Minneapolis
City of Lakes

Southwest Harriet Flood Mitigation Feasibility Study and Stormwater Master Plan

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Front Cover Photo:

Ponding at James Ave. and 50th St. intersection *by HR Green, Inc.*

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Acronyms and Abbreviations

ACRONYM	DEFINITION
AC-FT	Acre-Feet – 1 ac-ft of volume is equivalent to 12 inches of water over one acre of land
ADA	Americans with Disabilities Act
ArcGIS	A Geographic Information System used to produce maps and interpret geographic data
BMP	Best Management Practice
CFS	Cubic Feet per Second – A Measurement of flow rate
CIP	Capital Improvement Plan
EOPC	Engineer's Opinion of Probable Cost
EPASWMM	Environmental Protection Agency's Storm Water Management Model – Used to model the hydrology and hydraulics of a drainage system
FEMA	Federal Emergency Management Agency
LiDAR	Light Detection and Ranging – A surveying method used to generate digital elevation models.
MCWD	Minnehaha Creek Watershed District
MPRB	Minneapolis Park and Recreation Board
MOU	Memorandum of Understanding
TMDL	Total Maximum Daily Load
XPSWMM	XP Storm Water Management Model (XP is a proprietary name) – Used to model the hydrology and hydraulics of a drainage system

Executive Summary

The City of Minneapolis has a history of flooding challenges in its "Southwest Harriet" area. The area, generally represented south and west of Lake Harriet and north of Minnehaha Creek, will frequently experience impacts to structures during larger rainfall events. Based on models developed by the City, as many as 273 structures in this study area are potentially subject to flooding as a result of deficiencies in the City's storm sewer system during a 100-year storm event, of which 125 are residential, commercial or habitable structures (hereafter referred to as primary structures). In addition to flooding of structures during such events, streets and parks (Pershing Field and Lynnhurst Parks notably) will also be temporarily inundated with surface water.

The Southwest Harriet area is characterized by residential properties with commercial nodes (Lake Harriet in the foreground and Pershing Field Park is identified by the open fields in the background).

Stormwater management problems like this not only impact a variety of stakeholders, but the solutions to such problems often require the participation of multiple agencies. In recognition of this need, the City of Minneapolis recently executed a Memorandum of Understanding (MOU) with the Minnehaha Creek Watershed District (MCWD) and the Minneapolis Parks and Recreation Board (MPRB). The MOU documents a commitment among the three agencies to work together by integrating goals and management strategies for the Minnehaha Creek watershed in Minneapolis.

Specific to the Southwest Harriet project, the MOU partners have worked with the City to conduct a flood mitigation feasibility study in search of outcomes that include:

- Strategies and feasible solutions to reduce flooding in the Southwest Harriet study area
- Feasible solutions that will, at minimum, not adversely impact - in terms of water quality or quantity received - other water bodies including Lake Harriet, Minnehaha Creek, and the outlet channel connecting the two water resources
- Estimated costs of implementing a complete program of projects across the study area, and
- Proposed sequencing of projects in order to align solutions with funding opportunities or other potential capital improvement projects as applicable

Using the City's existing stormwater model, the project team conducted an evaluation of a variety of solutions, and combinations thereof, which could apply to this setting. Grounded in a set of design criteria related to flood reduction and water quality goals, the team developed feasible improvements that corresponded to the criteria measures of success. Ultimately, the identified solutions considered included replacing or enlarging existing pipes, development of underground and aboveground storage systems, and smaller dispersed "best management

practices" (BMPs) such as rain gardens in street boulevards. By working with its MOU partners, the City of Minneapolis was able to investigate opportunities in light of other ongoing planning efforts to create a set of solutions that have been optimized not only in terms of the anticipated physical benefits (e.g. reduced flooding of structures), but also in terms of ability to implement the solutions.

As noted above, this study is focused on flooding due to lack of capacity in the public storm sewer system. However, the models indicate that there are structures that could be impacted by flooding during large rain events due to drainage patterns internal to the parcels, such as how the land is sloped. Solutions for these types of flooding were not considered, but the pipe sizes recommended would accommodate drainage from the majority of those properties if the owners decide to implement changes to their properties in the future.

The set of recommended solutions is expected to result in a 96% reduction in the number of primary (residential or commercial) structures that experience flooding in a 10-year event. For the 100-year event, the number of primary structures that would experience flooding drops from 125 to 65 (a 48% reduction).

Similar improvements would also be expected in the amount of street flooding during large storm events. Modeling of the recommended solutions shows a 75% reduction in the linear feet of flooded streets in the 10-year event. Because much of the stormwater infrastructure for this area is located underneath city streets, opportunities to synchronize those improvements with other projects (such as street repaving or reconstruction) have been considered by the project team. Continued coordination between city departments (or with Hennepin County) could result in projects that achieve multiple city objectives while also reducing total construction effects to nearby residents and property owners.

Because many of the recommendations for stormwater infrastructure involve work in city streets, ongoing coordination between City departments is necessary to synchronize construction activities and minimize impacts to the surrounding neighborhoods.

In addition to addressing flooding challenges, the proposed projects are able to provide water quality benefits. Underground detention of stormwater used for rate attenuation also offers the potential reduce Total Suspended Solids (TSS) and Total Phosphorous (TP) discharges into their ultimate receiving water body (i.e. Lake Harriet or Minnehaha Creek). Given the design criteria that were established by the project team, underground detention systems provide the best opportunity to simultaneously achieve flood reduction objectives as well as provide effective water quality treatment.

The potential overall cost of the recommended solutions in this plan ranges to upwards of $72 million, and the timeframe to build out would be several years at minimum. Therefore, the phasing of projects and leveraging of other funding sources will be necessary to effectively implement solutions. In this regard, the project team has identified projects that should be considered as early priorities because they either maximize benefits relative to

the cost or the project is a critical foundation piece that enables the construction of other pieces of the proposed solution. Table 11 of the report lists a recommended phasing order in which the individual projects should be implemented.

Concurrent to this study, MCWD and MPRB are each conducting master plans for their facilities. These master plans will define future needs and a program of improvement projects that could be coordinated with flood mitigation solutions. Going forward, the City of Minneapolis will continue to work with its MOU partners to evaluate how the parallel studies impact recommendations from this study.

Introduction

Study Goals

The Southwest Harriet Study Area, as shown in Figure 1, has a long history of flooding due to inadequacies of the storm sewer system. Several studies have been completed in the past; however, the proposed solutions were never implemented for a variety of reasons including cost, constructability, and a lack of coordination among the City of Minneapolis (City), Minnehaha Creek Watershed District (MCWD) and the Minneapolis Park and Recreation Board (MPRB). These agencies have now executed a Memorandum of Understanding (MOU). The MOU memorializes a commitment to working together in order to integrate goals, plans and investment strategies that improve the environments within the Minnehaha Creek sub-watershed in Minneapolis. The MOU shapes how the three agencies will partner on multi-jurisdictional initiatives to achieve common goals such as:

- Reduce flooding;
- Achieve regional pollutant load reductions identified in Total Maximum Daily Loads (TMDLs);
- Reduce runoff volumes and peak flows to Minnehaha Creek

The purpose of this study is to collaborate with the MOU partners on achieving the following outcomes for the Study Area:

- Investigate strategies to reduce flooding, and through alternative analysis and optimization, develop feasible solutions;
- Conduct additional investigations to evaluate and describe solutions and their ability to meet other MOU goals listed above. To further clarify, this study will focus on developing feasible and constructable solutions to reduce flooding while ensuring that the developed solutions will not adversely impact Lake Harriet, Minnehaha Creek or an unnamed channel that connects Lake Harriet to Minnehaha Creek;
- Provide an engineer's opinion of probable cost (EOPC) and cost-benefit analysis for the feasible solutions;
- Provide a framework for how preferred solutions will be phased and integrated with other projects in the City's Capital Improvement Plan (CIP), if applicable.

Overview of Study Area

The Study Area, shown in Figure 1, is generally bound by France Avenue to the west, 45th Street to the north, an unnamed channel from Lake Harriet to Minnehaha Creek to the east and Minnehaha Creek to the south. Figure 2 shows the roughly 800-acre watershed area included in the City's hydraulic model; however, the study area is more focused and divided into four individual sub-watersheds based on storm sewer outfalls. These sub-watersheds are referred to as Pipesheds (Figure 2, and Appendix A). Pipesheds 1 and 2 drain to Lake Harriet, whereas Pipesheds 3 and 4 discharge directly to Minnehaha Creek and/or the unnamed channel.

FIGURE 1: STUDY AREA OVERVIEW

The project area can be described as mixed residential and commercial, with three prominent green spaces being notable exceptions: Pershing Field Park, Lynnhurst Park, and the Minnehaha Creek Park. Hennepin County roads (Xerxes Ave and 50th Street) are also included in the study area, and any improvements involving

the County right-of-way will need to be coordinated with the County. Note that Minnehaha Creek and its affected FEMA floodplain are not included in this review. This Study is not attempting to alter the mapped floodplain; it is only intended to review interior drainage issues.

FIGURE 2: SOUTHWEST HARRIET STUDY AREA PIPESHED BOUNDARIES

Background

Previous Reports

According to City records, the storm sewer system in this area was originally designed to convey a 2-year storm event. In response to the flooding issues that have occurred here, the City conducted a series of studies focused on alleviating flooding in 1978, 1987, 1997, 2001, 2005, and 2011. The 1978, 1987, and 1997 studies each concluded that a combination of increased stormwater conveyance and storage, especially at Pershing Field Park, was required to reduce flooding. One recommendation from the three reports has been implemented: additional pipe infrastructure with catch basins along West 47th from Zenith Ave to Lake Harriet. The 2005 study also discussed various conveyance and storage solutions, including a 24.5 acre-feet (ac-ft) detention pond at 50th and Chowen and an 11.5 ac-ft underground storage system with a lift station at Pershing Field Park, which would result in an increase of peak flow rates to Lake Harriet through an upsized the storm network. Due to potential impacts and the agreed upon basis of design parameters by the MOU partners, peak flow rate increases to the adjacent water bodies are no longer an acceptable solution. Cost and constructability concerns for the solutions identified in this series of studies meant that few solutions have been implemented as of 2018.

Existing Conditions

Baseline assumptions regarding existing flooded areas and surcharged pipes were provided in the City's XPSWMM model. These locations in the model became the focus areas of this study.

City Model

The City of Minneapolis XPSWMM model includes hydraulic results (i.e. flooding not associated with Minnehaha Creek or Lake Harriet) for the 10-year and 100-year storm events. The model determines this by combining land use data with delineated subwatershed areas to calculate the runoff produced throughout the system. This "one dimensional" model creates links between drainage areas to represent storm drain infrastructure, overland street flow, and overland flow routes outside of the street right-of-way. Stormwater storage locations exist in areas where there are physical low points in the ground surface. The runoff and storage node data were automatically generated in ArcGIS using LiDAR elevation data.

During the study, HR Green (the City's consultant) made base model edits: alterations or updates based on as-built or plat data or to improve the performance of the provided base model. These edits include eliminating links that were redundant, correcting links modeled incorrectly, or editing links that were causing inefficiencies or unstable results in the model itself. Modifications made to the City's model are outlined in Appendix A.

Flooded Areas and Streets

As mentioned in the City's 1997 Flood Report, parts of the storm system are designed to accommodate the 2-year storm event. Appendix B and Figure 3 below displays the impacts of flooding on structures and streets during 10- and 100-year events based on the City's XPSWMM model. The flooding extents are based on modeling results reflected on LiDAR elevation data; no survey data has been collected for the low opening elevations of the potentially impacted structures to verify if those structures are truly floodprone in the given storm event. Streets are considered flooded when the model results show stormwater flows in the street that are greater than 10 cubic feet per second (cfs), which corresponds to a flow depth of 6 inches. In the existing conditions

model, 27,834 linear feet of streets are flooded during a 10-year storm. These same streets, and more, are flooded in a 100-year storm, totaling 56,364 linear feet.

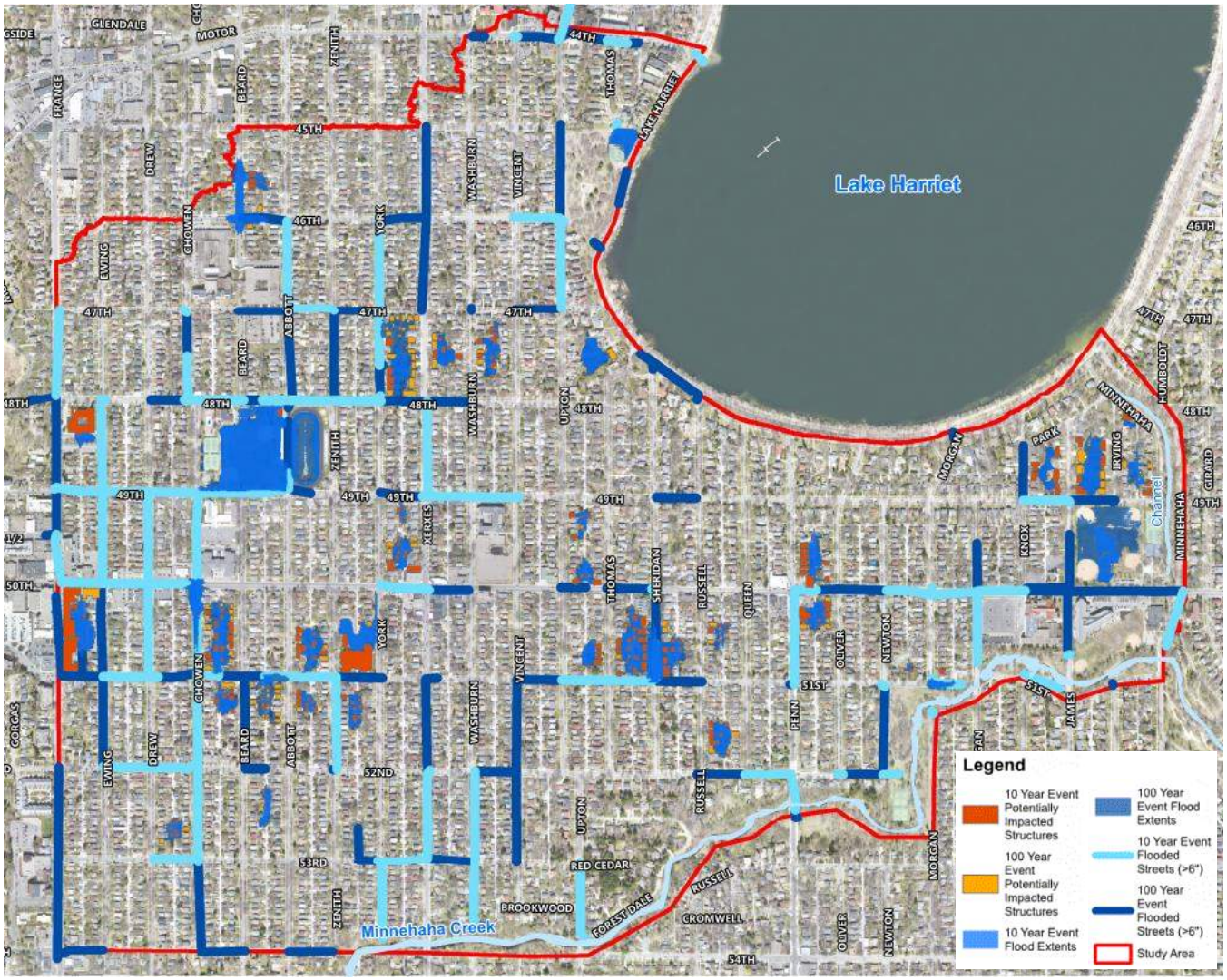


FIGURE 3: EXISTING FLOODING IMPACTS

Based on the model results, 227 structures are potentially impacted by flooding during the 10-year storm, and 343 structures are potentially impacted during the 100-year storm. Of these, 189 in the 10-year and 273 in the 100-year are due to City storm sewer deficiencies. All other structures are impacted due to backyard low points collecting interior drainage and will no longer be addressed from this point through the remainder of the report. The study primarily focuses on reducing flooding impacts to primary structures, which are residential homes, commercial businesses or other community buildings. There are 76 primary structures impacted in the 10-year event and 125 in the 100-year event. Secondary structures, which include garages, storage sheds and any other unoccupied accessory structure, were also tracked in this study. In the 10-year event, there are 113 secondary structures impacted, and 148 impacted in the 100-year event. Table 1 provides a summary of the existing

system's affected structures. Additional discussion on impacted primary and secondary structures is located in the Expected Outcomes from the Recommended Program of Projects section below.

TABLE 1: EXISTING AFFECTED STRUCTURES

	Existing Affected Structures	
Storm Event	**Primary***	**Secondary****
10-yr	76	113
100-yr	125	148

* Primary Structures = residential buildings, commercial businesses, or other community buildings
**Secondary Structures = garages, storage sheds, or other unoccupied accessory structure

Basis of Design

The project team (including MOU partners) collaboratively determined the basis of design for the study to ensure the priorities of each agency were represented in the eventual design outcomes. The basis of design criteria provided important guidance to the engineering team so that modeling and design decisions were aligned with overall project objectives. The City also indicated projects within the right-of way or on public property should be prioritized in order to avoid private property acquisition. Table 2 details the primary design metrics the project team used when completing the study.

TABLE 2: BASIS OF DESIGN CRITERIA

CRITERIA	MEASURE OF SUCCESS
FLOOD REDUCTION	
Storm Sewer	Design to accommodate the 10-year rainfall without surcharging onto the surface.
Structure Flooding	Eliminate primary structures impacted by City infrastructure deficiencies during 10-year rainfall event. Reduce primary structures impacted by City infrastructure deficiencies during 100-year rainfall event
Flow Rate	Maintain or reduce the cumulative peak flow rate from all outfalls to Lake Harriet. Reduce or maintain the peak flow rate per outfall to Minnehaha Creek and the unnamed channel.
WATER QUALITY	
Pollutant Loads	No quantifiable reductions are required. However, the project as a whole will look to reduce sediment and sediment bound pollutant load to the Lake, Creek, and the channel by incorporating water quality best management practices to the extent practical.
Green Infrastructure	Identify general areas of potential street Best Management Practices (BMPs) to reduce flows to the City storm system
Infiltration	Assume no infiltration at the proposed BMP locations due to high groundwater and lack of contaminated soils data.

Additional Design Considerations

Secondary design criteria were also agreed upon by the MOU partners. While these additional design considerations were included in the decision making and phasing decisions, they were not weighted as heavily as the criteria displayed in Table 2 above.

TABLE 3: SECONDARY DESIGN CRITERIA

CRITERIA	MEASURE OF SUCCESS
Tree Canopy	Designs shall consider the extents of the existing tree canopy and strive to preserve it whenever possible. This criterion is not inclusive of ash trees, which may be more acceptable to remove.
Capital Improvement Projects	Improvements should be incorporated with the City's CIP wherever possible and compatible.
Property Acquisition	No private property should be purchased, and the need for permanent easements should be minimized.
Utility Protection	Improvements will not significantly impact the operation of other utility systems, such as the public water main, sanitary sewer, and major power or gas supply lines, without mitigation.

Optimatics Evaluation

Optimizer™, software produced by Optimatics, allows for the evaluation of infrastructure improvements by running the system through hundreds of thousands of iterations of potential upgrade combinations while balancing hydraulics, costs/penalties, and more. Optimizer™ was used in conjunction with EPASWMM to analyze the City's XPSWMM model with a focus on meeting the 10-year level of service for the storm sewer system, reducing street flow in the 10-year storm event, and optimizing stormwater storage to minimize structure flooding in the 100-year event.

Parameters/Inputs

Optimizer™ balances the calculated "penalties" and "costs" of hundreds of thousands of possible combinations of storm sewer improvements and storage options. Penalties refer to unwanted or detrimental effects that may occur from the do-nothing scenario as well as any combination of upgrades that Optimizer™ has calculated. Penalties include flooded structures or increased peak flow rates to the creek or lake. More serious effects are represented as a higher penalty. Costs refer to an actual cost of the improvement, financial or otherwise, that is sustained to prevent penalties from occurring. The costs input into Optimizer™ are not necessarily representative of an expected construction cost, but they are better thought of as relative values used to represent infrastructure improvement capital costs. Further discussion of analysis procedures and input values are discussed in Appendix C.

Results

Optimizer™ requires human engineering judgement to make full use of its suggested optimal upgrades and to apply the suggestions in a way that best suits the real world conditions. The combinations of upgrades that Optimizer™ produced that best balanced the penalty and cost inputs were analyzed by HR Green for constructability, feasibility, cost effectiveness, and suitability to the Basis of Design. The Optimizer™ software

proposed extensive pipe upsizing throughout the Study Area, and suggested the need for many new stormwater detention facilities throughout the system. While the output guided HR Green on where priority solutions should lie, the software ultimately cannot assess construction practicality or feasibility. After a constructability review, a majority of the suggested pipe upgrades were deemed feasible as proposed, or as a dual pipe alternative to meet ground cover limitations. Alternatively, with the limited amount of space for storage and detention throughout the Study Area, many storage options proposed by Optimizer™ would not be feasible to construct as proposed. Smaller detention facilities in various locations were vetted and listed as feasible options in the recommendations. This cycle of review and modifications resulted in a majority of the 10-year street flow and pipe level of service goals to be met, but it could not meet all of the 100-year structure flooding goals.

Recommended Program of Improvements

Referencing the Optimizer™ outputs, HR Green prepared a series of proposed upgrades that were modeled in XPSWMM and subjected to a construction feasibility review. The full extents of the upgrades are displayed in Appendix D, Figures D.1 through D.4. These proposed upgrades are divided into their respective pipesheds and further reduced into “Subareas of Interest”, shown in Figure 4. These subareas serve as a way to divide the proposed improvements into smaller segments that address a common flooded area.

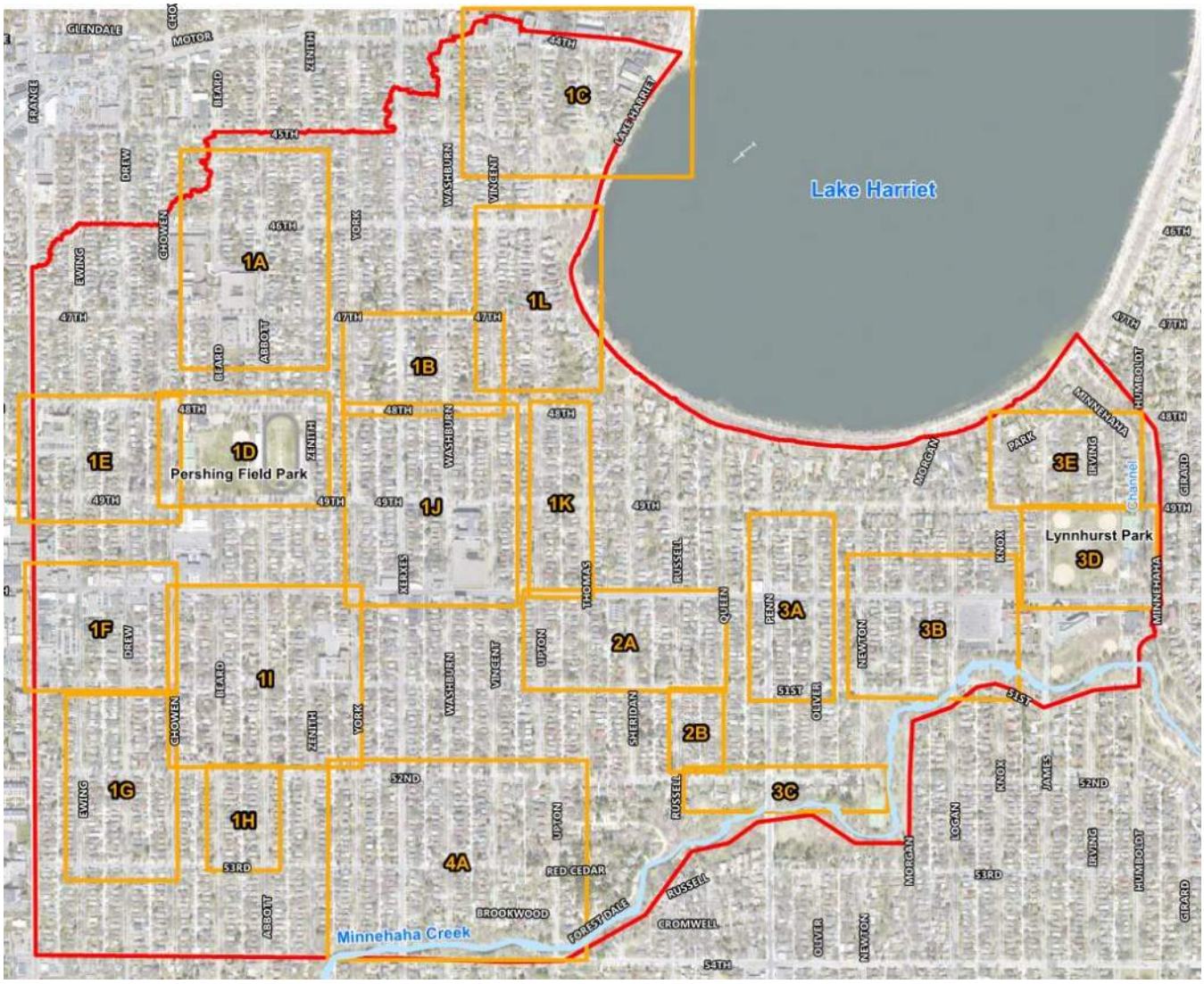


FIGURE 4: SUBAREAS OF INTEREST

It should be noted the proposed improvements are not expected to eliminate all of the existing flooded areas due to multiple limitations on the available solutions. Those restrictions included, but were not limited to, available pipe cover, construction access and space, utility conflicts, avoiding private property, downstream pipe connections, and steep streets. Also, flooding on private property not caused by City infrastructure was considered out of the

City's control and was not assigned proposed improvements. Should private property owners choose to address these issues independently, the proposed pipe upgrades adjacent to those flooding areas are adequately sized for the additional flows (with the exception of subarea 3E as discussed below). In addition to the following updates, HR Green recommends adding storm infrastructure on streets with no current system where there is a major low point at intersections capturing runoff from multiple streets. An example of this would be the intersection of Beard Ave and 46th St. Such an addition would help capture upstream runoff prior to the low points and provide some pipe storage, thereby reducing the extent of in-street flooding at the intersection.

Components of the Solution

HR Green, with the help of the MOU partners, evaluated proposed options with a multi-disciplinary approach and identified three main components to incorporate in the proposed solution: pipe upsizing, underground and aboveground storage, and boulevard boxes. Pipe upsizing allows for increased conveyance from areas where stormwater backs out of the pipe system ("surcharge") and onto the street or into private property. However, adding additional pipe capacity as the only solution would result in higher discharge rates into the receiving waters (Lake Harriet, the unnamed channel, and Minnehaha Creek), which would be counter to the Basis of Design criteria for flow rates.

This study area is fully developed, and offers little in the way of open space for solutions. For this reason, underground storage often took the form of "boulevard boxes": box culverts placed directly under the roadway and adjacent to the boulevard that could connect to catch basins. These boxes can also act as relief pipes for existing surcharged storm sewer by utilizing a built in weir structure. Boulevard boxes were assumed to only be feasible on the opposite side of the street from water mains to limit conflicts with utilities. Discussions with the City and MOU partners determined that the optimal location to be under the roadway as a means to limit or avoid impacts to adjacent trees. Appendix E provides more details for the proposed boulevard box concept.

With Pershing Field and Lynnhurst Parks being substantial green space areas, MPRB has been willing to explore regional underground storage facilities. These storage facilities are critical for meeting design objectives due to their ability to hold back vast amounts of stormwater while the downstream drainage flows out of the system. This delay in upstream conveyance reduces the peak flow rates into the waterbodies. Other benefits of larger underground detention facilities could include longer particle settling times (for water quality improvements) or providing source water for irrigation re-use, if the appropriate modifications are made to the design of the facilities. Large storage systems are also ideal locations for the implementation of additional water quality components because of the need for pretreatment and maintenance. The types of water quality devices and configuration options are endless, and can be determined during preliminary design. Two options for treating water quality in large underground storage facilities are discussed in Appendix F.

According to soil borings from Pershing Field and Lynnhurst Parks provided by the City (Appendix G), groundwater elevations would be near the bottom of the proposed underground storage facilities; therefore, HR Green assumed infiltration was not feasible at those locations. Backflow preventers were modeled within several pipes whenever they were beneficial for structure flooding or required for design. The specific type of backflow preventer is not specified.

Smaller aboveground storage facilities, such as stormwater ponds, were incorporated into Minnehaha Creek Park near existing outfalls where there appeared to be adequate space. The facilities could include a permanent pool of water or a filter bed to provide water quality treatment while simultaneously providing rate attenuation.

HR Green also investigated opportunities to implement green infrastructure techniques, such as curb cut rain gardens or overflow swales along the streets. However, given the high degree of variability in road slope, road width, tree canopies, etc., and the relatively small effect they would have on volume reduction, these were not included in the modeling or EOPC. Appendix D includes a map of potential locations where green streets could be implemented in the future if funding allows.

Expected Outcomes from the Recommended Program of Projects

Provided with an optimized set of project components for the study area as a whole, the XPSWMM model was updated and evaluated. Significant reductions in flooding were seen in all areas. The proposed 10- and 100-year flooding extents are displayed in Figure 5 below and in Appendix H.

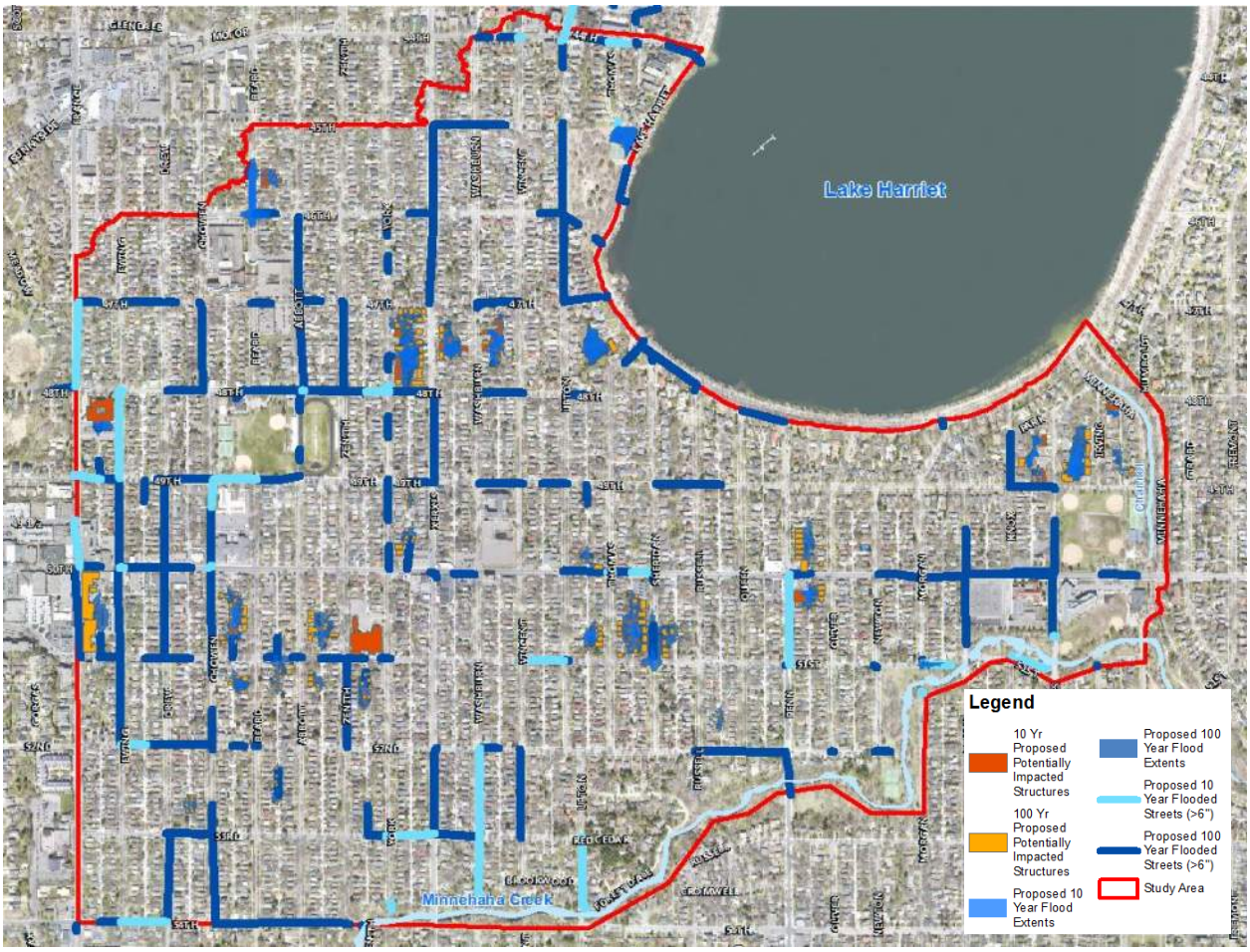


FIGURE 5: PROPOSED FLOODING IMPACTS

The focus for this study was the number of primary structures affected by surface water flooding. Table 4 shows the breakdown of the existing structures affected by inadequacies of City infrastructure and the structures that are expected to remain within the inundation areas if all proposed improvements described below are implemented. Structures impacted were determined based on LiDAR, not surveyed low opening elevations. As mentioned in the Optimatics section above, the proposed improvements include infrastructure or storage implementation that is feasible to construct. Eliminating all structures from the 10-year or 100-year flooding extents would require additional constructable storage options within the Study Area, likely on private property, or the allowance of increased flows to Lake Harriet or Minnehaha Creek.

TABLE 4: SOUTHWEST HARRIET AFFECTED STRUCTURES WITH PROPOSED IMPROVEMENTS

	Existing Affected Structures		Structures Still Affected after Implementation of the Proposed Improvements		Structures No Longer Affected after Implementation of the Proposed Improvements	
Storm Event	**P***	**S****	**P**	**S**	**P**	**S**
10-yr	76	113	3	15	73	98
100-yr	125	148	65	106	60	42

*P = Primary Structures (e.g. residential buildings, commercial businesses, or other community buildings)
**S = Secondary Structures (e.g. garages, storage sheds, or other unoccupied accessory structure)

Another Basis of Design parameter included restricting additional flow to Lake Harriet, the unnamed channel between Lake Harriet and Minnehaha Creek, and Minnehaha Creek. The program of recommendations for this project study area, as described below in each of the subareas results in an overall net increase in the 10-year flow to Lake Harriet of 0.8% (5.1 cfs), while there is no net increase to the unnamed channel or Minnehaha Creek. Increased conveyance in Pipesheds 2 and 3 are the primary drivers of the increase. More detailed hydraulic modeling will be required during preliminary design to update these results. Possible mitigation measures to ensure there is no increase could include installation of additional boulevard boxes, underground storage, or green infrastructure components should opportunities arise. Existing and proposed outfall flow rates are included in Appendix I.

Pipeshed 1 Improvements

Subareas of interest are identified by a subarea letter and displayed in Figure 4. The proposed improvements in each subarea within Pipeshed 1 are described below.

Subarea A (1A) – Area Surrounding the Intersection of 46th Street and Beard Avenue

Identified issues in Subarea A include surface ponding within streets and private property inundating three primary and five secondary structures in the 10-year event and six primary and five secondary structures in the 100-year event. After further investigation into the private property flooding, modeling

shows the low points on the properties collect runoff from the adjacent backyards in the 10-year event. No street overflow onto private property is expected. The goal in this area was to eliminate surface ponding at the low point at the intersection of Beard Ave and 46th St. and reduce street flooding along Abbott Ave and 47th St.

The Beard Ave and 46th St. intersection serves as a low point for the adjacent streets. There is a large amount of water flowing here on the surface due to the absence of catch basins and storm main upstream (north, west and south) of the low point. In order to reduce downstream effects, the project team recommends installing underground storage rather than upsize storm sewer pipes. The proposed improvements include:

- 220 linear feet of 4-foot x 6-foot Boulevard Box on Beard Ave with a 12-inch pipe connection to the existing storm sewer.
- 100 linear feet of 4-foot x 8-foot Boulevard Box on Abbott Ave with a 12-inch pipe connection to the existing storm sewer.
- 0.06 ac-ft of underground storage (100L x 10W x 4H) and associated connection piping within parking lot to capture roof runoff from school.
- Replace existing storm drain with 330 linear feet of 12-inch pipe with 24-inch pipe along 47th St.

The improvements limit 10- and 100-year ponding extents to the street and provide opportunity for water quality improvements through detention under the school parking lot. Modeling results show three primary and five secondary structures remaining in the flooded area in the 10-year event and three primary and five secondary structures in the 100-year event. Street flows are also reduced below 10 cfs in the 10-year event. Flooding impacts to the remaining structures are due to drainage issues internal to the properties and are unrelated to public drainage issues.

The intersection of 46th Street and Beard Avenue is a low point subject to flooding in the 10-year and 100-year events

Subarea B (1B) – 4700 Blocks of York, Xerxes, Washburn, and Vincent Avenues

Identified issues in Subarea B include flow above 10 cfs (6 inches in depth) within streets and private property flooding inundating eight primary and 20 secondary structures in the 10-year event and 30 primary and 29 secondary structures in the 100-year event. After further investigation into the private property flooding, modeling shows the low points on the properties collect runoff from the adjacent backyards in the 10-year event. No street overflow is expected into the backyards; therefore, no improvements on private property are proposed for this area. Some street flooding in this area will be abated due to improvements elsewhere in the Study Area.

Subarea C (1C) – Area Surrounding the Intersection of 45th Street and Upton Avenue

Identified issues in Subarea C include street flooding within several streets and surface ponding near the intersection of Thomas Ave and 45th St. Boulevard boxes were not considered feasible on steep streets. Underground storage is feasible on private property; however, it is not being proposed due to its potential to impact redevelopment. No improvements are proposed for this area at this time.

Subarea D (1D) – Pershing Field Park

Identified issues in Subarea D include surface ponding within streets and public property inundating one secondary structure in the 10-year and 100-year events. No street overflow into the park is expected during the 10-year event. The goal in this area was to eliminate street flooding along 48th St. and 49th St., eliminate ponding occurring within Pershing Field Park, provide upstream system rate control without disturbing downstream systems, as well as provide water quality improvement opportunities for upstream runoff.

Pershing Field Park represents the only large area of publicly owned land in Pipeshed 1. High volumes of water flow along its north side under 48th St., and even more flows beneath 49th St., all limited by existing storm sewer capacity. In order to allow for infrastructure upgrades upstream of Pershing Field Park, underground storage is proposed to be constructed under the softball fields. Concentrating a large amount of storage capacity at the park also reduces the need to upsize pipes downstream. Due to limited pipe cover, a double barrel pipe is proposed under Chowen Ave; however, several options can be explored for final design. The proposed improvements for Subarea D include:

- Install an underground stormwater detention system at Pershing Field Park providing a minimum storage volume of 17.5 acre-ft.
- Install 250 linear feet of 30-inch storm pipe from the intersection of 49th St and Chowen Ave to the Pershing Field Park underground stormwater detention system.
- Install 230 linear feet of 18-inch storm pipe from the intersection of 48th St and Beard Ave to the Pershing Field Park underground stormwater detention system.

- Install 250 linear feet of 36-inch storm pipe from the Pershing Field Park underground stormwater detention system to the intersection of 48th St and Abbott Ave.
- Replace existing storm drain with 375 linear feet of double barrel 33-inchx49-inch arch pipe on 48th St. from Chowen Ave to Beard Ave.
- Install backflow preventers on the two new pipes discharging to the underground stormwater detention system.

These improvements reduce a majority of the street flows, eliminate 10- year ponding extents in the park, remove the secondary structure from flooding impacts and provide the study area's best opportunity for significant water quality improvements. Since there are multiple options for water quality improvements, this component was not included in this analysis or Engineer's Opinion of Probable Cost (EOPC) and will be completed during preliminary design. The project team recommends looking at the feasibility of a stormwater reuse system for park irrigation as an add-on to the underground storage system in order to reduce volumes entering Lake Harriet, provide water quality benefits, and service the park.

Pershing Field Park

Since it is located downstream of several subareas of interest, the underground detention system is critical to the functionality of the proposed improvements to eliminate 32 primary structures upstream of Pershing Field Park in Pipeshed 1 during the 100-year event. This project will require continued collaboration with MPRB staff and eventual MPRB Commissioner approval.

Subarea E (1E) – West of Pershing Field Park

Identified issues in Subarea E include flooding within streets and private property impacts inundating one primary structure in the 10-year and 100-year events. After further investigation into the private property flooding, modeling shows the low points on the properties collect the site's interior drainage. No additional stormwater from the City right-of-way contributes to the identified flooding extents. The goal in this area was to eliminate street flooding above 10 cfs along 49th St. between France Ave and Chowen Ave, as well as along Ewing Ave and Drew Ave.

HR Green is proposing to upsize storm sewer pipes to prevent surcharging during the 10-year storm. Due to limited pipe

cover, a double barrel pipe is proposed; however, several options can be explored for final design. The proposed improvements include:

- 290 linear feet of 12-inch pipe upsized to 30-inch on 49th St from Ewing Ave to Drew Ave.
- 400 linear feet of 12-inch pipe upsized to double barreled 30-inch storm pipe on 49th St from Drew Ave to Chowen Ave.

These proposed improvements allow several street flows to be reduced in the 10-year event.

Subarea F (1F) – Southeast Quadrant of 50th Street and France Avenue Intersection

Identified issues in Subarea F include surface ponding within streets and private property inundating two primary and one secondary structure in the 10-year event and three primary and one secondary structure in the 100-year event. Significant street flooding is also occurring on 50th St and Drew Ave. The goal in this area was to eliminate street flooding along 50th St. and eliminate structure flooding occurring in the alley between Ewing Ave and France Ave.

In order to limit structure flooding occurring along France Ave, underground storage is proposed under the parking lot west of Ewing Ave, which is the only available space for a storage system. This underground storage reduces downstream effects and could provide water quality benefits from extended detention and settling. A double barrel pipe is proposed due to limited pipe cover and shallow downstream pipe connections. The proposed improvements include:

- Under the public parking lot west of Ewing Ave, install an underground stormwater detention system providing a minimum volume of 0.23 acre-ft.
- Replace existing storm drain with 330 linear feet of double barrel 24-inch storm pipe on 50th St. from Ewing Ave to Drew Ave
- Replace existing storm drain with 360 linear feet of double barrel 30-inch storm pipe on 50th St from Drew Ave to Chowen Ave
- Install backflow preventer on the outlet pipe of the underground detention system
- 70 linear feet of 4-foot x 8-foot boulevard box along 51st St

These improvements eliminate 10-year structure flooding and limit 100-year structure flooding to two primary structures, as well as eliminate almost all street flooding in the 10-year event.

Subarea G (1G) – Area Surrounding 52nd Street and Drew Avenue Intersection

Issues identified in Subarea G include surface ponding within streets and private property inundating nine secondary structures in the 10-year event and two primary and 11 secondary structures in the 100-year event. After further investigation into the private property flooding, modeling shows the low points on the properties collect runoff from surcharging in the alley during the 10-year event. The goal in this area was to eliminate surface ponding between Chowen Ave and Drew Ave, and to reduce street flooding occurring on 52nd St.

Since flooding in Subarea G is due to undersized storm infrastructure, the project team proposes to increase storm sewer conveyance. The proposed improvements include:

- Replace existing storm drain with 570 linear feet of 18-inch pipe on 52nd St and in the alley between Chowen Ave and Drew Ave.
- Install 100 linear feet of 4-foot x 8-foot Boulevard Box on 52nd St.
- Install 170 linear feet of 4-foot x 8-foot Boulevard Box on 53rd St.
- Install 340 linear feet of 4-foot x 8-foot Boulevard Box at the intersection of 53rd St and Chowen Ave.

The improvements significantly reduce 10- and 100-year flooding in the street, and modeling results show no structures remaining in the flooded area in the 10-year event and eight secondary structures in the 100-year event.

Subarea H (1H) – 5200 Blocks of Abbott and Beard Avenues

Identified issues in Subarea H include surface ponding within streets and private property inundating four secondary structures in the 10-year event and seven secondary structures in the 100-year event. After further investigation into the private property flooding, modeling shows the low points on the properties collect runoff from surcharging in the alley during the 10-year event. The goal in this area was to eliminate surface ponding between Abbott Ave and Beard Ave.

The proposed improvements are designed to reduce flooding caused by undersized storm infrastructure, including the following upsizes:

- Replace existing storm drain with 840 linear feet of 18-inch pipe on 52nd St and in the alley between Abbott Ave and Beard Ave.
- Install 70 linear feet of 4-foot x 8-foot Boulevard Box on Beard Ave.
- Install 170 linear feet of 4-foot x 8-foot Boulevard Box on Abbott Ave.

The improvements reduce 10- and 100-year flooding in the street, and modeling results show no structures remaining in the flooded area in the 10-year event and six secondary structures in the 100-year event.

Subarea I (1I) – Area Surrounding 51st Street and Abbott Avenue Intersection

Identified issues in Subarea I include surface ponding within streets and private property inundating 19 primary and 42 secondary structures in the 10-year event and 40 primary and 60 secondary structures in the 100-year event. After further investigation into the private property flooding, modeling shows the low points on the properties collect runoff from surcharging in the alleys between York Ave and Chowen Ave during the 10-year event. The Church of Christ the King, located on the northeast corner of Zenith Ave and 51st St., is shown as being flooded by the site's interior drainage. The goal in this area was to eliminate surface ponding and reduce street flooding during 10- and 100-year events.

Flooding is occurring in Subarea I due to undersized storm infrastructure; therefore, the project team is proposing to upsize storm sewer pipes and provide storage where possible. Since it is the only parcel with open space in Subarea I, the Church of Christ the King's parking lot is proposed for storage relief for the trunkline on 51st St. This option could be tied into the Church's interior drainage system if desired. Coordination with the church on this option is still required. If the space is not usable, a boulevard box within the right-of-way along Zenith Ave would serve as an alternative. The proposed improvements include:

Portions of several alleys in Subarea 1I are subject to flooding problems

- Replace existing storm drain with 420 linear feet of double barrel 40-inch x 65-inch arch pipe along Chowen Ave for one half block south of 49th St.
- Replace existing storm drain with 1575 linear feet of 54-inch x 88-inch arch pipe on Chowen Ave from one half block south of 49th St to 52nd St.
- Replace existing storm drain with 1125 linear feet of 24-inch and 36-inch pipe on 51st St.
- Replace existing storm drain with 865 linear feet of 12-inch to 24-inch alley pipe between York Ave and Chowen Ave.
- Install 380 linear feet of 36-inch new pipe along Zenith Ave.
- Under the parking lot of The Church of Christ the King, install an underground stormwater detention system providing a minimum volume of 0.6 Acre-Ft.
- Install 340 linear feet of 4-foot x 8-foot Boulevard Box at the intersection of 51st St and Beard Ave.
- Install 270 linear feet of 4-foot x 8-foot Boulevard Box at the intersection of 51st St and Zenith Ave.

The improvements reduce 10- and 100-year flooding in the street, and modeling results show one primary and eight secondary structures remaining in the flooded area in the 10-year event and 19 primary and 46 secondary structures in the 100-year event.

Subarea J (1J) – Area Surrounding the Intersection of 49th Street and Washburn Avenue

Identified issues in Subarea J include surface ponding within streets and private property inundating three primary and 12 secondary structures in the 10-year event and seven primary and 14 secondary structures in the 100-year event. After further investigation into the private property flooding, modeling shows the low points on the properties collect runoff from surcharging in the alleys between York Ave and Xerxes Ave during the 10-year event. The goal in this area was to eliminate surface ponding and reduce street flooding during 10- and 100-year events.

The project team proposes to increase conveyance to reduce flooding due to undersized storm sewer infrastructure. The proposed improvements include:

- Install 300 linear feet of inline 4-foot x 8-foot box culvert along 50th St. with 30 linear feet of 15-inch connection pipe
- Replace existing storm drain with 1320 linear feet of 36-inch pipe along York Ave.
- Replace existing storm drain with 300 linear feet of 12-inch and 18-inch alley pipe between Xerxes Ave and York Ave.
- Install 100 linear feet of 4-foot x 8-foot boulevard box along York Ave.
- Install 140 linear feet of 4-foot x 8-foot boulevard box along Xerxes Ave.
- Install 375 linear feet of 4-foot x 8-foot boulevard box along 49th St.

The improvements reduce 10- and 100-year flooding in the street, and modeling results show no structures remaining in the flooded area in the 10-year event and two primary and 11 secondary structures in the 100-year event.

Subarea K (1K) – 4900 Block Between Upton and Thomas Avenues

Identified issues in Subarea K include surface ponding within alleys and private property inundating four primary and five secondary structures in the 10-year event and four primary and six secondary structures in the 100-year event. After further investigation into the private property flooding, modeling shows the low points on the properties collect runoff from surcharging in the alley between Thomas Ave and Upton Ave during the 10-year event. The goal in this area was to eliminate surface ponding during the 10- and 100-year events.

Flooding is occurring in Subarea K due to undersized storm infrastructure. The project team proposes to increase conveyance to reduce flooding. The proposed improvements include:

- Replace existing storm drain with 540 linear feet of 18-inch alley pipe between Thomas Ave and Upton Ave.
- Install 850 linear feet of 18-inch new pipe along Thomas Ave.

The modeling results show no structures remaining in the flooded area in the 10-year event and one primary and three secondary structures in the 100-year event.

Subarea L (1L) – Area Surrounding the Intersection of 47th Street and Upton Avenue

Identified issues in Subarea L include flooding above 10 cfs within several streets and private property impacts affecting one primary structure during the 100-year event. After further investigation into the private property flooding, modeling shows the low point on the property collects runoff from adjacent backyards, with no additional flow from the City right-of-way.

Boulevard boxes are proposed to eliminate street flooding. The lengths and locations include:

- Install 70 linear feet of 4-foot x 8-foot boulevard box along Vincent Ave.
- Install 140 linear feet of 4-foot x 8-foot boulevard box along Upton Ave.

The modeled storage eliminates 1,019 linear feet of street flooding in the 10-year event.

Storage Additions outside of Subareas

Several locations of street flooding were identified outside of the designated subareas of concern. Improvements to alleviate flooding in these individual areas are identified below:

- At the intersection of 47th St and Chowen Ave, install a boulevard box amounting to a volume of 0.025 acre-ft (4-foot x 8-foot x 35-foot).
- At the intersection of 46th St and York Ave, install a boulevard box amounting to a volume of 0.1 acre-ft (4-foot x 8-foot x 140-foot).

Pipeshed 2 Improvements

The proposed improvements in Pipeshed 2 for each subarea are described below and displayed in Figure 4.

Subarea A (2A) – 5000 Blocks of Upton, Thomas, Sheridan, Russel, and Queen Avenues

Identified issues in Subarea A include surface ponding within streets and private property inundating 19 primary and 26 secondary structures in the 10-year event and 24 primary and 31 secondary structures in the 100-year event. After further investigation into the private property flooding, modeling shows the low points on the properties collect runoff from surcharge occurring in alleys between Queen Ave and Upton Ave. Street overflow also reaches private property at the intersection of 51st St and Sheridan Ave. This area serves as a major low point in the neighborhood that is surrounded by steep streets that drain to the low point quickly. The goal in this area was to eliminate structure flooding without disturbing existing pipes that run through private property, as well as reduce surface ponding occurring on Sheridan Ave.

Intersection of 51st Street and Sheridan Avenue (view looking north on Sheridan Avenue).

A pump station at 50th St and Sheridan Ave serves as the primary means for stormwater conveyance from the flooded areas and was recently rehabilitated in 2017. In order to minimize pump station rework, the project team proposes to retain the current pumping rates, increase underground storage upstream of the pump as well as upsize storm sewer pipes upstream and downstream. Due to the high elevation difference along the streets, underground storage will have to be shallow, tiered or equipped with internal barriers to detain the proposed volume. Slowing the flow rates or providing storage where possible in the upper ends of the drainage areas will help with the flooding extents. This could include installing infrastructure on streets without a current storm sewer system or exploring green infrastructure options. The proposed improvements include:

- Replace existing storm drain with 550 linear feet of 7-foot x18-foot Box Culvert on Sheridan Ave connecting to the existing pump station.
- Replace existing storm drain with 1850 linear feet of 60-inch pipe on Sheridan Ave, 50th St, and Queen Ave.
- Install 170 linear feet of new 18-inch pipe in the alley between Upton Ave and Thomas Ave.
- Install 380 linear feet of new 18-inch pipe in the alley between Sheridan Ave and Russell Ave.
- Install 250 linear feet of new 24-inch pipe in the alley between Russell Ave and Queen Ave.
- 500 linear feet of upsizing to 36-inch pipe along 51st St.

- Install 900 linear feet of 4-foot x 8-foot Boulevard box along Upton Ave.
- Install 560 linear feet of 4-foot x 8-foot Boulevard box along Thomas Ave.
- Install 40 linear feet of 4-foot x 8-foot boulevard box connected to existing storm pipe along Thomas Ave
- Install 500 linear feet of 4-foot x 8-foot Boulevard box along Sheridan Ave.

The improvements recommended in 2A will increase flow to Lake Harriet by 21 cfs in the 10-year event. This flow cannot easily be mitigated within the subarea due to the lack of public property and narrow right-of-way, which limits opportunities for new stormwater storage areas. Smaller green infrastructure practices on the ground surface, or additional improvements in other pipesheds could mitigate the increases produced in 2A. The improvements reduce 10- and 100-year ponding extents to levels below existing conditions and provide opportunity for water quality improvements. Modeling results show five secondary structures remaining in the flooded area in the 10-year event and 18 primary and 22 secondary structures in the 100-year event.

Subarea B (2B) – 5100 Block between Russel and Queen Avenues

Identified issues in Subarea B include surface ponding within alleys and private property inundating three primary and three secondary structures in the 10-year event and five primary and five secondary structures in the 100-year event. After further investigation into the private property flooding, modeling shows conveyance from the low point in the alley between Queen Ave and Russell Ave is restricted by the downstream pipe. The goal in this area was to eliminate structure flooding without upsizing pipe beneath private property.

The project team proposes the following improvements:

- Replace existing storm drain with 330 linear feet of 24-inch pipe along 51st St.
- Replace existing storm drain with 160 linear feet of 18-inch pipe along 51st St.
- Install 390 linear feet of new 18-inch pipe in the alley between Queen Ave and Russell Ave.

The improvements reduce 10- and 100-year ponding extents to levels below existing conditions. Modeling results show no structures remaining in the flooded area in the 10-year event and one secondary structure in the 100-year event.

Pipeshed 3 Improvements

Proposed subarea improvements in Pipeshed 3 are described below and displayed in Figure 4.

Subarea A (3A) – 4900 and 5000 Blocks of Penn and Oliver Avenues

Identified issues in Subarea A include surface ponding within streets and private property inundating 14 primary and five secondary structures in the 10-year event and 18 primary and seven secondary structures in the 100-year event. After further investigation into the private property flooding, modeling shows the low points on the properties collect runoff from storm sewer backups in the alleys between Oliver Ave and Penn Ave. The goal in this area was to eliminate structure flooding as well as reduce street flooding occurring on 50th St and Penn Ave.

An undersized storm system was identified to be the primary cause of structure impacts. The project team proposes to install underground storage to reduce street flooding and detain water upstream of the alley pipe connections. Due to the increased flows from alley improvements, the storm sewer system downstream of the alley pipes is proposed to be upsized as well. This will contain the 10-year flows in the pipe and serve as additional storage. The proposed improvements include:

- Replace existing storm drain with 315 linear feet of 24-inch pipe in the alleys between Oliver Ave and Penn Ave.
- Replace existing storm drain with 1250 linear feet of 36-inch pipe on 50th St and Oliver Ave.
- Install 325 linear feet of 4-foot x 8-foot boulevard box at the intersection of 50th St and Penn Ave.

The improvements recommended in 3A will increase flow to Lake Harriet by 21 cfs. Similar to Subarea 2A, this flow cannot easily be mitigated within this subarea due to steeper road slopes and limited public or open space. Reductions in flow may be seen if more opportunistic storage or green infrastructure practices could be implemented nearby. The improvements reduce 10- and 100-year street flooding and ponding extents to levels below existing conditions. Modeling results show one primary structure remaining in the flooded area in the 10-year event and 14 primary and five secondary structures in the 100-year event.

Subarea B (3B) – Area Surrounding the Intersection of 50th Street and Morgan Avenue

Identified issues in Subarea B include flooding within streets and private property inundating one primary and three secondary structures in the 10-year event and one primary and three secondary structures in the 100-year event. Large catchment areas for the storm sewer along 50th St. overwhelm the current system and cause flooding in the 10-year event. Modeling shows the low point in the alley between Newton Ave and Morgan Ave drains through an undersized City storm pipe, with overflows travelling down private properties to the southeast. Significant surface ponding also occurs at the intersection of 51st St and Morgan Ave.

In order to reduce structure and street flooding, HR Green is proposing the following improvements:

- Replace existing storm drain with 340 linear feet of 18-inch pipe along 50th St.
- Install 330 linear feet of new 18-inch pipe along 50th St.
- Under the parking lot of the Mt Olivet Church, install an underground stormwater detention system providing a minimum volume of 1.6 acre-ft.
- Install 100 linear feet of new 24-inch pipe connecting into the detention system from 50th St and Logan Ave.
- Install 75 linear feet of new 15-inch pipe as an outlet from the underground stormwater detention system to Logan Ave.
- Consider creating a stormwater pond providing a minimum of 1.05 acre-ft south of the intersection of 51st St and Morgan Ave in Minnehaha Creek Park. As MCWD has identified a potential BMP a few blocks east of this location, there may be opportunities to pair the two BMPs.
- Replace existing storm drain with 300 linear feet of 15-inch pipe in the alley between Morgan Ave and Newton Ave and along 51st St.
- Install 200 linear feet of new 18-inch and 30-inch pipe along 51st St connecting to the stormwater pond.
- Install 50 linear feet of new 18-inch pipe as an outlet to the stormwater pond.
- 80 linear feet of 24-inch pipe upsizing at the intersection of 51st St and Newton Ave.

The improvements reduce 10- and 100-year ponding extents to levels below existing conditions while also providing water quality benefits within the stormwater pond. Modeling results show no structures remaining in the flooded area in the 10-year event and two secondary structures in the 100-year event. These improvements also eliminate overland flow during a 10-year event that discharges into Minnehaha Creek at Outfall 23. Additional coordination with the church on this option is still required. Also, the possibility of the stormwater pond in Minnehaha Creek Park will be considered in the planning effort and brought forward in the collaborative three-agency Minnehaha Parkway Regional Trail Master Plan currently underway. Continued collaboration with MPRB staff and eventual Board approval will be required.

Subarea C (3C) – 52nd Street between Queen and Newton Avenues

Identified issues in Subarea C include flooding along 52nd Street during the 10- and 100-year event. The goal in this area was to eliminate the street flooding and provide flow rate reduction and water quality treatment prior to entering Minnehaha Creek.

The project team proposes the following improvements:

- Replace existing storm drain with 340 linear feet of 18-inch pipe along 52nd St.
- Replace existing storm drain with 700 linear feet of 24-inch pipe along 52nd St.
- Consider creating a stormwater pond providing a minimum of 0.375 acre-ft east of the intersection of 52nd St and Newton Ave in Minnehaha Creek Park.

The improvements reduce 10- and 100-year street flooding levels below existing conditions while also providing rate control and water quality benefits. The proposed stormwater pond in Minnehaha Creek Park will be considered in the planning effort and brought forward in the collaborative three-agency Minnehaha Parkway Regional Trail Master Plan currently underway. The project will require continued collaboration with MPRB staff and eventual Board approval.

Subarea D (3D) – Lynnhurst Park Area

Identified issues in Subarea D include surface ponding within streets and public property inundating Lynnhurst Park during the 10- and 100-year storm events. The goal in this area was to eliminate street flooding along James Ave, 48th St. and 49th St. and eliminate ponding occurring within Lynnhurst Park. The study did not include an analysis of the Minnehaha Creek or unnamed channel floodplain areas, so the interaction during higher creek scenarios (>10 year) is uncertain.

Lynnhurst Park represents the only large area of public property in Pipeshed 3. Large amounts of water flow along its west side along James Ave to the south into Pump Station PS16 and on its north side along 49th St. east into Pump Station PS03. The project team proposes to install an underground storage system on the north side of Lynnhurst Park. The storage will serve as a relief for storm sewer along 49th St, provide additional storage for PS03 and allow for less restricted flows from subarea E to enter the system. Construction of this project will help reduce flooding in subarea E by creating capacity in the system, but it is not required to be completed before 3E. 3D should be constructed prior to any additional connections into the 49th St. storm sewer.

Due to high groundwater at the park, preliminary design of the underground storage system will likely recommend a watertight liner or buoyancy restrictors. The EOPC for this Subarea did not include these items. The Park's interior drainage system could also be routed to the underground detention system to reduce saturated conditions on the surface. The proposed improvements include:

- Under Lynnhurst Park, install an underground stormwater detention system providing a minimum volume of 1.5 acre-ft.
- Install 170 linear feet of 24-inch storm pipe from the intersection of 49th St and James Ave to the Lynnhurst Park underground stormwater detention system.

- Install 100 linear feet of 12-inch storm pipe from the Lynnhurst Park underground stormwater detention system to 49th St.

These improvements eliminate 10- and 100-year ponding extents in the park and provide a significant opportunity for water quality improvements. Some street flows are also reduced below 10 cfs in the 10-year event. Similar to Pershing Field Park, improvements to Lynnhurst Park will require continued collaboration with MPRB staff and eventual MPRB Commissioner approval.

Subarea E (3E) – 4800 Blocks of Knox, James, Irving, and Minnehaha Avenues

Issues identified in Subarea E include surface ponding within streets and private property inundating 13 primary and one secondary structure in the 10-year event and 20 primary and one secondary structure in the 100-year event. After further investigation into the private property flooding, modeling shows the low points within the properties' backyards collect runoff without the ability to convey it out due to undersized pipes backing up from 49th Street. The goal in this area was to eliminate structure flooding without disturbing private property.

The improvements achieved in Subarea D also allow additional stormwater conveyance out of Subarea E. Any backyard drain connections to further reduce ponding extents would require City storm sewer improvements along 49th Street that are not proposed as part of this study. Should residents choose to tie in to the City system, further analysis of the 49th St system will be required.

HR Green proposes upsizing the alley pipe and placing backflow preventers on pipes directly connected to the backyard areas and alley way.

- Install three backflow preventers along 49th St
- Replace existing storm drain with 130 linear feet of 18-inch pipe in the alley between Minnehaha Parkway and Irving Ave.

The Subarea E improvements reduce 10- and 100-year ponding extents to levels below existing conditions. Modeling results show three primary and one secondary structure remaining in the flooded area in the 10-year event and 11 primary and one secondary structure in the 100-year event.

Pipeshed 4 Improvements

Pipeshed 4 subarea improvements are proposed below and displayed in Figure 4.

Subarea A (4A) – All of Pipeshed 4

Identified issues in Subarea A include surface ponding within streets. The goal in this area was reduce street flooding occurring on York Ave, Xerxes Ave, Washburn Ave, Upton Ave and 53rd St.

An undersized storm system was identified to be the primary cause of street flooding. In order to reduce downstream effects to the creek, the project team proposes to upsize storm sewer pipes with the inclusion of underground storage. The proposed improvements include:

- Replace existing storm drain with 600 linear feet of 30-inch pipe along Xerxes Ave.
- Install 200 linear feet of 4-foot x 8-foot boulevard box at the intersection of 53rd St and York Ave.

The improvements reduce 10- and 100-year event flooding in the streets.

Constructability Review

After modeling efforts were completed, HR Green conducted a constructability review of the proposed improvements. Using the proposed pipe size or storage volume from the XPSWMM model, HR Green investigated above ground and subsurface conditions in the vicinity of the proposed improvements. Data from the City and Gopher One Call provided existing utility depths, sizes and distances from centerline within the right-of-way. Water and sanitary sewer connection information was not requested for individual properties.

Referencing the available data, the proposed infrastructure components were placed in assumed “open space” and the proposed pipe depths were vetted for feasibility. In general, 3 feet of cover was given to new and upsized pipes and boulevard box installations. Smaller dual (parallel) pipes were proposed if minimum cover could not be met with one larger pipe.

Soil boring data was collected by the City at three locations: Pershing Field Park, Lynnhurst Park, and Minnehaha Creek Park. Groundwater elevations were measured using piezometers installed in Pershing Field and Lynnhurst Parks and were found to be near or above the modeled bottom elevations of stormwater detention systems. Because some variation in groundwater levels can be expected, the detention systems will likely need to be lined with impermeable membranes to prevent groundwater from seeping into the storage spaces. Additional preventive measures may need to be taken to ensure the stability of the structures against possible buoyant forces during and after construction.

Engineer's Opinion of Probable Cost

HR Green created an engineer's opinion of probable cost (EOPC) for the proposed projects. Unit costs for various construction items were held constant for all proposed projects. Even though project components varied in complexity, the unit costs remained the same. A more detailed EOPC will be required during preliminary design. General percentages were used for items that were unquantifiable during this feasibility study. The EOPC presented in Table 5 was calculated using 2018 dollars and includes construction costs with a 35% contingency. The EOPC costs do not include engineering fees. Since the groundwater data was received after the EOPC was completed, the cost estimates for underground detention systems do not include additional facilities required to be built for water quality purposes. Detailed EOPCs for each project with costing assumptions included in the comment column can be found in Appendix J.

TABLE 5: ENGINEER'S OPINION OF PROBABLE COSTS FOR ALL PROJECTS

Project	Cost Estimate ($)
Pipeshed 1	
1A	2,337,000
1B	NA
1C	NA
1D	9,022,000
1E	1,340,000
1F	2,110,000
1G	2,571,000
1H	2,018,000
1I	10,876,000
1J	3,379,000
1K	2,236,000
1L	470,000
Misc. Storage	485,000
Total	**36,844,000**

Project	Cost Estimate ($)
Pipeshed 2	
2A	16,797,000
2B	1,291,000
Total	**18,088,000**
Pipeshed 3	
3A	3,187,000
3B	3,157,000
3C	2,746,000
3D	2,308,000
3E	266,000
Total	**11,664,000**
Pipeshed 4	
4A/Total	**1,716,000**
GRAND TOTAL	**72,078,000**

Water Quality

Stormwater from the Southwest Harriet Study Area discharges to one of three waterbodies: Lake Harriet, Minnehaha Creek, or the unnamed channel connecting the two. For the feasibility study, the MOU partners agreed to qualitatively assess the water quality benefits to these waterbodies that can be achieved through the proposed infrastructure improvements. More detailed calculations of the expected water quality improvements would be completed during the next phase of design.

The two projects that offer the most potential for water quality benefit are the Pershing Field Park and Lynnhurst Park underground detention systems (projects 1D and 3D, respectively). For the function of mitigating flood risks, these underground detention systems were conceptualized as single-celled, open storage units operating entirely through gravity flow. The key benefit of such a design is that no pump station would be required to route stormwater through the system. To create water treatment functions in this type of detention system, additional elements would need to be included. A variety of methods are available, many of which would not impact the storage capacity of the underground detention system that has been described in this report.

In order to estimate the maximum water quality treatment of a modified underground structure at either location, an initial alternative was modeled in P8 (Urban Catchment Model) assuming capture and storage of sediment. A typical design for an additional underground system element includes a primary cell with a baffle and weir to remove floatables, grit, and grease, before spilling into a sedimentation chamber. Both the grit/oil separator and sediment chamber's wall would require routine maintenance activities which could be enabled by inclusion of a manual or automated gate valve. After sediment falls out of the stormwater, the water spills over into an exit outlet cell and to the downstream pipe. This cell was assumed to be an open chamber, though inclusion of enhanced sand filtration could be considered for the removal of dissolved phosphorus to further improve overall treatment capacity.

A second alternative considered the effects of harvesting stormwater from the proposed underground detention systems for irrigation of surrounding park lands. To estimate water quality treatment of a stormwater harvesting option, the Minnesota Stormwater Manual synthetic modeling results were referenced. In this alternative, a second cell would be required to take a portion of the water from the main system (described above) through a flow-splitting pipe. Water would be stored in this secondary cell and pumped to an irrigation system. This use of stormwater for irrigation would thereby reduce total volumes of stormwater and associated pollutants that discharge from the detention systems. The Minnesota Stormwater Manual synthetic analysis estimated irrigation rates by the frequency of irrigation needs between storm events, resulting in a required volume per year (growing season). The analysis used P8 to estimate the associated pollutant reductions. For this feasibility study, the results of the Minnesota Stormwater Manual were referenced to estimate water quality treatment for a stormwater harvesting/irrigation system.

The results for Pershing Field Park and Lynnhurst Park underground detention system water quality treatment alternatives are displayed in Tables 6 and 7 below. Note that the removal rates displayed in these tables are achievable only if water quality treatment systems were constructed in addition to the storage volumes already required. In other words, this evaluation of water quality benefits assumed that the flood mitigation capacity of these projects was not reduced in order to accommodate the treatment measures.

TABLE 6: ESTIMATED TREATMENT VALUES FOR PERSHING FIELD PARK UNDERGROUND STORAGE

Total Watershed Load			Detention System Only Load Reduction				Detention Plus Irrigation Load Reduction					
TSS lbs/yr	TP lbs/yr	Runoff Volume ac-ft/yr	TSS lbs/yr	TSS %	TP lbs/yr	TP %	Volume Reduction ac-ft/yr	Volume Reduction %	TSS lbs/yr	TSS %	TP lbs/yr	TP %
43,301	136	118	32,893	76	63	47	28	24	38,018	88	84	62

TABLE 7: ESTIMATED TREATMENT VALUES FOR LYNNHURST PARK UNDERGROUND STORAGE

Total Watershed Load			Detention System Only Load Reduction				Detention Plus Irrigation Load Reduction					
TSS lbs/yr	TP lbs/yr	Runoff Volume ac-ft/yr	TSS lbs/yr	TSS %	TP lbs/yr	TP %	Volume Reduction ac-ft/yr	Volume Reduction %	TSS lbs/yr	TSS %	TP lbs/yr	TP %
6,791	21	19	5,218	77	10	47	5	24	5,976	88	13	62

Several other minor opportunities for improving stormwater quality exist within the proposed infrastructure improvements. The three smaller underground detention systems included in the list of projects would likely contain a pretreatment device for gross solids and the main chamber would settle out particulates as water is attenuated. The Minnesota Stormwater Manual gives expected removal rates of up to 85% of TSS and 50% of TP for a standard constructed pond. Stormwater treatment enhancements, such as pretreatment forebays, can also be installed at the storm ponds being proposed in Pipeshed 3. Detailed models of the minor storage systems were beyond the scope of this project, but a preliminary water quality analysis was completed. Loading rates for the minor systems were based on similar land uses in the tributary areas to the Pershing Field and Lynhurst Park detention systems. Estimated reductions were calculated using the Minnesota Stormwater Manual rates.

Expected solids and phosphorus removal totals for the two proposed ponds and three proposed minor detention systems are displayed in Table 8. Treatment areas for the two large underground storage systems as well as the 5 minor systems detailed in Table 8 are displayed in Appendix K.

TABLE 8: ESTIMATED TREATMENT VALUES FOR MINOR STORAGE SYSTEMS

Location	Watershed			Detention System Only Load Reduction			
	TSS lbs/yr	TP lbs/yr	Runoff Volume ac-ft/yr	TSS lbs/yr	TSS %	TP lbs/yr	TP %
Pond @ 52nd/Newton	4,070	9	6	3,460	85	4	50
Pond @ 51st/Morgan	1,850	4	3	1,573	85	2	50
System @ 50th/Morgan	5,074	13	10	3,904	77	6	47
System @ 50th/Zenith	4,233	8	7	3,259	77	3	47
System @ 50th/Ewing	2,291	3	4	1,764	77	2	47

Total pollutant reduction rates entering each body of water from the Study Area are displayed in Table 9. Since boulevard boxes may be used as storage for higher flow events, they would not capture the first flush of pollutants; therefore, treatment estimates from boulevard boxes are not included in the table.

TABLE 9: TOTAL ESTIMATED TREATMENT VALUES PER WATER BODY

Location	Watershed			Detention System Only Load Reduction			
	TSS lbs/yr	TP lbs/yr	Runoff Volume ac-ft/yr	TSS lbs/yr	TSS %	TP lbs/yr	TP %
Lake Harriet	167,043	342	262	33,882	20	64	19
Minnehaha Creek & Channel	54,943	116	85	14,536	26	26	22

Recommendations

Recommended Project Phasing

The collective set of projects described in this study represents a major outlay of funding that will ultimately be competing with other City and MOU partner priorities and schedules to be implemented. Given the extensive nature of the Study Area and the proposed projects, it is reasonable to anticipate a lengthy timeline necessary for construction of the entire program. A thoughtful approach is needed for developing the implementation plan in order to optimize benefits and avoid problems associated with improper sequencing of projects (e.g. the creation of new problems downstream due to the implementation of a solution in upstream areas).

In order to develop a phasing plan, the team focused on factors including the sequencing of projects from downstream to upstream, the number of primary structures that would no longer be within 10- and 100-year inundation extents, and the cost per acre or linear foot of street removed from flooding. For example, project 3E was listed as the first project to construct due to the very low cost per structure removed from flooding locations, and because this work can be independent of any other project, therefore requiring less coordination. Project 1D was included as another early project due to its preferred sequencing (discussed further below). After that, HR Green generally set precedence to projects that would have the most benefit to flooded primary structures. If projects removed the same number or no structures, the length of street flooding and flooded area was then compared. See Tables 9 and 10 for project phasing.

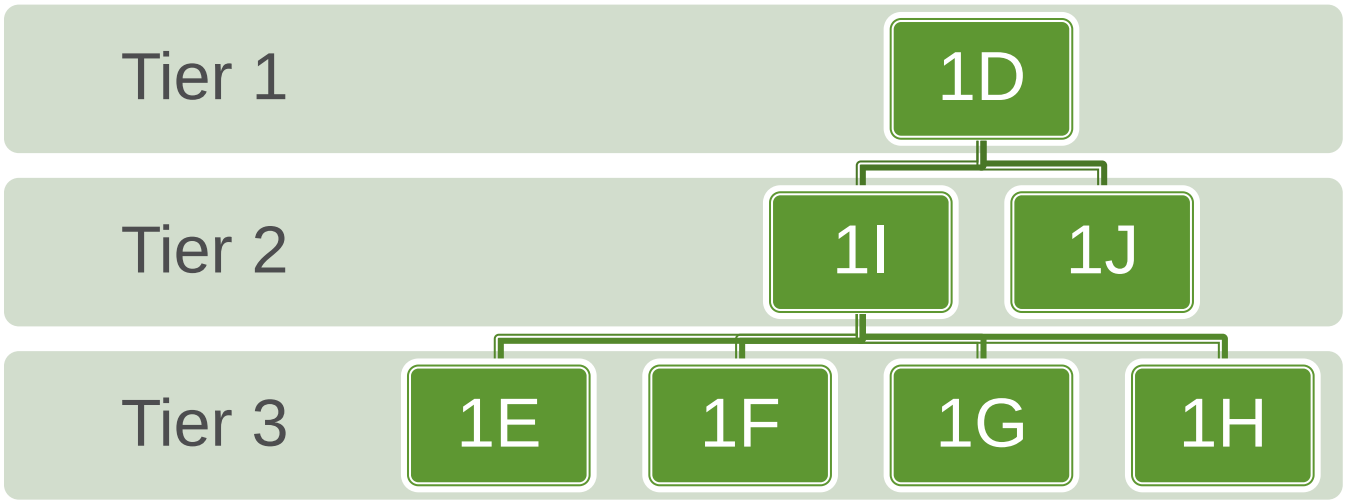
Sequencing of Projects

In general, the way to optimize a program of several projects and reduce adverse downstream effects within a pipeshed is to construct projects starting at the downstream end and work upstream with following projects. In Pipeshed 1, project 1D (underground storage in Pershing Field Park) should be the first project constructed. This project will provide adequate storage for the network upstream when all projects are complete. Project 1I will be required along the Chowen Ave trunkline after 1D in order to provide conveyance for all other improvements upstream (1F, 1E, 1G and 1H).

Construction of a project in an actively used park such as Pershing Field Park is a complex task and will require considerable coordination with MPRB. Given that challenge, the City may determine other projects to be ready for construction prior to the work in Pershing Field Park. If that happens, temporary modifications to the proposed improvement (e.g. the addition of a flow restrictor at the outlet of project 1I) will be necessary until the downstream improvement (Project 1D, underground storage at Pershing Field Park) can be built. This should be studied further before decisions can be made about an alternate sequencing plan.

The Pipeshed 1 hierarchy is presented in the following charts. The tiers indicate the preferred order where sequencing of the improvements is a consideration per the discussion above.

Pipeshed 1 Project Sequencing



Constructable at any time:

For the program of projects identified in this study, the only other project sequencing occurs in Pipeshed 2. Project 2A should be constructed before 2B, simply because it provides storage for the improvements in 2B. The proposed projects in Pipesheds 3 and 4 are not dependent on other projects and can be constructed individually at any time.

TABLE 10: PROJECT COST BENEFITS

Project Combinations	EOPC ($)	# of Primary Structures Removed (100-yr)	$/Primary Structure Removed	Inundated Area Removed (ac) (10-yr)	$/ac Removed	Flooded Streets Removed (Linear Feet) (10-yr)	$/Linear Feet Removed
Pipeshed 1							
All Proposed Projects (Option 1)	36,844,000	35	1,052,686	13.5	2,729,647	14919	2,470
Option 2 (Projects 1D and 1I only)	19,898,000	21	947,524	10.7	1,853,657	4833	4,117
Option 3 (Projects 1D, 1I, 1F, 1G, and 1H)	26,597,000	24	1,108,208	12.1	2,196,045	8640	3,078
Pipeshed 2							
All Proposed Projects (Option 1)	18,088,000	11	1,644,364	3.1	5,783,690	434	41,699
Option 2 (2A only)	16,797,000	6	2,799,500	2.7	6,320,804	434	38,723
Pipeshed 3							
All Proposed Projects (Option 1)	11,664,000	14	833,143	2.6	4,459,479	2833	4,117
Option 2 (3D and 3E)	2,574,000	9	286,000	1.7	1,505,263	344	7,489
Pipeshed 4							
All Proposed Projects	1,716,000	N/A[1]	N/A	N/A	N/A	1145	1,499

[1] There are no existing inundated structures or surface ponding present in Pipeshed 4.

TABLE 11: SOUTHWEST HARRIET PROJECT PHASING ORDER

Phasing Order	Project	Description	Number of Existing Primary Structures Affected (100-yr)	Change in Number of Affected Primary Structures (100-yr event)*	Basis of Design Criteria						Secondary Design Criteria			
					Storm Sewer Meets 10-year Level of Service	Removes Primary Structures from Flooding Impacts	No Overall Rate Increase to Lake Harriet	No Increase in Peak Flow Rate to Minnehaha Creek and Unnamed Channel	Facilitates Water Quality Improvement Opportunity	Includes Green Infrastructure	Preserves Existing Tree Canopy	Correlates with Capital Improvement Project Area	Avoids Private Property	Avoids Utility Relocations
9	1A	Project consists of constructing underground storage and increasing conveyance.	3	-3		■	■	N/A	■		■		■	■
2	1D	Project includes construction of underground storage system and connection pipes at Pershing Park.	See Note**				■	N/A	■			■	■	■
15	1E	Project increases conveyance along 49th St.					■	N/A			■	■	■	■
11	1F	Project includes constructing underground storage and increasing conveyance to Chowen Ave.	3	-1		■	■	N/A	■			■	■	
10	1G	Project involves installing Blvd. boxes for storage and increasing conveyance to Chowen Ave.	2	-2		■	■	N/A			■	■	■	■
13	1H	Project involves increasing alley conveyance to Chowen Ave and installing two Blvd. boxes.			■		■	N/A				■	■	■
3	1I	Project upsizes the storm sewer trunkline along Chowen Ave and 51st St to increase conveyance from 51st St.	39	-21		■	■	N/A	■			■		
6	1J	Project incorporates several Blvd. boxes for storage and pipe installations to increase conveyance to 48th St.	7	-5	■	■	■	N/A				■	■	■
8	1K	Project involves increasing conveyance from the alley to 48th St.	4	-3	■	■	■	N/A			■		■	■
16	1L	Project installs two Blvd. boxes along Vincent Ave and Upton Ave					■	N/A					■	■
18	Misc.	Project includes installing two Blvd boxes along 46th St and 47th St					■	N/A					■	■
4	2A	Project upsizes storage for the pump station and increases conveyance from 51st St and Sheridan Ave up to Lake Harriet Pkwy.	24	-6		■		N/A					■	
5	2B	Project installs pipes to increase conveyance to Sheridan Ave.	5	-5	■	■	■	N/A					■	
7	3A	Project adds storage and increases conveyance from 50th St and Penn Ave to Lake Harriet Pkwy.	18	-4		■		N/A			■		■	■
12	3B	Project involves constructing underground storage to reduce street flows along 50th St. and installing pipes to increase conveyance to a new storm pond south of 51st St.	1	-1	■	■	N/A	■	■	■				
19	3C	Project increases conveyance along 52nd St. to a new storm pond.			■		N/A	■	■	■			■	■
14	3D	Project incorporates underground storage and pipe connections on the north side of Lynnhurst Park.			■		N/A	■	■		■		■	■
1	3E	Project installs backflow preventers in three existing manholes.	19	-9	■	■	N/A	■			■		■	■
4A	17	Project increases conveyance along Xerxes Ave and installs a Blvd. box along York Ave.					N/A				■		■	■

*Not all structures are removed from the flooded areas due to conveyance and storage limitations applied to meet the basis of design criteria.
**Project 1D alone does not reduce the number of structures impacted by a 100-year event. However, Project 1D is a necessary component to achieving the other reductions identified in Pipeshed 1.

Other Capital Planning/Improvement Projects

The Southwest Harriet area is currently under review for potential street improvements funded through the City's Capital Improvement Plan (CIP). The consideration of the types of and timing of improvements will be coordinated with the stormwater recommendations made in this report. Improvements will likely range from full street reconstruction, in areas where the pavement infrastructure and curb and gutter have deteriorated significantly, to asphalt resurfacing (i.e., removing the top layer of asphalt from the street) in areas where the curb and gutter are still intact. Other improvements that would happen via the CIP funding could include new sidewalks, ADA ramps, signage, pavement markings, and improvements to the bicycle network, as needed. Should a street reconstruction project containing a proposed stormwater improvement project occur before a higher prioritized downstream project, flow restrictors could be put in place to reduce adverse effects downstream.

At the time of this report, MCWD is preparing designs for a series of erosion-repair projects within Minnehaha Creek. These MCWD projects are a first step in their longer-term effort to work with the city and MPRB to create a long-range capital improvement plan for the Minnehaha Creek corridor.

The open spaces at Pershing Field Park (shown here) and Lynnhurst Park play an instrumental role in this study's recommendations.

MPRB's related planning efforts include a Master Plan for their Southwest Service Area, which encompasses the entire study area of this feasibility study, and the Minnehaha Parkway Regional Trail Master Plan. Key facilities within both master planning areas, namely Pershing Field Park, Lynnhurst Park, and Minnehaha Creek Park are featured prominently in the solutions recommended in this study. The master plans will consider the facilities proposed in this study and make recommendations to the Board on their inclusion in individual park master plans. Furthermore, the possibility of the two aboveground ponds will be determined by the three MOU partners as part of the joint coordination for the Minnehaha Parkway Regional Trail Master Plan.

Private Property Impacts

As mentioned above, inundation mapping showed impacts to private property that are a result of interior drainage patterns, not City infrastructure capacity issues. Solutions for these areas are not addressed in this study. To allow private property owners the ability to pursue backyard drains and connections to the public storm main, the proposed program of projects accounted for potential additional flows from privately constructed storm systems to the adjacent storm sewer in the proposed improvements. The lone exception to this was in subarea 3E. Backyard drain connections in 3E would require City storm sewer improvements along 49th Street that are not proposed as part of this study.

Green Infrastructure

Minor improvements that are not integral to protecting structures from flooding, but offer natural strategies for addressing localized stormwater challenges, were referred to during this study as "Green Infrastructure."

Examples include rain gardens, curb cuts, swales, permeable pavers, tree boxes, ponds, or wetlands. Green Infrastructure can provide aesthetic improvements, water quality benefits and reduce the amount of flooding in streets on various scales. While completing this study, HR Green evaluated locations where green infrastructure practices could be incorporated to reduce flooding extents. With the limited green space and right-of-way, smaller curbside BMPs were difficult to place in areas where they would have a noticeable effect on the objectives of this study. Such smaller-scale practices could provide greater flood mitigation benefits if they were grouped together within a concentrated area or corridor. Future street reconstruction projects may provide opportunities to add smaller surface BMPs within the street right-of-way to create a designated “green street” or a “greenway.” Due to the uncertainty of where green infrastructure projects would be located and the limited flood reduction benefits (comparted to the strategies proposed in this report) smaller green infrastructure practices were not included in the flood inundation models or the EOPC.

Next Steps

Substantial planning and coordination is required for implementation of a program of projects as described in this study. The City has included its transportation planning group in discussions through the duration of this study in order to keep pipe upgrades in mind when planning a road reconstruction project. Further coordination with other Public Works divisions will also be needed to look at optimal locations for green infrastructure applications. Likewise, collaboration with MPRB and MCWD has also allowed these projects to be integrated in their concurrent planning efforts.

Collaboration between the MOU partners and other entities will continue to be required for further design and ultimately construction of the proposed improvement projects. Below is an initial list of other entities that the City may need to coordinate with to pursue some of the recommended options.

Hennepin County
Minneapolis Public Schools – Southwest High School
The Church of Christ the King
Mt. Olivet Church

More data will be required before the City moves forward with preliminary design of these projects as well. Examples of data needed for more detailed design include private stormwater systems, tie-in locations to the City system, roof drainage information, survey elevations, utility service connections, etc.

The sequencing schedule described above provides a path forward for scheduling projects in the CIP. By nature of the sequencing, the initial projects are larger in size and consequently are expensive to implement. Due to the large costs, they will likely require a collaborative effort between the MOU partners and other agencies to secure total project funding. Those projects that are not dependent upon a sequencing schedule can have a more opportunistic implementation schedule based on City or MOU partner activities.