Stormwater Water Quality Best Management Practice Retrofit Analysis

Aitkin, Minnesota

Mississippi Headwaters Board

September 14, 2015

AITKIN STORMWATER WATER QUALITY BEST MANAGEMENT PRACTICE RETROFIT ANALYSIS

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EXECUTIVE SUMMARY

This report summarizes an assessment of potential stormwater system improvements for Aitkin, Minnesota. The assessment evaluated the potential for water quality best management practices (BMP) retrofits to reduce phosphorous and sediment contribution to the Mississippi River, or other water bodies of interest within the Upper Mississippi River basin. A tiered approach was used, which included a desktop analysis, field reconnaissance, and treatment and cost evaluation. Results of the evaluation were reported in dollars per pound of total phosphorous removed over a 50-year project life cycle.

The project consisted of a review of the City's existing stormwater system (including stormwater infrastructure, catch basins, ponds and outfalls), zoning and land use information, and other records to identify potential locations for stormwater BMP retrofits that could reduce total phosphorous and total suspended solids loading to the Mississippi River, or other water resources of interest within the watershed. Data and specific areas of interest were reviewed with Mississippi Headwaters Board (MHB) and City staff (when available) to verify field conditions, identify site-specific issues that would factor into BMP selection, and to assess overall BMP design and performance limitations. Following the overall evaluation, specific Priority Management Areas (PMAs) and BMP retrofits were selected for analysis.

Water quality modeling was performed to determine existing conditions and to determine sizes for the BMP retrofits that would achieve various levels of treatment for total phosphorous and total suspended solids. Costs for each BMP retrofit were determined, and a present value analysis was performed. The present value analysis included capital (construction) costs, other project costs (design), regular maintenance costs, and replacement or rehabilitation costs (where applicable) for a 50-year period. Costs were then reported as a ratio of present value dollar per pound of total phosphorous removed. This value can be used to evaluate BMP cost effectiveness, and to help the City determine which options could provide the highest return on investment. A summary of the evaluation is provided in the Table 1.

Table 1: Summary of BMP Retrofit Analysis

BMP	BMP Option	Total Annual BMP Retrofit TP Removal (lbs)	Total Annual BMP Retrofit TSS Removal (lbs)	Capital Costs	Total Present Value of BMP Retrofit Costs ($)	Total Present Value / TP Removal ($/lb)
PMA 1 (51%)	Bioretention Cell	0.4	64	$25,152	$53,320	$2,666
PMA 2-P (52%)	Extended Detention Basin	0.5	164	$10,626	$52,275	$2,091
PMA 2-I (72%)	Bioretention Cell	2.0	341	$91,302	$172,419	$1,724

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1 INTRODUCTION

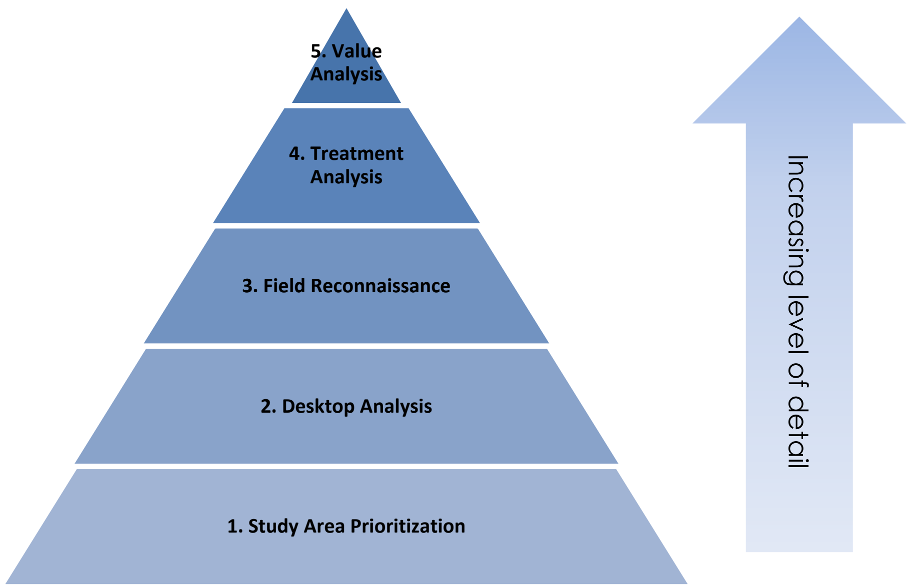
The Mississippi Headwaters Board (MHB) operates as a joint powers board of Clearwater, Beltrami, Cass, Hubbard, Itasca, Aitkin, Crow Wing and Morrison Counties to identify and protect the natural, cultural, scenic, scientific and recreational values of the first 400 miles of the Mississippi River. The 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 2014, MHB contracted with HDR to perform an assessment of water quality Best Management Practices (BMPs) for the Cities of Little Falls, Grand Rapids, and Bemidji, Minnesota. These analyses were completed in December 2014. In May 2015, MHB contracted with HDR to perform similar analyses for the Cities of Aitkin, Cass Lake, Cohasset, La Prairie, Palisade, Riverton, and Walker, Minnesota. This report is a result of the 2015 analysis for the City of Aitkin.

2 METHODS

The retrofit assessment followed an approach based on the Center for Watershed Protection's Urban Stormwater Retrofit Manual (CWP 2007). As the steps proceed, a finer resolution method was used to analyze the potential BMP retrofit performance and value (Figure 1. The BMP retrofit analysis approach used in this analysis.). Each step of the process helped refine a list of priority areas by eliminating areas or sites where BMP retrofits would likely be ineffective or highly difficult to install or maintain. A detailed description of the Center for Watershed Protection's approach is provided in this section.

Figure 1. The BMP retrofit analysis approach used in this analysis.



2.1 STUDY AREA PRIORITIZATION

The purpose of the study area prioritization, or retrofit scoping step, was to refine the retrofit strategy to meet local objectives. In this case, the overarching goal of the BMP retrofit project was to identify projects that would have a positive impact on water quality in the Mississippi Headwaters basin, including the Mississippi River and other water resources within its watershed. Discussions with MHB staff and representatives from each of the seven cities involved in this study helped to identify local goals and priority areas for stormwater BMP retrofits. Local knowledge was helpful in understanding past, current, and future stormwater conveyance and treatment issues. Alignment and coordination with local projects was an important consideration in evaluating BMP retrofit sites.

2.2 DESKTOP ANALYSIS

The purpose of the Desktop Analysis was to gather existing mapping and data, conduct a desktop search for BMP retrofits, and prepare base maps for field review. Available data for the City was reviewed as a first step in identifying areas of interest for BMP retrofits. Data was mainly geographic information systems (GIS)-based and included aerial photography, LiDAR, parcel information, soils, topography, land use, wetland, stream and lake locations, as well as existing municipal stormwater pipe and BMP type and location, when available.

City stormwater infrastructure data were imported into the GIS mapping file and a digital elevation model (DEM) and contours were used to manually digitize subwatershed boundaries. Subwatersheds that were most likely to contribute the majority of pollutant loading to water bodies of interest, and those that were either non-contributing or likely to have either significant treatment in place or less feasible options for BMP retrofits were identified. The resulting areas of interest were comprised of pipesheds or subwatersheds that either directly discharged to the Mississippi River (or water body of interest), had wetlands or stormwater BMPs that could be modified to improve water quality performance or those that, despite having existing BMPs, appeared to have potential to retrofit additional BMPs with primarily different pollutant removal processes. This process is outlined in Table 2: Process for Identifying Areas of Interest. Areas of interest were reviewed with MHB and City staff, when available, and were mapped for use in the field reconnaissance phase.

Each area of interest was reviewed to identify and develop initial concepts for mid- to large-scale storage-focused BMP retrofits (CWP 2007). These include:

1. Modification of existing ponds
2. Areas above roadway culverts
3. Areas below stormwater outfalls
4. Areas within the conveyance system (ditches or daylighting opportunities)
5. Transportation rights-of-way
6. Large parking lots

The areas of interest were then reviewed to develop concepts for on-site BMP retrofits (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

Table 2: Process for Identifying Areas of Interest

Step 1: Does the pipeshed or subwatershed contribute to the water resource of concern?
1. Review stormwater drainage and pipe infrastructure data 2. Evaluate using HydroCAD 3. Incorporate local knowledge If yes, then move to Step 2. If no, then exclude from further analysis.
Step 2: Does the pipeshed or subwatershed drain directly to the water resource of concern?
1. Review stormwater drainage or pipe infrastructure data If yes, then include the area as an Area of interest. If no, then move to Step 3.
Step 3: Does the pipeshed or subwatershed drain to a wetland?
1. Review stormwater drainage and pipe infrastructure data If yes, then move to Step 3A. If no, then move to Step 4.
Step 3A: Is it feasible to modify the wetland or treat the outflow with infiltration or filtration?
1. Review National Wetland Inventory, parcel, soil and topography data, and aerial photography If yes, then include as an Area of interest. If no, then exclude from further analysis
Step 4: Does the pipeshed or subwatershed drain to an existing stormwater BMP?
1. Review stormwater drainage and infrastructure data If yes, then move to step 4A. If no, then exclude from Area of interest.
Step 4A: Is it feasible to modify the existing BMP to improve performance or retrofit BMPs upstream that use different pollutant removal mechanisms than the existing BMP?
1. Review access easement, parcel, soil and topography data and aerial photography If yes, then include as an Area of interest. If no, then exclude from further analysis.

For each site, consideration was given to several types of BMP retrofits, or configurations. These are shown in Table 3: Stormwater treatment options by location (adapted from CWP 2007), which summarizes appropriate stormwater treatment practices for specific site conditions. The BMP retrofits were selected for specific parcels and identified for field reconnaissance.

Table 3: 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

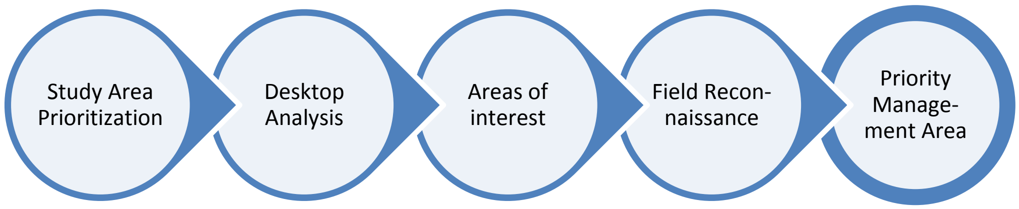
2.3 Field Reconnaissance

The objective of the field reconnaissance was to confirm drainage systems and investigate retrofit feasibility within the area of interest. The field visit allowed HDR, MHB and City staff to review the retrofit sites together and to investigate the feasibility of retrofit concepts in the field. This helped identify both potential BMP retrofit opportunities and non-contributing sites and sites with limited retrofit potential.

Meeting with the City and MHB staff was important in the evaluation of field conditions and in determining which areas should be carried through to the next step in the analysis. Field review and input from the City helped identify and confirm priority areas, and other potential areas for improvement that could have a larger impact on the water quality within the study area, as well as rule out certain areas that were determined to have minimal impact or be difficult to retrofit.

Using the information from the desktop analysis and field reconnaissance of the areas of interest, Priority Management Areas (PMAs) were selected for further analysis. The PMAs represent areas within the City that were determined to have high potential for water quality treatment and BMP retrofit installation, will align well with city planning, and have the potential to provide multiple benefits (i.e. water quality improvement and volume reduction). For each PMA, the total drainage area, land use, stormwater infrastructure, existing water quality BMPs and other subwatershed characteristics were assessed. BMP retrofits were selected for each location using the data and information gathered in the field. The process for selecting PMAs is summarized in Figure 2: PMA Selection Process.

Figure 2: PMA Selection Process



2.4 Treatment Analysis

PMAs were analyzed to estimate total phosphorous and total suspended solids loading, the level of treatment of any existing stormwater BMPs, as well as improved treatment that could be achieved with BMP retrofits. Water quality modeling was performed using a stormwater model developed for designing and evaluating runoff treatment schemes for urban developments. This model, called "Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds", or "P8", 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 user-defined drainage systems, 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 file, when available. 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). WinSLAMM's land use definitions were then used to "calibrate" P8 input parameters using the guidance in the P8 help file for watershed definition (Walker 2014; Appendix 3 – Parameterization of P8 Inputs to WinSLAMM).

2.4.1 Existing Treatment

Existing conditions were modeled using P8 to define baseline water quality conditions. Pollutant loading within the drainage area was estimated, including total phosphorous and total suspended solids. For those PMAs with existing water quality BMPs in place, including wetlands, ponds, and buffer strips, the pollutant removal efficiencies of these existing treatment features were modeled.

For existing ponds and wetlands, aerial photography was used to digitize an approximate permanent pool footprint. The 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 (when available) 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 depth and the ponds were constructed with 3:1 side slopes. Dry ponds that were observed during the field reconnaissance were modeled based on estimated depths and slopes from the site visit. 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.

2.4.2 Retrofit Treatment

Once existing conditions were established, the BMP retrofits were modeled. The 20-year continuous model was run in incremental steps, re-sizing the BMP retrofits at each step to achieve various levels of pollutant removals (typically 30%, 50%, and 70%). Where the existing treatment exceeded these levels, the BMP retrofits were sized to achieve up to a 90% pollutant removal. In some cases, the BMP size (and therefore treatment potential) was limited by site constraints. In these cases, the size of the BMP was optimized and the maximum removal was noted. The pollutant removal efficiency of the BMP retrofit was considered together with existing treatment to estimate overall PMA treatment levels.

Water quality BMPs evaluated in these assessments included permeable pavement, various bio-retention strategies, extended detention basins, and improved buffer strips. Conceptual treatment modeling assumed the following for each BMP:

- *Permeable pavement*: Asphalt parking stall located within a rebuilt parking lot such that it receives sufficient flow from the lot to achieve various levels of pollutant removals. Three feet of angular granite with a void space of 40%.
- *Curb-contained (boulevard) bioretention*: One high-flow bypass curb-cut inlet to each 50 ft^2 bioretention cell. Vertical side slopes with 6 inches of ponding depth and 2 feet of infiltration storage depth. Over-excavation of *in situ* soils. Infiltration material consists of sand/MNDOT Grade 2 Compost media mix (70%/30%).
- *Regional bioretention*: Improved grading to drain the subwatershed to a common location for BMP placement. Vertical side slopes and 1 foot of infiltration storage depth with overflow draining to the buffer strip or subwatershed outfall, depending on the downslope landscape. Over-excavation of *in situ* soils. Infiltration material consists of sand/MNDOT Grade 2 Compost media mix (70%/30%).
- *Extended detention*: New pond with 4-foot long weir overflow. Permanent pool depth of 1 foot, flat bottom, vertical side slopes. Live pool of 2 feet with vertical sides slopes.
- *Buffer strips*: Improved vegetation with tall, native grasses between sources of pollutant runoff and the receiving surface water. Length, width, and slope consistent with conditions where short grass vegetation is already present.

The BMPs were modeled in accordance with the criteria above. Design and construction of the BMPs may vary to allow for more gradual side slopes, perforated pipe underdrains, and forebays to support maintenance activities.

2.5 Value Analysis

Capital and operations and maintenance (O&M) costs for each BMP retrofit were determined, and a whole life cost approach was used to generate planning-level costs for the various BMP options. The cost analysis included capital (construction) costs, other project costs, which include design and project administration costs, as well as O&M costs, which include regular maintenance activities and infrequent or corrective costs (where applicable). Costs were tabulated over a 50-year period, and a present value was determined. Costs were then reported as a ratio of present value dollar per pound of total phosphorous removed to compare the cost effectiveness of various BMP retrofits, based on the annual total phosphorus treatment from the 20-year continuous model process described in Section 2.4 above.

A whole life cost tool developed by the Water Environment Research Foundation (WERF) was used to develop the present value of costs for each BMP retrofit option. The tool consists of a set of spreadsheets that combine capital costs and ongoing maintenance costs to estimate whole life costs. Simplified methods were used to determine capital costs for constructing BMP retrofits.

Maintenance costs included both regular 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.

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

3 City Watershed

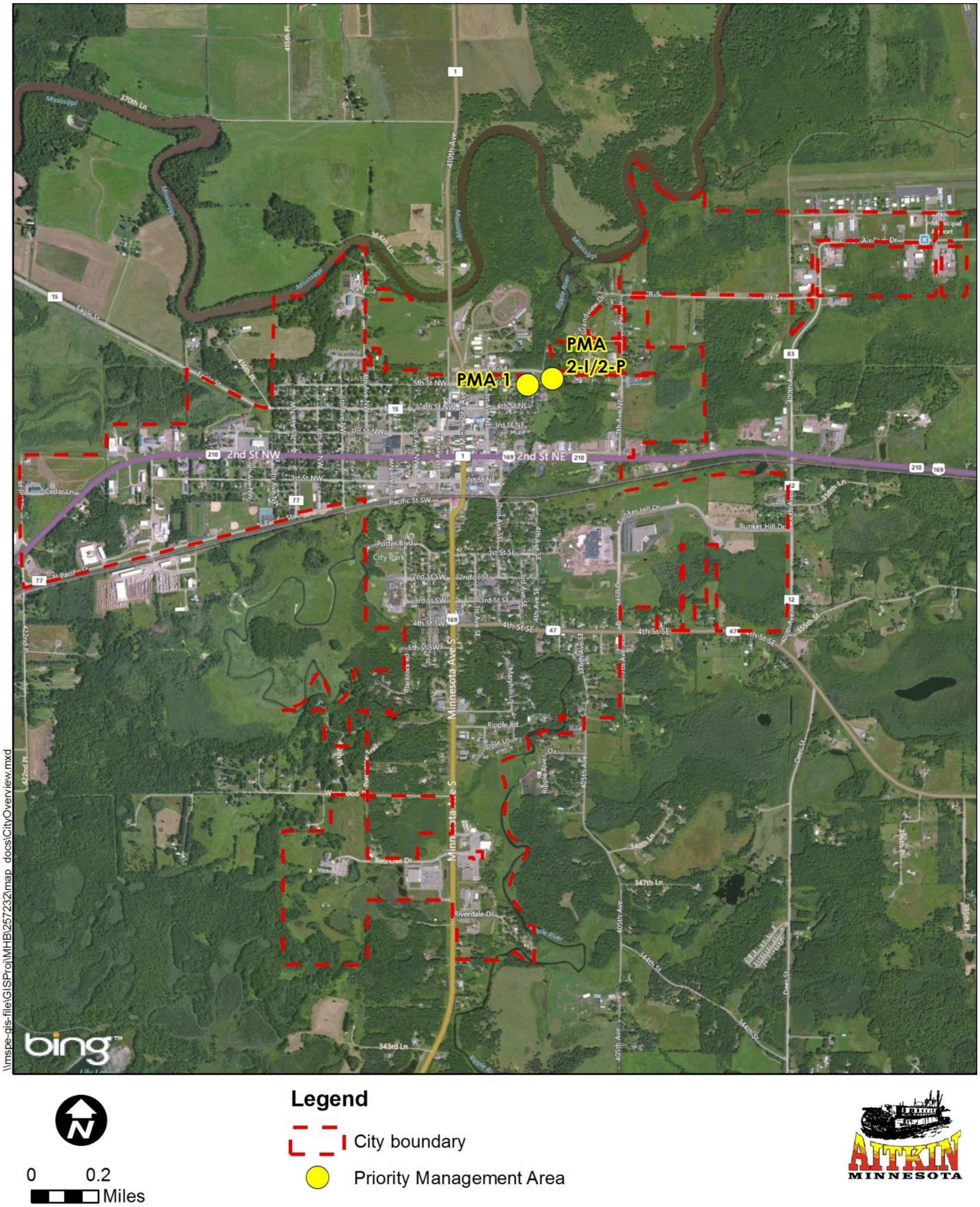
3.1 Watershed Characteristics

Aitkin is located along the south side of the Mississippi River. The Ripple River, which is a tributary to the Mississippi River, flows through the City from the southwest to the northeast. The majority of the City's stormwater runoff does not directly discharge into the Mississippi River. Most of the stormwater runoff either flows into the Ripple River or is disconnected from the Mississippi River by topographic features and vegetated buffer strips. The watershed primarily consists of residential areas and downtown commercial areas. The downtown area has predominantly impervious land cover and discharges to storm sewer infrastructure that drains to the Ripple River.

3.2 Stormwater Infrastructure

Information on the stormwater infrastructure in Aitkin was obtained from publicly available information, field reconnaissance, and Geographic Information System (GIS) databases. These sources were used to determine the locations of outlets, swales and ponds (Figure 3). The downtown area of Aitkin has storm sewer which drains to the Ripple River. The residential areas on the south side of the Ripple River have curbs, and areas northeast of downtown use ditches to convey stormwater to the Ripple River or outlying areas that are topographically disconnected from either river. This information was reviewed for flow routing and subsequent subwatershed delineation.

Figure 3: Overall Map of Potential BMPs



4 Results

4.1 Priority Management Area Identification

Within Aitkin, the majority of the drainage area is either disconnected from the Mississippi River or is offset by at least 100 feet of vegetated buffer prior to discharging into the Ripple River. There are three potential BMP retrofits located on the northeast side of the city which include:

> **PMA 1**. The potential BMP retrofit in the residential area would include a series of bioretention cells within the right-of-way (see Figure 4).
>
> **PMA 2-P**. The potential BMP retrofit would involve an extended detention basin upstream of the drainage area outlet into the Ripple River (see Figure 5).
>
> **PMA 2-I**. The potential BMP retrofit would involve constructing an infiltration basin upstream of the drainage area outlet into the Ripple River (see Figure 5).

Figure 4: Location of PMA 1

Figure 5: Location of PMA 2-I and PMA 2-P

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 total phosphorus (TP) and total suspended solids (TSS) removals associated with existing conditions, including existing stormwater BMPs. The P8 model was then applied to size BMP retrofits selected for the PMAs to achieve TP removal targets of 50% and 70% (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 1

The BMP retrofit for PMA 1 consists of constructing bioretention cells within the right-of-way in a residential neighborhood (see Table 4). There is currently a 100-foot buffer strip with a TP removal efficiency of 46% located downstream of the retrofit location that was modeled as the existing condition. The model computed a single BMP retrofit size associated with 51% TP removal; a larger BMP could not be sized due to site constraints. Results from modeling are summarized in Table 4.

Table 4. PMA 1 Results

PMA 1 51% Combined Total Phosphorous Removal Summary BMP Type: Bioretention Cell		
Drainage Area TP Load (lbs/year)	7.5	
Drainage Area TSS Load (lbs/year)	2,439	
Existing TP Treatment Efficiency (lbs/year)/(% Removal)	3.4	46%
Existing TSS Treatment Efficiency (lbs/year)/(% Removal)	1,639	67%
Additional TP Load Removed with BMP Retrofit (lbs/year)	0.4	5%
TP Treatment Efficiency with BMP Retrofit (lbs/year)/(% Removal)	3.8	51%
TSS Treatment Efficiency with BMP Retrofit (lbs/year)/(% Removal)	1,703	70%
Total BMP Area (ft^2)	600	
Total Live Volume (ft^3)	1,200	

4.2.2 PMA 2-P

The BMP retrofit for PMA 2-P consists of an extended detention basin at the neighborhood drainage area outlet into the Ripple River in the northeast area of the city (Table 5). A 100-foot buffer strip with a TP removal efficiency of 46% located upstream of the BMP retrofit was modeled as the existing condition. The proposed BMP retrofit, which was modeled as an extended detention basin on a private parcel, was assumed to have one foot of permanent pool storage and two feet of flood storage. The model computed a single BMP size associated with 52% TP removal. A larger BMP could not be sized due to site constraints. Results from modeling are summarized in Table 5.

Table 5. PMA 2-P Results

PMA 2-P 52% Combined Total Phosphorous Removal Summary BMP Type: Extended Detention Basin		
Drainage Area TP Load (lbs/year)	7.5	
Drainage Area TSS Load (lbs/year)	2,439	
Existing TP Treatment Efficiency (lbs/year)/(% Removal)	3.4	46%
Existing TSS Treatment Efficiency (lbs/year)/(% Removal)	1,639	67%
Additional TP Load Removed with BMP Retrofit (lbs/year)	0.5	6%
TP Treatment Efficiency with BMP Retrofit (lbs/year)/(% Removal)	3.9	52%
TSS Treatment Efficiency with BMP Retrofit (lbs/year)/(% Removal)	1,803	74%
Total BMP Area (ft^2)	4,356	
Total Live Volume (ft^3)	8,712	

4.2.3 PMA 2-I

The BMP retrofit for PMA 2-I consists of an infiltration basin at the neighborhood drainage area outlet into the Ripple River in the northeast area of the city (Table 6). A 100-foot buffer strip with a TP removal efficiency of 46% located upstream of the BMP retrofit was modeled as the existing condition. The proposed BMP retrofit was modeled as an extended detention basin located on a private parcel, and was assumed to have one foot of flood storage. The model computed a single BMP size associated with 72% TP removal. A larger BMP could not be sized due to site constraints. Results from modeling are summarized in Table 6.

Table 6. PMA 2-I Results

PMA 2-I 72% Combined Total Phosphorous Removal Summary BMP Type: Bioretention Cell		
Drainage Area TP Load (lbs/year)	7.5	
Drainage Area TSS Load (lbs/year)	2,439	
Existing TP Treatment Efficiency (lbs/year)/(% Removal)	3.4	46%
Existing TSS Treatment Efficiency (lbs/year)/(% Removal)	1,639	67%
Additional TP Load Removed with BMP Retrofit (lbs/year)	2.0	26%
TP Treatment Efficiency with BMP Retrofit (lbs/year)/(% Removal)	5.4	72%
TSS Treatment Efficiency with BMP Retrofit (lbs/year)/(% Removal)	1,980	81%
Total BMP Area (ft^2)	4,356	
Total Live Volume (ft^3)	4,356	

4.3 Cost Results

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

Table 7. PMA 1

PMA 1 51% Total Phosphorous Removal Cost Summary BMP Type: Bioretention Cell	
Capital Costs	$25,152
Totals, Regular Maintenance Activities ($/yr)	$316
Totals, Corrective & Infrequent Maintenance Activities ($/yr) (Maintenance activities occurring every 2-5 years with a total replacement cost at 30 years, averaged over the 50-year life cycle)	$1,029
Total Present Value of Costs (3% discount rate)	$53,320
Total Phosphorous Removal (lbs/yr)	0.4
50-year Total Phosphorus Removal (lbs)	20.0
Present Value per Pound of Total Phosphorous Removed ($/lb)	$2,666

Table 8. PMA 2-P

PMA 2-P 52% Total Phosphorous Removal Cost Summary BMP Type: Extended Detention Basin	
Capital Costs	$10,626
Totals, Regular Maintenance Activities ($/yr)	$593
Totals, Corrective & Infrequent Maintenance Activities ($/yr) (Maintenance activities including sediment removal every 10 years, averaged over the 50-year life cycle)	$1,050
Total Present Value of Costs (3% discount rate)	$52,275
Total Phosphorous Removal (lbs/yr)	0.5
50-year Total Phosphorus Removal (lbs)	25.0
Present Value per Pound of Total Phosphorous Removed ($/lb)	$2,091

Table 9. PMA 2-I

PMA 2-I 72% Total Phosphorous Removal Cost Summary BMP Type: Bioretention Cell	
Capital Costs	$91,302
Totals, Regular Maintenance Activities ($/yr)	$632
Totals, Corrective & Infrequent Maintenance Activities ($/yr) (Maintenance activities occurring every 2-5 years with a total replacement cost at 30 years, averaged over the 50-year life cycle)	$3,398
Total Present Value of Costs (3% discount rate)	$172,419
Total Phosphorous Removal (lbs/yr)	2.0
50-year Total Phosphorus Removal (lbs)	100.0
Present Value per Pound of Phosphorous Removed ($/lb)	$1,724

4.3 Results Summary

Results from the BMP modeling and cost evaluation are summarized in Table 10 below.

Table 10. Results Summary

PMA Modeling and Results Summary					
BMP	Total Annual BMP Retrofit TP Removal (lbs)	Total Annual BMP Retrofit TSS Removal (lbs)	Capital Costs	Total Present Value of BMP Retrofit Costs ($)	Total Present Value / TP Removal ($/lb)
PMA 1 (51%)	0.4	64	$25,152	$53,320	$2,666
PMA 2-P (52%)	0.5	164	$10,626	$52,275	$2,091
PMA 2-I (72%)	2.0	341	$91,302	$172,419	$1,724

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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

Retrofit Option	Ideal Conditions	Difficult Conditions
Within the conveyance system (ditches or daylighting opportunities)	• Gradient ranging between 0.5 and 2.0% • Contributing drainage area of 15 to 30 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 in natural condition and has adjacent mature forests or wetlands • 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 • 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

Retrofit Option	Ideal Conditions	Difficult Conditions
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 • 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	• 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 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 on-street 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

Retrofit Option	Ideal Conditions	Difficult Conditions
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 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