Houston Engineering Inc.

Maple Grove, MN | HEI No. 8177_004
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CITY OF GLENWOOD WATER QUALITY ASSESSMENT AND BMP PRIORITIZATION

Pope SWCD

CITY OF GLENWOOD

Water Quality Assessment and BMP Prioritization

March 8, 2017

HoustonEngineering Inc.

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision, and that I am a duly Licensed Engineer under the laws of the State of Minnesota

Houston Engineering, Inc.
6901 E Fish Lake Rd., Suite 140
Maple Grove, MN 55369
Phone # 763.493.4522

Joseph A. Lewis, PE
License Number 46215

Date

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1 INTRODUCTION

1.1 INTRODUCTION

A priority of the Pope Soil and Water Conservation District (SWCD) is to protect and improve the water quality in Lake Minnewaska as identified in the Pope County Water Plan (2013). Pope SWCD is actively planning and implementing measures in the rural portions of the watershed. They initiated this detailed water quality assessment of the area contributing runoff to Lake Minnewaska from within the City of Glenwood. An Accelerated Implementation Grant was awarded for this study through the Board of Soil and Water Resource's Clean Water Fund in 2015.

1.2 STUDY AREA

The watershed modeled and analyzed in this study is the area which contributes runoff to Lake Minnewaska in and through the City of Glenwood, as shown in **Figure 1**. The City of Glenwood lies along the northeast lakeshore of Lake Minnewaska and extends to the north and east. The study area is 4.07 square miles and includes 3.12 square miles within the City of Glenwood. 2.25 square miles of the City of Glenwood is outside the study area, most of which is the municipal wastewater treatment site (0.80 square miles) and the municipal airport (1.11 square miles), both lying east of the study area. This leaves 0.34 square miles of city land that is not within the study area and is not in the Lake Minnewaska watershed. The remaining city area not included in the study is mostly undeveloped.

1.3 BACKGROUND

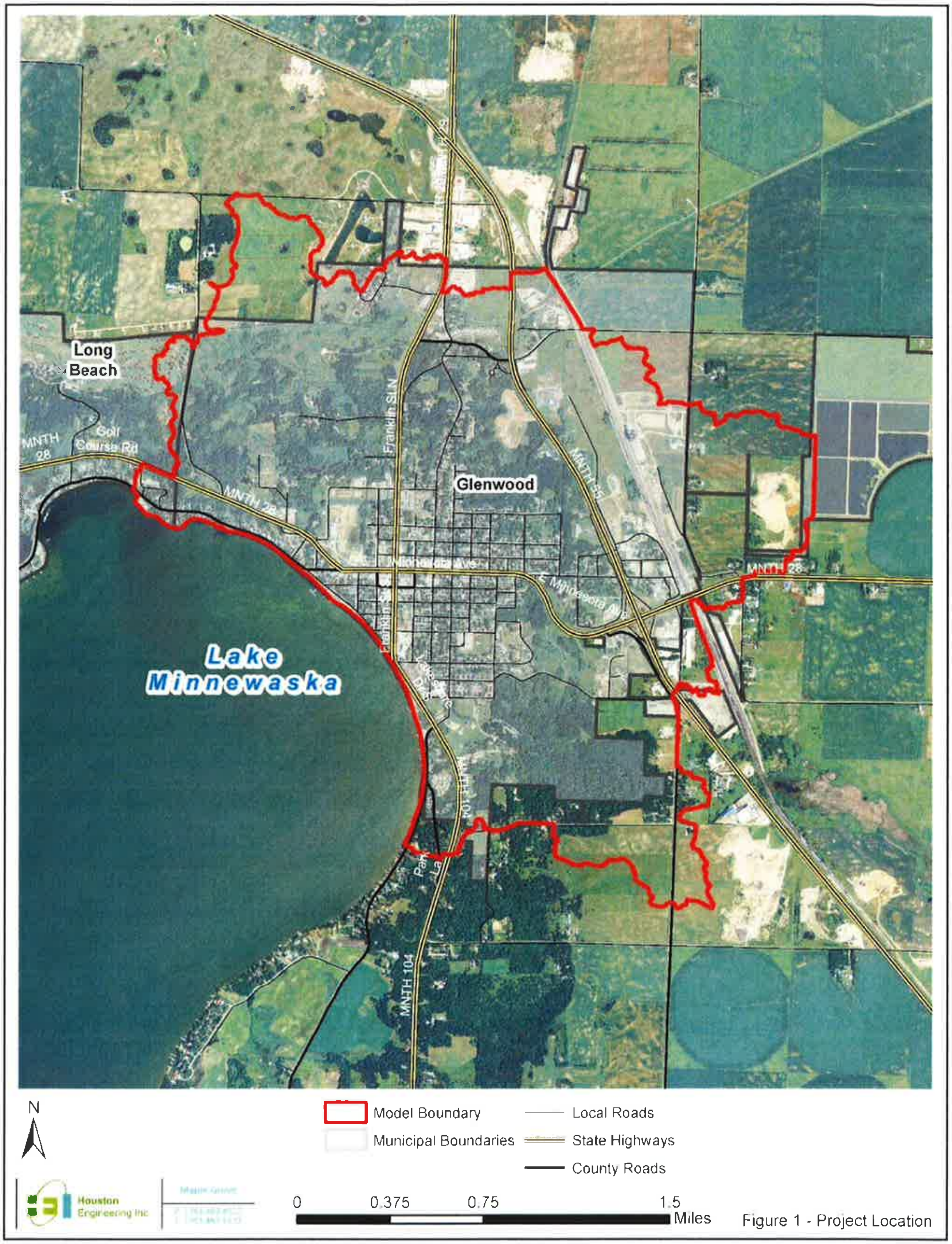
One of Pope County's and West Central Minnesota's largest water resource assets, Lake Minnewaska, is in the Chippewa River Watershed. Lake Minnewaska covers 8,050 acres and has a maximum depth of 32 feet, making it the 13th largest lake in Minnesota based on area in acres (not water volume). Lake Minnewaska is the largest lake within Pope County and provides shore land for the cities of Glenwood, Starbuck, and Long Beach.

The Lake Minnewaska Watershed is approximately 85 square miles in area. During a 2014 hydrologic conditioning and terrain analysis study completed by Houston Engineering, Inc. (HEI), the contributing drainage area during a 10-year, 24-hour rainfall event was estimated to be 48 square miles. Of that area, 27.4 square miles reach Lake Minnewaska through the Trappers Run channel that connects the Pelican Lake outlet to Lake Minnewaska. The remaining 20.6 square miles drain directly to Lake Minnewaska from the surrounding area.

Stormwater runoff from within the City of Glenwood is an important management issue to Lake Minnewaska. The City of Glenwood area makes up a relatively small portion of the overall Lake Minnewaska Watershed, but does have much of the watershed's developed impervious area. Stormwater runoff, which is largely untreated, from developed areas currently discharges directly to Lake Minnewaska. Developed areas and impervious surfaces are well known as significant contributors to the degradation of water quality. Additionally, increased runoff volumes and rates contribute to flooding and erosion issues if not managed properly.

A stormwater management plan was previously developed by the City of Glenwood in 1999. Several projects recommended in that plan have been implemented. Funds received in 2010 were used to address eroding ravines and untreated runoff originating upstream of Highway 55, which entered a ravine and was causing severe erosion. Detention ponds, riparian cover, and check dams were installed to reduce further erosion and reduce suspended sediment loads from high flow events, which ultimately entered Lake Minnewaska. In recent years, the Pope SWCD has been successful in acquiring grant funding to implement conservation practices that reduce sediment and nutrient loads from agricultural areas elsewhere in the Lake Minnewaska watershed.

Figure 1: Project Location



1.4 SUBWATERSHED ASSESSMENT GOALS AND OBJECTIVES

Planning is critical to effectively implement stormwater management practices across a watershed. A comprehensive watershed analysis can target sediment and nutrient source loading areas, and predict water quality load reductions from best management practice (BMP) implementation based on defensible technical analysis. Demonstrating a measurable water quality benefit is a prerequisite when seeking additional funding for implementation. For this reason, Pope SWCD sought funding from the Board of Soil and Water Resources (BWSR) for a water quality assessment in the City of Glenwood to supplement the previous analysis and target stormwater management practices. This will result in the identification of targeted subwatersheds and prioritized water quality BMP projects through detailed water quality and GIS analysis.

1.4.1 ASSESSMENT GOALS

The primary goal of this project is to realize an improvement in Lake Minnewaska's water quality by reducing the concentrations of sediment and nutrients originating from stormwater runoff within the City of Glenwood. A secondary goal is to assess the capacity of the stormwater conveyance system within the study area.

1.4.2 ASSESSMENT TECHNICAL OBJECTIVES

One or more technical objectives are needed to further describe the project goals. The technical objectives represent various attributes or project characteristics which collectively describe specific technical requirements. A conceptual project failing to meet technical objectives is considered incapable of achieving the project goal. The following technical objectives have been developed to support the project goals:

1. Water Quality
    a. Improve water quality by reducing sediment and nutrient loads delivered to Lake Minnewaska on an average annual basis;
    b. Evaluate BMPs in targeted watersheds based on high sources of pollutant loadings and runoff; and
    c. Evaluate potential BMPs on cost effectiveness
2. Assess the stormwater conveyance system capacity within the study area. Specifically identifying:
    d. Flooding of homes and other high value structures because of the 100-year event. The base event is defined as the 24-hour duration event using a precipitation amount of 6.17 inches as defined by Atlas 14 (NOAA, 2013); and
    e. Flooding of streets because of the 10% chance precipitation event (10-year flood, 24-hour event of 3.79 inches as defined by Atlas 14 (NOAA, 2013)).

2 STORMWATER CONVEYANCE SYSTEM ASSESSMENT

2.1 ASSESSMENT METHOD

The conveyance system assessment is being completed using XP-SWMM modeling software. The required data for the XP-SWMM model can be divided into two components: hydrologic and hydraulic inputs. Hydrologic analysis determines the amount of excess precipitation (i.e., runoff) and the rate at which excess runoff enters the hydraulic conveyance network. Inputs in this calculation include soil characteristics, land use, and impervious cover. The study area is divided into catchments (i.e., subwatersheds) based on elevation data and the stormsewer network. The hydrologic inputs are then computed for each individual catchment.

The hydraulic input or conveyance network is a series of features that collect and convey surface water. These features, called links and nodes, are typically streets, catch basins, underground storm sewer, manholes (storm sewer junctions), and open channel ditches and streams. Additionally, detention ponds or other sizeable surface depressions are contained within the hydraulic network as they temporarily store runoff and influence the timing of runoff to downstream locations.

Further detail of the SWMM model development process is discussed in **Appendix A – Data Summary** and **Appendix B – Stormwater Conveyance Assessment Methods**.

2.2 SUMMARY OF MODEL RESULTS

Surcharge depths and flooding footprints of storage areas under the 10- and 100-year synthetic rainfall events are displayed in **Figures 2-5**. **Figure 2** and **Figure 3** display the surcharge depth (i.e., the depth of flooding above the ground elevation) of all nodes through out the model for the 10- and 100-year rainfall events, respectively. **Figure 4** and **Figure 5** display the footprint of flooding within depressional areas (i.e., ponds or low-lying areas) for the 10- and 100-year event, respectively. **Figures 4** and **5** also show the building footprints that intersect the flood areas in red. The building footprints were obtained from the Minnesota DNR Light Detection and Ranging (LiDAR) dataset for Pope County.

Model nodes connecting two pipes are better described by the surcharge depths rather than flood depths. Surcharge depths, shown on **Figure 2** and **4**, are the depth of water over the ground surface (i.e., manhole rim elevation) rather than the pipe inverts. Nodes that are at the upstream or downstream end of an open channel ditch will generally show greater surcharge depths, but it is important to realize that the surcharge depths are calculated from the channel invert elevation compared to flood elevations.

2.2.1 NODE SURCHARGE DEPTHS AND FLOODED AREAS DURING 10-YEAR, 24-HOUR STORM

Analysis of **Figure 2** and **4** shows several locations that experience temporary flood inundation. **Figure 4** shows minimal flooded areas in developed areas outside of the Fairgrounds and TH 28 location. There are several locations where surcharge depths on the storm sewer system are greater than 1 foot as shown in **Figure 2**. These locations may or may not be problematic depending on the surrounding infrastructure and duration of flooding. These nodes are located within sag intersections and have a drainage area that is heavily developed with large percentages of impervious area.

2.2.2 NODE SURCHARGE DEPTHS AND FLOODED AREAS UNDER 100-YEAR, 24-HOUR STORM

Review of **Figures 3** and **5** indicate greater levels of inundation in the XPSWMM model during a 100-year rainfall event as expected. Again, the greatest extent of flooding is shown is in the Fairgrounds and TH 28 area. Flooding is also now shown along South Lakeshore Drive. Surcharge depths greater than 1 foot are more widespread along the stormsewer system in the developed areas of the City.

2.3 RECOMMENDATIONS

A detailed XP-SWMM model is a powerful tool for managing stormwater runoff. The integrated hydrologic and hydraulic analysis provides precise information on how stormwater runoff is affected by the stormsewer network and system storage. Model results can provide information on peak flow rates and flood elevations from a variety of storm magnitudes. Several potential uses of the XP-SWMM model are described in the following paragraphs:

- Capital Improvement Projects (e.g., Street Reconstruction) – It's common for utilities including stormsewer to be replaced, upgraded or extended during street reconstruction projects. The performance of the current stormsewer system can be assessed within the study area, and viable solutions to flooding or drainage problems can be identified during capital projects. Since the XP-SWMM encompasses the entire City of Glenwood (within the Lake Minnewaska watershed), the impact of stormsewer modifications can be traced all the way to the outlet into Lake Minnewaska. If a stormsewer improvement increases downstream flows and flood elevations, additional measures may be analyzed in XP-SWMM to offset those increases.
- Site Development or Redevelopment Projects – Like capital improvement projects, redevelopments can result in modifications to drainage patterns and stormsewer infrastructure leading to increased runoff volume and decreases in temporary storage. Similarly, new developments can result in additional runoff volume, higher peak runoff rates and downstream flood elevations unless managed. The XP-SWMM model can quantify the specific downstream impact from these projects and assess the benefit of stormwater management features to offset the impacts.
- Flood Mitigation Project Analysis – Various solutions to recurring flooding damage locations can be analyzed within XP-SWMM model and the most effective solutions be identified.

Previous efforts to develop hydrologic and hydraulic models to address flood issues at certain locations. This city-wide XP-SWMM model developed during this project serves as a uniform and complete "baseline" model for future analysis to analyze flooding related issues.

Hydrologic and hydraulic analysis has been performed recently as part of the upcoming TH 28 reconstruction project by the Minnesota Department of Transportation (MNDOT). Proposed changes to the drainage system from the project have not been incorporated into the XP-SWMM model. Based on preliminary design alternatives, the drainage system modifications will include a combination of additional culvert capacity under TH 28 at Perkins Creek, Perkins Creek channel repair, containment berms, TH 28 grade raise, and additional culverts alongside TH 28. When the TH 28 project design is finalized, the city-wide XP-SWMM should be updated for future uses.

Figure 2 - 10-year Noc

Scale
AS SHOWN

Drawn by
DFE

Figure 3 - 100-year

Scale AS SHOWN

Drawn by DFB

Figure 4 - 10-year F

Scale	Drawn by
AS SHOWN	DFE

Figure 5 - 100-yea

Scale
AS SHOWN

Drawn by
DFE

3 WATERSHED WATER QUALITY ASSESSMENT

3.1 ASSESSMENT METHOD

The Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds (P8) Urban Catchment Model software program was utilized to create a water quality model of the study area. P8 simulates rainfall, pollutant loading, and runoff from the watershed and subsequently routes the runoff through features such as water quality treatment devices (i.e., BMPs). These devices simulate pollutant particle settling, decay, and filtration/infiltration. The P8 model was utilized to estimate watershed loadings from the study area and removals from existing BMPs and natural depressions. This was done to calculate Total Phosphorous (TP) and Total Suspended Solids (TSS) loads delivered to Lake Minnewaska on an annual average basis. The P8 model was also used to calculated the anticipated TP and TSS removal of proposed BMPs. See **Appendix C – Water Quality Modeling Methods** for more details on the P8 model development.

3.2 SUMMARY OF MODEL RESULTS

3.2.1 EXISTING MODEL RESULTS

As a check for reasonability of the model results, **Table 1** and **Table 2** compare annual average TSS and TP yields. They also compare event mean concentrations (EMCs) model results to values reported in literature for various densities of development and land uses.

The P8 model results are within an acceptable range of the cited literature values, with one exception: the TSS medium density land use category. The lower values in that category were noted, but adjustements to the P8 model would not be defensible as the comparison is not to local montoring data. This general comparison indicates that the P8 model provides results which are adequate to allow for its intended use of evaluating the performance of existing BMPs, assessing the relative impact of future development and redevelopment, and prioritizing areas for future BMP implementation (when comparing results, relatively, across the watershed).

Table 1: Annual average TSS watershed load comparison

	Land Use			
	High Density	**Medium Density**	**Rural / Undeveloped**	**Overall TSS Conc. (ppm)**
Source	**Average TSS Load (lbs/ac/yr)**			
Glenwood P8 Model	317	135	24	104.2
Pitt/NSQD, 2011 (Residential)	--	--	--	135
Burton, 2002 (Residential)	670	250	10	--
Horner, 1994 (Residential)	420	190	--	--
Reinelt, 1996	312	--	45	--

Table 2: Annual average TP watershed load comparison.

	Land Use			
Source	**High Density**	**Medium Density**	**Rural / Undeveloped**	**Overall TP Conc. (ppm)**
	Average TP Load (lbs/ac/yr)			
Glenwood P8 Model	1.01	0.44	0.08	0.34
Pitt/NSQD, 2011 (Residential)	--	--	--	0.4
Horner, 1994 (Residential)	1	0.5	--	--
LimnoTech, 2007 (Urban)	1.34	1.03/0.81*	--	--
Burton, 2002 (Residential)	1	0.3	0.04	--
Burton, 2002 (Forest)	--	--	0.07	--

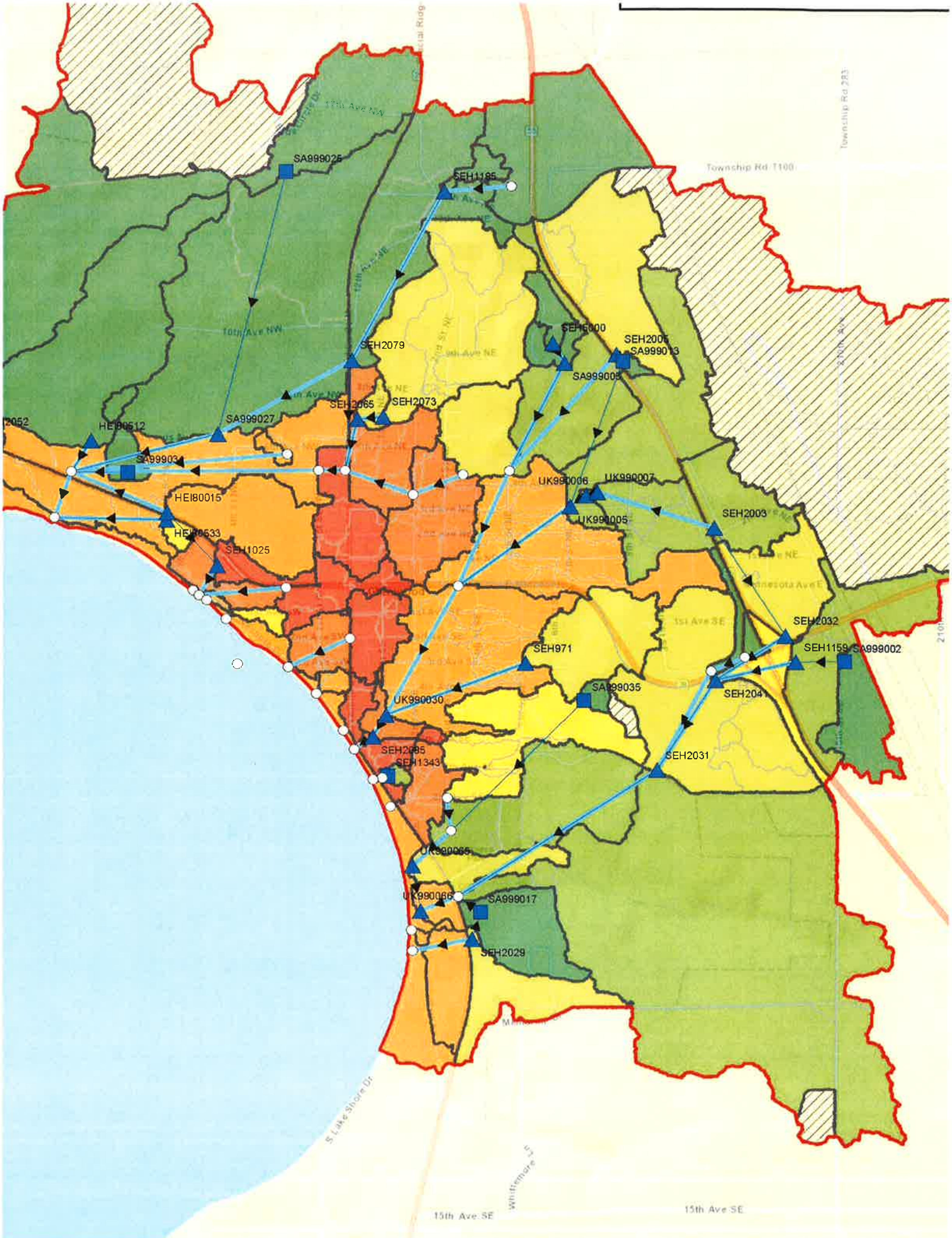
* Medium urban density / low urban density

3.2.2 CURRENT SUBWATERSHED LOADS, TREATMENT, AND YIELDS

The study area as modeled in the existing conditions annually contributes 81,369 and 342 pounds of TSS and TP, respectively, to Lake Minnewaska. Existing pollutant loads generated from each deviceshed (e.g., drainage area to a device within the P8 model) are tabulated in **Appendix C – Table 2**. The annual contributing TSS and TP loadings are calculated after existing ~~modeled devices remove~~ 53,618 pounds off TSS (or 40%) and 98 pounds of TP (or 22%) annually from runoff before it enters Lake Minnewaska. Treatment is modeled in both constructed stormwater practices and natural depression areas that store water. Existing pollutant removals from each modeled device and pollutant loads generated from each respective deviceshed (in pounds) can be found in **Appendix C – Table 3**.

Figure 6 and **Figure 7** show the average annual TP and TSS yields *delivered* to Lake Minnewaska under existing conditions. Delivered yield shows the amount of pollutants that an area is contributing to the downstream resource. This considers the load generated from the subwatershed and the removals provided by associated treatment devices, as well as any downstream treatment devices. Delivered pollutant yields are represented by annual average pounds delivered divided by the catchment runoff area (lbs/ac/yr).

The greatest pollutant load will be generated from the impervious area that is directly connected to the downstream resource. "Directly connected" refers to impervious area in which stormwater directly flows into the stormwater conveyance system before passing across any meaningful amount of pervious area that would otherwise capture a portion of the pollutant load through filtratrion or infiltration. Therefore, the highest yields are shown in the areas of the city with the greatest development. Conversely, other watershed areas with higher proportions of pervious land use, such as lawns, forests, or grassland, typically produce smaller amounts TP or TSS.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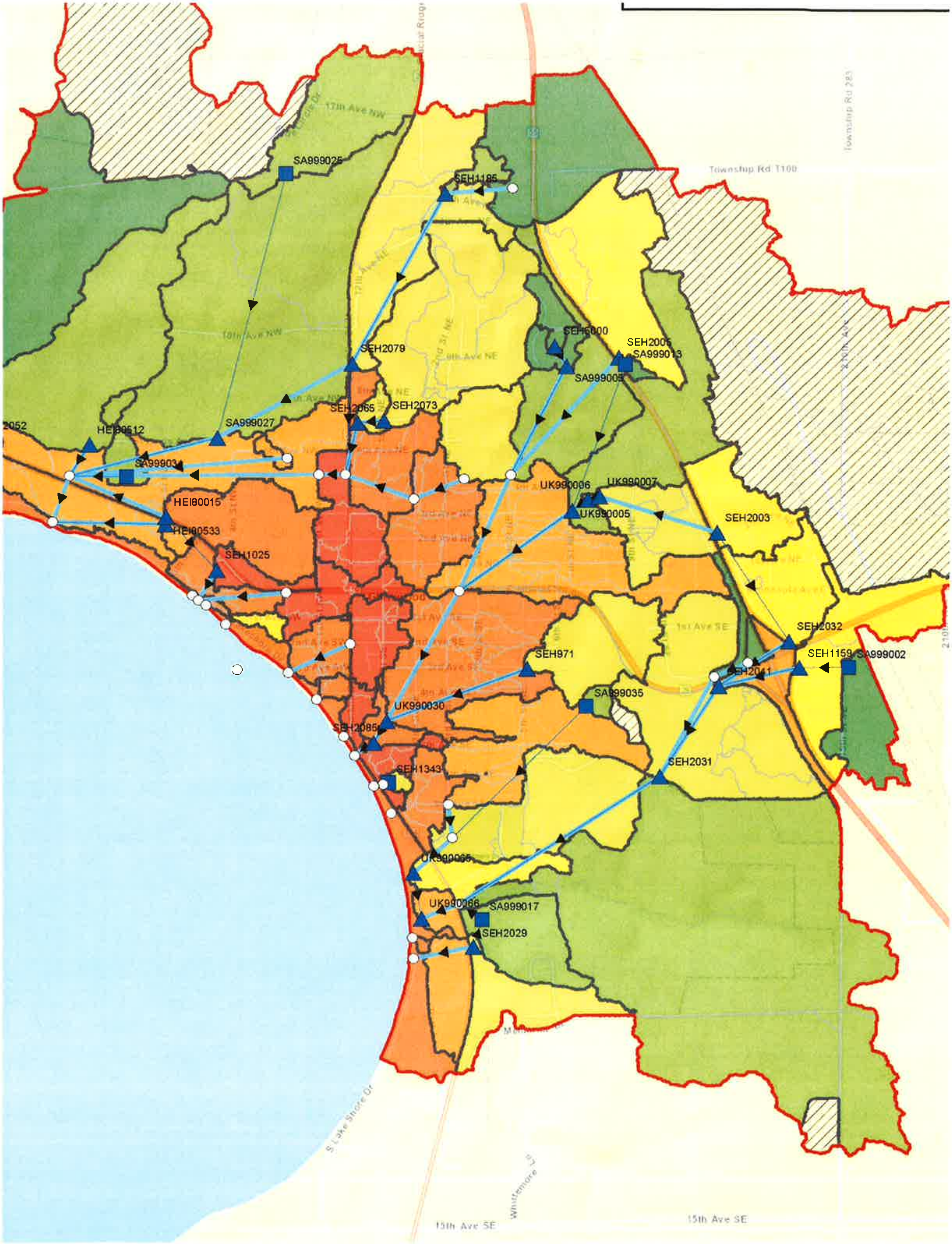
15th Ave SE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2nd St NE
210th Ave
SEH2065
SEH2073
2052
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SA999027
SA999031
UK990006
UK990007
UK990005
SEH2003
HEI80015
HEI80533
SEH1025
SEH2032
SEH1159
SA999002
1st Ave SE
SEH971
SEH2041
SA999035
UK990030
SEH2085
SEH1343
SEH2031
UK990065
UK990066
SA999017
SEH2029
S Lake Shore Dr
Whittemore Ln
15th Ave SE
15th Ave SE

4 WATER QUALITY IMPROVEMENT PLAN

4.1 TARGETING

The following sections outline the process of targeting areas in the study area for additional stormwater treatment measures and developing potential BMP locations for conceptual analysis.

4.1.1 SUBWATERSHED PRIORITIZATION

Results from the P8 water quality model were used to identify subwatersheds that contribute the highest pollutant yields to Lake Minnewaska (i.e., delivered yield). Delivered yield was the primary prioritization factor and is shown in **Figure 5** and **Figure 6**. Ideally, BMPs would be constructed to treat runoff from each high-yielding and targeted area.

4.1.2 IDENTIFYING POTENTIAL BMP LOCATIONS AND TYPES

The study area was reviewed to identify locations with opportunities to capture and treat stormwater runoff from sizeable upstream areas within prioritized subwatersheds. The criteria listed in **Table 3** was adapted from the Minnesota Stormwater Manual and used to determine the initial feasibility of potential BMPs. If a location's site and physical constraints appeared feasible for installing a BMP, performance and cost factors were used to select the most suitable and effective BMP type. Land availability was also a key factor in identifying potential BMP locations. A receptive public or private landowner must own the land available for BMP implementation.

In terms of BMP performance, volume control (e.g., infiltration) is generally regarded as the preferred stormwater treatment option as it is the most effective. An alternative to infiltration is filtration that passes stormwater runoff through a media filter, such as sand, before collecting the filtered water with perforated underdrains. Finally, sedimentation practices (e.g., stormwater ponds or wetlands) are generally used when sight constraints hinder other more effective BMP types. Stormwater ponds are typically better suited to treat larger drainage areas.

Table 3: BMP comparison matrix

		Site and Physical Constraints				Performance		Cost and Community Acceptance		
		Footprint Size (% of Drainage Area)	Drainage Area (acres)	Depth to Groundwater (feet)	Infiltration Rate (inches/hr)	TP Removal (Percent)	Peak Flow Reduction	Construction Cost	Ease of Long-term Maintenance	Communit Acceptanc
Sedimentation	Stormwater Ponds	1-3%	10-25	0	NA	50	Yes	Low	Easy to Medium	Medium-High
	Stormwater Wetlands	2-4%	25-200	0	NA	40	Yes	Medium	Medium	Medium-High
	Hydrodynamic	Varies	Varies	NA	NA	Varies	No	High	Medium	High
Filtration	Sand Filter	0-10%	0.5-5	0-3 feet	NA	50	No	Medium	Difficult	High
	Iron Enhanced Sand Filter	--	--	0-3 feet	NA	80	No	High	Difficult	High
	Bioretention	7-10%	0.5-2	≥3 feet	NA	44	No	Medium	Medium	High
Infiltration	Trench	0-10%	5-10	≥3 feet	>0.2	90	No	High	Difficult	High
	Basin	1-10%	0-10	≥3 feet	>0.2	90	Yes	Medium	Medium	Low

At multiple times throughout the targeting process, valuable perspective was provided by SWCD and City of Glenwood staff as to the preference and feasibility of BMP locations. Several BMPs initially identified were excluded for various reasons, such as a planned project limiting land availability or unsuccessful past efforts to engage private landowners. A total of 22 BMPs were identified as possible locations for future structural BMPs and are shown on **Table 4** and **Figure 8**.

In developed areas, it is difficult and expensive to install larger, regional treatment facilities due to the lack of available land. Rain gardens, small-scale Bioretention practices, are a common solution to provide treatment within developed neighborhoods or commercial sites that have little available land to construct a large BMP. The rain gardens can often be placed within existing street right-of-way upstream of catch basins. Several locations were identified for raingardens. It's expected that many more locations would be suitable for raingardens.

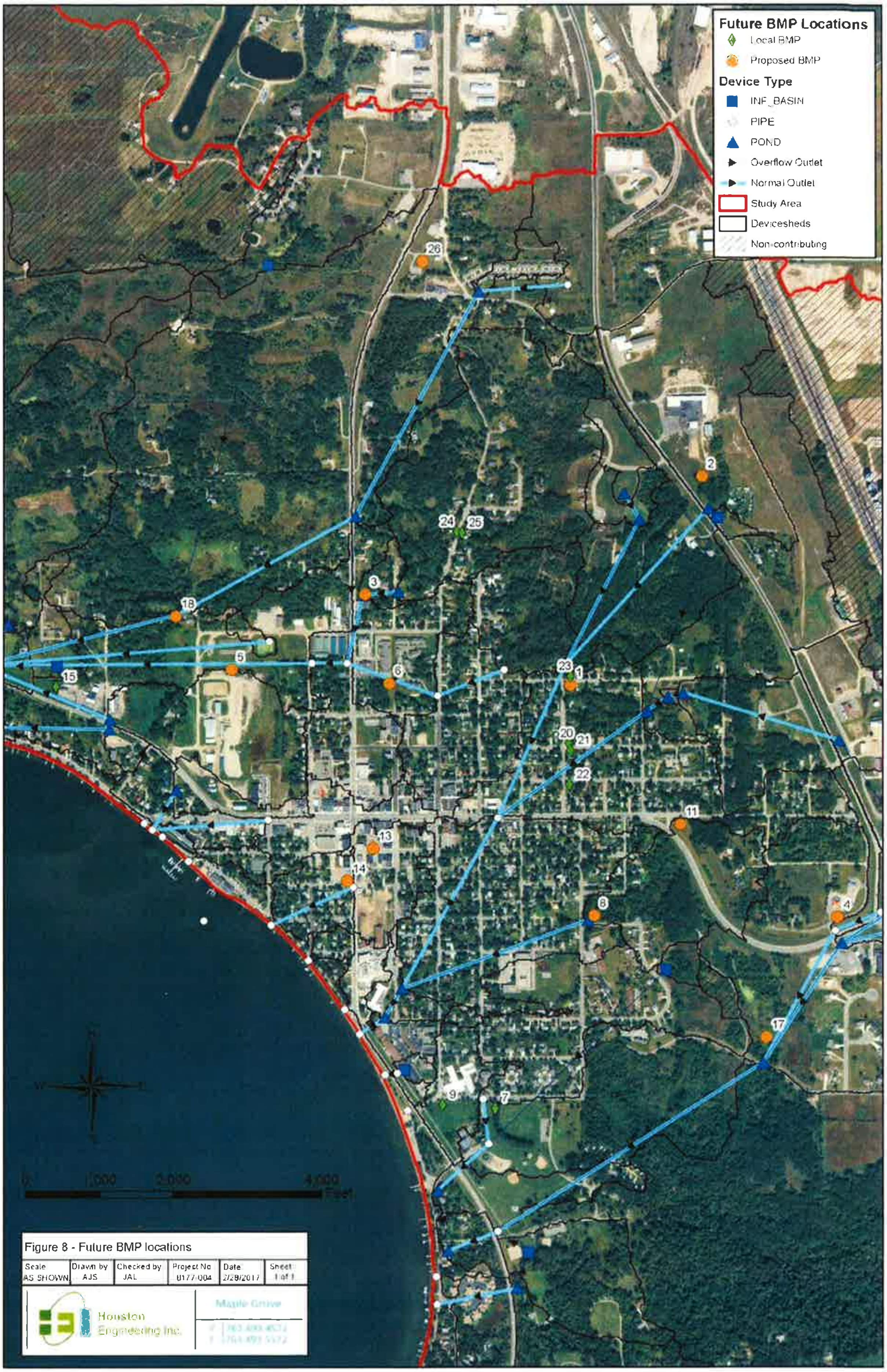
Table 4: Potential BMP descriptions

BMP ID	Drainage Area	BMP Type	Location	Land Authority	Description
1	0.3	Biofiltration	4th Ave NE and 5th St NE	Private	Local small-scale rain garden primarily capturing street runoff
2	56.0	Stormwater Pond	South of CLYDE Machines property	City & MnDOT	Treat runoff from Hwy 55 and other commercial/industrial developments
3	86.0	Dry Pond	Ravine N of 6th Ave NE	City & Private	BMP to utilize natural ravine as temporary storage; multiple basins in series; primarily rate control benefit
4	1.6	Bioretention	South of A&W Restaurant	MnDOT & Private	BMP to treat local business developments and CR 28 Frontage Road
5	206.9	Low Flow Iron Enhanced Sand Filtration	N side of County Fairgrounds	City	Previously proposed pond; a berm is needed in the ditch to divert water to an iron enhanced, low-flow sand filter
6	67.4	Stormwater Pond	Greenspace S of Glenwood Terrace Apts.	City & Private	BMP utilizing existing stormsewer to capture runoff from apartments and sizable upstream residential development
7	2.3	Biofiltration	N side of Barsness Park	City	Treatment of local street drainage via curb cut in open space; shallow ground water concerns.
8	34.1	Dry Pond	5th St SE and 6th Ave SE Ravine	City	BMP to utilize natural ravine as temporary storage; primarily rate control benefit
9	1.8	Biofiltration	E side of Barsness Park	County	Treatment of local street drainage via curb cut in open space; shallow ground water concerns; possible interception of stormsewer to capture larger treatment area
*10**	*8.5*	*Biofiltration*	*NW side of Minnewaska Elem. School*	*School*	*BMP to treat school or street runoff by intercepting local stormsewer*
11a	17.2	Stormwater Pond	Minnesota Ave Triangle	MnDOT	Option a is stormwater pond Option B is a biofiltration basin
*12**	*11.6*	*Infiltration Basin*	*2nd St NE and 2nd Ave NE*	*City*	*BMP on undeveloped city parcel to intercept stormsewer in street*
13	0.4	Underground/Tree Trench	1st Ave SE and 1st St SE	City	BMP retrofit to treat city parking lot and local runoff
14	0.6	Underground/Tree Trench	2nd Ave SW and Franklin St S	Private	BMP retrofit to treat private parking lot

BMP ID	Drainage Area	BMP Type	Location	Land Authority	Description
15	1.8	Biofiltration	Brownies Tire Services	Private	BMP to treat local commercial site. Open space on the west side of the property to capture parking lot and site runoff
*16**	*0.4*	*Underground*	*Pope County H&H Services*	*County*	*BMP retrofit to treat county parking lot*
17	189.9	Stormwater Wetland	Wetland N of Park Road	City	Natural wetland to be expanded and controlled with an outlet structure at existing embankment to treat a large upstream drainage area.
18	345.1	Outlet Structure Modification	Wetland outlet NW of Fairgrounds	Private	Reconstruct wetland outlet to provide multi-staged storage during rain events, and impoundment for treatment; potential to raise existing embankment for additional storage or reconstruct wetland for additional treatment
*19**	*108.3*	*Dry Pond/Wet Pond*	*Ravine at Hwy 29 S of 14th Ave NE*	*City*	*BMP to utilize natural ravine as temporary storage; rate control benefit or construct wet pond for treatment*
20	-	Biofiltration	503 2nd Ave NE	City & Private	Local small-scale rain garden primarily capturing street runoff.
21	-	Biofiltration	116 5th St NE	City & Private	Local small-scale rain garden primarily capturing street runoff.
22	-	Biofiltration	18 5th St NE	City & Private	Local small-scale rain garden primarily capturing street runoff.
23	-	Biofiltration	505 4th Ave NE	City & Private	Local small-scale rain garden primarily capturing street runoff.
24	-	Biofiltration	839 2nd St NE	City & Private	Local small-scale rain garden primarily capturing street runoff.
25	-	Biofiltration	838 2nd St NE	City & Private	Local small-scale rain garden primarily capturing street runoff.
26	17.0	Detention Pond	Dental practice near 2nd St NE and Hwy 29	Private	Route runoff via swales and stormsewer to BMP in open space; water quality benefit and rate control to mitigate downstream erosion issue.

** Italicized text indicates BMPs which were initially identified and later excluded from further analysis due to known land availability issues or recently completed projects.*

Figure 8: Future BMP locations



4.2 PROPOSED BMP EVALUATION

4.2.1 WATER QUALITY BENEFIT

The criteria for the conceptual design of proposed BMPs followed guidelines from the Minnesota Stormwater Manual. Infiltration and filtration BMPs were sized to treat a volume of 1.1 inch of runoff over the contributing impervious surface. Wet detention ponds and wetlands dead storage (i.e., volume below the normal water level) were sized to have 1,800 cubic-feet per acre of contributing area. Wet detention ponds and wetlands live storage (i.e., volume above the normal water level and below the overflow) were sized to treat a volume of 1.0 inch of runoff over the contributing impervious surface.

Conceptual BMP design sheets were prepared for eight of the 22 BMPs to be used as an example for the a BMP type or to depict unique BMP configurations. The conceptual design sheets include a design schematic, estimated load reduction and BMP cost, and other notes to be considered in the design and construction of the BMPs. They are located in **Appendix E – Conceptual BMP Design Sheets**. These sheets are limited to conceptual-level calculations and plan layouts that identify major design features to consider as well as limitations to be expected. Final design and construction plans will be required for construction of the proposed BMPs.

Load reduction estimates were developed for 13 BMPs. 12 of them were entered into a future conditions P8 model to quantify their effectiveness and estimate load reductions to Lake Minnewaska. Load reduction estimates for the remaining BMP (BMP1), a bioretention raingarden, was calcuated as an example using the Minimal Impact Design Standards (MIDS) calculator available to download from the Minnesota Stormwater Manual[1]. The proposed BMP list includes nine other rain garden locations that were not individually analyzed.

This study estimates that 342 pounds of TP annually are currently entering Lake Minnewaska from the Glenwood study area. As modeled, 46 lbs.[2] (or 13.5%) of the currently delivered TP load is removed by proposed BMPs. **Table 5** shows the future conditions delivered subwatershed yields for TSS and TP, respectively. Potential BMP removals are given in **Table 5,** as if each individual BMP was solely implemented.

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[1] https://stormwater.pca.state.mn.us/index.php?title=MIDS_calculator

[2] This total assumes all the proposed BMPs are constructed (including BMPs in series) as opposed to the sum of individual BMP removals which results in a higher total removal.

Table 5: Proposed annual averaged load reductions for individual BMPs.

BMP ID	Drainage Area (acres)	Annual TSS Load to BMP (lbs/yr)	BMP Efficiency (% TSS)	Annual TSS Reduction* (lbs/yr)	Annual TP Load to BMP (lbs/yr)	BMP Efficiency (% TP)	Annual TP Reduction* (lbs/yr)
1	0.3	99	94%	93	0.6	93%	0.5
2	56.5	2,774	82%	892	9.1	51%	3.2
3	86.4	3,145	72%	548	10.4	39%	2.0
4	1.6	432	100%	430	1.4	99%	1.4
5	213.7	17,353	57%	9,886	59.7	35%	21.0
6	68.4	6,217	83%	5,156	20.1	53%	10.6
8	38.2	1,497	67%	217	5.0	37%	0.9
11a	17.2	967	90%	873	3.1	61%	1.9
11b	17.2	967	81%	784	3.1	54%	1.7
13	0.4	170	99%	169	0.5	98%	0.5
14	0.6	255	99%	253	0.8	97%	0.8
17	200.0	8,958	83%	1,846	42.4	51%	7.1
18	345.2	4,537	78%	92	21.2	41%	0.3
26	19.7	770	85%	655	2.5	55%	1.4
Totals:				**21,893**			**53.1**

* Annual reductions are expressed as an increase in removals from existing conditions (i.e., Proposed BMP load reduction minus existing device load reduction).

4.2.2 CONSTRUCTION AND MAINTENANCE COSTS

A Preliminary Opinion of Probable Construction Costs (POPCC), engineering, administrative, and annual maintenance costs were estimated to determine BMP implementation costs over a 30-year period as shown in **Table 6**. The estimates are approximate and should not to be used for bidding or construction. They were developed without the benefit of a survey or geotechnical borings and are not intended to encompass all bid items. Also, the presence of bedrock, groundwater, significant utilities, access issues, or other unanticipated factors could inflate the cost higher than estimated. Therefore, a 20% contingency was added to each estimate and the actual costs should be expected to vary by ± 25%. Engineering and administrative costs were estimated at 30% of the POPCC.

Long-term maintenance of BMPs is critical to ensure that they continue to perform as designed. Most BMPs proposed here will require periodic sediment removal, inspection, mowing, repair, and/or replacement of filter material. Specific maintenance details are not included in this study, but operation and maintenance checklists were included in **Appendix F** from the Minnesota Stormwater Manual. To estimate the annual average cost for long term maintenance, methods from five sources (Chisago SWCD, 2011; EPA, 1999; Schueler, 1992; WCD, 2014; WERF, 2013) were applied and averaged over each BMP Type.

Table 6: Proposed BMP annual average cost estimate (dollars)

BMP ID	BMP Type	Construction Cost Est. (POPCC)	Engineering & Admin Cost Est.	Annual Maintenance Cost Est.	30-year Annual Average Cost
1	Biofiltration	$14,000	$4,000	$690	$1,300
2	Pond	$87,000	$26,000	$830	$4,600
3	Detention	$97,000	$29,000	$1,300	$5,500
4	Bioretention	$36,000	$11,000	$1,790	$3,400
5	Sand Filter	$160,000	$48,000	$10,040	$17,000
6	Pond	$210,000	$63,000	$2,010	$11,100
8	Detention	$29,000	$9,000	$390	$1,700
11a	Pond	$69,000	$21,000	$660	$3,700
11b	Biofiltration	$92,000	$28,000	$4,560	$8,600
13	Tree Trench	$99,000	$30,000	$660	$5,000
14	Tree Trench	$148,000	$44,000	$990	$7,400
17	Wetland	$130,000	$39,000	$2,140	$7,800
18	Detention	$31,000	$9,000	$410	$1,700
26	Pond	$70,000	$21,000	$670	$3,700

5 RESULTS

5.1 RECOMMENDATIONS

5.1.1 BMP PRIORITIZATION

The proposed BMPs were prioritized by cost-effectiveness in **Table 7**. Secondary factors for flooding and ravine erosion are also shown. The cost-effectiveness is quantified by the anticipated average annual cost over a 30-year period (from **Table 6**) divided by the annual TP load reduction. The result is a cost per pound of TP reduction. The flood and erosion benefit is qualitatively ranked based on the BMP's proximity to a downstream flooding or ravine erosion issue.

Table 7: Proposed individual BMP prioritization

Rank	BMP ID	Drainage Area (acres)	Water Quality Benefit (lbs. TP/yr)	Treatment Value ($/lbs. TP/yr)	Flood Priority	Erosion Priority
1	6	68.4	10.6	$1,230	High	Low
2	5	213.7	21.0	$1,290	Low	Low
3	17	200.0	7.1	$1,400	High	Medium
4	2	56.5	3.2	$1,720	Medium	Medium
5	11a	17.2	1.9	$2,270	Low	Medium
6	8	38.2	0.9	$2,370	Medium	Low
7	26	19.7	1.4	$3,140	Medium	High

Rank	BMP ID	Drainage Area (acres)	Water Quality Benefit (lbs. TP/yr)	Treatment Value ($/lbs. TP/yr)	Flood Priority	Erosion Priority
8	3	86.4	1.8	$3,700	High	Medium
9	4	1.6	1.4	$3,780	Low	Low
10	1	0.3	0.5	$3,880	Low	Low
11	18	345.2	0.3	$6,600	High	Low
12	11b	17.2	1.7	$7,740	Low	Medium
13	14	0.6	0.8	$10,600	Low	Low
14	13	0.4	0.5	$10,610	Low	Low

It should be noted that it is not cost effective to construct a larger downstream regional BMP and another BMP within the same watershed (i.e., in series). The upstream BMP will have minimal treatment gain if that runoff is already being substantially treated by a downstream device. E.g., it would likely not be advised to construct BMP 4 if it is also planned to construct BMP 17. Therefore, constructing all proposed BMPs may not be recommended. However, it would be beneficial to construct a peak flow reducing BMP in series with a water treatment BMP for the benefit of flood reduction and erosion control.

Channel erosion is another known contributor of sediment to Lake Minnewaska. Several channels and ravines in the study area are monitored for signs of worsening erosion, and in some cases channel protection practices have already been implemented. Although this study did not incorporate an assessment of water quality degradation from erosion, multiple potential BMPs reduce discharges to these sites.

5.1.2 IMPLEMENTATION

Its recommended that grant funding, such as the Board of Soil and Water Resource's Clean Water Fund Projects and Practices grant, be pursued to further study the feasibility, design, and construction of the highest ranking structural BMPs. Additionally, the Community Partners grant category, which requires a non-governmental partner, is an option to implement the smaller scale raingarden BMPs. The BMPs are prioritized based on cost-efficiency of TP load reductions delivered to Lake Minnewaska. Other factors such as flooding, timing of capital or development projects, project scale, staff capacity, and landowner interest should also be considered

In addition to the prioritized structural BMPs, non-structural BMPs should be considered and implemented if possible. Non-structural practices include street sweeping, limiting road deicing salt applications, and public education regarding stormwater issues, such as lawn fertilizers, animal waste, and yard waste. These non-structural BMPs are more difficult to estimate load reductions but are consistently included in stormwater management plans because of their established effectiveness.

5.2 LAKE MINNEWASKA WATER QUALITY

Lake Minnewaska is not currently impaired or in need of restoration due to eutrophication. Rather, Lake Minnewaska presently meets water quality numeric standards for nutrients established by the State of Minnesota. Therefore, the water quality goal set for this lake is based on the Lakes of Phosphorus

Sensitivity Significance (LPSS) eutrophication protection goal established by several Minnesota State Agencies[3]. The approach upon which the protection goal is based consists of using an empirical (regression) relationship, where the independent variables are the long-term (existing 10-year) average in-lake total phosphorus concentration, the lake volume, and the hydraulic inflow rate. The dependent variable is the estimated long-term total phosphorus load. The empirical equation is used to "back calculate" an existing load to the lake.

The protection goal for Lake Minnewaska is established as the 25th percentile total phosphorus concentration using the concentration data for the 10-year period. The (annual) load protection goal is then established by back calculating the load using the 25th percentile total phosphorus concentration, and further reducing the estimated annual total phosphorus load by 10%. **Table 8** shows the goals for Lake Minnewaska, based on the Lakes of Phosphorus Sensitivity Significance analysis.

Table 8: Eutrophication protection goals for Lake Minnewaska the empirical equation estimated annual Total Phosphorus (TP) reduction is the amount necessary for protection.

	Lake Minnewaska
10-year TP Average Conc. (ug/l)	30.9
Target TP Conc. for Protection (ug/l)	24.9
Empirical Equation Estimated Current Annual TP Load (lb/yr)	6,264
Empirical Equation Estimated Annual TP Load Target (lb/yr)	5,230
Empirical Equation Estimated Annual TP Reduction (lb/yr)	1,034
% Empirical Equation Estimated Annual TP Reduction	16.50%
Estimated Annual TP Load in Study Area (lb/yr)	342
Goal Annual TP Load in Study Area (lb/yr)	287

As mentioned earlier, this study estimates that 342 pounds of TP are entering Lake Minnewaska per year from the Glenwood study area. A TP load reduction goal of 16.5% is needed to meet the LPSS eutrophication goal for protecting Lake Minnewaska. This corresponds to an annual TP loading goal of 287 pounds per year from the Glenwood study area. As modeled, 13.5% of TP (46 pounds) is reduced from watershed loading by proposed BMPs. By implementing the proposed BMPs, it is estimated that 84% of the total target load reduction goal of 287 pounds TP per year will be reached, without claiming benefits of existing practices.

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[3] see LPSS, June 14, 2016; and https://gisdata.mn.gov/dataset/env-lakes-phosphorus-sensitivity

APPENDIX A – DATA SUMMARY

A.1 STORM SEWER

A.1.1 CITY GIS DATABASE

The City of Glenwood provided GIS data for the city's sanitary, transportation, and storm infrastructure. The storm infrastructure data was used to help develop the XP-SWMM model. The storm infrastructure data provided includes storm manholes, catch basins, and storm sewer lines. The following is a summary of the storm sewer feature attributes:

- Storm Sewer Lines: There are 365 storm sewer line features in the GIS and includes attribute fields for pipe length, pipe size, pipe material, and pipe grade.
  - Pipe Size (units are assumed to be inches) - 187 features have a "0" value.
  - Pipe Length (units are assumed to be feet) – 319 features have a "0" value
  - Pipe Material – 302 features are null and the 63 remaining features are identified as either HDPE, PVC-Drain Tile, or RCP.
  - Pipe Grade (assumed to be in percent slope) – 319 features have a "0" value. The 46 features having values range from 0.1 to 34.55.
- Storm Manholes: There are 119 storm manholes in the GIS and contains attributes for rim and invert elevations. 21 features are attributed with rim and invert elevations. The remaining 98 manholes have "0" or null values.
- Catch Basins: There are 202 catch basins in the GIS and includes attributes for rim and invert elevations. 29 features are attributed with rim and invert elevations. The remaining 173 catch basins have "0" or null values.

Spatially, most of the catch basins and manholes seem to be offset approximately 30-40 feet north and west of their actual locations.

A.1.2 RECORD DRAWINGS

The City of Glenwood provided record drawings for several projects. They include:

- The 2004 Water Main Improvements record drawings dated October 13, 2006 that include plan and profile views of storm sewer at two locations: 1) the intersection of 2nd Street SW and 3rd Ave SW and 2) 5th Street NE and 4th Avenue NE.
- The 2010 Ravine Stabilization record drawings dated May 2011 that include details of storm sewers along 3rd Avenue NE at 5th Street NE, 3rd Avenue NE, and 9th Street NE.
- The 2009 Dual Cell Attenuation Pond construction drawings dated November 11, 2009 that include details for the pond geometry and outlets.
- The 2014 Construction Plans for Lakeshore Drive Improvements dated June, 2014 that include removals and additions to stormwater sewers and private connections near the intersection of Lakeshore Drive and Minnesota Avenue. These additions include the inverts, materials, alignments, and sizes of several storm mains.
- The 2016 Construction Plans for Glenwood Retirement Village and TH 104 Drainage System plans dated March, 2016 that include several areas along TH 104 that have improvement designs to culverts and storm sewers.

The drawings include the necessary stormsewer information for SWMM model development at several locations and at the flood attenuation ponds constructed in 2009.

A.1.3 FIELD SURVEY

Short Elliot Hendrickson, Inc. (SEH) conducted a field survey of most stormsewer manholes throughout the city of Glenwood, MN. Through these surveys, the invert elevation, pipe size, pipe material, and alignment of most of the network could be synthesized into a GIS geodatabase. This survey included 113 Catchbasins and Manhole Sturctures.

Additional field survey information was collected by the Pope SWCD and City of Glenwood in the spring of 2016 to fill the remaining data gaps.

A.2 CULVERTS

A.2.1 POPE COUNTY HIGHWAY DEPARTMENT

Pope County provided construction plans dated March 16, 2015 for culvert replacements on CSAH 17 (South Lakeshore Drive) between 13806 MI South of TH 104 and TH 104. Sheets 3-6 and 9 were omitted from the plans. The plans include a note stating that one of the planned pipes was never placed. Four culverts with dimensions, invert elevations, and material type are shown in the study area.

A.2.2 MNDOT GIS DATABASE

The GIS data provided by the Minnesota Department of Transpiration (MnDOT) contains data on culverts, end structures, and inlets along State Highway 104, 28, and 29, and MN Highway 55 in the study area. Data for culverts includes material, shape, span, width, and height, but does not include invert elevations or the exact pipe alignments. Data for end structures includes material type and location. Data for inlets includes type, material, and size. The MNDOT data is useful for identifying culvert and storm sewer locations but must be supplemented with field survey or LiDAR to collect invert elevations.

A.2.3 FIELD SURVEY

Culvert data from surveys comes for two sources. One source, SEH, conducted a field survey of many culverts throughout the city of Glenwood, MN. Through these surveys, the invert elevation, pipe size, pipe material, and alignment of most of the network could be synthesized into a GIS geodatabase. This survey included 97 culvert inlet/outlets and storm sewer network outlets into Lake Minnewaska.

The second source of survey data for culverts was conducted by HEI in 2011 for the Alternatives Analysis to Address TH 28 High Water, which was in response to an approximately 4.5" rainstorm that occurred in July 2011. This survey focuses mainly on slope, shape, and existing culverts of Perkins Creek and ditches along TH 28 near 4th St. NW, to an area west of 6th St. NW. Approximately 25 culverts were surveyed by HEI.

A.3 WATERSHED INFORMATION

A.3.1 LIDAR

The project utilized data from the State of Minnesota's Elevation Mapping Project's Light Detection and Ranging (LiDAR) mapping project that collected elevation data to a vertical root mean square error (RMSE) of plus or minus six inches. A Digital Elevation Model (DEM) derived from the LiDAR data will be used for multiple purposes. For the XP-SWMM model development, the DEM was used to extract approximate channel dimensions, channel slopes, and determine surface flow directions and overlay predicted flood elevations to create inundation areas.

Minnesota Department of Natural Resources' (DNR) mapping project also produced polygon areas of building footprints using automated methods and the LiDAR data. The building footprints was used as one parameter in the estimate of the amount of impervious area in the watershed.

A.3.2 LAND COVER

The 2011 National Land Cover Dataset (NLCD) was utilized to develop runoff Curve Numbers as hydrologic model inputs.

A.3.3 SOILS

Hydrologic Soil Group designations from the Natural Resources Conservation Service's (NRCS) SSURGO database was used to develop runoff Curve Numbers as hydrologic model inputs. These designations were also used in estimating infiltration for devices in the water quality model.

APPENDIX B – STORMWATER CONVEYANCE ASSESSMENT METHODS

B.1 METHODS

The model of the conveyance system within the study area was created using XP-SWMM 2016 software program (version 17.0; engine version 12.0). These were the most current versions of the respective software as of the initiation of the model development (July 2016). The model input data is also being structured in an ArcGIS Personal Geodatabase, utilizing ArcGIS version 10.3.0.4322.

B.2 HYDROLOGIC INPUTS

B.2.1 CATCHMENTS

The catchment boundaries for the model were delineated by combining GIS mapping of the existing stormwater infrastructure with bare-earth LiDAR topography. The locations of the catchment pour points are based on inlet (catch basin and manhole) locations, localized topography, and the desired level of modeling detail. Additional drainage details available (as-builts and aerial images) were utilized to increase detail and accuracy. The catchment boundaries were developed using automated methods within the ArcGIS software and the Spatial Analyst extension hydrology toolbar. This process involves defining pour points on the LiDAR data based on stormwater infrastructure and automating the catchment delineation based on drainage to these pour points. In certain areas, where GIS or plan set data indicated private stormwater connections and rooftop drainage that are not represented by LiDAR data, rooftop catchment boundaries were delineated manually. Connections that were not in the GIS data at the time the model was developed are not included in the model. The catchment delineation process involves multiple iterations and delineation review to ensure adequate drainage boundaries are obtained. Catchment geospatial data includes all necessary hydrology data for direct import into the model. The determination of these parameters is described in the following sections.

A total of 238 catchments were delineated. Catchment sizes range from as small as 0.05 acres in highly developed areas, to as large as 200 acres in the undeveloped areas of the study area. The average catchment size across the study area is approximately 10 acres. Within the developed area, catchments average 4.6 acres. Catchments were assigned to runoff nodes in the model. These locations are where excess precipitation enters the hydraulic conveyance system.

B.2.2 NRCS CURVE NUMBER (RUNOFF METHOD)

The NRCS curve number method was used to estimate the initial abstractions and infiltration capability of the soil, therefore the amount of excess precipitation (i.e., runoff) for the synthetic events was analyzed. Composite curve numbers were developed for each subwatershed based on the estimated impervious area and pervious land cover data. For the synthetic events, the NRCS unit hydrograph method was used to convert excess precipitation into a runoff hydrograph. The parameters needed to estimate the amount of excess runoff and develop the shape of the runoff hydrograph include a rainfall hyetograph, subwatershed areas, NRCS composite curve numbers (for estimating losses), and times of concentration. For continuous simulation modeling, the NRCS curve number method was also used to estimate the amount of excess precipitation. Separate curve numbers were used to represent pervious and impervious areas within each subwatershed. The EPA-SWMM non-linear reservoir routing method was used to develop the runoff hydrograph. Additional inputs required for this routing method include pervious curve number, impervious surface percentage, equivalent width, and average slope. Land use and land cover data along with soils information were used to derive the NRCS composite curve number, a key model hydrologic input parameter. The land-use data for the existing conditions model was obtained from the National Land Cover Database (NLCD) as a GIS shapefile. SSURGO soil information was obtained from the Natural Resources Conservation Service (NRCS). These data provide information about the hydrologic soil groups throughout the watershed.

B.2.3 TIME OF CONCENTRATION

The time of concentration for each catchment was calculated using an algrothim developed by the Minnesota Department of Natural Resources (DNR). This algorithm uses slope, flow direction length, flow accumulation, and land use to caclulate a travel time across cells using flow velocity in Manning's equation. The cell to cell travel times are accumulated in the downstream direction. The product is a raster that represents the travel time of any given cell to its most downstream cell on the given cell's flowpath. The difference in downstream travel time values between the most upland point of a catchment and the outlet of a catchment then becomes the travel time of that catchment.

B.3 HYDRAULIC INPUTS

The general process for the development of the hydraulic model network is as follows:

1. Develop the node model structure based on input from the City stormwater GIS database, surveys, and detailed construction plans.
2. Determine storage node locations and develop stage-area storage relationships for these nodes.
3. Develop the subsurface (pipe) network based on input from the City stormwater GIS database, surveys, and detailed construction plans.
4. Add any special structures (BMPs, pumps, and orifices) present in the study area.
5. Determine surface flow paths from storage nodes and surcharging non-storage nodes.
6. Add appropriate street, channel, and weir overflows into the model network from surcharging nodes.
7. Run largest desired storm event (500-year, 24-hour) through the model and iteratively modify any surface conveyances or surcharge elevations based on flood loss, model continuity, or inaccurate flood mapping.
8. Use areal extent of 100-year, 24-hour storm event flooding to determine where storage may be double counted (i.e., surface channels that overlap storage areas filled during flooding) and modify surface channels to remove double counting of storage.
9. Adjust model run parameters (time step, configuration parameters, etc.) to improve model continuity and stability.

The specifics of this process are described below.

B.3.1 NODES

Each created model node is given a unique identifying name. A two to three letter prefix of the model node is given based on the original data source used to create the node. This prefix is followed by a six-digit number that is unique to each feature of the model.

Table 1: Model link naming information

Prefix	Description	Data Origination
SEH	Based on SEH survey points	SEH
HEI	Based on HEI survey points from TH 28 Study	HEI
SA	Storage areas	LiDAR DEM
UK	Nodes created from un-surveyed features	HEI/construction plans

Additional model node information derived from the City GIS data, survey data, and construction plans includes mainly manhole/inlet inverts. Comments and assumptions about all the node data used in the model are documented as attributes in the model node GIS shapefile.

B.3.2 STORAGE AREAS

The initial storage node component of the model was built to a depression storage resolution of two feet (i.e., all depression areas in the study area greater than two feet deep were included as storage nodes). Potential storage areas that are higher in the watershed and outside of the city were vetted with an additional requirement of having at least 0.5 acres under two feet of depth. Typical locations of storage nodes include storm water ponds, sag intersections, and any additional sizeable depression areas.

In the cases where the City's GIS infrastructure are located near the low point of the storage areas, these nodes were used as storage nodes. In the cases where no municipal infrastructure exist, nodes were added. Polygons were created around each storage node to the extent of the available storage, allowing sufficient height above the outflow threshold for hydraulic bounce. These polygons were then used with advanced GIS tools and LiDAR data to develop storage-area curves for each storage node.

B.3.3 PIPE NETWORK

Model data pertaining to the pipe network such as alignment, size, upstream/downstream inverts, materials, etc., was synthesized using data collected from the City GIS data, survey data, and construction plans. As with the nodes, the link IDs are based on a prefix that corresponds to a description of the feature and a six-digit number that is unique to the feature, as shown in **Table 2**.

Table 2: Model link naming information

Prefix	Description
SM	Storm sewer mains
CU	Culvert

Pipes are one form of conduit (i.e., conveyance link) in the multi-link design of the model, therefore they are also identified using a conduit ID. In the case of pipes, they were given a conduit ID prefix of "PI" followed by their six-digit identifier denoted above.

Pipe material is used to determine the roughness coefficient (Manning's 'n' value) used in the model. **Table 3** shows the description of the various pipe materials, the roughness that was used in the model, and a reference for the values. The model guidance was used whenever possible.

Table 3: Pipe material descriptions and roughness coefficients used

Materials	Description	n value
CMP	Corrugated Metal Pipe	0.024
HDPE	High Density Polyethylene	0.014
PVC	Polyvinyl Chloride	0.014
RCP	Reinforced Concrete or Concrete	0.013

Pipes were assigned conduit factors, specifically entrance and exit loss coefficients. The entrance loss coefficients were set to 0.5 for all pipes in the model. The exit loss coefficients were set to 0.5 for all manhole outlets and 1.0 for all external outlets and outfalls. Comments and assumptions about all the pipe data used in the model was documented as attributes in the model pipe GIS shapefile.

B.3.4 STREETS AND OVERFLOWS

When the pipe network capacity is exceeded, additional flow paths are needed to provide surface conveyance. One way of achieving this in the model is by creating either street or overflow channels. By using multi-links and conduit IDs, street and overflow naming was directly tied to the geodatabase. The same link ID was used in cases where street channels or overflows are directly above pipes. In cases where a street channel was required but no pipe alignment exits, a prefix of “OV” (overflow) is used in conjunction with a unique six-digit suffix. Surface conveyance in streets and overflows are represented by a trapezoidal channel with a bottom width of four feet, channel side slopes of 1:50, and a channel depth of typically two feet.

A new multi-link reference shapefile was created for natural channels. The Link ID for this multi-link has prefix “CN” (Channel). Generally, these features were created to model the various open channel sections of Perkins Creek and the ditches along TH 28. Stationing for cross sections of channel links was calculated and imported into the model. The station for each link was cut for LiDAR and HEI surveys of Perkins Creek and TH 28 ditches.

The conduit ID prefix for all street and channel multi-link features was changed to “DD” (Drainage Ditch) since all such features were created to be modeled as an open channel flow. Additional model street and overflow information was derived from GIS data, including the upstream/downstream invert elevations (surface elevations) and length. The length of the street or overflows are based on pipe length beneath them or by direct GIS measurement. Roughness was assumed to be 0.013 (concrete or asphalt) for streets and overflows. In the case of open ditches, such as Perkins Creek, the manning’s values for the overbanks and main channel are 0.08 and 0.045, respectively.

Once nodes begin to surcharge, as is typical during low recurrence events (100- and 500-year 24-hour storms), the accuracy of the modeling is very dependent on the surface conveyance. Generally, 1-D models of this type attempt to keep the surcharged water in the general vicinity of its expected conveyance until it is able to enter the subsurface system. This is very likely the case in the study area model with both the 100- and 500-year, 24-hour events. The magnitude of the 500-yea,r 24-hour event (8.24 inches), combined with the relatively flat topography of the model area, makes accurately representing every possible surface conveyance challenging. However, the primary purpose of modeling the 500-year, 24-hour event is to make sure that future modifications to the study area model do not result in lost water for the 100-year, 24-hour event. During model development, surface conveyance for