Stormwater Water Quality Best Management Practice Retrofit Analysis

Bemidji, Minnesota

Mississippi Headwaters Board

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Bemidji Stormwater Water Quality Best Management Practice Retrofit Analysis

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ABSTRACT

An analysis was performed of the potential for retrofitting water quality stormwater best management practices (BMP) into the City. A tiered approach was performed starting with a review of existing spatial data and the local knowledge of City Staff to identify areas least likely to be conducive to retrofitting, were regularly non-contributing to the Mississippi River or other water bodies of interest or already received significant water quality treatment. What catchments remained were designated Priority Management Areas (PMA) and were modeled to estimate existing delivery of phosphorus and sediment. A second review of watershed data was performed to identify the locations and types of structural BMPs that each PMA would support. A field inspection of each PMA was made with City Staff to confirm assumptions as well as collect information on the physical drivers on the conceptual BMP design. Though this study was relatively rapid in approach, leaving out modeling of options in other catchments, the results provide the highest return on investment options the City can initiate a retrofit plan with.

Each PMA's potential BMP(s) was then analyzed for treatment value. Each BMP was modeled at various levels of phosphorus treatment relative to the entire PMA whether it received water from the entire PMA or only a portion of it. When a single BMP reached a 70% phosphorus reduction for the drainage area leading to it, which in several cases represented only a portion of the PMA, design tuning was stopped as the incremental costs for additional treatment reduced overall value of the system. Costs associated with design, installation and both annual and significant maintenance events were tallied for each of 50 years of operation for each BMP. The value of money was adjusted for each year to then determine a present day value for the 50-year operational term. The present day value was divided by the sum of 50 years of phosphorus removal to determine a BMP treatment value. This value informs the City on which BMPs options provided the highest return on investment.

Priority Management Area	BMP Option	Annual TP Loading (lbs/yr)	Annual TSS Loading (lbs/yr)	BMP TP Treatment (lbs/year)/(% Removal)	BMP TSS Treatment (lbs/year)/(% Removal)	50 Year Value ($/lb-TP
PMA 6 opt 1	Permeable Parking Lot	16.4	5,206	4.4/27%	1,457/28%	$1078
PMA 6 opt 2	Parking Lot Bioretention	16.4	5,206	4.9/30%	1,699/60%	$700
PMA 7 opt 1	Stormwater Reuse	154.5	48,786	34.7/23%	15,402/32%	$393
PMA 7 opt 2	Extended Detention	154.5	48,786	46.3/30%	29,197/70%	$294
PMA 7 opt 3	Extended Detention	154.5	48,786	61.8/40%	34,115/70%	$392
PMA 25	Iron-Chloride System	551.9	175,077	149.8/27%	45,741/26%	$213

Contents

1 Introduction

The Mississippi Headwaters Board (MHB) operates as a joint powers board of Clearwater, Beltrami, Cass, Hubbard, Itasca, Aitkin, Crow Wing and Morrison Counties to protect and preserve the first 400 miles of the Mississippi River in Minnesota. The MHB works with municipal and other jurisdictions within these counties on various projects to enhance water quality and stewardship of the water resources within the watershed.

In June of 2014 the Mississippi Headwaters Board contracted with HDR to perform an assessment of water quality Best Management Practices for the Cities of Little Falls, Grand Rapids, and Bemidji, Minnesota.

The purpose of this report is to summarize the results of an assessment of potential municipal stormwater water quality best management practice (BMP) retrofit locations for the City of Bemidji, Minnesota. The project consisted of a review of the City's existing stormwater system (including storm sewer infrastructure, catch basins, ponds and outfalls), zoning and land use information, and other records to identify potential locations for stormwater quality BMPs. These areas were identified as Priority Management Areas, or PMAs. Each PMA was visited with City staff to field verify conditions, identify site-specific issues that would factor into BMP selection, and to assess overall BMP design or performance limitations. Following the site assessments, specific BMPs were selected for each PMA for further evaluation.

After potential BMP concepts and locations were finalized, water quality modeling was performed to determine BMP size for up to three different levels of treatment (e.g. total phosphorus treatment at 30%, 50%, and 70% level) for total phosphorus and total suspended solids. Costs for each BMP option and treatment level were determined, and a present worth analysis was performed. The present worth analysis included capital (construction) costs, regular maintenance costs, and replacement costs (where applicable) for a 50-year period. Costs were then reported on a present worth dollar per pound of pollutant removal ratio.

2 City Watershed

2.1 Watershed Characteristics

Bemidji is situated between Lake Bemidji and Lake Irving. A majority of the City drains to those two lakes and the Mississippi River is the outlet for each lake. The northwest portion of the City sits higher than the rest of the City and is mainly residential and academic by land use. Bemidji State University takes up a large amount of land follows the shore of Lake Bemidji and has large areas of drainage flowing through it to Lake Bemidji. The older portion of town is located on the southwest side of Lake Bemidji and is mostly impervious area filled with commercial and government buildings. The southeast portion of Bemidji is mostly industrial and residential areas that mostly drain towards Lake Irving.

2.2 Stormwater Infrastructure

The City of Bemidji provided Geographic Information Systems (GIS) databases of public stormwater infrastructure containing inlets, pipes, outlets, swales and ponds (Figure 1). This information was reviewed for flow routing and subsequent pipeshed delineation. Many of the outfalls to Lake Bemidji and Lake Irving are located within easements that run through private land and have little to no treatment prior to discharging into the lakes and subsequently the Mississippi River.

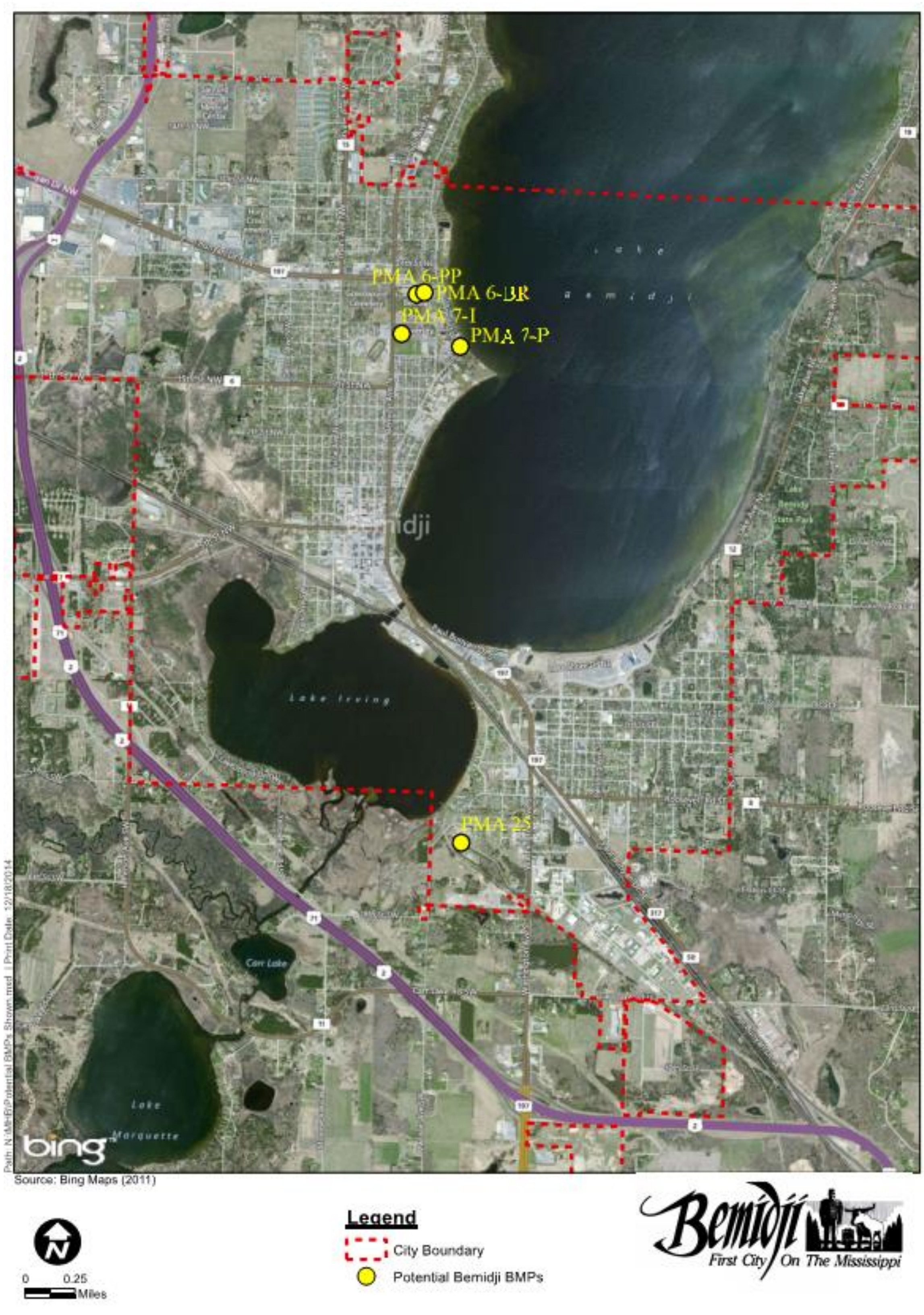
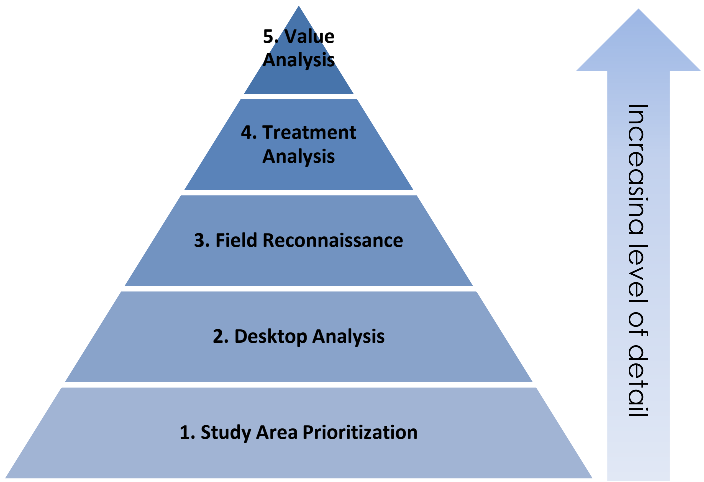


Figure 1: Overall Map of Potential BMPs

3 METHODS

The retrofit assessment followed an approach based on the Center for Watershed Protection's Urban Stormwater Retrofit Manual (CWP 2007). Each step of the process eliminated areas or sites were potential BMPs would likely be ineffective or highly difficult to install or maintain (Figure 2). As the steps proceed, a finer resolution method was used to analyze the retrofit performance and cost potential.

Figure 2. The hierarchal retrofit analysis approach used in this analysis.



3.1 SELECTION OF STUDY AREA

3.1.1 Pipeshed Delineation

City stormwater conveyance infrastructure data were imported into a project GIS file. Two foot contour lines were used along with this data to manually digitize pipeshed boundaries. These boundaries were made available to the City staff members for review and validation purposes.

3.1.2 Study Area Prioritization

The entire City was reviewed in GIS using aerial photography, parcels, soils, topography, land use, wetland, streams and lakes as well as municipal stormwater pipe and BMP data sets to identify a refined Study Area (Table 1). This step of analysis identified those pipesheds that are most likely to contribute the majority of pollutant loading to water resources and those that were either non-contributing or likely to have either significant treatment in place or less feasible options for additional retrofit opportunities. The resulting study area was comprised of those pipesheds that either directly discharged to the water body of interest, had wetlands or stormwater BMPs that could be easily modified to improve water quality performance or, despite having in-pipeshed BMPs, have potential for retrofitting additional BMPs with primarily different pollutant removal processes.

Table 1. Key to study area prioritization for further analysis

Criteria	Include in Further Analysis?	Method(s) of Determination
1A Pipeshed is non-contributing (10-year storm does not flow to the water resource of concern; landlocked)	No	1. Local expert knowledge 2. HydroCAD 10yr, 24 hr 3. Review of stormwater pipe infrastructure data in GIS
1B Pipeshed ultimately drains to a water resource of concern	Move to step 2	
2A Pipeshed directly drains to water resource of concern	Yes	• Review of stormwater pipe infrastructure data in GIS
2B Pipeshed drains to intermediary waterbody	Move to step 3	
3A Pipeshed drains to wetland(s)	Move to step 3A1	• Review of stormwater pipe infrastructure data in GIS
3A1 It is not likely feasible to modify the wetland or treat the effluent	No	• Review of NWI, parcel, soil, topography and aerial photography in GIS
3A2 It may be feasible to modify the wetland and/or treat the effluent via infiltration of filtration	Yes	
3B Pipeshed drains to stormwater BMP feature(s)	Move to step 3B1	• Review of stormwater pipe and BMP infrastructure data in GIS
3B1 It is not likely feasible to modify the feature to improve performance nor obtain upstream BMPs that primarily use differing pollutant removal mechanisms than the existing feature	No	• Review of access easement, parcel, soil, topography and aerial photography in GIS
3B2 It is likely feasible to modify the feature to improve performance and/or obtain upstream BMPs that primarily use differing pollutant removal mechanisms than the existing feature	Yes	

3.2 Desktop Identification of Potential Retrofit Sites

The Study Area was reviewed with the City Engineer and City staff members, in GIS, for areas conducive to retrofitting mid- to large-scale storage-focused BMP options (CWP 2007). These include:

1. Existing pond modification potential
2. Above roadway culverts
3. Below stormwater outfalls
4. Within the conveyance system (ditches or daylighting opportunities)
5. Transportation right of ways
6. Large parking lots

The Study Area was then reviewed for potential on-site retrofit locations (CWP 2007), including:

1. Hotspot operations (e.g., gas stations, industrial, chemical/fuel storage yards, etc.)
2. Small parking lots
3. Residential streets/blocks
4. Open space/pervious areas for disconnecting pervious areas
5. Urban hardscape
6. Large rooftops
7. Underground treatment

Each site was viewed using aerial photography to identify any limitations for retrofitting (Appendix 1 – Ideal and Difficult Scenarios for Various Retrofit Locations). Sites were excluded from further analysis if the desktop review identified less than ideal situations. For each site, consideration was given to several types of BMPs, or configurations (i.e., treatment-trains; Table 2). The potential retrofit options were assigned to specific parcels and flagged for field reconnaissance.

Table 2. Stormwater treatment options by location (adapted from CWP 2007)

	Stormwater Treatment Option (BMP)						
Location	**Extended Detention**	**Wet Ponds**	**Stormwater Wetlands**	**Bioretention**	**Filtration**	**Infiltration**	**Swales**
Existing pond modification	●	●	●	▲	▲	○	○
Above roadway culverts	●	▲	●	○	○	○	○
Below stormwater outfalls	●	●	●	▲	▲	○	○
Within the conveyance system	▲	○	●	●	○	○	●
Transportation right of ways	●	●	●	●	▲	○	▲
Large parking lots	●	●	●	▲	▲	▲	○
Hotspot operations	○	○	○	●	●	X	○
Small parking lots	○	○	○	●	●	●	●
Residential streets/blocks	○	○	○	●	▲	▲	○
Open space	○	○	○	●	▲	●	●
Urban hardscape	○	○	▲	●	▲	▲	▲
Large rooftops	○	○	○	●		▲	●
Underground treatment	▲	○	○	▲	●	▲	○

● = Preferred stormwater treatment option
▲ = Feasible in some circumstances
○ = Seldom used for the retrofit
X = Not recommended under any circumstances

3.3 Field Reconnaissance

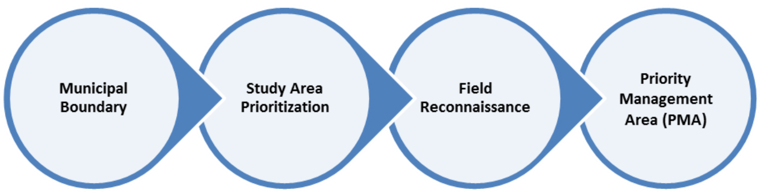
A field visit to key locations identified in the desktop review of the Study Area allowed HDR and City staff to review each site together, and identify both potential BMP retrofit opportunities as well as non-contributing and sites with limited retrofit potential.

A meeting with the City was beneficial in ruling out certain areas that were determined to be not ideal or difficult to retrofit, and in identifying additional areas for improvement that could make a larger impact on the quality of the water discharged into the Mississippi River.

3.4 Priority Management Areas

As a result of the study area prioritization, desktop identification of potential retrofit sites and field reconnaissance, Priority Management Areas (PMAs) were selected for further analysis, including water quality modeling. The PMAs represent areas within the City that have been determined to have high potential for water quality treatment and the greatest ease of retrofit installation, will align well with city planning, and have the potential to provide multiple benefits. For each PMA, the total drainage area, land use, stormwater conveyance system, existing water quality BMPs and other characteristics were assessed and used as inputs into the water quality modeling process. The process for selecting PMAs is summarized in Figure 3.

Figure 3. PMA Selection Process



3.5 Water Quality Modeling

Priority management areas were modeled to estimate total watershed pollutant and stormwater generation, the level of treatment of any existing stormwater BMPs as well as improved treatment by recommended retrofit strategies. Water quality modeling was performed using P8, a stormwater model developed for designing and evaluating runoff treatment schemes for urban developments. P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds) predicts the generation and transport of urban stormwater constituents, and has the ability to model the performance of BMPs placed within the drainage area. It accounts for both the effects of physical infrastructure, like detention ponds, and operational practices, such as street cleaning. The model uses estimates of impervious area, pervious land area runoff coefficients, and sediment-pollutant associations to calculate both volume and water quality of urban runoff. Continuous water-balance and mass-balance calculations are performed on a user-defined drainage system consisting of up watersheds; runoff storage/treatment areas, and various water quality components. Simulations are driven by hourly rainfall and daily air temperature values.

City zoning maps were imported into the project GIS as polygon files. Each zoned use was reviewed, along with aerial photography, and compared to land use definitions provided in WinSLAMM documentation for reclassification purposes (Pitt, et. al., 2014; Appendix 2 – WinSLAMM Land Use Descriptions). WinSLAMM's land uses definitions were then used to "calibrate" P8 Urban Catchment Model input parameters as per guidance found in the P8 help file for watershed definition (Walker 2014; Appendix 3 – Parameterization of P8 Inputs to WinSLAMM).

3.5.1 Existing Treatment

Existing water quality BMPs were incorporated into the analysis as a basis for water quality predictions. In several cases there were no existing water quality BMPs identified within PMAs during the study area prioritization or site visit phases of evaluation. For those PMAs with existing treatment schemes, including wetlands and ponds, however, the effects of these features were estimated using P8.

Ponds and wetlands: Aerial photography was used to digitize the extent of the presumed permanent pool footprint. A Digital Elevation Model (DEM) was used to determine the acreage of potential live storage above the permanent pool. Pipe size data from the City stormwater infrastructure was used to establish outlets for these features, set at the permanent pool elevation. Since no bathymetry data was available, it was assumed that there was 3 feet of permanent pool volume with 3:1 side slopes to a modeled pond bottom. Drainage areas connected to these BMPs were defined and a 20-year, continuous model was run. The results were designated as existing conditions for the PMA.

3.5.2 Retrofit Network Treatment

The recommended retrofit BMPs were modeled for each PMA. BMP sizes were incrementally sized for up to three different overall PMA treatment level goals (30%, 50% and 70% removals) for phosphorus. In some cases, the BMP size (and therefore treatment potential) was limited by site constraints, and overall PMA treatment performance. In other words, the size of the BMP was optimized in an iterative manner to a point where the site limited its further expansion or the BMP reached 70% removal of the targeted pollutant. In those cases where 70% removal was not possible, the maximum removal was noted. The contributing treatment from the BMP retrofit was considered together with existing treatment, as well as conceptual treatment-train effects, to estimate overall PMA treatment levels.

Water quality BMPs evaluated in these assessments included permeable pavement, curb-contained bioretention, regional bioretention, extended detention, and stormwater re-use for irrigation (underground storage). Conceptual treatment modeling assumed the following for each BMP strategy:

Permeable pavement: Asphalt parking stall located within the rebuilt parking lot such that it receives flow from 90% of the lot. Three feet of angular granite with a void space of 40%.

Parking lot bioretention: Two high-flow bypass curb-cut inlets located at either end of the treatment cell (dividing parking lot into two roughly equal sub drainage areas) each with a Rainguardian™ forebay. No retaining walls but with 3:1 sideslopes and 1.5 foot of ponding depth. No underdrain.

Curb-contained (boulevard) bioretention: One high-flow bypass curb-cut inlet to each 250 ft^2 bioretention cell. A Rainguardian™ forebay. No retaining walls but with 3:1 sideslopes and 1.5 foot of ponding depth. Over-excavation of *in situ* soils. Three feet of 70:30 sand:MNDOT Grade 2 Compost media with a perforated underdrain 6 inches off the bottom of the interface between *in situ* soil and backfilled media. Underdrain connected to adjacent manhole.

Regional bioretention: Live pool forebay of approximately 5000 ft^2 with v-notch/orifice weir spilling over into bioretention area. No retaining walls but with 3:1 sideslopes and 1.5 foot of ponding depth with riser overflow. Over-excavation of *in situ* soils. Three feet of 70:30 sand:MNDOT Grade 2 Compost media with a perforated underdrain 6 inches off the bottom of the interface between *in situ* soil and backfilled media. Underdrain connected to adjacent storm sewer structure.

Extended detention: New pond with 36 hours of detention time. Permanent pool of 6-ft depth, flat bottom, 3:1 slopes. Live pool of 3-ft with 5:1 sides slopes.

Stormwater re-use for irrigation: Below-ground cistern sized to store the 1-inch rain event from contributing drainage area. Pumps and appurtenances. Filtration equipment. Overflow to a similarly-sized infiltration cistern. OptiRTC Controller, cloud-based Microsoft Azure Application and PC operation dashboard automated outlet control from irrigation cistern to infiltration cistern. Treatment estimates were based on guidance within the Minnesota Stormwater Manual (2014) for Hydrologic Soil Group B watersheds for various levels of imperviousness.

Regional Chemical Treatment System: Information from the Prior Lake-Spring Lake Watershed District was used to roughly estimate the performance and costs associated with this strategy. It was beyond the scope of work to develop costs into more detail.

3.6 Value Analysis

Capital and whole life cycle costs for each BMP option and treatment level were determined, and a present worth analysis was performed. The cost analysis included capital (construction) costs, and maintenance costs, which include regular maintenance activities and infrequent or corrective costs (where applicable). Costs were tabulated over a 50-year period, and a present day value was determined for each BMP option. Costs were then reported on a present worth dollar per pound of pollutant removal ratio to compare the costs and treatment benefits of various BMPs.

A whole life cost tool developed by the Water Environment Research Foundation (WERF) was used to develop the present day value of each BMP option. The model consists of a set of spreadsheet tools that combine capital costs and ongoing maintenance costs to estimate whole life costs. Simplified methods were used to determine capital costs for constructing BMPs, including permeable pavement, cisterns (for irrigation storage), curb-contained bio-retention, and extended detention basins.

Maintenance costs included regular maintenance and infrequent maintenance activities. Regular maintenance included inspection, vegetation management, and trash removal, among other activities. Infrequent or corrective maintenance activities included any intermittent activities to rehabilitate or replace all or portions of the BMP. These might include sediment removal from detention basins, or replacement of pavement sections, and other intermittent activities. Schedules (months or years between maintenance periods) were estimated for each activity which factored into the whole life cost determination.

Once capital and annual costs were determined, whole life costs were calculated for each BMP. A discount rate of 3 percent was used to bring annual costs accrued over a 50-year period to a common present day value. The present day value was then divided by the estimated pollutant removal (in pounds of phosphorus or TSS over the 50-year life) to determine the cost efficiency of each level of treatment.

4 RESULTS

4.1 PRIORITY MANAGEMENT AREA IDENTIFICATION

Within Bemidji there were several areas within the vicinity of the Mississippi River identified as Priority Management Areas, with potential BMP opportunities (see Figure 1). These included:

PMA 6-PP. Redesigning a parking lot located near Oak Hall off of Birchmont Drive NE and 23rd Street NE. Potential BMPs would include pervious pavement, increasing the number of islands for treatment, and regrading the lot to drain more towards the playing fields (see Figure 4).

PMA 6-BR. The areas in front of Oak Hall have potential to treat drainage from the parking lot and future buildings using a bioretention system (see Figure 4).

PMA 7-I An area within the playing fields located off Bemidji Avenue North and 17th Street NE which would be a partnership with Bemidji State University. A potential retrofit would be an underground cistern and use the water for irrigating the surrounding playing fields (see Figure 4).

PMA 7-P. In front of Decker Hall on Birchmont Drive NE there is an existing pond that has potential to be expanded to increase the treatment time prior to discharging into Lake Bemidji (see Figure 4).

PMA 25. A City-owned parcel southeast of Roosevelt Road SW and west of a series of townhomes. This retrofit would include an extended detention basin where the stormwater from the area could be chemically treated with FeCl prior to discharging into Lake Irving (see Figure 5).

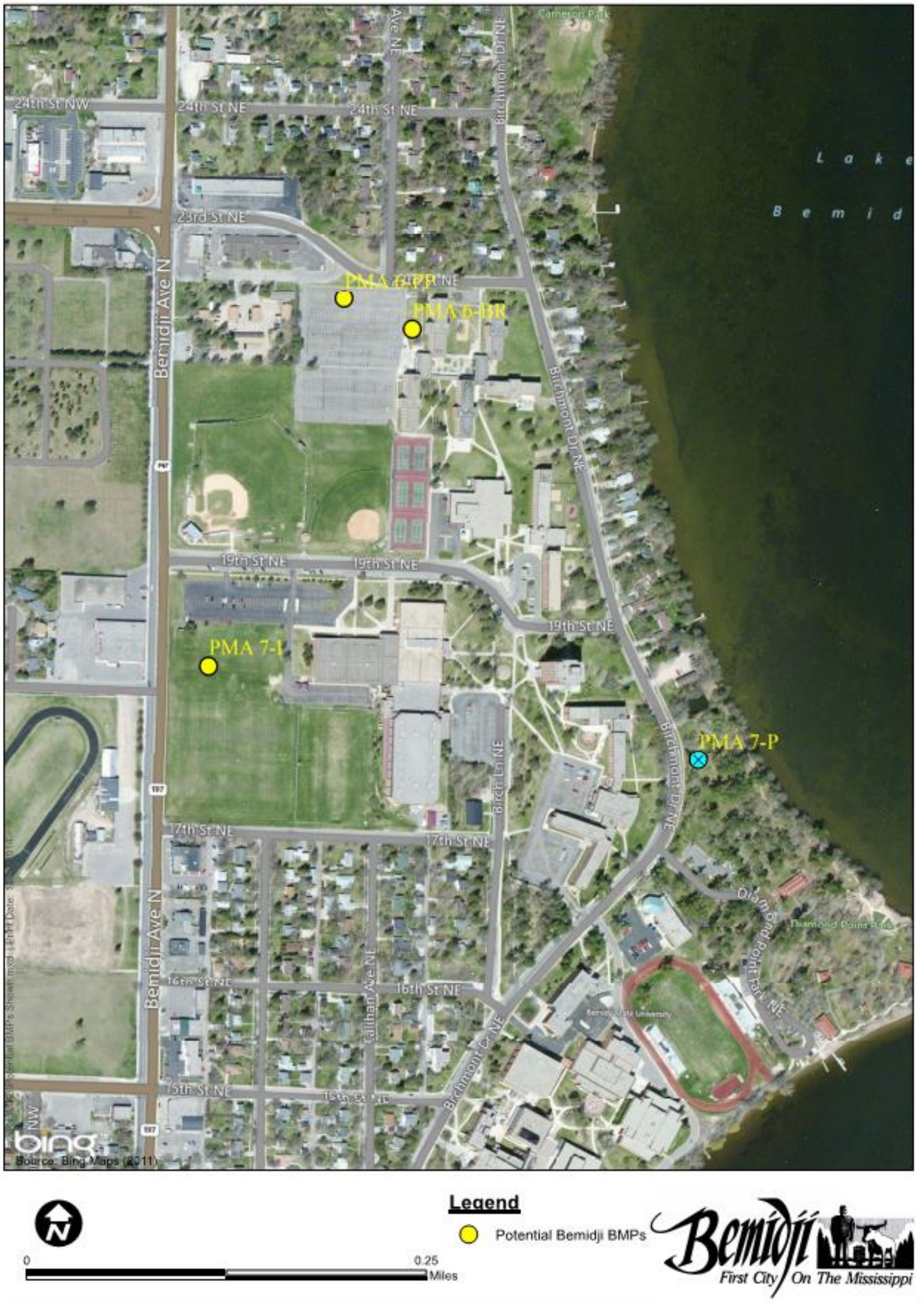


Figure 4: Location of PMA 6-PP, PMA 6-BR, PMA 7-I, and PMA 7-P

Figure 5: Location of PMA 25

4.2 Model Results

For each PMA, stormwater runoff volume and water quality were modeled using P8. A model of the existing conditions was run to determine baseline TP and TSS removals associated with existing stormwater BMPs, including ponds at PMA 7-P and PMA 25. The P8 model was then applied to size BMPs to achieve total phosphorus (TP) removal targets of 30% and 40% (including existing BMP treatment), or to optimize pollutant removal when the targets were not achievable due to site or other constraints. The results for each PMA are summarized below.

4.2.1 PMA 6-PP

The BMP for PMA 6-PP consists of installing permeable pavement in a parking lot located near Oak Hall off of Birchmont Drive NE and 23rd Street NE (see Figure 4). There is currently no stormwater BMP at this location. The model computed a single BMP size associated with 27% TP removal. Results from modeling are summarized in Table 3.

Table 3. PMA 6-PP Results

PMA 11 BMP Type: Pervious Pavement, 27% TP Removal	
Drainage Area TP Load (lbs/year)	16.4
Drainage Area TSS Load (lbs/year)	5,206
BMP TP Treatment Efficiency (lbs/year)/(% Removal)	4.4/27%
BMP TSS Treatment Efficiency (lbs/year)/(% Removal)	1,457/28%
Total BMP Area (ft^2)	9,496
Total Flood Volume (ft^3)	28,488

4.2.2 PMA 6-BR

The BMP for PMA 6-BR consists of a bioretention area located in the front of Oak Hall (see Figure 4). There is currently no stormwater BMP at this location. The model computed a single BMP size associated with 27% TP removal. Results from modeling are summarized in Table 4.

Table 4. PMA 6-BR Results

PMA 6-BR BMP Type: Bioretention, 30% TP Removal	
Drainage Area TP Load (lbs/year)	16.4
Drainage Area TSS Load (lbs/year)	5,206
BMP TP Treatment Efficiency (lbs/year)/(% Removal)	4.9/30%
BMP TSS Treatment Efficiency (lbs/year)/(% Removal)	1,699/60%
Total BMP Area (ft^2)	4,355
Total Flood Volume (ft^3)	4,355

4.2.3 PMA 7-I

The BMP for PMA 7-I consists of a stormwater capture and irrigation system at the athletic fields located off Bemidji Avenue North and 17th Street NE (see Figure 4). There is currently no stormwater BMP at this location. The BMP size and configuration were based on the available irrigation area and the runoff volume associated with a 1-inch storm event. Results are summarized in Table 5.

Table 5. PMA 7-I Results

PMA 7-I BMP Type: Stormwater capture and subsurface storage for irrigation	
Drainage Area TP Load (lbs/year)	154.5
Drainage Area TSS Load (lbs/year)	48,876
BMP TP Treatment Efficiency (lbs/year)/(% Removal)	34.7/23%
BMP TSS Treatment Efficiency (lbs/year)/(% Removal)	15,402/32%
Total Irrigation Volume (gallons)	125,000
Total Overflow/Infiltration Volume (gallons)	210,000
Total Volume (gallons)	335,000

4.2.4 PMA 7-P

The BMP for PMA 7-P consists expanding an extended detention basin situated front of Decker Hall on Birchmont Drive NE (see Figure 4). The existing pond in the drainage area removed an estimated 7% and 27% of annual TP and TSS loading, respectively. The model computed BMP sizes associated with 30% and 40% TP removal. Results from modeling are summarized in Table 6.

Table 6. PMA 7-P Results

PMA 7-P BMP Type: Extended Detention Basin , 30%, 40% TP removal	
Drainage Area TP Load (lbs/year)	154.5
Drainage Area TSS Load (lbs/year)	48,876
30% TP Removal	
BMP TP Treatment Efficiency (lbs/year)/(% Removal)	46.3/30%
BMP TSS Treatment Efficiency (lbs/year)/(% Removal)	29,197/70%
Total BMP Area (acres, flood stage)	0.77
Total Volume (ft^3)	119,015
40% TP Removal	
BMP TP Treatment Efficiency (lbs/year)/(% Removal)	61.8/40%
BMP TSS Treatment Efficiency (lbs/year)/(% Removal)	34,115/70%
Total BMP Area (acres, flood stage)	1.52
Total Volume (ft^3)	119,015

4.2.5 PMA 25

The BMP for PMA 25 consists of an existing extended detention basin with a chemical (ferric chloride) treatment system to enhance pollutant removal. The BMP site is located on a City owned parcel southeast of Roosevelt Road SW and west of a series of townhomes (see Figure 5). Existing BMPs further upstream in the drainage area remove an estimated 7% and 11% of annual TP and TSS loading, respectively. It was assumed that the BMP with treatment system would remove 20% of the remaining TP in the system, increasing total TP removal to 27%. Results are summarized in Table 7.

Table 7. PMA 25 Results

PMA 25 BMP Type: Extended Detention Basin with Chemical Treatment	
Drainage Area TP Load (lbs/year)	551.9
Drainage Area TSS Load (lbs/year)	175,077
BMP TP Treatment Efficiency (lbs/year)/(% Removal)	149.8/27%
BMP TSS Treatment Efficiency (lbs/year)/(% Removal)	45,741/26%

4.3 Cost Results

Costs for each Priority Management Area BMP option and treatment level were determined, and a present worth analysis was performed. The present worth analysis included capital (construction) costs, regular maintenance costs, and more infrequent corrective or replacement costs (where applicable) for a 50-year period. Costs were then reported as a present value dollar per pound of total phosphorus (TP) removal ratio. Results for each PMA are summarized in the tables below.

Table 8. PMA 6-PP

PMA 6-PP BMP Type: Permeable Pavement, 27% TP Removal	
Capital Costs	$183,550
Totals, Annual Regular Maintenance Activities	$247
Totals, Corrective & Infrequent Maintenance Activities	$3,800
Total Present Value of Costs	$237,106
Phosphorus Removal (lb/year)	4.4
Total 50-year Phosphorus Removal (lb)	220
Present Value per Pound of Phosphorus Removed	$1,078

Table 9. PMA 6-BR (30%)

PMA 24 BMP Type: Curb-Contained Bioretention, 30% TP Removal	
Capital Costs	$91,281
Totals, Annual Regular Maintenance Activities	$632
Totals, Corrective & Infrequent Maintenance Activities	$3,943
Total Present Value of Costs	$ 171,419
Total Phosphorus Removal (lb)	4.9
Total 50-year Phosphorus Removal (lb)	245
Present Worth Value per Pound of Phosphorus Removed	$700

Table 10. PMA 7-I

PMA 7-I BMP Type: Stormwater capture and subsurface storage for irrigation	
Capital Costs	$591,477
Totals, Annual Regular Maintenance Activities	$989
Totals, Corrective & Infrequent Maintenance Activities	$3,066
Total Present Value of Costs	$ 681,757
Total Phosphorus Removal (lb)	34.7
Total 50-year Phosphorus Removal (lb)	1,735
Present Worth Value per Pound of Phosphorus Removed	$393

Table 11. PMA 7-P (30%)

PMA 7-P BMP Type: Extended Detention Basin, 30% TP Removal	
Capital Costs	$473,743
Totals, Annual Regular Maintenance Activities	$593
Totals, Corrective & Infrequent Maintenance Activities	$1,744
Total Present Value of Costs	$529,371
Total Phosphorus Removal (lb)	36.0
Total 50-year Phosphorus Removal (lb)	1,800.0
Present Worth Value per Pound of Phosphorus Removed	$294

Table 12. PMA 7-P (40%)

PMA 7-P BMP Type: Extended Detention Basin, 40% TP Removal	
Capital Costs	$941,333
Totals, Annual Regular Maintenance Activities	$593
Totals, Corrective & Infrequent Maintenance Activities	$2,473
Total Present Value of Costs	$1,011,668
Total Phosphorus Removal (lb)	51.5
Total 50-year Phosphorus Removal (lb)	2,575.0
Present Worth Value per Pound of Phosphorus Removed	$392

Table 13. PMA 25 (26%)

PMA 42 Description: FeCl Treatment	
Capital Costs	$682,625
Totals, Annual Regular Maintenance Activities	$18,593
Totals, Corrective & Infrequent Maintenance Activities	$1,482
Total Present Value of Costs	$1,192,015
Total Phosphorus Removal (lb)	111.1
Total 50-year Phosphorus Removal (lb)	5,555
Present Worth Value per Pound of Phosphorus Removed	$ 213

4.3 Results Summary

Results from the BMP modeling and cost evaluation are summarized in Table 14 below.

Table 14. Results Summary

PMA Modeling and Results Summary				
BMP	**Total Annual BMP TP Removal (lb)**	**Total Annual BMP TSS Removal (lb)**	**Total BMP Present Value ($)**	**Total Present Value / TP Removal ($/lb)**
PMA 6-PP (27%)	4.4	1,457	$171,419	$1078
PMA 6-BR (30%)	4.9	1,699	$237,106	$700
PMA 7-I (23%)	34.7	15,402	$ 681,757	$393
PMA 7-P (30%)	36.0	16,100	$529,371	$294
PMA 7-P (40%)	51.5	21,018	$1,011,668	$392
PMA 25 (27%)	111.1	27,343	$1,192,015	$ 213

5 References

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6 Appendices

Appendix 1 – Ideal and Difficult Scenarios for Various Retrofit Locations

Retrofit Option	Ideal Conditions	Difficult Conditions
Existing pond modification potential	• Regional flood control or detention ponds • Dry stormwater detention ponds • Dry extended detention ponds • Farm and ornamental ponds • Public golf course ponds • "Modern" stormwater quality ponds	• Older and/or highly urban subwatersheds where development occurred prior to the advent of stormwater pond requirements • Dry ponds that have utilities running through the pond bottom or are used for dual purposes (e.g., recreational ball fields) • Older ponds that have lost their original flood storage capacity due to additional upstream development, sediment deposition or both • Stream corridors with flood prone structures present in the flood plain • Landlocked ponds that cannot be accessed by construction equipment
Above roadway culverts	• The existing culvert has sufficient hydraulic capacity to pass desired storm flows. • Upstream land is in public ownership . • Channel has ephemeral flow (e.g., zero or first order stream). • Upstream channels are low gradient, are connected to the floodplain, and have short streambanks. • The retrofit is timed to coincide with scheduled repair/replacement of the existing culvert. • The retrofit is upstream of a proposed stream restoration or wetland mitigation project.	• Existing culvert lacks hydraulic capacity but is not scheduled for replacement. • Stream has perennial or intermittent flow (e.g., second order stream or larger) or is used by migratory fish. • Proposed upstream storage area contains high quality wetlands or mature forests. • The project storage area contains sewer lines or other utilities that often run adjacent to streams or parallel to the road. • Contributing drainage area to the crossing is greater than 250 acres • Upstream channel has a steep gradient, is deeply incised, or has a confined floodplain. • Existing structures encroach into the floodplain and would be subject to a greater flooding risk.
Below stormwater outfalls	• Enough pipe/channel gradient to divert flows for treatment and return them to the stream via gravity flow • A good existing manhole to split flows and 5 to 10 feet of head to drive the retrofit • Unutilized turf available on one or both sides of pipe • A cutoff outfall (i.e., an outfall that discharges to the floodplain well short of the stream channel	• Private land must be purchased • Stream corridors are confined and lack land for surface treatment • Stream valley parks where tree clearing would be controversial • Very large outfalls (Pipe diameter greater than 60 inches) • Perennial flow exists in the storm drain pipe or ditch • Steep gradients or steep stream valley slopes limit available storage volume • Low gradient causes unacceptable backwater conditions in the pipe system • Outfall is subject to tidal or storm surges • Fill would need to placed in the floodplain
Within the conveyance system (ditches or	• Gradient ranging between 0.5 and 2.0% • Contributing drainage area of 15 to 30	• Is in natural condition and has adjacent mature forests or wetlands

Retrofit Option	Ideal Conditions	Difficult Conditions
daylighting opportunities)	acres of in humid regions with tight soils. Minimum drainage areas for conveyance retrofits are greater in arid and semi-arid regions with permeable soils. • Been altered to promote efficient drainage (e.g., ditch, swale or concrete lined channels; Figure 2) • Less than three feet of elevation difference between the top of bank and the channel bottom • Been used for roadway drainage in the right of way • An unutilized parcel of public land located adjacent to the channel.	• Is rapidly degrading/incising or has a knickpoint advancing upstream • Has a channel gradient of 5% or more and/or steep side slopes • Has perennial flow • Is located close to a residential neighborhood • Is privately owned or lacks a drainage easement
Transportation right of ways	• Cloverleaf interchanges (Figure 2) • Depressions created by approach ramps • Open section drainage within a right-of way that is wider than 30 feet and located down-gradient from the road and free of utilities • Drainage leading to bridges that cross streams with extensive floodplains • Highway drainage that can be diverted to adjacent public land • Targets of opportunity in highway widening/realignment construction projects	• Are likely to be widened or expanded in the future to handle increased traffic flow • Have guard rails, steep side-slopes or limited sight distance • Require lane closures to provide construction or maintenance access • Are slated to be used as a staging area for future road construction projects
Large parking lots	• Parking lots serving large institutions, corporate campuses and colleges that tend to have even lower percentage of impervious cover for the whole site. • Municipally-owned parking lots such as commuter lots, park access, and schools adjacent to open areas • Industrial parking lots designated as stormwater hotspots • Any parking lot served by an existing stormwater detention pond (use SR-1)	• Parking lot is smaller than five acres in size (but try on-site parking lot retrofits described in Profile Sheet OS-8) • Older lots located in highly urban areas, such as downtown central business districts • Parking lots that discharge directly to waterfronts or waterways • Open space adjacent to the parking lot is designated as a jurisdictional wetland, stream buffer or forest reserve.
Hotspot operations	• Found to be a severe hotspot during a hotspot site investigation • Covered by an existing industrial stormwater permit or specifically designated as a stormwater hotspot in the local water quality ordinance • Where site investigation shows that pollution prevention practices alone are not sufficient to remove pollutants in stormwater runoff	• Field investigations indicate that the hotspot is not severe • Legal responsibility to manage the property is unclear (e.g. operator leases the space from property owner) • Community does not offer technical assistance to help operators install low cost stormwater treatment options • Site is severely constrained by a lack of head or space
Small parking lots	• Communities retrofit a municipally owned parking lot as a demonstration project • New parking lots are constructed as part of redevelopment or infill projects • Existing parking lots are slated for resurfacing, reconfiguration or renovation (their normal design life is about 15 to 25 years) • Local stormwater regulations trigger water quality control at time of lot renovation or rehabilitation	• Over-crowded parking lots • Older parking lots built prior to modern design standards for screening, drainage, and landscaping • Owners are reluctant to sacrifice parking spaces and/or are unwilling to perform future maintenance • Dry or wet utilities run underneath the parking lot • The parking lot is located in flat terrain and lacks adequate head • The parking lot is already served by an

Retrofit Option	Ideal Conditions	Difficult Conditions
	• Parking lots were built with generous landscaping, open space, screening or frontage setbacks • Parking lots are not fully utilized because they were designed using excessive parking demand ratios	effective stormwater treatment practice.
Residential streets/blocks	• Streets classified as having a moderate to severe pollution severity, as measured by field surveys. • Neighborhoods that request traffic calming devices to slow residential speeding • Streetscaping projects or neighborhood revitalization efforts where street drainage can be modified • Bundling retrofits as part of upcoming water and/or sewer rehabilitation projects • Wider streets that serve large lots (1/2 acre lots and up) • Wide street right of ways that provide room for stormwater treatment options • Streets where utilities are located underneath the pavement or on only one side of the street	• Are not currently scheduled for streetscaping or renovation • Have longitudinal slopes greater than 5% • Are classified as arterial or connector Roads • Have extensive upland contributing drainage area • Are slated to be widened to accommodate future traffic capacity • Have mature street trees or intensive residential landscaping • Have a narrow right of way or heavy onstreet parking demand • Have very small lot sizes (i.e., the driveway effect) • Lack an active homeowners association • Have wide sidewalks on both sides of the street
Open space/pervious areas for disconnecting pervious areas	• Is located on publicly-owned land such as a park or school • Would serve an educational or demonstration function • Is in close proximity to a large pervious area • Would alleviate an existing drainage or erosion problem • Can take advantage of soils with a high infiltration rate • Can be linked with a planned reforestation project for the site	
Urban hardscape	• Commercial, municipal, institutional and urban park settings • Redevelopment and infill projects • Public spaces with high exposure • Area where urban water features are being designed as an amenity • Downtown central business districts • Waterfront developments • Development constructed through public/private partnerships • Neighborhood beautification and revitalization projects	• No party is willing to undertake routine maintenance • Retrofit would need to be shut down in winter to avoid ice problems
Non-residential rooftops	• Is being built as part of redevelopment or infill project • Is owned or being built by a municipality or a cooperative institution • Can discharge to landscaping or open space adjacent to the building • Has reached the end of its design life and	

Retrofit Option	Ideal Conditions	Difficult Conditions
	needs replacement. • Is large, flat and directly connected to the storm drain system • Owner is interested in green building certification	
Underground treatment	• Ultra-urban areas that lack available space on the surface for treatment • Redevelopment or infill projects where stormwater treatment requirements are triggered • Severe stormwater hotspots or central business districts • Sites where untreated direct stormwater discharges to extremely sensitive waters (e.g., intake for drinking water supply, swimming beaches, harbors, shellfish beds, waterfronts; Figure 3) • Sites where pretreatment is needed prior to another retrofit • Regions that have underlying soils with exceptionally good infiltration rates (e.g., glacial till, outwash plains, sandy plains) • Parking lots that cannot be served by a surface retrofit • Public works yards where crews can perform frequent maintenance	• Excavation is limited by bedrock or a high water table • Multiple utilities run underneath the site • Terrain is flat and/or adequate head is lacking to drive the retrofit • The receiving storm drain system is only a few feet below ground level • Owner/operator is unwilling or unable to frequently maintain it

APPENDIX 2 – WINSLAMM LAND USE DESCRIPTIONS

RESIDENTIAL LAND USES

HDRNA - High Density Residential without Alleys: Urban single family housing at a density of greater than 6 units/acre. Includes house, driveway, yards, sidewalks, and streets.

HDRWA - High Density Residential with Alleys: Same as HDRNA, except alleys exist behind the houses.

MDRNA - Medium Density Residential without Alleys: Same as HDRNA except the density is between 2 - 6 units/acre.

MDRWA - Medium Density Residential with Alleys: Same as HDRWA, except alleys exists behind the houses.

LDR - Low Density Residential: Same as HDRNA except the density is 0.7 to 2 units/acre.

DUP - Duplexes: Housing having two separate units in a single building.

MFRNA - Multiple Family Residential: Housing for three or more families, from 1 - 3 stories in height. Units may be adjoined up-and-down, side-by-side; or front-and-rear. Includes building, yard, parking lot, and driveways. Does not include alleys.

HRR - High Rise Residential: Same MFRNA except buildings are High Rise Apartments; multiple family units 4 or more stories in height.

MOBH - Mobile Home Park: A mobile home or trailer park, includes all vehicle homes, the yard, driveway, and office area.

SUB - Suburban: Same as HDRNA except the density is between 0.2 and 0.6 units/acre.

COMMERCIAL LAND USES

SCOM - Strip Commercial: Those buildings for which the primary function involves the sale of goods or services. This category includes some institutional lands found in commercial strips, such as post offices, courthouses, and fire and police stations. This category does not include buildings used for the manufacture of goods or warehouses. This land use includes the buildings, parking lots, and streets. This land use does not include nursery, tree farms, vehicle service areas, or lumber yards.

SHOP - Shopping Centers: Commercial areas where the related parking lot is at least 2.5 times the area of the building roof area. Parking areas usually surrounds the buildings in this land use. This land use includes the buildings, parking lot, and streets.

OFPK - Office Parks: Land use where non-retail business takes place. The buildings are usually multi storied buildings surrounded by larger areas of lawn and other landscaping. This land use includes the buildings, lawn, and road areas. Types of establishments that may be in this category includes: insurance offices, government buildings, and company headquarters.

CDT - Commercial Downtown: Multi-story high-density area with minimal pervious area, and with retail, residential and office uses.

INDUSTRIAL LAND USES

MI - Medium Industrial: This category includes businesses such as lumber yards, auto salvage yards, junk yards, grain elevators, agricultural coops, oil tank farms, coal and salt storage areas, slaughter houses, and areas for bulk storage of fertilizers.

LI - Non-Manufacturing: Those buildings that are used for the storage and/or distribution of goods waiting further processing or sale to retailers. This category mostly includes warehouses, and wholesalers where all operations are conducted indoors, but with truck loading and transfer operations conducted outside.

INSTITUTIONAL LAND USES

SCH - Education: Includes any public or private primary, secondary, or college educational institutional grounds. Includes buildings, playgrounds, athletic fields, roads, parking lots, and lawn areas.

INST - Miscellaneous Institutional: Churches and large areas of institutional property not part of CST and CDT.

HOSP - Hospital: Multi-story building surrounded by parking lots and some vegetated areas.

OTHER URBAN LAND USES

PARK - Parks: Outdoor recreational areas including municipal playgrounds, botanical gardens, arboretums, golf courses, and natural areas.

OSUD - Undeveloped: Lands that are private or publicly owned with no structures and have a complete vegetative cover. This includes vacant lots, urban fringe areas slated for development, greenways, and forest areas.

CEM - Cemetery: This land use file covers cemeteries, and includes road frontage along the cemetery, and paved areas and buildings within the cemetery.

FREEWAY LAND USES

FREE - Freeways: Limited access highways and the interchange areas, including any vegetated rights-of-ways.

APPENDIX 3 – PARAMETERIZATION OF P8 INPUTS TO WINSLAMM

Land Use	Depression Storage (in)	Pervious Fraction	Indirectly-Connected Fraction	Directly Connected Fraction
DUP	0.02	0.609	0.121	0.271
FREE	0.022	0	0	1
HDRNA	0.017	0.469	0.131	0.399
INST	0.017	0.364	0.036	0.6
LDR	0.026	0.796	0.079	0.126
LI	0.029	0.205	0.088	0.707
MDRNA	0.029	0.622	0.135	0.242
MFRNA	0.025	0.462	0.063	0.474
OFPK	0.019	0.263	0.006	0.731
OSUD	0.027	0.951	0	0.049
PARK	0.01	0.856	0.041	0.103
SCH	0.026	0.421	0.014	0.565
SCOM	0.025	0.079	0.014	0.907
SHOP	0.023	0.083	0	0.917
SUB	0.04	0.904	0.04	0.056