Parks, Commercial, and Agricultural |
| **Volume (ac-ft./yr.)** | 3,410.9 |
| **TP (lb./yr.)** | 71.0 |
| **TSS (lb./yr.)** | 7,433 |




North of Meadowvale Rd, stormwater is directed to an engineered pond for initial treatment. Overflow from the pond spills south through the city stormwater sewer system. The residential area south of Meadowvale Rd. drains to this same sewer network which eventually drains to Lake Orono. Current BMPs in PMA 1 include the stormwater pond (believed to be in good working order) and street sweeping (2x annually).

### *Treatment Calculations and Cost Analysis*

| *Iron-Enhanced Sand Filter Bench, Size Options 1-3* | | | | | | | |
|---|---|---|---|---|---|---|---|
| | ***Cost/Removal Analysis*** | **New Treatment** | **Percent Reduction** | **New Treatment** | **Percent Reduction** | **New Treatment** | **Percent Reduction** |
| ***Treatment*** | **BMP Size Option** | 1 | - | 2 | - | 3 | - |
| | **Total Size (sq-ft)** | 980 | - | 1,546 | - | 2,722 | - |
| | **Volume (cu-ft/yr)** | 466 | 10.3 | 922 | 20.4 | 1,385 | 30.6 |
| | **TP (lb/yr)** | 7.10 | 10.0 | 14.10 | 19.9 | 21.10 | 29.7 |
| | **TSS (lb/yr)** | 994 | 13.4 | 1,854 | 24.9 | 2,701 | 36.3 |
| ***Cost*** | **Administration & Promotion** | $53,250 | | $57,964 | | $67,763 | |
| | **Design & Construction** | $113,890 | | $124,365 | | $146,140 | |
| | **Total Initial Costs** | $167,140 | | $182,329 | | $213,903 | |
| | **30-year Oper. & Maint (yr)** | $20,017 | | $20,498 | | $21,496 | |
| ***Efficency*** | **30-yr Cost/lb-TP** | $3,604 | | $1,885 | | $1,357 | |
| | **30-yr Cost/1,000lb-TSS** | $25,743 | | $14,334 | | $10,598 | |

### *Treatment Calculations and Cost Analysis, continued*

| *Iron-Enhanced Sand Filter Bench, Size Options 4-6* | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***Cost/Removal Analysis*** | | **New Treatment** | **Percent Reduction** | **New Treatment** | **Percent Reduction** | **New Treatment** | **Percent Reduction** |
| ***Treatment*** | **BMP Size Option** | 4 | - | 5 | - | 6 | - |
| | **Total Size (sq-ft)** | 4,262 | - | 6,316 | - | 9,365 | - |
| | **Volume (cu-ft/yr)** | 1,841 | 40.7 | 2,290 | 50.7 | 2,736 | 60.5 |
| | **TP (lb/yr)** | 28.20 | 39.7 | 35.20 | 49.6 | 42.30 | 59.6 |
| | **TSS (lb/yr)** | 3,538 | 47.6 | 4,383 | 59.0 | 5,218 | 70.2 |
| ***Cost*** | **Administration & Promotion** | $80,559 | | $97,772 | | $123,124 | |
| | **Design & Construction** | $174,665 | | $212,715 | | $269,165 | |
| | **Total Initial Costs** | $255,224 | | $310,487 | | $392,289 | |
| | **30-year Oper. & Maint (yr)** | $22,803 | | $24,546 | | $27,134 | |
| ***Efficency*** | **30-yr Cost/lb-TP** | $1,110 | | $991 | | $951 | |
| | **30-yr Cost/1,000lb-TSS** | $8,850 | | $7,962 | | $7,706 | |

# Literature Cited

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# Appendix A: Tributary Monitoring Data

**Orono @ Concord-Intermittent culvert (*downstream of BMP Strategy 1 & 2 location*)**

| Date | Time | Ttube | DO | Temp | PH | Conductivity | Velocity | Flow (cfs) | TP (mg/L) | TSS (mg/L) | OP (mg/L) | TD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/7/2015 | 10:21 | 100 | 6.13 | 15.88 | 7.52 | 0.42 | 0.17 | | 0.089 | 4 | 0.019 | 1.96 |
| 8/11/2015 | 11:15 | 100 | 6.96 | 20.09 | 6.94 | 0.361 | 0.04 | | 0.098 | 4 | 0.029 | |
| 8/18/2015 | 15:55 | | | | | | | | | | | |
| | | | | | | | | | | | | |
| 5/24/2016 | 12:30 | | | | | | 4 | 14.4 | 0.073 | 2 | 0.016 | |
| 8/11/2016 | 10:20 | | | | | | 5.73 | 30.94 | 0.095 | 2 | 0.039 | |

| Flow-weighted Mean TP (mg/L) |
|---|
| 0.088 |

| Average TP (mg/L) |
|---|
| 0.059 |

**Orono @ Islandview-flowing culvert (*downstream of BMP Strategy 3 location*)**

| Date | Time | Ttube | DO | Temp | PH | Conductivity | Flow (cfs) | TP (mg/L) | TSS (mg/L) | OP (mg/L) | TD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/7/2015 | 11:00 | 92 | 7.65 | 6.78 | 7.63 | 0.43 | 5.76 | 0.118 | 16 | 0.019 | |
| 8/11/2015 | 11:45 | 100 | 7.23 | 18.75 | 6.89 | 0.434 | 5.76 | 0.118 | 5 | 0.029 | 2.31 |
| 8/18/2015 | 16:05 | | | | | | | | | | 2.45 |
| 9/8/2015 | 10:50 | | | | | | 2.38 | 0.089 | 4 | 0.022 | |
| 10/20/2015 | 14:15 | | | | | | | 0.05 | 4 | 0.036 | |
| | | | | | | | | | | | |
| 3/8/2016 | 8:30 | | | | | | | 0.062 | 5 | 0.014 | |
| 3/24/2016 | 13:25 | | 11.95 | 6.03 | 7.97 | 0.557 | | 0.062 | 5 | 0.014 | 2.42 |
| 4/20/2016 | 11:50 | | | | | | 1.57 | 0.047 | 2 | 0.013 | 2.68 |
| 5/24/2016 | 11:58 | 100 | 7.51 | 16.73 | 7.68 | 0.509 | | 0.075 | 11 | 0.014 | 2.56 |
| 6/16/2016 | 9:40 | 100 | 7.15 | 16.32 | 7.66 | 0.516 | 3.01 | 0.069 | 5 | 0.026 | 2.55 |
| 7/12/2016 | 11:40 | 100 | 7.34 | 18.96 | 7.81 | 0.578 | 0.93 | | | | 2.64 |
| 8/11/2016 | 9:55 | 75 | 6.02 | 19.42 | 7.63 | 0.393 | | 0.149 | 8 | 0.033 | 2.27 |

| Flow-weighted Mean TP (mg/L) |
|---|
| 0.100 |

| Average TP (mg/L) |
|---|
| 0.086 |

**Ditch 31 @ 196th (*upstream of BMP Strategy 3 location*)**

| Date | Time | Ttube | DO | Temp | PH | Conductivity | Flow (cfs) | TP (mg/L) | TSS (mg/L) | OP (mg/L) | TD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/8/2016 | 9:10 | | | | | | | 0.036 | 3 | 0.015 | 2.52 |
| 3/24/2016 | 12:43 | | 12.52 | 3.59 | 7.61 | 0.49 | 1.92 | 0.063 | 3 | 0.015 | 2.33 |
| 4/20/2016 | 12:05 | | | | | | 1 | 0.088 | 6 | 0.009 | 2.28 |
| 5/24/2016 | 11:20 | 100 | 7.07 | 17.34 | 7.59 | 0.45 | | 0.094 | 6 | 0.01 | 2.29 |
| 6/16/2016 | 9:10 | 100 | 6.27 | 16.93 | 7.46 | 0.448 | 2.65 | 0.068 | 3 | 0.062 | 2.22 |
| 7/12/2016 | 11:05 | 100 | 6.3 | 22.01 | 7.73 | 0.453 | 0.86 | | | | 2.35 |
| 8/11/2016 | 9:25 | 68 | 4.61 | 20.31 | 7.7 | 0.345 | 3.1 | 0.299 | 24 | 0.076 | 1.87 |

| Flow-weighted Mean TP (mg/L) |
|---|
| 0.041 |

| Average TP (mg/L) |
|---|
| 0.070 |