Lake Orono
Stormwater Retrofit Analysis

Storm water pond, City of Elk River (Photo: Sherburne SWCD, 2016)

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Project Summary

A completed TMDL study on the Mississippi River – St. Cloud Watershed has specified for significant phosphorus loading reductions in the watershed, including 47,710 lbs. (a 48% 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 rural areas, urban storm water 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 storm water phosphorus loading in order to meet TDML 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 storm water contribution. The partnership's goals were to identify priority contributing areas, determine applicable Best Management Practices for these areas, and to examine a cost effective storm water treatment strategy to move forward with. The study resulted in several potential options, with a single treatment strategy selected due to its cost effectiveness, feasibility for implementation and impact on local water quality. The selected practice was an iron-enriched sand filter which would reduce phosphorus loading of Lake Orono's second largest tributary by 40%. This practice has a high likelihood of success and a very long-term lifespan due to the practice's effectiveness and commitment by the City of Elk River towards maintaining its structure and pollutant mitigation potential.

While a comprehensive strategy and other applications are planned to occur in the rural watershed, this project outlines best efforts to reduce storm water loading to a 303d listed waterbody from the City of Elk River's urban storm water management area. It is recommended that the City of Elk River and Sherburne SWCD pursue grant funding to implement the iron-enriched sand filter bench project identified within this report in order to take further steps towards meeting the city's TMDL load reduction requirement and improve conditions within Lake Orono.

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 48,249.56 lbs. per year. In order for Lake Orono to meet its phosphorus goal of 60 µg/L (state shallow lake standard), a full reduction of 48% would be required.

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, which drains to Lake Orono (Figure 1).

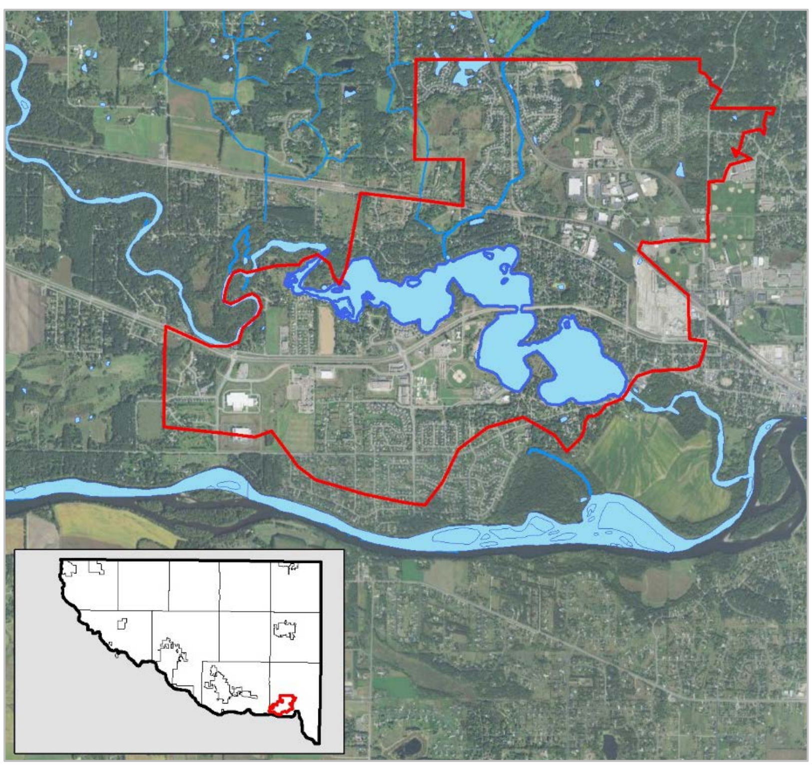

Figure 1: City of Elk River (west) storm water service area. Red line indicates roughly 2,500 acres of the City of Elk River's 8,680 acre service area.

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

- Examine areas of storm water 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 storm water remediation.
- Prioritize potential BMPs based upon the level of feasible implementation, pollutant mitigation, and financial efficiency (return on investment).

Being that urban environments are typically quite developed to begin with, addressing sources of storm water pollution can be quite difficult due to having to work around existing infrastructure. Pollution mitigation must address storm water 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, storm water management is often addressed through structure retrofitting, making use of current infrastructure and existing regulatory guidelines. The process of storm water 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 limited situations.

In addition to working towards the goals set forth for the City of Elk River by the aforementioned 2014 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 storm water impacts through storm water 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. Further, the Lake Orono Improvement Association (LOIA) has voiced much support for the project through the formation of a Lake Orono Water Quality Committee (LOWQC). This committee is focused upon improving water quality conditions within the lake and includes members of the City of Elk River and Sherburne SWCD on its panel. It is anticipated that implementation of this project's recommendations, as well as further projects down the road, will be highly successful due to the large and diverse support structure this waterbody has.

Methods

Desktop Analysis

Sherburne SWCD, City of Elk River and WSB & Associates staff met on February 11th, 2016 to review preparatory materials for field visits and further analyses. During the meeting, existing storm water plans were examined along with drainage patterns of the nearby subwatershed, maps depicting aerial imagery and existing pipeshed delineations. The purpose of the desktop analysis would be to identify a list of potential project subwatersheds 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. The storm water management team determined several criteria which was used to guide selection of the first tier of locations:

- 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 was given to locations on publically-owned lands and in the lower watershed
    - Retrofit new BMPs within public spaces
    - Retrofit new BMPs within neighborhoods

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.

Field Reconnaissance

Following the desktop research and discussion, potential sites were visited within the Lake Orono storm water subwatershed. Actual visits to the locations assisted the storm water management team in understanding structural limitations as well as BMP suitability. Photographs and detailed notes were collected at each site.

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, WSB & Associates staff was able to move forward with computer modeling of three scenarios.

Water Quality and BMP Modeling

Following the desktop and in-field investigations, it was decided upon by the storm water management team to examine BMP incorporation in three scenarios. These scenarios took place on two locations, with the first location modeled for two potential BMP treatment options and a single option available for the second location. Figure 2 displays the location of the potential retrofit sites along with their drainage areas, or Priority Management Areas. Each treatment strategy is discussed further in the Results Section.

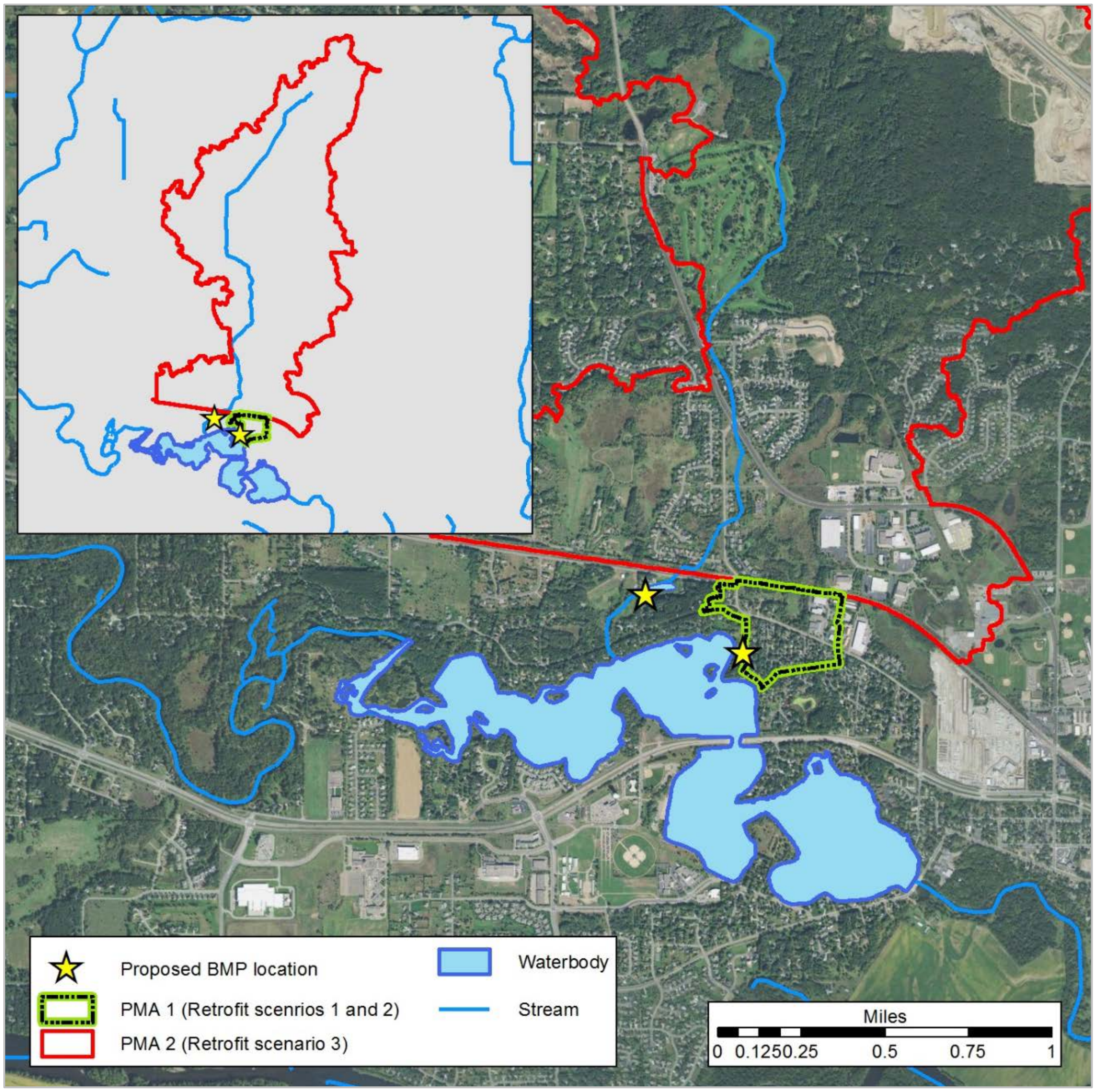

Figure 2: City of Elk River priority management areas and proposed BMP locations. .

Modeling was completed by WSB & Associates through the use of the P8 Urban Catchment Model (*Program for Predicting Polluting Particle Passage thru Pits, Puddles and Ponds*, version 3.5, Walker and Walker 2015). The P8 program determined catchment area inflow variables for two Priority Management Areas (PMAs), which were determined based upon the desktop analysis and field reconnaissance exercises. Table 1 indicates the drainage area inflow parameters and modeling estimates for each PMA, based upon a 20-year average (1988-2008). BMPs were entered into the program to determine potential remediation values for water flow, TP and TSS.

Table 1. Modeled inflow specifications. Inflow parameters utilized in P8 software within Priority Management Areas 1 and 2.

Modeling Inflow Data			
PMA #	Model Variables		
	Runoff (ac-ft)	TP (lbs)	TSS (lbs)
1	968.0	36.8	11,273.0
2	4,521.0	71.0	7,433.0

Cost Valuation

Following Implementation costs of the various modeled BMPs were estimated based upon current practices and rates. In an effort to gain an understanding of cost–benefit ratio, modeled annual total phosphorus reductions were coupled with BMP costs in the *Water Environment Research Foundation's BMP and LID Whole Life Cost Model*, Version 2.0 (Moeller and Pomeroy, 2009). 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. Dredging of accumulated fill (BMP option 3) was included when necessary. To determine relative cost-benefit ratio, average annual TP removal was divided by the 30-year costs.

Cost-benefit analysis can be a subjective topic; often a final decision stemming from a cost-benefit analysis is better informed but not necessarily determined by this exercise. In some circumstances, the benefit is not easily measured or valued. For example, it is difficult to determine the dollar value of clean air or clean water, or the existence of an imperiled mammal. However, pounds of reduction may be quantified, such as in this project, through software modeling programs. This allows for a single dollar value to be determined (cost of BMP divided by amount of pollutant reduction). To determine relative cost-benefit ratio for this project, average annual TP removal was divided by the 30-year costs. These values were compared between several scenarios for each BMP type and location. Additionally, cost-benefit values were compared amongst BMP types and locations. 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 decision making in addition to the cost-benefit analysis results.

Tributary Monitoring

During summer 2015, during initial discussions held on the project, the storm water 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 2016 and 2017 in order to gain a better understanding of the tributaries and their nutrient loads.

Results

Priority Management Area 1 – Treatment Strategy 1

The first treatment strategy evaluated by WSB & Associates includes a series of curb cut bioretention cells (rain gardens) that would be located on private properties within pipeshed 16A of PMA 1 (Figure 3). Each bioretention cell would allow for one foot of live storage depth, with each cell estimated to be average in size (250 ft^2). Infiltration rates were estimated at 1.2 inches per hour (Minnesota Storm Water Manual rates for NRCS A-type soils).

Figure 3: Priority Management Area 1, proposed area for bioretention cells. .

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. Each bioretention cell estimate includes a below-grade underdrain that acts as an emergency draw-down apparatus in case soils would not drain properly within a 48-hour timespan.

Figure 4: Sherburne county curb cut bioretention cell.

Curb-cut bioretention cells offer a number of environmental benefits. Storm water enters the cells as it flows alongside of street curbs. Upon entering, water is treated through sedimentation and nutrient uptake by native plants. Water is primarily drained into underlying soils, reducing surface water flow capacity and increasing groundwater inputs. Water is also taken up by the planted vegetation and released to the atmosphere via evaporation. Any water surplus experienced through intense rain events is released through an overflow mechanism back to the street or another location. Finally, additional benefits may be realized through the inclusion of native plants which attract pollinators and are aesthetically pleasing. Figure 4 displays a photo of a Sherburne County rain garden.

To examine multiple levels of potential pollutant reduction, six options were modeled in P8 and examined for cost – benefit. The six options were based upon the number of bioretention cells to be constructed. Each cell was modeled with average variables based upon a 20-year average (1988-2008, Table 2). Costs were derived from current market value estimates for facility costs (excavation / grading, disposal, vegetation, soil amendments, edging and curb construction) capital costs (engineering design, geotechnical) and maintenance (inspection, vegetation management, drain maintenance). Table 2 displays the pollutant removal and cost specifications for curb-cut bioretention option.

Table 2. Curb-cut bioretention option specifications. Modified from WSB & Associates, 2016. Table displays treatment estimates as well as cost estimates for scenarios.

Curb-cut Bioretention							
Strategy and # of BMPs @ 250 ft^2	Annual removal Runoff (ac-ft)	TP (lbs)	TSS (lbs)	Facility & Capital Base Costs	Maintenance Costs (30yr)	30-yr maintenance Cost-Benefit	30-yr Total Cost-Benefit
A (5)	4.2	3.7	3,318.3	$58,017	$74,043	$667	$1,190
B (12)	8.7	7.4	4,781.1	$138,689	$166,116	$748	$1,373
C (20)	13.2	11.0	5,898.7	$220,826	$276,603	$838	$1,507
D (29)	17.7	14.7	6,875.9	$313,264	$409,413	$928	$1,639
E (41)	22.0	18.4	7,781.4	$473,748	$574,586	$1,041	$1,899
F (56)	26.5	22.1	8,635.6	$647,069	$786,969	$1,187	$2,163

** Maintenance costs divided by lbs TP over a 30 year period*
*** Total (base and maintenance) costs divided by lbs TP removed over a 30 year period*

The modeling scenarios show that more BMPs results in an increase in storm water treatment (runoff, TP, TSS). Each bioretention cell that is added to the strategy increases price however, so very little "bulk discount" advantage is realized through this strategy. Therefore, price increases displays a very similar trend line to that of the TP removal line seen in Figure 5. When comparing the TP removal with the 30-year cost of implementation, it is apparent that the optimization point is between 20 and 29 bioretention cells for this strategy. If 25 bioretention cells were constructed within this storm water management area, it would be expected that TP reductions would be roughly 13 lbs. per year at a total base cost of about ~$275,000.

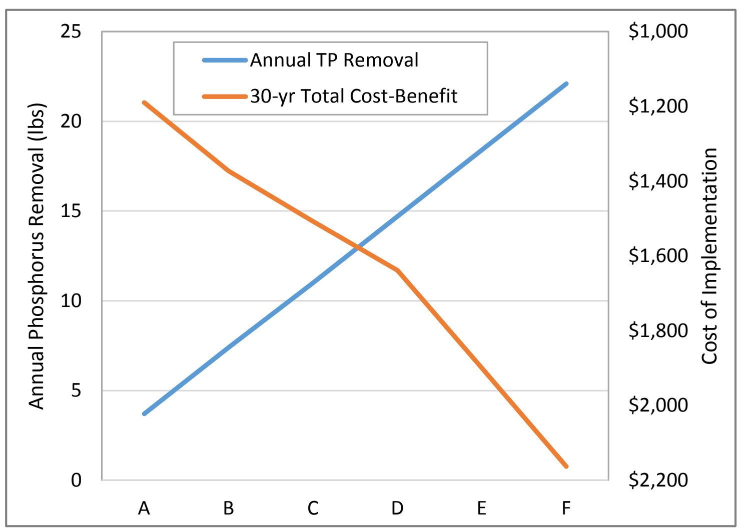

Figure 5: Phosphorus reduction vs 30-year cost-benefit for six bioretention cell scenarios. Adapted from WSB & Associates, 2016.

While substantial load reductions could occur through this strategy, the cost-benefit ratio is moderate when compared to strategy 3 (discussed further below). Additionally, the storm water management team felt it would be difficult to retain cooperation from ~25 property owners in this area to participate in the construction of bioretention cells on their private property.

Priority Management Area 1 – Treatment Strategy 2

The second treatment strategy evaluated by WSB & Associates includes a single BMP – a sub-surface sedimentation and filtration system – which would be located at the "outlet" of PMA 1 (Figure 6). At this location, water is currently funneled to a single drainage culvert which empties directly into Lake Orono. Sub-surface sedimentation and filtration systems are underground multi-chamber units that are designed to settle out suspended solids from storm water 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.

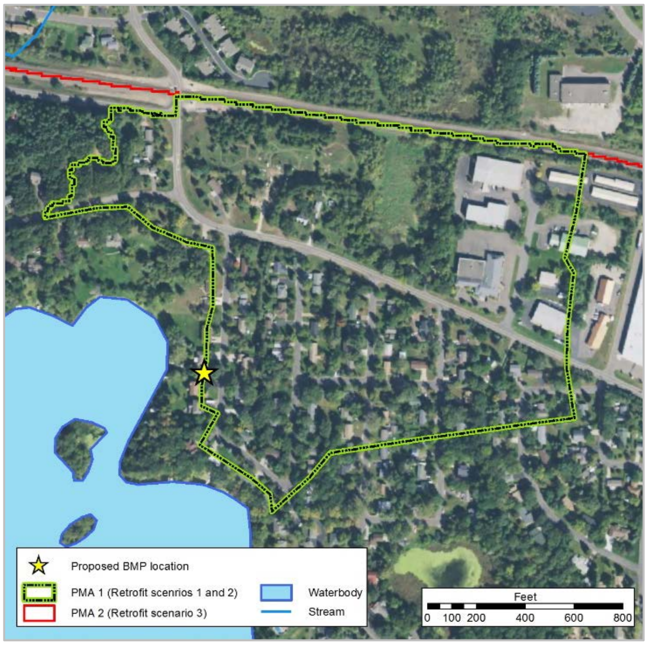

Figure 6: Priority Management Area 1, proposed area for sub surface sedimentation and filtration basin. .

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 7 displays a side profile of a typical sub-surface sedimentation and filtration system.

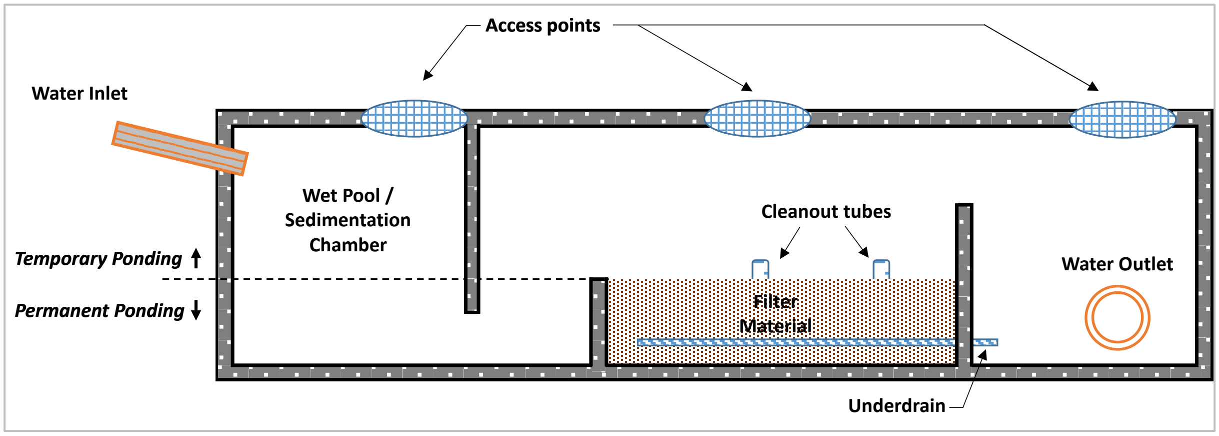

Figure 7: Sub-surface sedimentation and filtration system schematic, side profile.

The sub-surface sedimentation and filtration system option was examined from a cost-benefit standpoint in a similar manner as previously computed; a 30-year TP reduction estimate was compared to the overall costs (both base costs and maintenance). The result is the most economical cost-benefit ratio of all strategies included in this report (Table 3). From a cost standpoint, this was determined to be a very implementable project. The project would also have a high level of feasibility because it would be constructed on a small parcel of land that is owned by the City of Elk River; thus, no private property landowner participation would be required. However, while the costs for this option are relatively low and feasibility of implementation high, the level of impact upon receiving waters was not deemed to be adequate compared to alternative strategies. It was estimated that removal efficiency with the subsurface detention basin would be roughly 7.9 lbs. per year. The storm water management team decided that the level of phosphorus reduction from this project would be too minimal and that investigation of other strategies was warranted.

Table 3. Subsurface Detention Basin option specifications. Modified from WSB & Associates, 2016. Table displays treatment estimates as well as cost estimates for scenarios.

Subsurface Detention Basin							
Strategy	Annual removal			Facility & Capital	Maintenance	30-yr maintenance	30-yr Total
	Runoff (ac-ft)	TP (lbs)	TSS (lbs)	Base Costs	Costs (30yr)	Cost-Benefit	Cost-Benefit
3,610 ft^2 Basin	881	7.9	5,249.0	$130,347	$25,800	$109	$659

** Maintenance costs divided by lbs TP over a 30 year period*
*** Total (base and maintenance) costs divided by lbs TP removed over a 30 year period*

Priority Management Area 2 – Treatment Strategy 1

The third and final treatment strategy evaluated by WSB & Associates was located in PMA2, through which Lake Orono's second largest tributary other than the Elk River runs (Figure 8). The small stream drains 3,410 acres to the north of Lake Orono and runs through a storm water pond before entering the lake. The storm water pond, roughly 1.2 acres in size, was built in the 1950's and has seen little maintenance since that time. The site was selected for examination due to it being a significant tributary to the lake (not intermittent as the stream in PMA 1 is) and because it condenses runoff to a single point before entering Lake Orono. Additionally, signs of erosion around the pond indicated that maintenance work would be required in the near future.

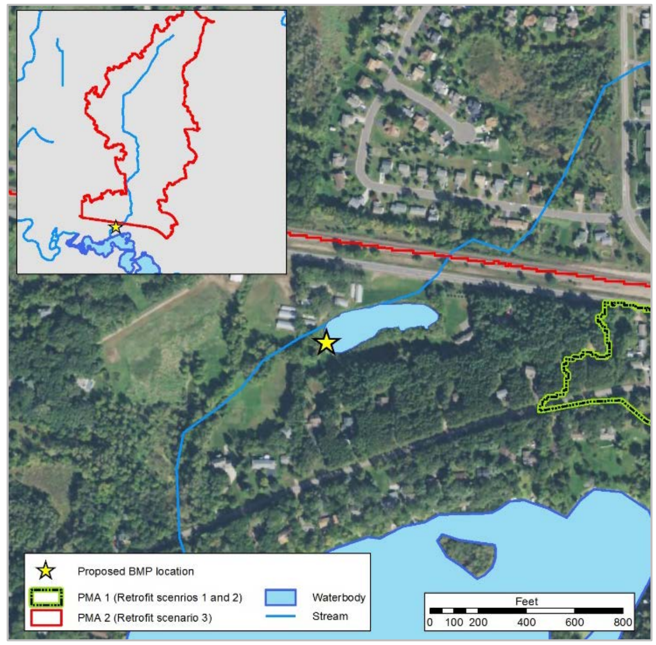

Figure 8: Priority Management Area 2, proposed area for iron-enriched sand filter bench. .

Several BMP types were considered for this location and discussed amongst the storm water management team. The concept of an iron-enriched sand filter came up, and the team examined this opportunity further in order to address not only suspended solids and particulate phosphorus but dissolved phosphorus as well. Dissolved phosphorus is not easy to treat and can be a larger nuisance than particulate bound phosphorus; it can escape traditional filtration and sedimentation treatments and is readily accessible to organisms such as algae whereas particulate phosphorus must be broken down before it becomes "biologically available".

Iron-enriched sand filters are a concept that was designed by researchers at the University of Minnesota St. Anthony Falls Laboratory, Minnesota. For this project, the filter bench would be combined with maintenance (dredging) of the storm water pond at this location. The advantage of this technique is that storm water entering the pond would first have an opportunity to "settle" particulates into the pond itself. An iron- enriched sand filter bench would be constructed around the outlet of the pond. The filter bench would capture additional particulates, while allowing the transport of water through it. These first stages are physical treatment mechanisms (particulate settling and screening). However, iron-enriched filters are unique in that they utilize a chemical reaction process as well. The BMP includes a mixture of raw iron filings and fine filter aggregate sand. 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. 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. Figure 9 is a side-profile diagram of an iron-enriched sand filter (also known as a "Minnesota Filter" in place on a storm water pond.

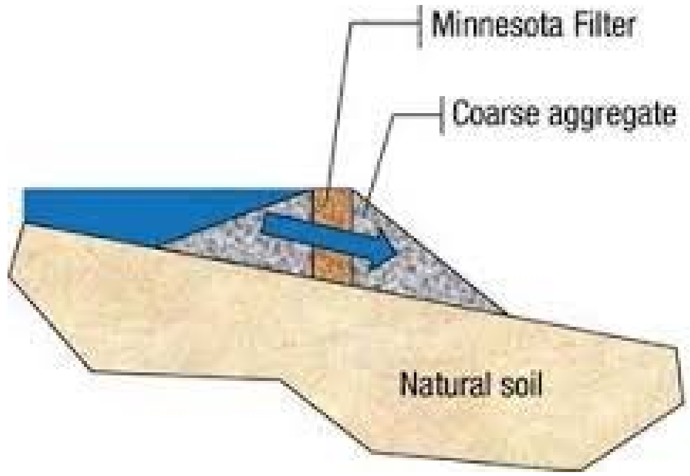

Figure 9: Iron-enriched sand filter bench (Minnesota filter). Diagram designed by University of Minnesota St. Anthony Falls Laboratory staff. The pond bench described in this report would employ a slightly different design, including an outlet structure.

The software P8 was used to model tributary inputs to this storm water pond as well as phosphorus and sediment detention through the use of iron-enriched sand filter benches in six size scenarios (Table 4). With an increase in filter bench size, the surface area of treatment increases and thus a larger retention of pollutants occurs. Though the upfront costs for benches of any size are relatively high, Table 3 displays that with an increase in BMP size only a relatively small increase in price occurs with each larger option. As such, as the bench size increases the cost-benefit value decreases and the cost of pollution mitigation decreases. This is in contrast to Option 1 (curb-cut bioretention), whereas the number of BMPs increased there was an associated increase in cost-benefit (Table 2). This exercise demonstrates that the iron-enriched sand filter, though carrying higher initial costs, has a higher level of efficiency at removing pollution from storm water.

Table 4. Iron-Enriched Sand Filter Bench. Modified from WSB & Associates, 2016. Table displays treatment estimates as well as cost estimates for scenarios.

Iron-Enriched Sand Filter Bench							
Strategy	Annual removal			Facility & Capital	Maintenance	30-yr maintenance	30-yr Total
(Bench area, ft^2)	Runoff (ac-ft)	TP (lbs)	TSS (lbs)	Base Costs	Costs (30yr)	Cost-Benefit	Cost-Benefit
A (980)	466	7.1	994	$167,140	$600,522	$2,819	$3,604
B (1,546)	922	14.1	1,854	$182,329	$614,934	$1,454	$1,885
C (2,722)	1,385	21.1	2,701	$213,903	$644,874	$1,019	$1,357
D (4,262)	1,841	28.2	3,538	$255,224	$684,090	$809	$1,110
E (6,316)	2,290	35.2	4,383	$310,487	$742,392	$697	$991
F (9,365)	2,736	42.3	5,218	$392,289	$814,026	$641	$951

** Maintenance costs divided by lbs TP over a 30 year period*

*** Total (base and maintenance) costs divided by lbs TP removed over a 30 year period*

Conclusions

Three options for storm water pollution mitigation were examined by representatives of the City of Elk River, Sherburne SWCD and WSB & Associates in 2015-2016. The team used pre-determined criteria in selecting which options were viable for further examination. Then, a P8 model was utilized to estimate pollution loading to the sites as well as treatment potential. Estimated costs were compared to the amount of pollution reduction achieved in order to develop a comparable cost-benefit value across all three BMP options. Feasibility of implementation, price ceilings, impact on water quality goals, and opportunities to engage or display to the public were factors that were considered additionally in determining appropriate BMP strategies to move forward with.

Cost-Benefit Comparison

Figure 10 displays the cost-benefit value (total 30 year value) and the amount of TP removed from each treatment option. The graph is oriented with ascending order of the total cost-benefit metric. Overall, a subsurface sedimentation and filtration system (sub surface detention) was calculated to have the lowest cost-benefit value, or the lowest price per pound of TP removal. This was followed by iron-enriched sand filter bench F (9,365 ft^2), bench E (6,316 ft^2), bench D (4,262 ft^2) and then curb cut bioretention option A (5 BMPs). The iron-enriched sand filter bench option A (980 ft^2) had the highest price per pound of TP removal. As previously discussed, there is an initial high cost for installation of this practice as it includes dredging of the pond where it would be located.

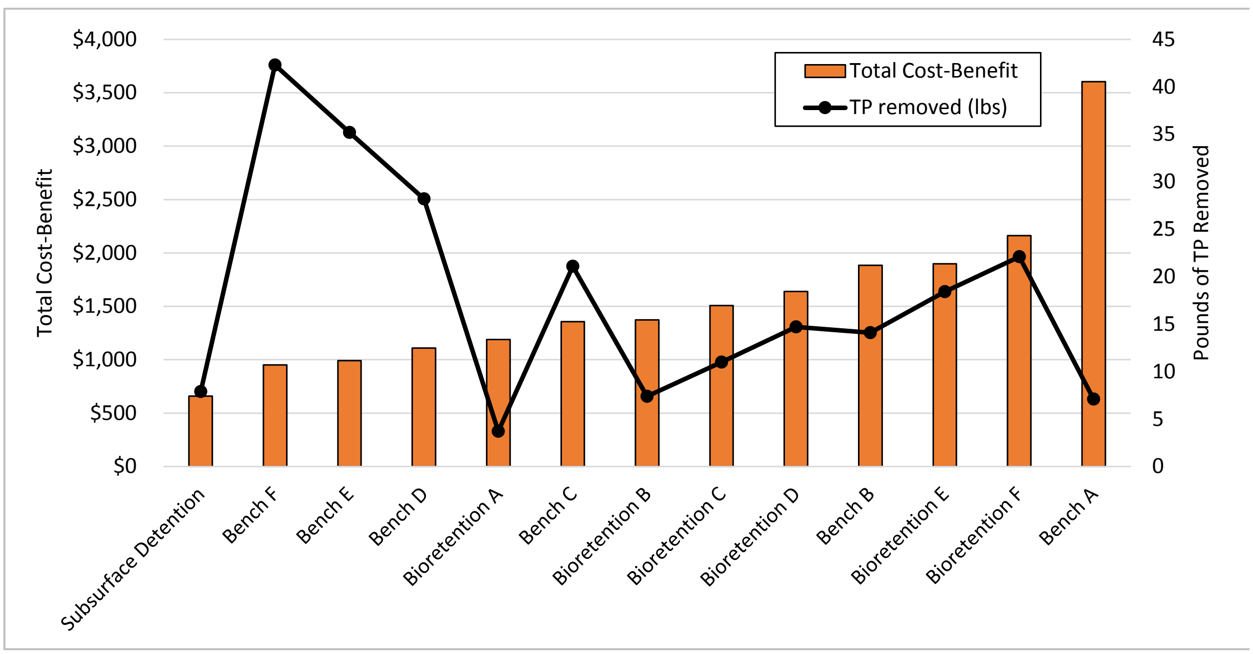

Figure 10: Iron-enriched sand filter bench (Minnesota filter). Diagram designed by University of Minnesota St. Anthony Falls Laboratory staff. The pond bench described in this report would employ a slightly different design, including an outlet structure.

Implementation Feasibility

Each of the three treatment options have a certain level of viability in their implementation, based upon costs, location, level of pollutant reduction, etc. The curb cut bioretention treatment strategy was determined to be most effective at 25 installed bioretention units. The cost associated with implementation would be about $275,000. This was considered to be a cost that was relatively high, but still achievable through grant funding opportunities. For this option, participation of private property owners was assessed. There are approximately 66 private residences within PMA 1; in order to achieve 25 curb cut bioretention units in this area, 38% of residences would have to participate by installing unit on their property. However, not all properties would be suited for such a practice due to inadequate slope profiles, zoning or transportation requirements, localized soil anomalies or other factors that would make for unsuitable conditions. If 70% of those 66 residences were deemed to be suitable for BMP installation, participation in bioretention unit installation would need to reach 54% in order to reach the optimal number of BMPs (25) for PMA 1. It was generally felt by the storm water management team that while there is support for storm water pollution mitigation amongst area residents, it would be very difficult to get adequate participation in the curb cut bioretention program in order to reach the desired number of units. The curb cut bioretention option was determined to have a low to moderate level of feasibility, due to the required involvement of private property owners.

The sub surface sedimentation and filtration system, with its low cost and public property location, was determined to have a high level of implementation feasibility. With support from the project partners as well, very few barriers were identified. However, concern was expressed on its level of impact.

The iron-enriched sand filter bench would be located on a pond that the City of Elk River owns through an easement, and is adjacent to private property. Through early conversations with the private property owner it was learned that the property owner was very encouraging of the project. The property owner also has concerns regarding soil erosion along the pond's shoreland as well as upland areas on their property which drain to the pond. The owner further voiced support for placing dredging spoils on their property in areas that had eroded away. The only potential barrier to implementation for this treatment strategy would be the high cost associated with installation. However, with a grant program available for potential funding and the City of Elk River having storm water pond maintenance funds as match, this was determined to be a minimal barrier. This treatment strategy was determined to have a high level of implementation feasibility. Figure 11 displays a relative comparison of implementation feasibility amongst the three treatment options.

Figure 11: Relative implementation feasibility graphic for three City of Elk River storm water options.

Price Ceilings

While cost-benefit is a good tool to examine and compare return on investment, there is a point in which the expense of implementing a BMP is too great for consideration. Such is the case when BMPs are funded through grant programs that have match requirements and maximum cash amounts. It was anticipated by the Sherburne SWCD and City of Elk River that a grant would be written in August 2016 to the Clean Water Fund program, a grant program administered by the Board of Water and Soil Resources. There is no defined project cost cap in this program, however higher priced proposals are typically harder to receive funding for. Additionally, a 25% match is required by the sponsor and partners; with a higher project cost, the match responsibility is increased as well. It was determined by Sherburne SWCD and City of Elk River staff that a proposal budget should not exceed $250,000 to $300,000 if it were to have a high level of success.

Figure 10 displays several iron-enriched sand filter bench options (Bench F, E, and D) which provide over 30 lbs. of TP removal per year and have a cost-benefit of less than $1,110. Bench F and E provide the highest level of TP reduction, however the facility and capital costs for these BMPs were estimated to start at over $310,000 with additional maintenance costs to follow (Table 3). Curb cut bioretention strategies D, E and F also would have a large (>$310,000) up front cost. Iron-enriched sand filter bench option D provides the highest TP removal rate for options under $300,000 for base costs.

Impact on Water Quality Goals

As previously mentioned within this report's Introduction, the Town of Big Lake, City of Big Lake and City of Elk River are required to reduce their loading by 50% to a combined 468.11 lbs. of TP per year. If this load is divided evenly amongst the three municipalities, the City of Elk River would be responsible for a 156 lb. reduction of TP annually. None of the modeled scenarios in this project produce a load reduction of this level; so, efforts brought forth from this project would need to be coupled with additional pollution mitigation projects in the City of Elk River MS4 watershed in order for this goal to be reached. However, projects determined to be suitable through this study would be a good start. The storm water management team decided to prioritize BMP implementation that would result in as large of a TP reduction as possible, given cost restraints and overall feasibility. While the sub surface sedimentation and infiltration system would be a cost-effective project, its level of TP reduction is quite low relative to other treatment options. Bioretention treatment options A, B and C result in relatively low levels of pollution mitigation as well. Bioretention treatment options D through F result in over 14 lbs. of TP removed per year, while iron-enriched sand filter bench options C through F would allow for between 21 and 42 lbs. of TP removal.

Further, it was decided that between PMA 1 and PMA 2 that the latter management area should be prioritized for treatment as it was determined to carry a larger water volume and phosphorus load. Targeting this larger load first would have a larger impact on reaching the City of Elk River's MS4 load allocation goal as well as the overarching Lake Orono TMDL goal.

Public Engagement / Education

Public engagement or education with a storm water project was an aspect considered complimentary, but not critical, to treatment strategy determination. By involving or notifying the public of an activity, there is a greater understanding of what regional water resource professionals are doing to address water quality concerns. Educational programs also provoke further opportunities from the public, as people see demonstrations of pollution mitigation practices and might voice support for more work to be completed.

All three options could be shared with the public through media, including SWCD social media and newsletters as well as the quarterly newsletter the City of Elk River produces. The curb cut bioretention option required a great amount of public involvement, so much in fact that there was concern over how practical this option was. The sub surface sedimentation and filtration system and iron-enriched sand filter bench would be located on public property, so the opportunity exists. The sub surface sedimentation and filtration system would be located near a suburb road, where signage could be placed. The filter bench is located off of the nearby road, however the adjoining private property owner has a business that is located on their property next to the pond where the bench would be established. The property owner has agreed with the idea of placing signage near the pond to educate business customers on the impacts of the BMP that the pond utilizes.

Treatment Strategy Selection

Ultimately, the Sherburne SWCD and City of Elk River decided that an iron-enriched sand filter bench of 4,262 ft^2 (option D) would be the best option to pursue. This practice was located within PMA 2, an area determined to have larger impact towards the City of Elk River MS4 reduction allocation and Lake Orono water quality goals. This option included the 4^{th} lowest cost-benefit value out of 13 total options, making it a cost effective treatment strategy. The strategy also held a high level of implementation feasibility due to it being located on City of Elk River property and having a good working relationship with the neighboring private property owner. While the cost of iron-enriched sand filter bench options E and F were considered to be too high, option D fell within the parameters that the Sherburne SWCD and City of Elk River determined were necessary for a grant proposal. And finally, though of lesser importance, an educational opportunity would be available to showcase this BMP and its ability to address storm water pollution to the public.

It is recommended that the Sherburne SWCD and City of Elk River move forward with pursuing funding for an iron-enriched sand filter bench on the pond located near the outlet of PMA 2. Specifically, the partnership may apply for a Projects and Practices grant through the Clean Water Fund grant program administered by BWSR. The grant application should include costs for the practice itself, as well as program development to prepare permit paperwork and conduct general oversight, administrative time, costs for site-specific engineering surveys and minimal funds for BMP education through the preparation of signs to be placed near the pond. The City of Elk River will provide over 25% match through funds to be utilized for preparation of the pond; specifically, dredging of settled material from the pond's bottom.

It should be noted that additional practices within PMA 1, though not receiving priority recommendation through this report, would still be viable means of reducing storm water input to Lake Orono. The sub surface sedimentation and filtration system would be a good second consideration due to its low cost, "end-of-pipe" public property location, and overall feasibility to install. This practice, or a similar option, may be considered in the future as the City of Elk River continues to work at reducing the storm water TP load and meeting its MS4 load allocation requirements.

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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