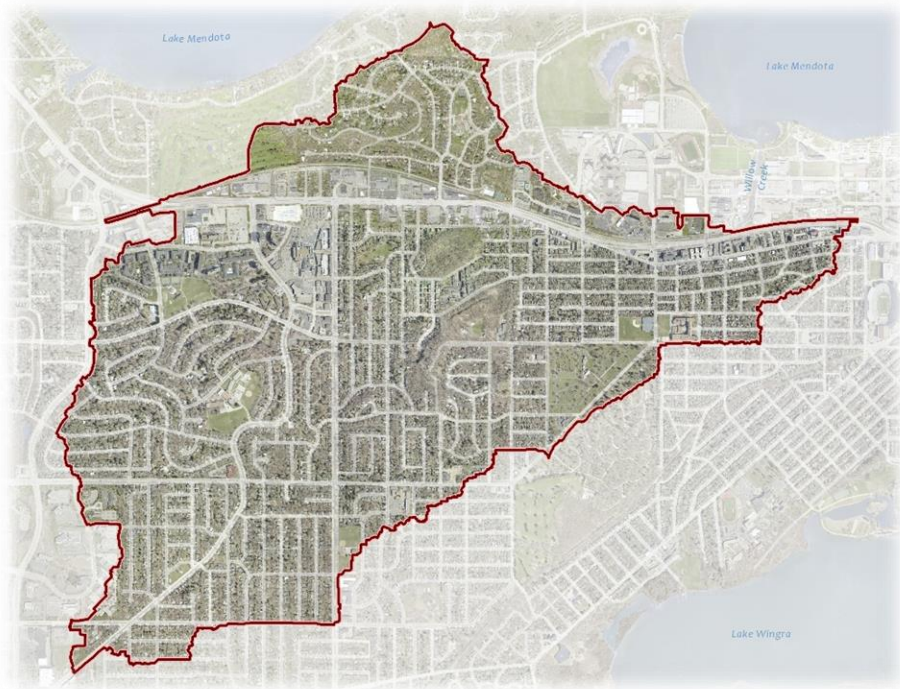


Willow Creek Watershed Study Report – Final Draft

City of Madison, Dane County, WI

December 27, 2022



MSA Professional Services

1702 Pankratz St, Madison WI 53704

Project 00373093



*The City makes no representation about
the accuracy of these records and shall
not be liable for any damages.*



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- Greg Fries, Assistant City Engineer

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- Bill Selbig, Research Hydrologist

MSA Professional Services

- Eric Thompson, Project Manager, Water Resources Team Leader
- Alistair Hancox, Water Resources Engineer
- Amber Converse, Senior GIS Analyst
- Margaret Dresen, Senior Engineering Technician II
- Sean Thiboldeaux, Engineer
- Sarah Morrison, GIS Technician

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1 Executive Summary

Background

Recognizing the changing rain patterns, and likelihood of more frequent future large rain events, the City of Madison (City) is conducting a multi-faceted approach to address stormwater flooding. As one component of that approach, the City is developing comprehensive stormwater management studies for each watershed within the City. The studies are conducted in two phases. Throughout both phases, the City incorporates multiple opportunities for public involvement and interaction.

Phase 1, Existing Conditions: Development of a hydrologic/hydraulic stormwater runoff model representing the physical and drainage properties of the watershed under existing conditions. The model is then calibrated to measured runoff events and used to identify the areas of the watershed most likely to flood under various rain conditions.

Phase 2, Recommended Solutions: Using the model, evaluate alternative methods and/or infrastructure improvements to eliminate, or reduce flooding impacts from large rain events.

It should be noted that the improvements documented in this report are not meant to be full design-level efforts; they are conceptual solutions that help the City's Engineering Division understand the magnitude of solution needed in a given area to meet the targets. As projects are looked at further, and if they move to the point they are contemplated for programming, then projects will then go into a more detailed design phase. This project phase collects detailed data needed for design and looks at refined design, permitting, and environmental issues associated with the particular project.

This document reports the methods, procedures, and results of the Willow Creek Watershed Project. The project area covers approximately 1,913 acres (3.0 square miles) on the near west side of Madison. **Figure ES-1** shows the extent of the project area.

City's Flood Mitigation Targets

The City developed a set of flood mitigation targets that exceed their current minimum design standards, so as to better understand where targets are being met and where the flooding conditions could be improved. The City's flood mitigation targets for the Willow Creek Watershed Study are as follows, grounded by Annual Exceedance Probability (AEP) design storm event. Note that these targets may change in the future.

10% AEP design storm event:

- a) No surcharging onto the street for up to the 10-year design storm; water shall be contained within the pipes and structures. *When using rain-on-grid hydrology, the target is met if there is less than 0.25' of curb depth.*
- b) For locations limited by known inlet capacity, allow no more than 0.5 feet of water above storm sewer inlet rim. *Note that this target was not included in the scope for the Willow Creek Watershed Study.*

4% AEP design storm event:

- a) Centerline of street to remain passable during 25-year design storm with no more than 0.5 feet of water at the centerline.

1% AEP design storm event:

- a) No home or business will be flooded during the 100-year design storm. *This is defined as no more than 0.5 feet of water at the 5-foot buffer around a structure.*
- b) Enclosed depressions to be served to the 100-year design storm (which can include safe overland flow within street, easements, greenways or other public lands). *For purposes of this watershed study, enclosed depressions are defined as depressions in public right-of-way where stormwater needs to reach private property to overflow from the depression.*
- c) Greenway crossings at streets to be served to the 100-year design storm.

0.2% AEP design storm event:

- a) Safely convey stormwater; i.e. limited impact on private property. *For purposes of this watershed study, limited impact is defined as no more than 0.5 feet of water at the 5-foot buffer around a structure.*

Existing and Recommended Solution Conditions Results

The existing conditions analysis found numerous locations where the system does not meet the identified flood mitigation targets, as outlined in **Table ES-1**. Following the existing conditions analysis, an extensive process was conducted to brainstorm, evaluate and select a series of solutions that would reduce flooding across the watershed. The all of the recommended solutions were integrated into the model and compared against the flood mitigation targets, to assess the anticipated flood reduction. **Table ES-1** shows how the recommended solutions reduce flooding relative to the City's targets, and **Figure ES-2** shows the location of the recommended solutions.

There are still some locations within the watershed where the flood mitigation targets are not yet met, even with the recommended solutions. This is due to a variety of reasons, including the lack of physical space for improvements, lack of topographical relief to adequately drain regions, and localized flooding on private property that cannot be remedied with public improvements.

Table ES.1: Existing Conditions and Recommended Solutions Results based on the City's Flood Mitigation Targets for the Willow Creek Watershed

Design Storm Event	ID	Target	Watershed-wide metric	Existing Condition	Recommended Solutions Condition
10% AEP	1a	No surcharging onto the street	104.2 miles of curbline	17.3 miles of curb with more than 0.25-ft of water (16.6%)	15.4 miles of curb with more than 0.25-ft of water (14.8%)
	1b	No more than 0.5' of water at locations limited by inlet capacity	<i>Inlet capacity restrictions not included as part of this watershed study</i>		
4% AEP	2a	Centerline of street remain passable	58.1 miles of road centerlines	7.7 miles of roads with more than 0.5-ft of water (13.2%)	6.4 miles of roads with more than 0.5-ft of water (11.0%)
1% AEP	3a	No homes or businesses will be flooded	5,040 buildings/structures	353 buildings/structures impacted (7.0%)	322 buildings/structures impacted (6.4%)
	3b	Enclosed depressions served	48 enclosed depressions	12 enclosed depressions impact private property when overflowing (25.0%)	12 enclosed depressions impact private property when overflowing (25.0%)
	3c	Greenway crossings at streets served	6 greenway crossings	5 greenway crossings overtopping the road (83.3%)	5 greenway crossings overtopping the road (83.3%)
0.2% AEP	4a	Safely convey stormwater; i.e. limited impact on private property	5,040 buildings/structures	551 buildings/structures impacted (10.9%)	536 buildings/structures impacted (10.6%)

Recommended Solutions Cost

Improvements were recommended across the watershed by upsizing existing piped infrastructure. New regional ponds were not feasible for the Willow Creek Watershed since the watershed is effectively entirely developed. **Table A.2** lists the final recommended solutions, along with an estimated design and construction cost for each. Figures of the recommended solutions are included later within this report.

Table ES.2: Recommended Solutions Project Cost Estimates for the Willow Creek Watershed

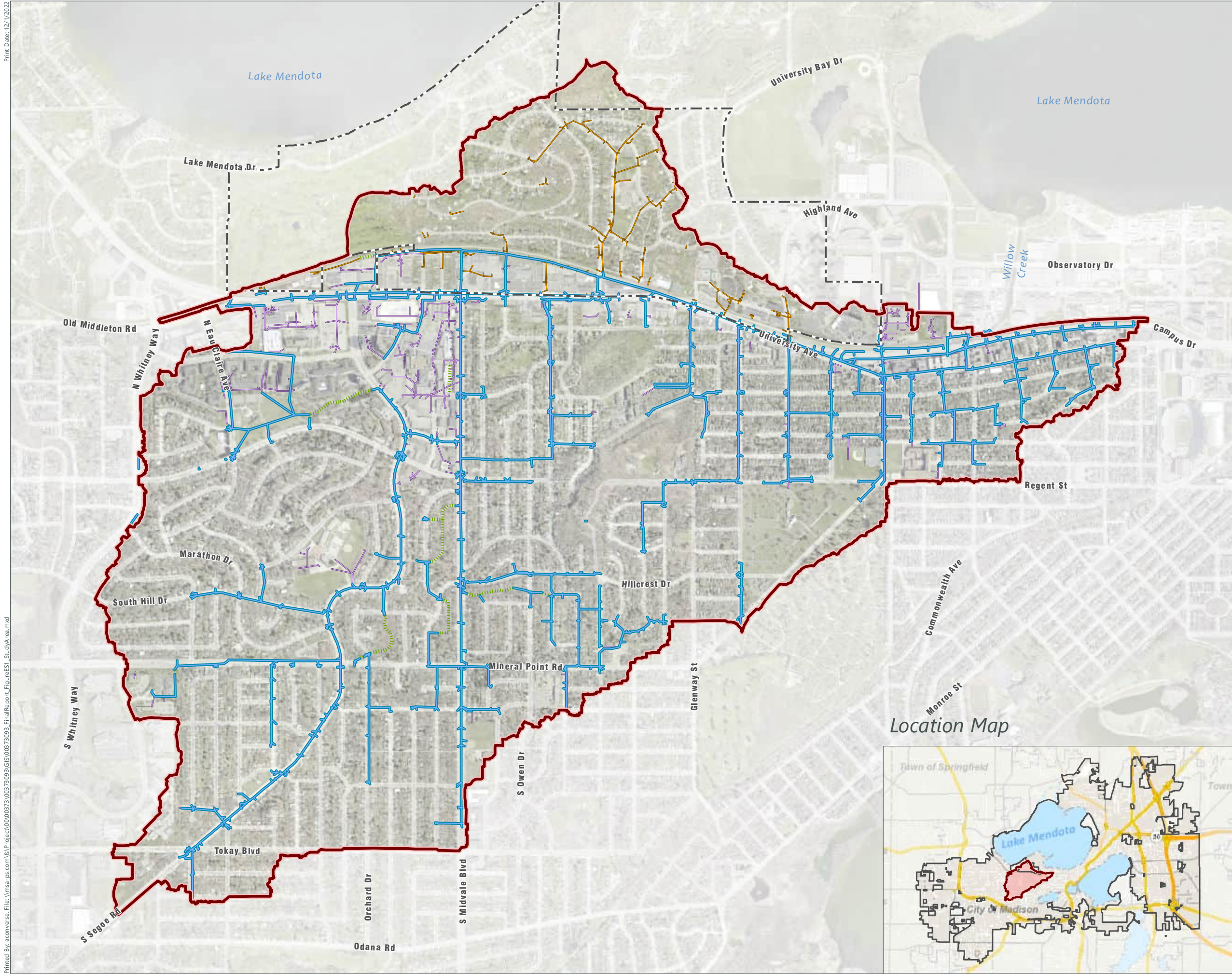
Project	<i>Estimated Design Cost</i>	<i>Estimated Construction Cost</i>	Estimated Total Cost
University Ave Storm System Improvements	--	--	Currently under construction
N Midvale Blvd Parallel Storm System Improvements	\$1.25 M	\$15.59 M	\$16.84 M
South Hill Dr, Segoe Rd, and Vernon Blvd Storm System Improvements	\$1.55 M	\$19.35 M	\$20.90 M
Regent St and Owens Dr Storm System Improvements	\$147 K	\$1.84 M	\$1.99 M
N Eau Claire Ave, Regent St and Rennebohm Park Storm System Improvements	\$85 K	\$1.06 M	\$1.15 M
S Segoe Rd Storm System Improvements	\$293 K	\$3.66 M	\$3.95 M

Study Area

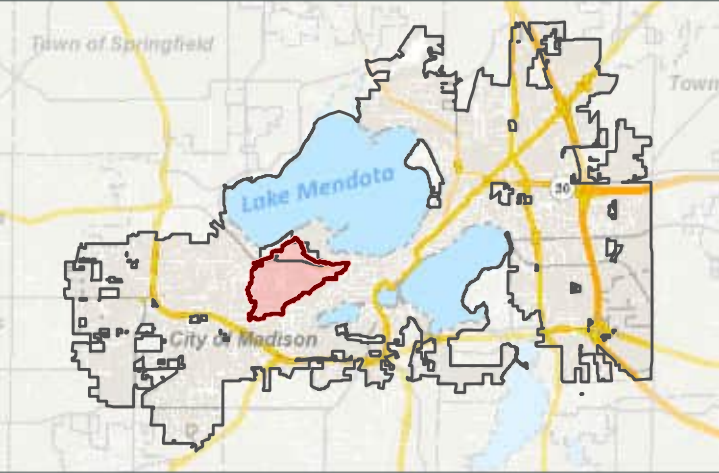
FIGURE ES-1
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

-  Watershed Study Area
-  Village of Shorewood Hills
-  Public Storm System
-  Private Storm System
-  Shorewood Hills Storm System
-  Open Channel



Location Map



Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison



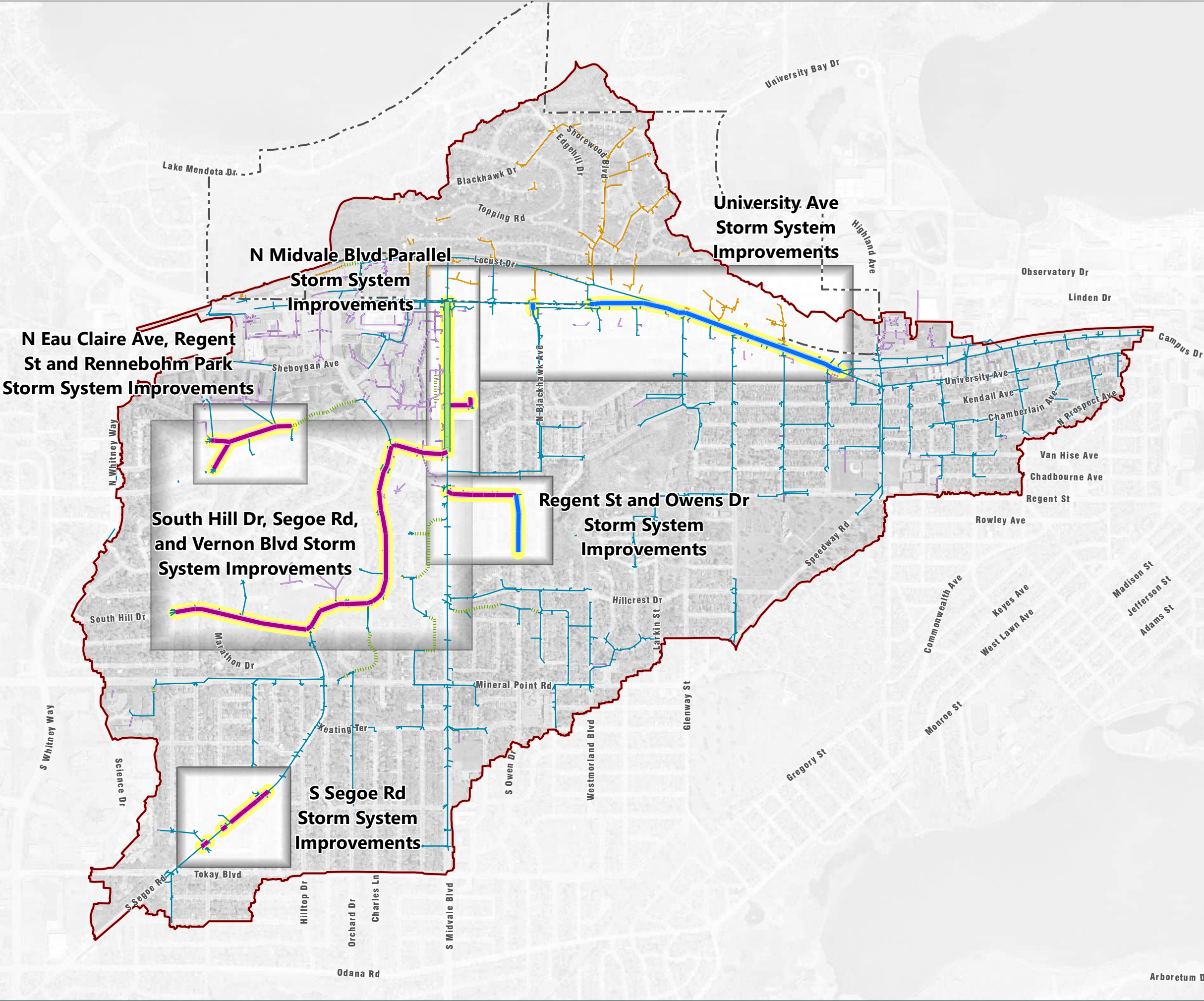
0 0.125 0.25 Miles



Recommended Solutions Map

FIGURE ES-2
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI



- Map Extents (Figures 29 A-F)
- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow
- Improvement Area of Interest
- Recommended Improvements**
 - Replacement Pipe
 - New Pipe
 - New Parallel Pipe

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Reported Flooding: City's Online Public Reporting (through July 2020)
Historic Flooding, Observations and Priority Inlets: City of Madison
Observations by City Staff: Based on discussions of known flooding concerns with City Engineering Staff and prior Watershed Studies



2 Introduction

2.1 Project Background and Purpose

The City of Madison has experienced increased frequency and intensity of rainfall events over the past ten to fifteen years. In August 2018, an unprecedented rainfall event occurred on the City of Madison's west side. A nearby United States Geological Survey (USGS) rain gauge in Middleton's Pheasant Branch Conservancy (site # 05427948) recorded 10.5 inches of rain over a 12-hour period. For reference, NOAA Atlas 14 statistics show the 12-hour 0.1-percent chance recurrence interval storm at 8.92 inches for the Madison area. This event caused flash flooding, most significantly across the western half of Madison, and prompted the City of Madison (City) to begin a comprehensive watershed planning process.

In response to the 2018 summer floods, the City of Madison initiated a city-wide focus on identifying and addressing issues within the urban drainage system. This includes creating comprehensive watershed plans for watersheds throughout the City, including the Willow Creek watershed (the watershed).

Figure 1 provides a detailed view of the watershed, with an inset map to show its location within the City.

2.2 Scope of Study

The scope of work includes:

- Development of an existing conditions XP-SWMM rain-on-grid computer model of the 1,950 acre watershed
- Calibration of the model against rainfall and flow/depth data collected at selected locations within the watershed during the summer of 2021
- Evaluation of calibrated model output for purposes of identifying locations within the watershed where the existing stormwater management system does not meet City of Madison flood mitigation targets
- Evaluation of flood mitigation alternatives

During the course of this project, significant resources were allocated to public involvement including multiple public information meetings, focus group meetings, and online data reporting efforts. Information collected during the public information meetings was used in the model development and the problem identification efforts of this project.

The first half of this report documents the development and calibration of the existing conditions Willow Creek watershed model. Flood mitigation alternatives are documented in the second half of the report.

2.3 Historic Flooding in the Watershed

Within the Willow Creek watershed, there are several areas that have experienced flooding in the past. **Figure 2** depicts known flooding reports provided by the City in the Willow Creek watershed. The known flooding locations include flood reports from a variety of data sources, including resident reports, emergency services reports, operations staff reports, and inlets with repetitive clogging history. These flood reports are limited to areas within the City of Madison.

Known flooding locations were discussed with City staff throughout the project. A summary of the major flooding locations are described below and displayed in **Figure 2**.

University Ave/Midvale Blvd Intersection:

This intersection occurs in a topographic low spot (sag point) and recurring flooding has been reported with anecdotal evidence indicating that the condition has existing for more than 50 years. The lowest spot in the sag point is actually located approximately 200 feet north of the intersection. When storm sewer capacity is exceeded, this area fills up and eventually overtops to the west to a low area within the Village of Shorewood Hills. Subsequent to the August 2018 flood event, nineteen homes in this area, known as the Garden Homes Neighborhood, were purchased and demolished. One other home in this area was raised to protect it from future flooding.

Previous studies have indicated the trunk storm sewer serving this area has capacity to pass peak flows from the 10% AEP (10-yr) event; however, this study has shown surface overflows from the sag point occur under events of 50% AEP (2-yr) event and greater.

University Ave/Shorewood Blvd Intersection:

This intersection is located at a topographic low spot (sag) and recurring flooding has been reported by the City of Madison. When the capacity of the trunk storm sewer serving this area is exceeded, surface flows travel north along Shorewood Blvd into the Village of Shorewood Hills to a point just north of Locust Street where flows accumulate before running east along the railroad tracks.

During the August 2018 flood event, flows overtopping the intersection of Shorewood Blvd. and Locust Dr. also passed across the railroad tracks east of Shorewood Blvd. washing away the railroad ballast.

Further east along the railroad tracks is the Village of Shorewood Hills community pool. The City has received reports from the Village that the pool is frequently flooded.

University Ave/Farley Ave Intersection:

There is a topographic low point (sag) on University Avenue approximately mid-block between Farley Ave. and Franklin Ave. Frequent surface flooding has been observed by the City at this location. Modeling results from this study indicate that surface flooding will occur for events of approximately 50% AEP (2-yr event)

Midvale Blvd/ Vernon Blvd Intersection:

The City has observed frequent flooding at this intersection and upstream along both Vernon Blvd to the west and Midvale Blvd to the north of this intersection. There is a shallow sag point in the vertical profile of Midvale Boulevard just north of Vernon Avenue where stormwater accumulates when the trunk storm sewer capacity is exceeded. Past studies have indicated that this location experiences surface flooding under approximately 50% annual exceedance probability (2-yr) storms. This frequency of flooding was confirmed by this study.

Blackhawk Ave/Bluff St Intersection:

The City has observed frequent flooding at this intersection. The original storm sewer system serving this location flows south from this intersection approximately 200 feet before flowing west through the midblock area north of Regent Street – another area that has experienced frequent flooding. In 2018 the City constructed a 48" relief storm sewer conveying some flows away from the Blackhawk/Bluff Street intersection. At the time of the drafting of this report, this storm sewer system currently necks down to smaller diameter before connecting to the trunk line at University Avenue and so full capacity isn't yet realized; however, this connection will be made as part of the 2022 University Avenue reconstruction.

Midblock flooding north of Regent St:

There is a branch storm sewer flowing west from Blackhawk Ave. to Midvale Blvd approximately 250 feet north of Regent Street. This storm sewer connects a string of low points directly along the storm sewer alignment. Previous modeling studies indicate surface flooding of these areas under 5-yr (20% AEP) to 10-yr (10% AEP) severity. This current study indicates they may be subject to slightly more frequent flooding.

Sunset Park Neighborhood:

Sunset Park lies at the confluence and subsequent split of two branches of an extensive and complex storm sewer system. There are reported problems in the area upstream along one branch (the Westmoreland Blvd. low point) as well as downstream from this system (midblock flooding north of Regent Street). Capacity issues associated with this location likely don't have significant impacts upstream; however surface overflows during larger events are predicted by this study to occur at the intersection of North Sunset Ct and West Sunset Court ultimately draining overland north along Owen Drive contributing to the midblock flooding on Regent Street.

Westmorland Blvd:

There is a topographic low point (sag) on Westmorland Blvd approximately 175 feet north of Hammersley Avenue that has experienced reoccurring flooding in the past. In 2018, the City installed a new 54" diameter reinforced concrete pipe storm sewer to divert a large portion of flows collecting on Hammersley Ave., which previously would have drained to the low spot, to instead flow south towards Mineral Point Road. From Mineral Point, this new storm sewer flows west to East Sunset Ct., where it turns north and flows to the northeast corner of Sunset Park where flows are split into two smaller 36" pipes; one running west along North Sunset Ct. and one discharging to the open channel on the north side of the park. Flows in these two systems ultimately come together again at the intersection of North Sunset Ct and West Sunset Court as described above.

The construction of the new 54" pipe on Westmorland Blvd has been shown by this study to greatly reduce the frequency of flooding of existing homes adjacent to the sag point.

Mineral Point Rd/Segoe Rd Intersection:

There is a large (7' x 4') box storm sewer pipe flowing north along Segoe Road at its intersection with Mineral Point Road. At this location a 30" reinforced concrete pipe storm sewer serving areas east along Mineral Point joins the box culvert. When peak flows exceed the capacity of either system, the primary overland flow path is north along Segoe Rd., but when flows become high enough, they will also flow east along Mineral Point Rd. to a topographic low point only approximately 200 feet further east. The storm sewer serving this low point is much smaller, only 24" in diameter and when its capacity is exceeded, flows pass overland to the north and east onto private property potentially causing property damage.

North Eau Claire Ave./Buffalo Trl Intersection:

This intersection has been subject to chronic reoccurring flooding. When flooding becomes extreme, overflows occur which pass east through Rennenbohm Park, ultimately contributing to flooding of North Segoe Rd at the east end of the park.

2.4 Flood Mitigation Targets

The following flood mitigation targets have been established by the City of Madison, grouped by Annual Exceedance Probability (AEP) design storm event, with a final target focused on ensuring the solutions do not have negative impacts elsewhere within the watershed:

10% AEP design storm event:

- a) No surcharging onto the street for up to the 10-year design storm; water shall be contained within the pipes and structures. When using rain-on-grid hydrology, the target is met if there is less than 0.25' of curb depth. *There are locations within the City where low points exist that pond water; these low points are excluded from this target and will be addressed as streets are redesigned.*
- b) For locations limited by known inlet capacity, allow no more than 0.5 feet of water above storm sewer inlet rim.

4% AEP design storm event:

- a) Centerline of street to remain passable during 25-year design storm with no more than 0.5 feet of water at the centerline. *Note that the Watershed Study modeling approach will not explicitly account for cross flow conditions where more gutter flow on one side of the street can overtop the crown.*

1% AEP design storm event:

- a) No home or business will be flooded. This is defined as no more than 0.5 feet of water at the 5-foot buffer around a structure.
- b) Enclosed depressions to be served (which can include safe overland flow within street, easements, greenways or other public lands). *For purposes of this watershed study, enclosed depressions are defined as depressions in public right-of-way where stormwater needs to reach private property to overflow from the depression.*
- c) Greenway crossings at streets to be served.

0.2% AEP design storm event:

- a) Safely convey stormwater; i.e. limited impact on private property. For purposes of this watershed study, limited impact is defined as no more than 0.5 feet of water at the 5-foot buffer around a structure.

Provide flooding solutions that do not negatively impact downstream properties.

The City also stated that 'due to the inherent variability and complexity of stormwater conveyance systems, it may not be practical to meet the above level of service targets in all areas of the City.'

The focus of the Watershed Study is on the capacity/deficiencies within City-owned infrastructure and the right-of-way and that the Watershed Study should be considered a "planning-level" analysis. Therefore, there are several limitations to the study that are documented further in Section

2.5 Summary of Past Studies

There are records of drainage studies within Willow Creek watershed dating back to as long ago as 1945. The 1997 Stormwater Management Study completed by Strand Associates (see below) references studies from 1945, 1954, 1964, and 1966. While copies of these studies no longer appear to exist, each study was seemingly primarily concerned with addressing the flooding conditions at/near the intersection of University Avenue and Midvale Boulevard. It was with these earlier studies that the concept of the relief sewer (tunnel) outlet directly to Lake Mendota appears to have been first introduced.

- **West End Relief Sewer under Black Hawk County Club (Warzyn Engineering & Service Co., August 1965)**

This technical memorandum presents the findings of a subsurface investigation intended to support the engineering design of a potential 78-inch diameter storm sewer running from the intersection of University Ave. and Midvale Blvd. northwest through the Black Hawk Country Club to Lake Mendota. Discussion within the memo indicates that some construction would be through traditional open-cut methods, but that the majority would be constructed through tunneling methods. The memo concluded that the tunnel alignment would pass through sandstone of the Franconia formation and the findings of 11 soil boring investigations are presented.

- **Stormwater Management Study - University Avenue / Midvale Boulevard Area (Strand Associates, October 1997)**

This report analyzed runoff conditions within the Willow Creek watershed and evaluated flooding conditions along the Midvale Blvd. and University Ave. corridors. The study divided the watershed into six primary subwatersheds. Event based flows were estimated for each subwatershed using the HEC-1 model and the capacity of the Midvale/University trunk storm sewer was evaluated using the EXTRAN (a module of the SWMM program) hydraulic model using the HEC-1 flows. The significant finding of the study was that the existing trunk storm sewer system serving Midvale Blvd. and University Ave. had insufficient capacity to convey 10-yr peak runoff rates. Significant widespread flooding was anticipated for larger events.

The study evaluated several alternatives including:

- Adding additional surface flood storage within Rennebohm Park and Lucia Crest Park,
- Construction of underground flood storage at the Kohl's (now Walgreens) parking lot at the northeast corner of University Ave. and Midvale Blvd.,
- Construction of a relief storm sewer running east from the intersection of University Ave. and Midvale Blvd. to Willow Creek
- Construction of a 78" diameter relief storm sewer (tunnel) running north from the intersection of University Ave. and Midvale Blvd. directly to Lake Mendota, and
- Floodproofing of existing buildings (principally the Garden Homes) near the intersection of University Ave. and Midvale Blvd. to Willow Creek

Analyses of increased flood storage alternatives indicated that between 60 and 80 acre-feet of flood storage would be required to provide 100-yr flood protection. This magnitude of project was found to be not cost-effective. The recommended alternative was to construct the relief storm sewer to Lake Mendota at an estimated cost of \$6.7M (1997 value).

- **Environmental Report – Stormwater Relief Culvert (Strand Associates, February 2001)**

This report provided further details on the relief storm sewer (tunnel) recommended by the 1997 study previously described. Additional information in the form of more detailed concept designs, anticipated event-based runoff rates and volumes, and estimated annual pollutant loads produced by Willow Creek Watershed were summarized. The conclusion of the report was that the construction of the relief storm sewer would not have significant environmental effects.

- **Alternative Stormwater Management Analysis (Applied Ecological Services, June 2001)**

This report documented the findings of a study which further refined data and models developed as part of Strand Associates 1997 study. The study identified 18 sites across the Willow Creek watershed potentially

suitable for providing additional flood storage. If all practices were constructed as conceived in the study, an additional 199.2 acre-feet of flood storage volume could be provided which would reduce peak flows from the watershed such that the then-existing trunk storm sewer system could convey 50-yr peak flows. The report did not provide comment on what effect additional storage had on the capacity of existing storm sewers serving as tributary branches to the trunk storm sewer.

- **Willow Creek Watershed Existing Conditions Study (Strand Associates, August 2002)**

This report presented the findings of a refined analysis of the watershed drainage system initially developed as part of the 1997 study presented previously. Of particular significance was the expansion of the hydraulic analysis of storm sewer systems beyond the Midvale Blvd and University Avenue corridor to include approximately 16 branch lines. The study offered the following observations regarding existing storm sewer system capacity:

- **Mainline** – the trunk storm sewer running north and east from the intersection of University Ave. and Midvale Blvd. has only approximately 10-yr capacity until it reaches Ridge Street where capacity was estimated to increase to 50-yr to 100-yr service levels. There is surface flooding predicted under 2-yr conditions at Hill St., 5-yr conditions at Ridge St., and 10-yr event conditions at Franklin Ave
- **Midvale Blvd** – trunk storm sewer flowing north along Midvale Blvd has only approximately 2-yr capacity between Vernon Blvd and University Ave.
- **Regent St. east of Midvale Blvd.** – This area was shown to experience surface flooding during 5-yr to 10-yr event severity.
- **Regent St. at Eau Claire Ave.** – This area was shown to experience surface flooding during 10-yr to 25-yr event severity.

This study was only an existing conditions assessment and did not offer any specific recommendations; however, references were made to potential improvements that could be realized through construction of the relief storm sewer (tunnel) evaluated in prior studies.

- **Willow Creek Watershed Drainage Evaluation (Strand Associates, June 2003)**

This study was a further expansion of studies completed previously and focused on two particular conceptual improvements:

- **East End Culvert** – This portion of the study focused on improvements to the drainage system at the outlet of the Willow Creek Watershed and recommended two projects. The first project, expressed as ‘phase 1’, involved construction of approximately 400 feet of parallel box culvert system running between the existing Willow Creek outfall west and north across Campus Drive and connecting to the trunk storm sewer system (the City of Madison implemented this project, although along a different alignment with a different sized structure).

A second phase of this project was to install another the box culvert which would begin at the bend of the culvert installed under phase 1 which would extend west along the RR tracks north of Campus Drive approximately 2,500 feet to University Bay Drive.

- **Rennebohm Park** – This analysis looked at the flood reduction potential resulting from construction of a large stormwater detention pond within the park. A conceptual plan is included in the study which identifies a pond occupying the eastern ½ of the park, which would back-up water west onto the soccer

fields during larger events. The pond as identified would be able to store up to 22.0 acre-feet of floodwaters under 100-yr conditions, but modeling showed it to have little effect on reducing downstream flooding conditions, including along University Ave. at the intersections of Midvale Blvd. and Shorewood Blvd.

- **Neighborhood Plans 2008-2016**

- Regent Street – South Campus Neighborhood Plan (Vierbicher Associates & Potter Lawson, July 2008)
- Midvale Heights/Westmoreland Joint Neighborhood Plan (Vierbicher Associates, September 2009)
- Hoyt Park Area Joint Neighborhood Plan (Vandewalle & Associates, Inc., January 2014)
- University Avenue Corridor Plan (Planning and Design Institute, Inc. & GRAEF, May 2014)
- University Hill Farms Neighborhood Plan, Urban Assets, LLC, Cuningham Group, and City of Madison Planning Division, January 2016)

Each of these neighborhoods is at least partially within the Willow Creek watershed and while many of the documents referenced historic flooding, the scope of the documents were not specifically geared towards drainage improvement, flood reduction, or stormwater management. Regardless, every one of the plans recommended increased stormwater management practices for new and redevelopment projects with a heavy emphasis on stormwater infiltration with a general intent of reducing flood risk, as well as overall stormwater runoff quality.

The University Hill Farms Neighborhood Plan did include a specific assessment of various public spaces which contain stormwater management features including Rennebohm Park and the Robin Greenway which incorporated some new water features; however, they were conceptual in nature and no speculation was made on potential flood reduction benefit.

One particularly relevant recommendation found within the Hoyt Park Area Joint Neighborhood Plan was the development of an Owen Drive Pilot Program, which, amongst other issues, would explore use of alternative street construction practices to improve stormwater management. While not within the Willow Creek watershed, the City of Madison did recently complete several street reconstruction projects in the Westmorland Neighborhood as a pilot project to determine the benefits of designs focusing on alternative stormwater management practices.

- **Informally Documented Studies and Design Evaluations, 2018-2019**

In 2018, Madison contracted with KL Engineering to design the reconstruction of University Avenue from Shorewood Blvd to University Bay Dr. The City's engineering department constructed an InfoSWMM model of Willow Creek watershed to guide stormwater design for that project.

Later in 2018, Madison hired AE2S to modify Madison's internal model to explore the effects of installing the previously conceived large relief storm sewer (tunnel) from the University Ave/Midvale Blvd intersection to Lake Mendota under the Blackhawk County Club. The revised modeling study confirmed that, if large enough, the relief storm sewer could substantially decrease flooding along the University Avenue corridor

Still later in 2018, the City of Madison contracted with KL Engineering (with AE2S as a subconsultant) to complete a feasibility study to explore the potential to install a large (10' diameter) stormwater relief culvert via a tunneling project. Preliminary results from that study were presented to City of Madison and Village of

Shorewood Hills staff and residents on September 17, 2019. Based on the results of the study, the City of Madison elected to not pursue the relief storm sewer tunnel project.

- **University Avenue Flood Mitigation Alternatives (AE2S, May 2019)**

AE2S was hired by the Village of Shorewood Hills to conduct some additional modeling studies, presumably building off work AE2S had done for the City of Madison within Willow Creek Watershed. There were apparently many informal documents prepared which provide output data from various simulations; however, a memorandum posted to the Shorewood Hills website is seemingly the only published document describing alternatives evaluated and discussing the findings of each analysis. This memo documented evaluations of four alternatives including the following:

- **Filling of the Garden Homes sites.** Homes historically located in this area had been repeatedly subjected to flooding and were largely bought-out and removed from this area. This analysis showed that loss of floodplain storage within this area would cause flood elevations to increase along University Avenue between Midvale Blvd and Shorewood Blvd by between 0.1 and 0.2 feet.
- **Add flood storage near Shorewood Blvd intersection.** Details were not provided regarding storage provided, but it was concluded that additional storage at this location would not result in improved flooding conditions at Midvale Blvd.
- **Upstream flood storage.** This evaluation determined that approximately 210 acre-feet of flood storage would be required within the upper watershed to provide 100-yr protection along the University Ave. corridor. If this storage were provided as rain gardens with a depth of approximately 3-inches, this would equate to approximately 600 to 750 acres of area.
- **Relief storm sewer.** Specific details regarding the alignment of this pipe were not provided; however, it is assumed that this storm sewer begins somewhere near Shorewood Blvd and extends east to an existing 96" storm sewer beginning near Grand Avenue. This evaluation concluded that there would be little improvement in flooding at Shorewood Blvd even due to limitations in the capacity of the existing 96" storm sewer.

3 Water Resources Inventory

3.1 Study Setting

The Willow Creek watershed is located on the near west side of the City of Madison, as shown in **Figure 1**. Generally the watershed is bounded by Tokay Blvd to the south, N Whitney Way to the west, encompassing a large fraction of the Village of Shorewood Hills to the north, and following Speedway Rd to the east. The watershed encompasses portions of the following neighborhoods: University Hill Farms, Midvale Heights, Westmorland, Sunset Village, Rocky Bluff, VanChaMasShe, Radio Park, Regent, and a small portion of the University Apartments.

The majority of the watershed is fully developed, where 52% of the land area is residential homes, 25% is used for transportation, 9% is institutional/government (including schools, state offices, hospitals, Stormwater Utility land, and cemeteries), 7% is commercial (including the Hilldale Mall and the University Ave corridor), and 7% is used for recreation (including city parks).

Prominent features within the watershed include:

- University Avenue Corridor/Campus Drive
- Hilldale Mall
- Madison Yards at Hill Farms
- Fire Station #9 (201 N. Midvale Blvd)
- Midtown Police District (4018 Mineral Point Rd)
- Portions of the UW Hospital
- Van Hise Elementary School & Hamilton Middle School
- Midvale Elementary School
- Madison West High School
- Hoyt Park
- Quarry Park
- Shorewood Hills Pool and Tennis Courts
- Resurrection Cemetery

3.2 Watershed

The Willow Creek watershed is bounded by the major watersheds listed below (**Figure 3**). Of these, Spring Harbor and Wingra West have ongoing Watershed Studies.

- Spring Harbor
- Wingra West
- Wingra Proper
- Near West
- UW-Madison Campus

The Willow Creek watershed (as defined by this study) is approximately 1,913 acres (3.0 square miles). However, under runoff conditions above a certain threshold, some of the stormwater runoff that during smaller rain events would flow to

the south along South Franklin Avenue (SW of Resurrection Cemetery) to the Wingra Proper watershed will instead flow to the northeast into Willow Creek. The exact conditions which cause this to occur are currently unknown; however, for this study, rainfall events simulated by the calibrated model of 5.7 inches or larger show a connection to the Willow Creek watershed. Due to the nature of the Willow Creek model design (see **Section 5**) this portion of the Wingra Proper watershed (37 acres) was included in the Willow Creek modeling, but the primary outlet should be considered the Wingra Proper watershed. **Figure 3** shows the connection between these two watersheds.

3.3 Topography

The following data sources were used for topography within the watershed. Topographic data was needed for delineating the model study area and defining overland flow paths/channels.

- 2017 and 2020 Aerial Photography obtained from Dane County and 2018 Aerial photography from the City of Madison
- 2017 LiDAR DEM obtained from Dane County, and 1-foot contours generated from that DEM
- GIS data describing storm drainage infrastructure provided by the City of Madison
- Construction drawings for recent street projects provided by the City of Madison (Hillcrest Dr, Westmorland Blvd, Shepard Terrace/Chamberlain Ave, N Blackhawk Ave/ Heather Bruce Ct/Heather Crest, and Hammersley Ave)
- Record Drawings from Hilldale Mall and the Madison Yards
- Site observations by MSA staff

3.4 Drainage System

The Willow Creek watershed has full urban drainage, with most streets/neighborhoods being served by stormwater infrastructure. The major drainage system is comprised of large storm sewer pipes and five (5) greenways; there are not any regional public stormwater ponds. **Appendix B** contains a photolog of a site visit to the major greenways within the study area. The largest storm sewer runs north under Segoe Rd and Midvale Blvd leading to University Ave, then heading east to the outfall at Willow Creek along Campus Drive. The major system is supplemented by the minor drainage system, which consists of street storm sewer, street surface flow and private stormwater infrastructure.

The overall drainage system is shown schematically in **Figure 1**.

3.5 Runoff Conditions

Runoff conditions within the watershed are dictated primarily by three components: land use, impervious area and underlying soils.

3.5.1 Land Use

Land use within the watershed is shown in **Figure 4**. As previously mentioned, the majority of the watershed is fully developed, with more than half of watershed consisting of residential properties. The remaining land is associated with the road network, commercial properties, institutional/governmental properties, and recreational parks. In recent years, there has been redevelopment in the watershed, but land use types have generally remained the same (i.e. a commercial property is redeveloped into a different commercial property). The largest recent redevelopments are the Madison Yards at Hill Farms which ultimately will be a mixed use property including office space, some medical

facilities, and commercial enterprises. At the time of this study, this project is still under construction, with only a portion of the redevelopment completed.

The northern portion of the watershed encompasses a fraction of the Village of Shorewood Hills. This region was included within the modeling to ensure any stormwater runoff from the Village was incorporated into the existing conditions results. However, Village lands were not included within the targets analysis.

3.5.2 Impervious Area

The total impervious area for the watershed is displayed in **Figure 5**. Impervious area for this study was obtained from several sources:

- Dane County's building footprints
- City of Madison's Stormwater Utility impervious layer for nonresidential properties
- Digitized impervious area by MSA using the most recent high-resolution aerial imagery available at the time (2017 and 2018) to supplement data gaps, specifically driveways, sidewalks and streets. More recent aerial imagery (2020) was not available at the start of this project.

The watershed as a whole is approximately 1,950 acres (including a portion of Wingra Proper) and is occupied by 831 acres of impervious, making it on average roughly 43% impervious.

3.5.3 Soils

The Hydrologic Soil Group (HSG) classifications within the watershed are shown in **Figure 6**. The HSG is a parameter that quantifies a soil's ability to infiltrate stormwater runoff. Well-drained soils with high infiltration rates are classified as 'HSG A', while poorly drained soils with correspondingly low infiltration rates are classified as 'HSG D'. Soils with classifications as 'HSG B' or 'HSG C' fall between these two values. Soils that have dual classifications such as B/D, indicate the respective HSG for drained and undrained conditions. Dual classed soils were treated as though they were in the drained condition; the City of Madison modeling guidance recommended treating dual classed soils as though they were in the undrained condition, but this was modified during the Willow Creek model calibration process.

Most soils in this study are classified as HSG B or HSG C. Some regions are classified as HSG D near Hoyt Park, Quarry Park and part of Shorewood Hills. Swathes of dual classification HSG 'B/D' near the center of the watershed were treated in the drained HSG B condition.

4 Guidance and Data Sources

4.1 Model Guidance Documentation

The most current version of the Modeling Guidance Document that was available during model development was applied to the existing conditions calibrated model (**Appendix A**). Differences between the existing conditions modeling approach and the Modeling Guidance are noted in this report.

All elevations listed in this report are relative to the National Adjusted Vertical Datum of 1988 (NAVD88) unless otherwise noted.

4.2 Data Sources

The following is a list of data used in this analysis:

- Dane County 2017 LiDAR DEM
- City of Madison 2018 and 2020 Aerial Imagery
- NRCS Soils Data for Web Soil Survey (downloaded 10/29/2020)
- Observed impervious surfaces as digitized by MSA using recent aerial photographs
- Existing storm sewer, inlet and structure data from the City's GIS database
- Various construction drawings provided by the City
- Limited survey data provided by the City
- Site observations performed by MSA staff
- Input obtained through Focus Groups (**Figures 7A-E**)
- Rainfall and pipe flow monitoring data collected by the City and the USGS

5 Model Development

5.1 Modeling Software

The version of XP-SWMM that was used for this study was XPSWMM 2020.1

5.1.1 Modeling Approach

This XP-SWMM rain-on-grid model can be viewed as two separate parts, the 2D hydrologic/hydraulic surface model and the 1D-hydraulic model. The rain-on-grid approach utilizes the model surface to simulate the runoff resulting from various rainfall events. Runoff will then flow across the 2D surface until it reaches a location where there is a connection to the 1D hydraulic model (storm sewer network).

The one-dimensional (1D) portion of the model only includes subsurface drainage systems (storm sewer and culverts) and their connection to the surface drainage system. The surface drainage was modeled entirely in two dimensions (2D).

5.2 Rainfall Files

Two different rainfall data sources were needed for this study:

- Design rainfall distributions, and
- Measured rainfall data (gauged data) used for the model calibration

5.2.1 Design Rainfall Events

The MSE 24-hour rainfall intensity distribution with NOAA Atlas 14 rainfall depths were used for event-based modeling. **Table 5.1** lists the design depths used in the analysis.

Table 5.1: NOAA Atlas 14 Design Storm Rainfall Depths

Rainfall Duration	50% AEP (inches)	20% AEP (inches)	10% AEP (inches)	4% AEP (inches)	2% AEP (inches)	1% AEP (inches)	0.2% AEP (inches)
24-hours	2.8	3.5	4.1	5.0	5.7	6.6	8.8

5.2.2 Measured Rainfall Events

Rainfall data was collected in a series of incrementally-recording tipping-bucket style rain gauges operated by the USGS across the near west side of Madison between Spring and Fall, 2020.

The City of Madison engineering staff developed a Thiessen polygon for each rain gauge indicating the area of influence that each gauge was to be assigned for purposes of calibrating the various watershed models. The Willow Creek watershed was divided into two separate regions corresponding to two separate rain gauges (**Table 5.2, Figure 8**).

Although the Willow Creek watershed extended into three other rain gauge Thiessen polygons, they covered only a small fraction of the watershed overall. After discussing with City staff, it was decided to use the two rain gauges physically located within the watershed for calibration.

Table 5.2: Rain Gauge Locations for the Willow Creek Watershed

Gauge Location	Operated by
Vernon Blvd	USGS
Segoe Park	USGS

Rain events to be used in the model calibration process were selected in coordination with the City of Madison engineering staff. The event selection criteria focused on the largest events recorded, with the most complete rainfall station records during the monitoring period. The total depth, total duration, and 5-Day antecedent rainfall for the 3 selected calibration events used in the study are summarized in **Table 5.3**.

Table 5.3: Calibration Events Rainfall Summary

Name	Start	Stop	Duration	Total Rainfall Depth		5-Day Antecedent Rainfall	
				Vernon	South Hill	Vernon	South Hill
8-Sep	9/8/2020 1:00	9/11/2020 1:00	72.0 hours	1.85"	1.82"	0.59"	0.56"
21-Oct	10/21/2020 19:50	10/23/2020 13:50	44.0 hours	3.17"	3.20"	0.20"	0.22"
10-Nov	11/10/2020 12:00	6/25/2020 17:30	5.5 hours	1.05"	1.00"	0.00"	0.00"

In addition to the 3 calibration events, the August 2018 flood event was evaluated based on rainfall hyetographs passed on to MSA by the City. Specific rainfall was applied to all watersheds located within each Thiessen polygon to produce this simulation. At the Public Information Meeting #2 (PIM 2), residents in the Sunset Village neighborhood noted that the calibrated modeled inundation extents for the August 2018 event did not reflect their observations on their properties. Based on this feedback, the City revised the rainfall distribution data for this event to include significantly more detail. The number of individual rainfall distributions included in the August 2018 simulation went from 5 to 65. The results of this additional analysis did not significantly change the August 2018 inundation results.

5.3 Hydrologic Model Development

5.3.1 Methodology

The study area boundary was delineated using the Dane County 2017 LiDAR DEM. This boundary was then used for the 2D grid extent and Rainfall / Flow Area polygons, as runoff is generated everywhere within the model simultaneously. Rainfall polygons were created for each design event and were toggled to “active” or “inactive” depending the scenario modeled.

A runoff volume is generated each timestep within each grid cell depending on the applied rainfall and the land use of the individual cell. If a cell has an impervious land use (i.e. Building, Street, etc.) all rainfall will be converted to runoff after the initial abstraction (Ia) of 0.04 inches has been reached. The Modeling Guidance parameter of 0.05 in of Depression Storage for impervious area was not used in this instance. Rather a Depression Storage depth of 0.04 in was used as the TR-55 RCN method indicates that this is a more appropriate value for impervious surfaces with a curve number of 98. This would have been updated, had the calibration process necessitated it. Pervious cells are categorized by soil type and by wooded / turf grass. Each of these different pervious classifications has infiltration parameters applied, as detailed in the modeling guidance. Pervious cells have the added function of losing volume to infiltration. This applies to rainfall directly onto the cell or runoff arriving from an adjacent cell.

5.3.2 Subwatershed Input Data

Subwatersheds were not delineated within the Willow Creek study area. Unlike prior studies, this step could be skipped because runoff is not being loaded at concentrated locations (runoff nodes).

5.4 1D Hydraulic Model Development

5.4.1 Level of Detail

City of Madison Modeling Guidance requires, with flexibility, the following level of detail for the 1D hydraulic model:

- **Public System**
 - Standard: 18” pipes (or equivalent) and larger
 - Process exemptions: Provided justification for reason that the pipe does not need to be modeled in order to evaluate the system relative to the City’s Flood Mitigation Targets that are outlined in the Modeling Guidance.
 - Process for requiring inclusion of smaller pipes: Necessary when they are only pipes draining a part of the public system
- **Private System**
 - Standard: Not included
 - Process for requiring inclusion of private pipes: Necessary for modeling stormwater detention facilities or when they are a major part of the system (e.g. Hilldale Mall drainage)

Due to the rain-on-grid modeling approach, all pipes 18” or larger were included in the model, as well as many smaller pipes and portions of the private system. Where there were locations which were served by a pipe smaller than 18” or a

private pipe, they were included in the model if the location was sag point with a significant drainage area, or if the 1D flow went in a different direction from that of the overland flow.

Figure 9 illustrated the 1D storm sewer system that is included in the model.

5.4.2 Hydraulic Conveyance Systems Analysis

All storm sewer and culverts were modeled with inputs consistent with the Modeling Guidance referenced previously. Inverts, pipe sizes, pipe types, and pipe shape were input from a variety of sources as outlined in Section 4.2. Where conflicts in data sources existing, the most reliable data source was used.

During the course of the development of the existing conditions model of the Willow Creek watershed, the City of Madison was in the process of redesigning the University Avenue Corridor, including upsizing the major stormwater infrastructure conveying water from the Midvale Blvd/University Ave intersection east towards the intersection of Grand Ave/University Ave. The project design was not yet complete at the time of the preparation of this report, but the major stormwater elements were reviewed within the model as requested by the City. The following improvements are likely to occur along the University Ave Corridor:

- Re-connection of stormwater pipes at Midvale Blvd and University Ave
- Upsizing of pipes at the intersection of Blackhawk Ave and University Ave
- A T-Connection at the intersection of Shorewood Blvd and University Ave
- A new 96" pipe along University Ave from Shorewood Blvd to connect with an existing 96" pipe just east of Grand Ave

The existing conditions model does not include the recommended University Ave corridor design, as the construction date is still forthcoming. However, the recommended system will be included in the alternative analysis within the next phase of this study.

5.4.3 Inlet Capacity Analysis

The Willow Creek watershed model was constructed using the rain-on-grid approach. During the calibration phase of the project, it was found that inlet capture was being under predicted. To remedy this, 1D/2D interface lines were drawn throughout the model at on-grade locations in the upper watershed. This wasn't deemed necessary in places where 10-year flows were filling the storm sewer or at sag locations. Per the scope of work for this specific study, inlet capacity analysis was not included in this watershed study. MSA worked with City staff to evaluate inlet capacity against drainage capacity at several areas of interest, but that evaluation is separate from the work summarized in this report and is included as an **Appendix C**.

5.5 Detention Pond Analysis

There are no public stormwater detention ponds within the Willow Creek watershed. All private stormwater detention ponds were reviewed as part of this study, and modeled using the 2D terrain. Hydraulic structures controlling discharges from the ponds were entered into the 1D model system according to the information provided by construction plans, GIS databases, topographic survey and visual inspections.

5.5.1 Connections to the Wingra Proper Watershed

The Willow Creek watershed (as defined by this study) is approximately 1,913 acres. However, under runoff conditions above a certain threshold, some of the stormwater runoff that during smaller rain events would flow to the south along South Franklin Avenue (SW of Resurrection Cemetery) to the Wingra Proper watershed will instead flow to the northeast into Willow Creek. The exact conditions which cause this to occur are currently unknown; however, for this study, rainfall events simulated by the calibrated model of 5.7 inches and larger show a connection to the Willow Creek watershed. This equates to the 2% AEP event and above. Due to the nature of the model design this portion of the Wingra Proper watershed (37 acres) was included in the Willow Creek modeling. **Figure 3** shows the connection between these two watersheds.

To incorporate this, the flood 2D Grid Extent and Rainfall Inflow Areas were both extended to encompass the additional watershed area. The section of storm sewer on Franklin Ave draining this area was added to the model, including a 1D outfall on Speedway Rd. Contributions of runoff to the cemetery were then observed only when the capacity of this storm sewer was exceeded and available storage on the modeled surface at the Franklin Ave/Hillcrest Dr intersection was breached.

5.6 2D Hydraulic Model Development

5.6.1 2D Modeling Area

Due to the nature of the rain-on-grid modeling technique, the entire watershed area was modeled in 2D. This was necessary to distributed rainfall evenly throughout the model.

5.6.2 2D Terrain Data

The 2017 LiDAR DEM was used for the 2D terrain with the following changes:

- The DEM was modified according to the available construction plans to reflect an approximately finished grading condition. This was needed in certain areas where the 2017 LiDAR DEM contained construction projects where the ground surface was temporarily lowered and ultimately filled in.
- The DEM was also modified at selected public inlet leads, in order better connect the 1D stormwater system with the 2D terrain. A 20-ft buffer was created around all of the identified inlet leads, to identify the lowest elevation within that area. All of the pixels within the 2D terrain that touched one of the select inlet leads were depressed 6 inches below this lowest elevation value. A python script was written to automate this process and will be provided to the City for future use. This ensures better connectivity between the 1D and 2D surface, allowing water to enter into the 1D system more accurately. The driving force behind this change was to ensure that the coarseness of the 15-ft grid cell size was not the reason why some inlets would capture runoff and others would not.

5.6.3 2D Grid

For the Willow Creek watershed, a 15-foot grid cell was assigned. A grid orientation default of 0 degrees was used as this visually appeared to match the orientation of most public streets within the watershed.

5.6.4 2D Land Use and Roughness Values

Figure 10 shows the Manning's n roughness value that was assigned to the 2D terrain. All values assigned were in accordance with City modeling Guidance. Variable roughness values for Turf Grass and Wooded areas, as shown on this figure in the right side tables, were developed to simulate sheet flow roughness at very low depths (<1 ft) decreasing to channel flow roughness as the flow depth increased (>1 ft). Variable roughness for Buildings is simulated with very low roughness at initial depths, increasing dramatically once a flow depth of 0.3 ft has been reached. This is so that runoff generated on a building roof can sheet off quickly. Once inundation gets to a depth greater than 0.3 ft, the surface then acts as an obstacle to the flow.

Figure 11 shows the Land Use designation which were assigned throughout the watershed. Previous model studies used Land Use to determine hydrology inputs such as DCIA and UCIA. This was not applicable when using the rain-on-grid approach, as runoff generated on DCIA will inherently reach a point of concentration faster than runoff which travels across an intermediate pervious area.

5.6.5 Inactive Areas

Per the Modeling Guidance, all buildings are supposed to be modeled as inactive areas within the 2D surface. However, this approach was not possible with rain-on-grid as that would limit runoff generation to all areas except buildings. The Willow Creek watershed had no channels which were modeled in 1D, as the 2D surface appeared to be sufficient for modeling overland flow through all open channels.

5.6.6 1D-2D Interface Lines

As discussed in section 5.4.3, 1D-2D interface lines were added throughout the watershed to accurately reflect inlet capture of surface flow.

5.6.7 2D Boundary Conditions

2D boundary conditions were added at all locations where overland flow could leave the model boundary. These include:

- Willow Creek Outfall
- Campus Dr sag point, east of the Willow Creek Outfall
- Blackhawk Country Club golf course
- Holly Ave
- South Midvale Blvd sag point, north of Tokay Blvd
- Speedway Rd

6 Model Calibration

6.1 Recorded Rainfall and Flow Data

Refer to **Figure 8** for locations of the three storm sewer Level Loggers and two Rain Gages which recorded data from Spring to Fall 2020.

6.2 Baseflow Conditions

Level logger data obtained during the metering process was very steady in periods without rainfall. Baseflow conditions within the watersheds were considered to be negligible.

6.3 Selected Runoff Events

As described previously in Section 5.2.2, 3 rainfall events were used to calibrate the model using rainfall, water level and flow monitoring data collected by the USGS under a separate contract with the City.

The 3 events for use in the calibration were selected in collaboration with City staff. Events were selected with the following considerations (generally in order of importance):

- Total rainfall/recurrence interval estimate
- Functioning monitoring equipment
- Differences between events (i.e. attempting to avoid similar events)

Based on these factors, the events summarized in Section 5.2.2 were selected for use in the calibration.

6.3.1 Metering Gauge Issues

Data collected at the Midvale Blvd level logger appeared to be inconsistent any time a flow depth of 0.3 ft or greater was observed. Results from this meter were subsequently given less weight when analyzing model accuracy. Refer to the Calibration Memo for further detail.

6.4 Calibration Performance

The criteria for calibration are as follows:

- Overall average model bias for water surface elevations (or flow) is within +/- 5% with reasonable effort made to minimize the largest absolute error while at the same time balancing that effort with the relative importance of the model results at each monitoring site location.
- The largest absolute error at each monitored location is defined as +/- 25 percent.
- These calibration criteria are set recognizing that there may be some circumstances where calibration at a specific location cannot be accomplished. For example, in order to calibrate a larger portion of the model and/or produce results that are more accurate for the larger events, a particular gage may have an error that exceeds the 25 percent threshold.

6.4.1 Calibration Results

Tables 6.1, 6.2 and 6.3 summarizes the model bias for each event at each level logger. Graphs comparing model results against metered data are shown in the Calibration Memo, seen in **Appendix D**. The metric of Stage x Time was used to estimate overall simulation bias.

Table 6.1: South Hill Dr Level Logger Bias Summary

Event	Metered Data		Modeled Data			
	Maximum Stage (ft)	Stage x Time (ft-s)	Maximum Stage (ft)	% Difference	Stage x Time (ft-s)	% Difference
Sept 8	1.35	26,499	0.94	-30%	33,252	+25%
Oct 21	2.51	38,592	1.62	-35%	37,351	-3%
Nov 10	3.7	10,074	3.82	+3%	10,363	+3%
Combined		75,165			80,966	8%

Table 6.2: Midvale Blvd Level Logger Bias Summary

Event	Metered Data		Modeled Data			
	Maximum Stage (ft)	Stage x Time (ft-s)	Maximum Stage (ft)	% Difference	Stage x Time (ft-s)	% Difference
Sept 8	0.40	11,921	0.63	+57%	11,953	+0%
Oct 21	0.30	10,219	0.91	+206%	18,318	+79%
Nov 10	0.50	2,277	1.29	+160%	4,771	+110%
Combined		24,417			35,042	+44%

Table 6.3: Farley Ave Level Logger Bias Summary

Event	Metered Data		Modeled Data			
	Maximum Stage (ft)	Stage x Time (ft-s)	Maximum Stage (ft)	% Difference	Stage x Time (ft-s)	% Difference
Sept 8	0.36	18,901	0.47	+30%	13,600	-28%
Oct 21	0.62	26,107	0.71	+15%	36,422	+40%
Nov 10	0.92	2,252	1.09	+19%	3,277	+28%
Combined		47,260			53,299	+13%

7 Results Evaluation

As noted in the Executive Summary, **Figures 13-21** illustrate the calibrated model results for the design storm events. Inundation figures were prepared for the 50% AEP, 20% AEP, 10% AEP, 4% AEP, 2% AEP, 1% AEP, 1% AEP as a long duration storm, 0.2% AEP and simulating the August 18th, 2020 event.

7.1 Model Results Compared to City Observations

Existing conditions model results can be compared against the City Staff observations outlined in **Section 2.3**. **Figure 12** displays the reported flooding records along with the August 20th, 2018 flooding inundation map. It should be noted that the XPSWMM model of existing conditions that was used to simulate the 2018 flood event reflects the current conditions within the watershed; any improvements to the stormwater system between the event and the spring of 2021 were included in the model design.

In general, flooding report locations, anecdotal evidence from residents, and August 2018 surveyed highwater marks all correlate well with simulation results from this model. To better understand and quantify the modeling results, a set of 27 locations were identified by the City that have historically been impacted by flooding. Maximum flooding depth and duration of flooding was tabulated for a range of design storm events to use as quick reference for City staff. A map of the identified locations and associated tables are included in **Appendix E**.

7.2 Model Results Compared to Flood Mitigation Targets

The City identified five (5) major Flood Mitigation Targets. **Figures 22 - 27** show that there are numerous locations where the system does not meet the identified flood mitigation targets. Note that for each target, only regions within the City limits were included within the analysis, excluding the portions of the study area within the Village of Shorewood Hills. MSA prepared a series of GIS python scripts to determine problem locations based on the inundation maps produced by the Willow Creek model and other GIS datasets; these scripts will be provided to the City at the end of the project for future use.

Note that some of the Target criteria refer to “street centerlines” and “street curblines”. Centerlines are defined as the centerline of the road; for most roads, there is a single centerline but there are two centerlines for boulevards where there is a median between each side of traffic. Curblines are the edges of the road pavement, including both edges of the road. An urban curb is commonly 3-6” tall and can help channel stormwater runoff into the designed stormwater system. Typically there are two curblines for each road segment, but a boulevards will have four curblines (one set for each side of the boulevard).

Target 1: 10% AEP design storm event:

- a) **No surcharging onto the street for up to the 10-year design storm; water shall be contained within the pipes and structures*.**

**There are locations within the City where low points exist that pond water; these low points are excluded from this target and will be addressed as streets are redesigned.*

This criteria was evaluated by clipping the edge of pavement to 50-foot segments and intersected with the 10% AEP inundation raster to determine locations where the average water depth was 0.25' or greater along the curb line.

There are 17.3 miles of road curblines (16.6% of all curblines) with an average depth of 0.25-feet or more during a 1% AEP design storm (**Figure 22**).

- b) For locations limited by known inlet capacity, allow no more than 0.5 feet of water above storm sewer inlet rim.**

Evaluating inlet capacity restrictions was beyond the scope of this watershed study. See **Section 5.4.3**.

Target 2: 4% AEP design storm event:

- a) Centerline of street to remain passable during 25-year design storm with no more than 0.5 feet of water at the centerline**.**

***Note that the watershed study modeling approach will not explicitly account for cross flow conditions where more gutter flow on one side of the street can overtop the crown.*

This criteria was evaluated by using a road centerline dataset, split at 50-ft intervals and intersected with the 4% AEP inundation raster. Any segments with an average of 0.5-feet or more of water depth were classified as a 'potential problem location'.

There are 7.7 miles of road centerlines (13.2% of all centerlines) with more than 0.5 feet of water at the centerline during the 4% AEP design storm (**Figure 23**).

Target 3: 1% AEP design storm event:

- a) No home or business will be flooded during the 100-year design storm.**

This criteria was evaluated by buffering all buildings by 5-ft, and intersecting them with the 1% AEP inundation raster. The analysis was further refined to only include regions with 0.5 acres of continuous inundation. Any buffered building with an inundation depth of 0.5-feet or greater was classified as a 'potential problem location'. Note that this analysis does not account for modifications residents take to mitigate flooding on their own properties.

There are 353 structures (7.0% of all structures) that could be impacted by the 1% AEP design storm (**Figure 24**).

- b) Enclosed depressions to be served to the 100-year design storm (which can include safe overland flow within street, easements, greenways or other public lands).**

This criteria was evaluated by identifying all of the enclosed depressions at least 0.25 acres in size, based on the 2017 LiDAR DEM. This was completed using the LiDAR processing GIS tool created by Dr. Qiusheng Wu (<https://github.com/giswqs/lidar>). All depressions were intersected with the 1% AEP inundation raster. Any

depression that had a maximum depth of 1-foot or more and touched public land (e.g. street ROW, greenway or SWU lands, etc) was flagged for review. The public lands and private ponds were removed from this subset of enclosed depressions, to determine if the depression also encompassed a portion of privately owned land.

Any enclosed depression that touched public land, included at least 0.25 acres of private land, and had more than 1-foot of inundation depth during the 1% AEP event was classified as a potential problem area.

There are 12 depressions within the watershed at that not adequately draining during the 1% AEP design storm (**Figure 25**).

c) Greenway crossings at streets to be served to the 100-year design storm.

This criteria was evaluated by identifying all of the locations where channelized overland flow enters the piped stormwater system at roadway. Each location was intersected with the 1% AEP inundation raster, to determine the maximum water depth at the road centerline. See **Figure 26**.

The Willow Creek watershed has six greenways: Merlham Drive Section, Regent Street Section, South Owen Drive Section, Hillcrest Drive Section and Robin Drive Sections 1 and 2. Five of the locations overtop the road during the 100-year storm with a maximum depths ranging from 0.4' to 1.2':

- **The Merlham Drive Section** has additional water on the road due to overland drainage flowing north along Midvale Blvd, and therefore not all of the water depth should be attributed to inadequate service of the greenway itself. Maximum water depth on the road: 1.2'
- **The Regent Street Section** the inundation map shows water on the road downstream of this greenway; however, the water present on the road is from surface flow on the street itself. Therefore, the greenway crossing is not considered to be a problem area.
- **The South Owen Drive Section** has two inlet leads for the overland drainage. More water appears in the street adjacent to the more northern connection point. Maximum water depth on the road: 0.4'
- **The Hillcrest Drive Section** overtops Hillcrest Drive as water flow to the northeast. Maximum water depth on the road: 1.1'
- **The Robin Drive Section 1** overtops Orchard Drive as the storm system passes under the road before re-entering the greenway. Maximum water depth on the road: 1.1'
- **The Robin Drive Section 2** overtops Gregg Road as water re-entered the piped storm system heading north. Maximum water depth on the road: 0.9'

Target 4: 0.2% AEP design storm event:

a) Safely convey stormwater; i.e. limited impact on private property

This criteria was evaluated by buffering all buildings by 5-ft, and intersecting them with the 0.2% AEP inundation raster. The analysis was further refined to only include regions with 0.5 acres of continuous inundation. Any

buffered building with an inundation depth of 0.5-feet or greater was classified as a ‘potential problem location’. Note that this analysis does not account for modifications residents take to mitigate flooding on their own properties.

There are 551 structures (10.9% of all structures) that could be impacted by the 0.2% AEP design storm (**Figure 27**).

Target 5: Provide flooding solutions that do not negatively impact downstream properties

This will be incorporated into the recommended improved designs (See **Section 9**)

7.3 Limitations of Study

The Willow Creek Watershed Study is a planning-level study, and as such, it has several limitations for using the model and results beyond the scope of this study. While not an exhaustive list, the following limitations should be considered when reviewing results of using the study for future work:

- Flooding on private property due to localized drainage issues (such as backyards that do not drain well) are outside the scope of this study. However, due to the nature of rain-on-grid modeling, all surface variability has been incorporated into the hydrology and hydraulic model. Inaccuracies in the LiDAR DEM due to the coarseness of the 15 ft grid cell could introduce some errors where a finer detail would not. An example of this would be a narrow landscaped swale from a back of lot to the street. Such grading may not be reflected in the modeled surface.
- Because this study covers more than 3 square miles, it is not possible to review and confirm flood inundation (or lack thereof) at every location throughout the watershed. Further model calibration has its limitations as well, as described in **Section 6**.
- Inlets were modeled as simplified combined inlets into the system. Further, storm sewer laterals were in general not included in the analysis. Therefore, additional site-specific evaluations that more accurately looks at each individual inlet may be needed.
- Because every inlet was not modeled, there may be locations where there is more or less bypass flow or flooding depth on one side of the road than the other than what is shown in the model results.
- As noted in the calibration discussion (see **Appendix D**), the model may be biased to estimate marginally more runoff volume than actual rainfall would produce. Peak runoff rates appears to closely match with that of actual rainfall.
- This study is not intended to be used for FEMA floodplain mapping purposes.

8 Public Engagement

As part of the Willow Creek Watershed Study, the City carried out an extensive public information effort. In addition, various social media and web-based communication methods and public meetings were held. Key elements in the public information program are summarized below; with additional information available via the City's project website:

<https://www.cityofmadison.com/engineering/projects/willow-creek-watershed-study>

It should be noted that this project began in the spring of 2020, and the public informational meetings and focus groups were scheduled throughout the remainder of the year. However, due to the Covid-19 global pandemic, in-person meetings were canceled and replaced with online meetings conducted over Zoom. This unfortunately meant that on-site focus group meetings (where residents walked through their neighborhood to report historical observations) was not feasible. These focus groups were conducted as online break-out sessions, where residents viewed maps of the calibrated inundation depth rasters from different storm events. While not ideal, residents were still able to communicate their thoughts on the current model calibration, provide feedback on their observations across the entire watershed and ask questions of City and MSA staff.

8.1 Public Informational Meeting

An initial public information meeting (PIM #1) was held on September 17, 2020 over Zoom. The purposed of the meeting was to inform the public that the study was ongoing, provide an overview of what will be accomplished by the study, and collected feedback from residents on experienced flooding.

A second public information meeting (PIM #2) was held on March 10th, 2021, also over Zoom. Attendance was estimated to be around 20 individuals, and 'break out sessions' were held to allow residents to provide comments based on Focus Group areas. The discussion focused on the existing conditions modeling results, asking residents if the maximum inundation depth maps aligned with their local understanding of flooding within their neighborhoods.

The final public information meeting (PIM #3) was held on September 29, 2022 over Zoom. This presentation restated the targets of the watershed studies and presented the recommended solutions within the Willow Creek Watershed. Attendees were encouraged to ask questions about the project and recommended solutions within the meeting, either by writing in comments into the "chat" feature or asking questions aloud.

8.2 Focus Groups

Conversations with residents for on-site Focus Group discussions was not possible for this project, due to the on-going Covid-19 pandemic. However, between 15-20 individuals participated in break-out sessions conducted immediately after the PIM #2. This meeting was intended to allow residents to ask questions and provide historical observations on local flooding. Since the online platform allowed for residents outside of the designated Focus Group areas to attend, residents provided feedback on known flooding concerns across the watershed. Their comments are summarized in **Figures 7A-E**.



9 Recommended Solutions Development

Upon completion of the Existing Conditions analysis (outlined in Chapters 1-7 of this report), a draft Existing Conditions report was approved by the City, and the project team moved into the second phase of the study, evaluating different flood mitigation alternatives. The recommended solutions development process focused on “Peak Flow Control (PFC) solutions. PFC solutions are defined by the City as any stormwater control measure that has the ability to store or convey water, but not infiltrate water.

The use of green infrastructure (GI) was considered. MSA looked at the benefits of widespread implementation of GI throughout the watershed by way of converting DCIA to UCIA. This was done within the Rain-on-Grid model by artificially adding storage at 1D nodes systematically throughout the model. The results suggested marginal benefits with 25% DCIA reduction, mainly evident during the 50% AEP event. Results were somewhat negligible during the 1% AEP event. The memo documenting this analysis is attached in **Appendix H**.

9.1 Overall Process Methodology

This chapter outlines the methodology or process used to identify the recommended solutions and elicit feedback from different agencies within the City. A list of all of the solutions considered, including those that were not ultimately recommended, is included with brief descriptions of each potential solution. **Section 10** will provide more specifics on each of the recommended alternatives.

9.1.1 Data Review

The existing conditions modeling was reviewed to identify locations within the watershed where City targets were not met for one or more targets. These locations were identified by reviewing the existing flood conditions and identifying a qualitative cause(s) at each location. Possible causes of flooding include: where a larger storm sewer discharged to a smaller sewer, a storm system is undersized, inadequate inlet capacity, storage deficiencies, and inadequate overland flow channels.

However, during the course of this study, the City was in the process of redesigning a portion of University Ave with plans to begin construction in the summer of 2022. The University Ave piped stormwater system is the main conveyance route for the entire Willow Creek watershed. Because of this, the City requested that MSA complete a careful review of the piped capacity along University Ave and run a series of different simulations for stormwater design alternatives. This effort happened immediately after the existing conditions model was calibrated.

Since there was a sense of urgency due to the construction schedule, the University Ave improvements were addressed first and passed along to the design engineering firm to incorporate into the final plans. More details on this recommended solution are provided in **Section 10.1**. Other potential solutions were considered once this effort was completed.

9.1.2 Solution Brainstorming

After the initial data review, MSA met with the City Engineering staff on December 8th, 2021 to discuss the existing conditions model results, discuss conceptual scenarios and identify potential opportunities for flood mitigation

measures. The Willow Creek watershed, unlike some other watersheds within the City, is restricted by conveyance system to the outfall which cannot be easily improved.

The first step was to determine the maximum capacity for a newly designed system along University Ave (see **Section 10.1**). Although the pipes were optimized to maximize conveyance, they are restricted by the existing topography in the region; increasing the pipe capacity further would not reduce flooding issues simply because there was not enough elevation drop along the University Ave corridor to effectively convey the water to the outfall.

Once the University Ave design was completed, MSA conducted a series of analysis to determine the “level of service” that this main corridor would provide to the entire system. For this exercise, MSA focused on one of the Watershed targets: no more than 0.5' of water on the road centerlines (which would impact emergency vehicle access). This target was met for the 20% AEP design storm along most of University Ave with the recommended design in place, but was not met for the 10% AEP design storm. Therefore, it was determined that the newly designed University Ave improvements would only be able to serve the 20% AEP design storm, before water no longer remains within the piped system.

Making improvements upstream will increase the flows, and potentially cause flooding downstream where there is not adequate capacity. Considering that the newly designed University Ave system only had capacity for the 20% AEP design storm, it was determined by MSA in conjunction with the City that any upstream improvements to the piped system beyond this design storm would violate the City's target to “Provide flooding solutions that do not negatively impact downstream properties.” Therefore, all recommended improvements to the piped system would optimize to convey the 20% AEP design storm flows, to prevent simply transferring any flooding concerns from one part of the Study Area to a different location further downstream.

All of the pipes that were currently undersized for the 20% AEP design storm was classified as constriction points and considered for improvements.

Improvements were grouped by areas/neighborhoods and nearly all locations involve a combination improvements, ranging from upsizing piped infrastructure, changing routing to reduce strain on intersections prone to flooding, revising greenway grading and adding storage capacity. Solutions were targeted within street-right-of-way areas and lands already owned by the City for stormwater use. Solutions on private property were considered as part of this study, simply because there is not much, if any, available public open space within the study area for regional storage.

9.1.3 Evaluation of Potential Solutions

Following the brainstorming sessions, MSA developed preliminary solutions to meet the flood mitigation targets for each of the identified constriction points. The calibrated existing conditions XPSWMM model was used to evaluate each of the flood control solutions (see **Section 9.2** for a brief description of all of the solutions considered throughout this phase of the study).

9.1.4 Discussions of Potential Solutions with City Engineering Staff

Throughout the solutions modeling, MSA met with the City on a monthly basis to review the intermediate modeling results, and discuss the benefits and drawbacks of each. These discussions ultimately lead to some new solutions being added to the list, and while others were removed from further consideration. Some solutions were modeled individually at first, and then subsequently modeled in tandem with other improvements to determine their relative contribution to flood reductions.

9.1.5 Convergence on Solutions

As the evaluation progressed, a set of solutions (described in **Section 9.2.2**) were determined to provide the most viable path towards meeting the flood control targets for the project. This convergence was based on performance of the solutions, technical feasibility, and input from the City Engineering staff. All of the recommended solutions were subsequently mapped using the City's preferred template (to ensure that all of the recommended solutions from the various watershed studies appeared in the same format) and provided to the City for internal review.

9.1.6 City Agency Meetings

Once there was a convergence on solutions, the City Engineering Staff met with different City of Madison agencies to discuss the potential solutions and discuss the challenges/obstacles to implementation with each. Meetings were held with the Mayor's Office, Water Utility, Parks Division, Fire Department, Metro Transit, Planning Division, Community Development Division, Economic Development Division, Streets Division, Forestry, Transportation Engineering, Streets Design Section, and Engineering Operations Section.

9.1.7 Finalization of Solutions

The City agency meetings did not result in any revisions to the solutions developed for the Willow Creek watershed. Following this, the solutions were finalized.

9.1.8 Drafts sent to all City Agencies for Comment

A copy of the recommended solution designs and cost estimates were provided to the City Agencies for additional comment. There were no changes or comments on the recommended solutions.

9.2 Description of All Solutions Considered

Stormwater control measures were considered in various locations across the Willow Creek watershed. Ultimately, a variety of solutions were recommended for implementation, and there were a number of solutions that were reviewed, but not recommended. The following sections provide information about all solutions that were considered.

9.2.1 Solutions Not Recommended

The following flood mitigation methods were considered within the evaluation process; however, they were not recommended. Alternative solutions described in the following subsection were evaluated only so far as was necessary to find them infeasible or to be less feasible than other solutions addressing the same flooding concern. If, in the future, recommended alternatives are abandoned in favor of any of the solutions described herein, additional detailed investigations into the feasibility of each alternative will be required.

9.2.1.1 Increasing the Piped Capacity throughout the Watershed

- **Conceptual Project Description:** Increase the pipe size/capacity within the existing storm sewer system throughout the watershed beyond the 20% AEP design event.
- **Reason for Exclusion:** Increasing the pipe sizes throughout the watershed would alleviate some of the local flooding issues in the upstream portions of the watershed. However, since the watershed is restricted at the

University Ave corridor, upsizing pipes in the upstream areas would cause more flooding issues downstream, specifically along Midvale Blvd and University Ave. Therefore, pipes were only considered for upsizing if they did not currently serve the 20% AEP design storm (see **Section 9.1.2**)

9.2.1.2 Stormwater Detention on Public and Privately Own Lands

- **Conceptual Project Description:** Construct new stormwater detention facilities on some public and privately owned properties. The Willow Creek watershed does not have much available open space for regional stormwater detention. Therefore six (6) locations with known flooding concerns were identified, and modeled as stormwater detention basins to increase storage capacity and reduce flows to limit the required size of downstream infrastructure. These included lands near Robin Park Greenway, the Hillcrest Cunette, Merlam Dr Greenway, property in the Regent St neighborhood, and a property SW of Shorewood Blvd and University Ave.
- **Reason for Exclusion:** Increasing the upstream storage capacity within the watershed would significantly reduce flooding within the Willow Creek watershed. However, converting privately owned residential land into a stormwater basin is general not preferred by local residents. Residents would need to volunteer in large enough quantities to sell their properties, and this is unlikely to occur and therefore not considered a viable option. The available storage in publically owned land was not adequate to reduce flooding without private property acquisition.

9.2.1.3 Redesigning Mid-Block Storm Sewer Immediately North of Regent St

- **Conceptual Project Description:** The neighborhood directly north of Regent St, east of Midvale Blvd is an enclosed depression with existing storm sewer designed to help drain surface waters from private land. This solution increased the piped capacity of this mid-block system.
- **Reason for Exclusion:** Increasing the pipe capacity along this area actually increased the amount of flooding within this region. The frequency and magnitude of the flows conveyed along the Midvale Blvd trunk main are such that the line draining this area currently backflows with regularity. During the peak of each rainfall event, the tailwater condition at Midvale Blvd is such that an increase in pipe capacity would result in increased flood elevations within this residential area.

9.2.1.4 Redesigning Rennebohm Park Greenway and Constructing Detention Basin on Currently Private Land

- **Conceptual Project Description:** Redesigning the greenway to improve the stormwater conveyance of the channel, and also converting the adjacent privately owned property (currently the Karen Arms Apartments) into a regional stormwater detention basin.
- **Reason for Exclusion:** Redesigning the storm system within Rennebohm Park would alleviate some of the flooding issues, specifically at N Eau Claire Ave and Regent St. However, this park is one of the few large, heavily used parks within the area, and it was not considered feasible to reduce the footprint of the park. The adjacent privately owned parcel is currently an apartment complex, and has been considered for other redevelopment efforts. The adjacent land is also relatively high in elevation, relative to the greenway to the north, and would require a significant amount of cut to create regional stormwater detention basin. Considering all of these limitations, this solution was not recommended for more detailed consideration.

9.2.1.5 University Bay Relief Pipe

- **Conceptual Project Description:** Since the Willow Creek watershed is capacity limited near the outfall, this solution was intended to provide additional relief to the current University Ave stormwater system. A similar idea was included within the 2003 study by Strand Associates (see **Section 2.5**). The solution included installing a 72" circular pipe (that ties into the existing 12x6 box and the newly designed 96" pipe along University Ave) at the University Bay Dr. The new 72" pipe would roughly parallel the railroad tracks north of Campus Dr and eventually cross the railroad and discharge directly into Willow Creek. The relief pipe did provide flooding reduction benefits, but was not necessarily needed in order to complete other improvements within the watershed.
- **Reason for Exclusion:** While this improvement provided flood reduction benefits, the project was deemed by the City to be very unlikely to be implemented in the future. The Campus Dr corridor has many potential utility conflicts posing a significant design challenge. In addition, University Dr is currently under construction at the time of writing this report (Summer 2022) and this road is unlikely to be reconstructed again for many years into the future. Finally, the project would require coordination with the Wisconsin DOT, the University of Wisconsin and potentially the US Veterans Affairs (VA) Hospital. This solution was not ultimately recommended, but a brief description of the modeling results is included within **Appendix F** in case this option is recommended for more detailed analysis in the future.

9.2.1.6 Deep Tunnel from Midvale Blvd/University Ave to Lake Mendota

- **Conceptual Project Description:** Several prior studies considered constructing a tunnel extending from the University Dr/Midvale Blvd intersection to the northwest to discharge directly into Lake Mendota (see **Section 2.5**). The Willow Creek watershed is capacity limited in the downstream stretches, with little topography available to convey water away from the Midvale Blvd/University Dr intersection. Providing a second outlet for the watershed would reduce the piped flows heading east along University Ave, and reduce surface water runoff. Two different circular pipe sizes were considered (9' and 12') with the understanding that the pipe would be bored heading northeast, through the community of Shorewood Hills underneath the Blackhawk Country Club golf course. The alignment and diameter alternatives of the pipe were based on the 1997 Strand study, without any additional design on feasibility. The target was simply to determine if the additional outfall would reduce flooding.

This solution was only modeled in tandem with other possible solutions (specifically within the upstream piped improvements in place). Flood reductions were significant, greatly reducing surface waters along University Ave and along Midvale Blvd.

- **Reason for Exclusion:** As seen within prior studies, the deep tunnel concept does provide flood reduction benefits for the watershed, but it is large enough in scale to be cost prohibitive. It would also require a partnership with the Village of Shorewood Hills, since the entirety of the project would be within their municipal boundaries. It is anticipated that public feedback would also be a challenge to project design, since the tunnel would pass underneath private properties. Additional complications would also be encountered to ensure that there is adequate inlet capacity at the Midvale Blvd/ University Dr intersection to safely allow stormwater to enter the large pipe while also not posing a safety risk to the public. Modeling with all of the upstream pipe improvements in place (i.e. all of the recommended solutions are implemented) indicated that there would be an additional 584 cfs of overland flow to be captured at this intersection or adjacent to, since much of the flows would already be contained within the piped system (approximately 1780 cfs). While this is possible, it would

also require all of the upstream improvements (most specifically a parallel box culvert along Midvale Blvd, see **Section 10.2**) in order to function properly. This solution was not ultimately recommended, but a brief description of the modeling results is included within **Appendix F** in case this option is recommended for more detailed analysis in the future.

9.2.2 Solutions Recommended

The following flood mitigation methods were recommended for implementation within the Willow Creek watershed. The locations of all the solutions are displayed in **Figure 29** and further details about each design is provided in **Chapter 10**. The solutions include only included local improvements (storm sewer and inlet capacity) as the watershed did not have available space for new detention basins and there are no existing regional detention basins to retrofit.

9.2.2.1 University Ave Storm System Improvements

- **Conceptual Project Description:** University Ave is the main stormwater conveyance system for the entire watershed and has historically flooded (see **Section 2.3**). University Ave was scheduled for reconstruction in the summer of 2022, from Shorewood Boulevard/Hill St to University Bay Drive/Farley Ave as a joint project between the City of Madison and the Village of Shorewood Hills. MSA coordinated with the design engineering firm to optimize the addition of a new 96" stormwater pipe to maximize conveyance, with the understanding that the topography of the region will limit the piped capacity to approximately the 20% AEP design storm event (see **Section 9.1.2**).
- **Iterations Considered:** Various pipe sizes were considered, accounting for existing elevations and utility conflicts. Several options were considered to connect the new 96" pipe to the existing storm system at Shorewood Blvd and University Ave. Several downstream connections options near University Ave and Farley Ave were also considered. Modeling was also completed at the connection point at Midvale, opening up a previously walled off connection to a 4'x12' box. A new connection at N Blackhawk Ave was also considered.

9.2.2.2 N Midvale Blvd Parallel Storm System Improvements

- **Conceptual Project Description:** Midvale Blvd is part of the main conveyance system through the watershed, ultimately connecting to the redesigned system at University Ave. A 5'x10' box is currently under the road, and this solution would run a parallel second 5'x10' box to improve capacity at this constriction point.
- **Iterations Considered:** Various pipe sizes were considered, accounting for existing elevations and utility conflicts. A parallel culvert was recommended (rather than simply increasing the size of the existing culvert) to reduce costs and still achieve the desired capacity. Increasing past the 20% AEP design flows was not considered, but could be in the future if a new outlet is constructed for the watershed (see **Section 9.2.1.6**, the large tunnel option).

9.2.2.3 South Hill Dr, Segoe Rd, and Vernon Blvd Storm System Improvements

- **Conceptual Project Description:** This improvement focused on increasing the capacity of the trunkline sewer conveying water from the SW portion of the watershed, ultimately intersecting at Midvale Blvd. The solution was sized considering the downstream capacity of the University Ave stormwater system could only accommodate 20% AEP design flows.

- **Iterations Considered:** Various pipe sizes were considered, accounting for existing elevations and utility conflicts. Increasing past the 20% AEP design flows was not considered, but could be in the future if a new outlet is constructed for the watershed (see **Section 9.2.1.6**, the large tunnel option).

9.2.2.4 Regent St and Owens Dr Storm System Improvements

- **Conceptual Project Description:** The Regent St neighborhood has experienced regular flooding. This improvement entails adding in a new storm pipe along Owens Dr and upsizing the pipes along Regent St connecting at Midvale Blvd.
- **Iterations Considered:** Various pipe sizes were considered, accounting for existing elevations and utility conflicts. Increasing past the 20% AEP design flows was not considered, but could be in the future if a new outlet is constructed for the watershed (see **Section 9.2.1.6**, the large tunnel option). Pipes just north of Regent St (in backyard areas) were also considered for this improvement. However, this location experiences significant backflow from the Midvale Blvd trunk main and increasing the pipe sizes actually resulted in worse flooding for their area. Therefore, these pipes were not upsized as part of this solution.

9.2.2.5 N Eau Claire Ave, Regent St and Rennebohm Park Storm System Improvements

- **Conceptual Project Description:** Flooding occurs at N Eau Claire Ave and Regent St just west of Rennebohm Park (see **Section 2.3**). Increasing both the pipe sizing and inlet capacity for the infrastructure leading to the downstream greenway would reduce overland flows impacting both the park and adjacent private owned land. The solution was sized considering the downstream capacity of the University Ave stormwater system could only accommodate 20% AEP design flows.
- **Iterations Considered:** Various pipe sizes were considered, accounting for existing elevations and utility conflicts. Redesigning the downstream greenway and creating a regional detention basin to the east were also considered but ultimately not recommended. Increasing past the 20% AEP design flows was not considered, but could be in the future if a new outlet is constructed for the watershed (see **Section 9.2.1.6**, the large tunnel option).

9.2.2.6 S Segoe Rd Storm System Improvements

- **Conceptual Project Description:** Much of the existing storm system along Segoe Rd is within the center Blvd greenspace. One portion of the storm system has a larger storm sewer (36"x72" box) discharging to a smaller sewer (34"x53" HERCP). This improvement would increase the capacity pipes to match those downstream, and reduce local flooding issues.
Iterations Considered: Just one pipe size was considered (to match the downstream sizing). Increasing past the 20% AEP design flows was not considered, but could be in the future if a new outlet is constructed for the watershed (see **Section 9.2.1.6**, the large tunnel option).

10 Recommended Solutions

The recommended solutions were introduced in **Section 9.2.2** and **Figure 28** is an index map, displaying all of the recommended solutions within the Willow Creek watershed. Within this chapter, all of the solutions are described in more detail, with specific reference to the flood reduction benefits, the land ownership for the project, known utility conflicts, other known concerns (e.g. wetlands, archeological, etc.), any anticipated permit requirements, and potential water quality benefits. A detailed figure is provided along with each recommended solution using the City's preferred template, to allow for easy comparison with recommended improvements from other watershed studies. **Figures 29 A-F** display each of the recommended improvements at a zoomed in scale, with all of the City's mapped utility information. **Figures 30-37** display predicted maximum inundation depths with all of the solutions implemented.

It should be noted that while there are improvements to the stormwater system functionality, even with all of the solutions implemented, there are some locations where targets were not met. These are described in further detail in **Chapter 11**.

It should also be noted that the improvements documented in this report are not meant to be full design-level efforts; they are conceptual solutions that help the City's Engineering Division understand the magnitude of solution needed in a given area to meet the targets. As projects are looked at further, and if they move to the point they are contemplated for programming, then projects will then go into a more detailed design phase. This project phase collects detailed data needed for design and looks at refined design, permitting, and environmental issues associated with the particular project.

10.1 University Ave Storm System Improvements

Detailed Project Description

The University Ave corridor is at the northern part of the Willow Creek watershed, and conveys much of the water from the upper reaches to the outfall at Willow Creek. Land Use consists primarily of commercial spaces, with some mixed use residential, and also is the main access point to the UW Madison Hospital. University Ave has flooded historically (see **Section 2.3**) most notably at the Midvale Blvd/University Ave and Shorewood Blvd/University Ave intersections. Cars were stranded on University Ave during the August 2018 flooding due to high waters on the road. The topography of the University Ave corridor is relatively flat with no overland flow route from the Shorewood Blvd/University Ave intersection. For this reason, all runoff which exceeds the capacity of the storm sewer system contributes to increased flood elevations of this area.

The current storm sewer trunkline consists of a 5' x 12' box that heads north along Midvale Blvd and turns east to parallel the railroad tracks along Locust Dr. The box transitions to a 5' x 15' box at Shorewood Blvd, with a 42" pipe connecting to it from the south. The box then enters to the University Ave right-of-way near Ridge St and transitions to a 6' x 15 box. Just east of the University Ave/Campus Dr split, the box continues to the southeast, but an additional "waterfall" connection exists to a 96" pipe immediately south of campus Dr providing a secondary pipe to the Willow Creek outfall. The main 6' x 12' box continues east along University Ave turning north just past Walnut St to cross Campus Dr and discharge to Willow Creek.

University Ave was scheduled for reconstruction in the summer of 2022, from Shorewood Boulevard/Hill St to University Bay Drive/Farley Ave as a joint project between the City of Madison and the Village of Shorewood Hills. The City requested that once the existing conditions model was calibrated for the watershed that the first priority was to model a

new stormwater pipe beginning at the Shorewood Blvd/University Ave intersection and tying back into an existing 96" pipe between Campus Dr and University Ave (just east of Grand Ave). The design engineering firm (KL Engineering) already had a pipe alignment in place, and required guidance on pipe sizing, the style of connection at both the upstream and downstream ends, and inlet capacity requirements/placement across the design. MSA met with the City to model a variety of different design solutions. This included different connection options to the University Ave system at Midvale Blvd, N Blackhawk Ave, Shorewood Blvd, and at the end of the newly design 96" pipe just east of Grand Ave. The following elements were included within the final recommended solution:

- **Reconnecting the box at Midvale Blvd and University Ave:** An existing 4'x12' box leaves this intersection and heads east along University Ave. The connection was walled off historically because further downstream the influx of flows within the box was causing issues within the piped system, causing manholes to pop off along University Ave due to lack of capacity downstream (specifically at the Shorewood Blvd/University Ave intersection). This design reconnected the 4'x12' University Ave box to the upstream Midvale Ave storm sewer, in tandem with the newly designed 96" pipe. Model results showed enough downstream capacity to handle the increased flows within the box.
- **New Connection at N Blackhawk Ave and University Ave:** N Blackhawk Ave was resurfaced in 2019, including spot repairs for curb and gutter and utility replacement. However, it was anticipated that the functionality of the storm sewer on N Blackhawk Ave would be improved by having a second connection to the trunkline along University Ave. With the increased capacity along University Ave from the 96" pipe, this additional connection was feasible and included within the recommended solution design. The storm sewer on Blackhawk Ave is currently a 48" circular pipe in parallel with a 19"x30" HE pipe. These both flow into a 24" and then an 18", which is well undersized. The recommended solution discharges this line directly into the existing 4'x12' University Ave box culvert via a 48" circular pipe.
- **Start of the new 96" Pipe at Shorewood Blvd and University Ave:** The new 96" pipe along University Ave will run roughly parallel to the existing storm system that follows the railroad track corridor to the north and eventually enters the University Ave right-of-way. This new secondary pipe will provide additional capacity to capture flows from the majority of the upstream watershed. There is an existing 4'x12' box that reaches from Midvale Blvd to Shorewood Blvd (historically walled off) that turned 90 degrees to the north along Shorewood Blvd. This was hydraulically inefficient, and caused issues during high flow events and therefore is not currently used. The new pipe design would instead allow the box to continue flowing directly east along University Ave, but the existing connection to the north along Shorewood Blvd would remain intact for overflow conditions.
- **End of the new 96" Pipe east of Grand Ave and University Ave:** The new 96" pipe was designed to connect to the existing 96" pipe just east of Grand Ave. University Ave is currently served by a 6'x12' box which diverts some flow at this location into the 96" pipe and continues as a 6'x12' box. With the addition of the new 96" pipe upstream of this connection point, various alternatives were considered to open this up or close it off completely. It was determined that maintaining the existing level of cross-connectivity was the best alternative.

While all of these improvements would improve water conveyance along the University Ave corridor, the recommended design is limited by the topography of the region. Much of the new 96" pipe is laid at a very flat slope (near zero in some locations) simply due to restrictions with other utilities and the ground surface elevation. As such, the recommended system supports roughly a 20% AEP design storm based on the City's watershed targets. This was

determined by iteratively mapping the inundation extents with the design solution in place and visualizing where water left the piped system and pooled within the right-of-way or private property.

Since there is limited downstream capacity within the University Ave corridor to the outfall, this acted as a boundary condition for increasing the piped capacity anywhere further upstream within the watershed. Increasing the piped flows to the University Ave corridor would cause new flooding concerns in downstream areas, unless it was possible to add in storage locations within the upper parts of the watershed. Since, it was determined that there were not any realistic possible storage locations within the fully developed Willow Creek Watershed (see **Section 9.2.1.2**), all of the other recommended pipe improvements were limited to increasing the piped capacity to match the 20% AEP design storm.

A map of the recommended storm sewer improvements for the University Ave corridor are shown on **Figure 29-A**.

Associated Flood Reduction Benefits

As a result of the local storm sewer improvements, the City's flood control targets will be met as follows:

- **Target 1a:** Inundation along the curblin decreases with this recommended improvement, with 0.56 miles of additional curblin along the University Ave corridor no longer having 0.25-ft of water during the 10% AEP design storm. However, this improvement does not remove all water at the curblin within the watershed since the study area has limited downstream capacity.
- **Target 2a:** Inundation along the street centerline decreases with this recommended improvement, with 0.5 miles of additional centerline along the University Ave corridor no longer having 0.5-ft of water during the 4% AEP design storm event. However, this improvement does not remove all water at the centerline within the watershed since the study area has limited downstream capacity.
- **Target 3a:** 17 additional buildings/structures along the University Ave corridor are no longer impacted by the 1% AEP design storm. Note that several structures within the University Ave corridor could still be impacted since the study area has limited downstream capacity.
- **Target 3b:** There five enclosed depressions along the University Ave corridor still do not meet this target under recommended conditions, since the system has limited downstream capacity.
- **Target 3c:** There are not any greenways within this area.
- **Target 4a:** 8 additional buildings/structures along the University Ave corridor are no longer impacted by the 0.2% AEP design storm. Note that several structures within the University Ave corridor could still be impacted since the study area has limited downstream capacity.

Project Constraints/Considerations

All of this recommended solution is piped infrastructure, and will be contained with the City right-of-way.

The entire corridor was already slated for redesign and then reconstruction in 2022, the street has been surveyed for utility conflicts and designed by KL Engineering accordingly.

Anticipated permits

All of the necessary permits were assumed to be accounted for during by the project's design engineer.

Water Quality Benefits

Local storm sewer improvements will not provide water quality benefits.

Additional Notes/Information

There are no other notes or information to reference for this recommended solution, as the construction of the new piped infrastructure is currently underway in the summer of 2022.

Note that **Figures 30-37** show the inundation after all of the improvements have been built. Flood reductions in this area are likely do to a combination of improvements.

10.2 N Midvale Blvd Parallel Storm System Improvements

Detailed Project Description

N Midvale Blvd is a trunkline system, connecting much of the upper reaches of the watershed to University Ave. Approximately 55% of the entire Willow Creek watershed area passes through the N Midvale Blvd storm system. Land use adjacent to the N Midvale Blvd and University Ave connection is mixed, with commercial properties to the west (including the Hilldale Mall) and residential properties to the east (including some apartment buildings and single family homes). The Midvale Blvd and University Ave intersection has historically flooded (see **Section 2.3**). The current storm sewer trunkline consists of a 5' x 12' box which was installed in the 1950's, that heads north along Midvale Blvd and turns east to parallel the railroad tracks along Locust Dr.

Increasing the pipe capacity along N Midvale Blvd could alleviate flooding concerns in portions of the upper reaches of the watershed; however, there is limited downstream capacity along the University Ave corridor. Therefore, recommending any improvements to the N Midvale Blvd system could potential shift flooding issues from one area of the watershed to another location.

However, the University Ave corridor was scheduled for reconstruction in the summer of 2022 as a joint project between the City of Madison and the Village of Shorewood Hills (see **Section 10.1**) providing an increase in the downstream pipe capacity to approximately the 20% AEP design storm event. Since, it was determined that there were not any realistic possible storage locations within the fully developed Willow Creek Watershed (see **Section 9.2.1.2**), all of the other recommended pipe improvements were limited to increasing the piped capacity to match the 20% AEP design storm.

Since there are not any indication that the existing box culvert under N Midvale Blvd is in poor condition, replacing the culvert might not be needed. Instead, putting a parallel 5' x 10' box culvert adjacent to the existing culvert would provide the improved capacity, while potentially reducing the project costs. Increasing the height of the box was not appropriate, given the upstream and downstream connections, therefore additional width was required.

Within this region, two existing pipes along Heather Crest and N Meadow Ln were identified as being undersized for the 20% AEP design storm. Therefore, this improvement recommended increasing the pipe sizing to a 24" pipe to help reduce some of the localized flooding, while accounting for the fact that the system is capacity limited downstream.

A map of the recommended storm sewer improvements for the N Midvale Blvd are shown on **Figure 29-B**.

Associated Flood Reduction Benefits

As a result of the local storm sewer improvements, the City's flood control targets will be met as follows:

- **Target 1a:** Inundation along the curblin decreases with this recommended improvement, with 200-ft of additional curblin along N Midvale Blvd/Heather Crest no longer having 0.25-ft of water during the 10% AEP design storm. However, this improvement does not remove all water at the curblin within the watershed since the study area has limited downstream capacity.
- **Target 2a:** Inundation along the street centerline decreases with this recommended improvement, with 250-ft of additional centerline along N Midvale Blvd no longer having 0.5-ft of water during the 4% AEP design storm event. However, this improvement does not remove all water at the centerline within the watershed since the study area has limited downstream capacity.

- **Target 3a:** 5 additional buildings/structures along N Midvale Blvd/Heather Crest are no longer impacted by the 1% AEP design storm. Note that several structures along N Midvale Blvd could still be impacted since the study area has limited downstream capacity.
- **Target 3b:** The 1 enclosed depression at the intersection of N Midvale Blvd and University Ave still does not meet this target under recommended conditions, since the system has limited downstream capacity.
- **Target 3c:** There are not any greenways within this area.
- **Target 4a:** 6 additional buildings/structures along N Midvale Blvd/Heather Crest are no longer impacted by the 0.2% AEP design storm. Note that several structures along N Midvale Blvd could still be impacted since the study area has limited downstream capacity.

Project Constraints/Considerations

All of this recommended solution is piped infrastructure, and will be contained within the City right-of-way. The improvements along Heather Crest and N Meadow Ln are pipe replacements, and therefore there are not known utility conflicts.

The new 5' x 10' box culvert that will parallel the existing 5' x 12' box culvert along N Midvale Blvd is anticipated to have utility conflicts. The eastern side of the boulevard has a water main and a sanitary main. Both of these would need to be considered with any recommended design solution, and potentially re-routed/replaced to provide adequate space for the additional box. Any existing stormwater inlets on the eastern side of the boulevard would likely be connected into the new box. Careful design consideration would need to be taken at the start/end of the parallel box system, starting at N Midvale Blvd and Vernon Blvd and ending at N Midvale Blvd and University Ave.

Anticipated permits

Based on the planning level design, the following environmental permits would be needed:

- City of Madison Erosion Control

Water Quality Benefits

Local storm sewer improvements will not provide water quality benefits.

Additional Notes/Information

Note that **Figures 30-37** show the inundation after all of the improvements have been built. Flood reductions in this area are likely due to a combination of improvements, including the University Ave corridor and South Hill Dr, Segoe Rd, and Vernon Blvd storm system improvements.

Some commercial/residential properties near the Vernon Blvd and N Midvale Blvd intersection have been undergoing re-development as of 2022, and therefore piped system routing on private properties will likely be changing. Modeling the private storm system in these areas was not completed as part of this study.

10.3 South Hill Dr, Segoe Rd and Vernon Blvd Storm System Improvements

Detailed Project Description

South Hill Dr, Segoe Rd and Vernon Blvd can be considered a trunkline system, connecting much of the upper reaches of the watershed to University Ave. Approximately 10% of the entire Willow Creek watershed area passes through this system. Land use adjacent to the South Hill Dr and Segoe Rd is primarily residential. At Vernon Blvd the land use is mixed use, with some commercial properties and apartments.

Portions of this trunkline have experienced flooding, but to a lesser extent than locations further downstream (see **Figure 2**). However, the intersection of N Midvale Blvd and Vernon Blvd has been an area of concern, since the pipes system from Vernon enters the 5' x 12' box culvert along N Midvale which can be at capacity during storm events.

Increasing the pipe capacity along these roads could alleviate flooding concerns in portions of the upper reaches of the watershed; however, there is limited downstream capacity along the University Ave corridor. Therefore, recommending any improvements to the South Hill Dr, Segoe Rd and Vernon Blvd system could potentially shift flooding issues from one area of the watershed to another location.

However, the University Ave corridor was scheduled for reconstruction in the summer of 2022 as a joint project between the City of Madison and the Village of Shorewood Hills (see **Section 10.1**) providing an increase in the downstream pipe capacity to approximately the 20% AEP design storm event. Since, it was determined that there were not any realistic possible storage locations within the fully developed Willow Creek Watershed (see **Section 9.2.1.2**), all of the other recommended pipe improvements were limited to increasing the piped capacity to match the 20% AEP design storm.

The existing piped system along South Hill Dr begins as a 24" pipe, increasing to a 30" pipe. This recommended solution would increase the capacity by starting with a 30" pipe, increasing to a 54" pipe when the South Hill intersects with Segoe Rd.

Along Segoe Rd, the existing storm system is a 4' x 7' box. This recommended solution increases the box to first 5' x 8', then to a 5' x 10' and ultimately a 5' x 12' when it intersects with Vernon Blvd.

The existing storm system along Vernon Blvd is a 2.5' x 12' box, transitioning to a 4' x 12' box. The recommended solution would replace this with a 5' x 12' for the entire length. Note that this improvement is intended to join with the N Midvale Blvd Parallel Storm System Improvement (see **Section 10.2**). The condition of the existing 4' x 12' box is thought to be poor, therefore the marginal size increase may be necessary simply for maintenance purposes.

A map of the recommended storm sewer improvements for the South Hill Dr, Segoe Rd and Vernon Blvd corridor are shown on **Figure 29-C**.

Associated Flood Reduction Benefits

As a result of the local storm sewer improvements, the City's flood control targets will be met as follows:

- **Target 1a:** Inundation along the curblines decreases with this recommended improvement, with 0.4 miles of additional curblines in this area no longer having 0.25-ft of water during the 10% AEP design storm. However, this improvement does not remove all water at the curblines within the watershed since the study area has limited downstream capacity.

- **Target 2a:** Inundation along the street centerline decreases with this recommended improvement, with 0.25 miles of additional centerline in this area no longer having 0.5-ft of water during the 4% AEP design storm event. However, this improvement does not remove all water at the centerline within the watershed since the study area has limited downstream capacity.
- **Target 3a:** This solution does not prevent any additional buildings/structures within this area from impacted by the 1% AEP design storm.
- **Target 3b:** There are no enclosed depressions within this area.
- **Target 3c:** There are not any greenways impacted by this improvement.
- **Target 4a:** 3 additional buildings/structures in this area are no longer impacted by the 0.2% AEP design storm. Note that several structures could still be impacted since the study area has limited downstream capacity.

Project Constraints/Considerations

All of this recommended solution is piped infrastructure, and will be contained within the City right-of-way. All of the pipes within this solution are pipe-replacements, without known major utility conflicts. Additional costs associated with minor utility conflicts that are likely as part of any construction project within developed areas are included in the contingency allowance. There are no other known or potential issues that could impact costs or the ability to construct the improvement.

Anticipated permits

Based on the planning level design, the following environmental permits would be needed:

- City of Madison Erosion Control

Water Quality Benefits

Local storm sewer improvements will not provide water quality benefits.

Additional Notes/Information

Note that **Figures 30-37** show the inundation after all of the improvements have been built. Flood reductions in this area are likely due to a combination of improvements, including the University Ave corridor and South Hill Dr, Segoe Rd, and Vernon Blvd storm system improvements.

Some commercial/residential properties near the Vernon Blvd and N Midvale Blvd intersection have been undergoing re-development as of 2022, and therefore piped system routing on private properties will likely be changing. Modeling the private storm system in these areas was not completed as part of this study.

10.4 Regent St and Owens Dr Storm System Improvements

Detailed Project Description

The residential neighborhoods near the Regent St and S Owen Dr intersection have historically experienced regular flooding downstream (see **Figure 2**). The land use within this area is residential, primarily single family homes. There are two piped systems that connect to this region to the Midvale Blvd trunk system to the west. One follows along Regent St in the right-of-way. The second is approximately 250 feet north of Regent St (mid-block) designed to pass underneath two enclosed depressions and collect any water accumulating in these areas.

This recommended solution recommended increasing the piped capacity of the system passing underneath Regent St and adding in new storm sewer along S. Owen Dr. Increasing the piped capacity of mid-block system actually caused more flooding concerns, and therefore it was not included in the final recommendations (see **Section 9.2.1.3**)

Increasing the pipe capacity along these roads could alleviate some of the flooding concerns in this area; however, there is limited downstream capacity along the University Ave corridor. Therefore, recommending any improvements to the Regent St and Owen Dr system could potential shift flooding issues from one area of the watershed to another location.

However, the University Ave corridor was scheduled for reconstruction in the summer of 2022 as a joint project between the City of Madison and the Village of Shorewood Hills (see **Section 10.1**) providing an increase in the downstream pipe capacity to approximately the 20% AEP design storm event. Since, it was determined that there were not any realistic possible storage locations within the fully developed Willow Creek Watershed (see **Section 9.2.1.2**), all of the other recommended pipe improvements were limited to increasing the piped capacity to match the 20% AEP design storm.

The existing piped system along Regent St is a 24" pipe. This recommended solution would increase the capacity by starting with a new 24" pipe on S Owen St and increasing to a 30" pipe before the intersection with Regent St. Along Regent St, the pipe would be a 36" transitioning to a 42" pipe before the connection at Midvale Blvd.

A map of the recommended storm sewer improvements for the Regent St and Owens Dr area are shown on **Figure 29-D**.

Associated Flood Reduction Benefits

As a result of the local storm sewer improvements, the City's flood control targets will be met as follows:

- **Target 1a:** Inundation along the curbline decreases with this recommended improvement, with 0.2 miles of additional curbline in this area no longer having 0.25-ft of water during the 10% AEP design storm. However, this improvement does not remove all water at the curbline within the watershed since the study area has limited downstream capacity.
- **Target 2a:** Inundation along the street centerline decreases with this recommended improvement, with 350-ft of additional centerline in this area no longer having 0.5-ft of water during the 4% AEP design storm event. However, this improvement does not remove all water at the centerline within the watershed since the study area has limited downstream capacity.
- **Target 3a:** 7 additional buildings/structures within this neighborhood are no longer impacted by the 1% AEP design storm. Note that several structures could still be impacted since the study area has limited downstream capacity.

- **Target 3b:** The 2 enclosed depressions at the intersection of N Midvale Blvd and University Ave still do not meet this target under recommended conditions, since the system has limited downstream capacity.
- **Target 3c:** There are not any greenways impacted by this improvement.
- **Target 4a:** This solution does not prevent any additional buildings/structures within this area from impacted by the 0.2% AEP design storm.

Project Constraints/Considerations

All of this recommended solution is piped infrastructure, and will be contained within the City right-of-way. The pipes along Regent St are pipe-replacements, without known major utility conflicts. The new pipes along S Owen Dr will need to account for existing sanitary and water mains, and potentially re-design the Owen Dr and Regent St intersection to minimize conflicts. Additional costs associated with minor utility conflicts that are likely as part of any construction project within developed areas are included in the contingency allowance. There are no other known or potential issues that could impact costs or the ability to construct the improvement.

Anticipated permits

Based on the planning level design, the following environmental permits would be needed:

- City of Madison Erosion Control

Water Quality Benefits

Local storm sewer improvements will not provide water quality benefits.

Additional Notes/Information

Note that **Figures 30-37** show the inundation after all of the improvements have been built. Flood reductions in this area are likely due to a combination of improvements, including the University Ave corridor and N Midvale Blvd storm system improvements.

10.5 N Eau Claire Ave, Regent St and Rennebohm Park Storm System Improvements

Detailed Project Description

This recommended improvement centers around Rennebohm Park, which consists of open grass fields for recreation, a pavilion, tennis courts, a basketball court and a playground. The park is a major draw for neighborhood residents, and therefore any recommended improvements in this area were limited to underground improvements that would not impact how the park is currently used. The land use surrounding the park is primarily residential, a blend of single family homes and larger apartment complexes.

The N Eau Claire Ave and Buffalo Trail intersection has historically experienced flooding (see **Figure 2**). When flooding becomes extreme, overflows occur which pass east through Rennebohm Park, ultimately contributing to flooding of North Segoe Rd at the east end of the park. This improvement focused on increasing the piped capacity at the road intersections, under the main piped system under the Rennebohm Park that discharges into the greenway. Redesigning the greenway was considered, but ultimately not recommended as a recommended improvement (see **Section 9.2.1.4**).

Increasing the pipe capacity within the park could alleviate some of the flooding concerns in this area; however, there is limited downstream capacity along the University Ave corridor. Therefore, recommending any improvements to the Rennebohm Park system could potential shift flooding issues from one area of the watershed to another location.

However, the University Ave corridor was scheduled for reconstruction in the summer of 2022 as a joint project between the City of Madison and the Village of Shorewood Hills (see **Section 10.1**) providing an increase in the downstream pipe capacity to approximately the 20% AEP design storm event. Since, it was determined that there were not any realistic possible storage locations within the fully developed Willow Creek Watershed (see **Section 9.2.1.2**), all of the other recommended pipe improvements were limited to increasing the piped capacity to match the 20% AEP design storm.

The existing piped system leaving the N Eau Claire Ave and Buffalo Trl intersection is 21" and the recommended solution would increase this to a 48" pipe. The existing pipe leaving the N Eau Claire Ave and Regent St intersection is 24" and the recommended solution would increase it to a 42" pipe. The main pipe passing underneath Rennebohm Park is currently a 30" pipe that transitions to a 36" pipe near the outlet to the greenway. The recommended solution would increase the pipe for the entire length to a 66".

A map of the recommended storm sewer improvements for the N Eau Claire, Regent St and Rennebohm Park area are shown on **Figure 29-E**.

Associated Flood Reduction Benefits

As a result of the local storm sewer improvements, the City's flood control targets will be met as follows:

- **Target 1a:** Inundation along the curblin decreases with this recommended improvement, with 0.3 miles of additional curblin in this area no longer having 0.25-ft of water during the 10% AEP design storm. However, this improvement does not remove all water at the curblin within the watershed since the study area has limited downstream capacity.
- **Target 2a:** Inundation along the street centerline decreases with this recommended improvement, with 750-ft of additional centerline in this area no longer having 0.5-ft of water during the 4% AEP design storm event. However, this improvement does not remove all water at the centerline within the watershed since the study area has limited downstream capacity.

- **Target 3a:** 1 additional buildings/structure within this neighborhood is no longer impacted by the 1% AEP design storm. Note that several structures could still be impacted since the study area has limited downstream capacity.
- **Target 3b:** There are no enclosed depressions within this area.
- **Target 3c:** The Regent St greenway downstream of this improvement was not overtopping during the 1% AEP design storm, and it is not overtopping after the recommended improvement.
- **Target 4a:** This solution does not prevent any additional buildings/structures within this area from impacted by the 0.2% AEP design storm.

Project Constraints/Considerations

All of this recommended solution is piped infrastructure, and will be contained with the City right-of-way and within a City-owned park. City staff will need to coordinate with the Parks Division to ensure the project aligns with other planned park improvements.

The recommended solution is comprised entirely of pipe-replacements, without known major utility conflicts. Additional costs associated with minor utility conflicts that are likely as part of any construction project within developed areas are included in the contingency allowance. There are no other known or potential issues that could impact costs or the ability to construct the improvement.

Anticipated permits

Based on the planning level design, the following environmental permits would be needed:

- City of Madison Erosion Control

Water Quality Benefits

Local storm sewer improvements will not provide water quality benefits.

Additional Notes/Information

Note that **Figures 30-37** show the inundation after all of the improvements have been built. Flood reductions in this area are likely do to a combination of improvements, including the University Ave corridor, N Midvale Blvd, and South Hill Dr, Segoe Rd and Vernon Blvd storm system improvements.

10.6 S Segoe Rd Storm System Improvements

Detailed Project Description

Much of the Segoe Rd neighborhoods are served by box culverts under the road, roughly increasing in capacity of upstream to downstream. This improvement location is a 'pinch point', the existing box culvert reduces capacity for a short stretch; the box transition from a 3' x 5' to a 3' x 6' the back down to 3' x 5', then to a 2.5' x 6' and finally a 3' x 6' again at the intersection of Hillview Ter and S Segoe Rd.

Portions of this area were surveyed by City of Madison staff, but not all of the structures could be found in their survey. Therefore, the XPSWMM model was designed using the available survey data and filling in blank information with the original GIS sizing and inverts. It is therefore possible that the pipe sizing modeled does not match the underground infrastructure in areas.

Increasing the pipe capacity within this area could alleviate some of the flooding concerns; however, there is limited downstream capacity along the University Ave corridor. Therefore, recommending any improvements to the S Segoe Rd system could potential shift flooding issues from one area of the watershed to another location.

However, the University Ave corridor was scheduled for reconstruction in the summer of 2022 as a joint project between the City of Madison and the Village of Shorewood Hills (see **Section 10.1**) providing an increase in the downstream pipe capacity to approximately the 20% AEP design storm event. Since, it was determined that there were not any realistic possible storage locations within the fully developed Willow Creek Watershed (see **Section 9.2.1.2**), all of the other recommended pipe improvements were limited to increasing the piped capacity to match the 20% AEP design storm.

This recommended improvement would increase the pipe sizing for all of the smaller pipes in this area to become a 3' x 6' box culvert, removing the bottleneck from the system.

A map of the recommended storm sewer improvements for S Segoe Rd are shown on **Figure 29-F**.

Associated Flood Reduction Benefits

As a result of the local storm sewer improvements, the City's flood control targets will be met as follows:

- **Target 1a:** Inundation along the curblin decreases with this recommended improvement, with 0.5 miles of additional curblin in this area no longer having 0.25-ft of water during the 10% AEP design storm. However, this improvement does not remove all water at the curblin within the watershed since the study area has limited downstream capacity.
- **Target 2a:** Inundation along the street centerline decreases with this recommended improvement, with 0.25 miles of additional centerline in this area no longer having 0.5-ft of water during the 4% AEP design storm event. However, this improvement does not remove all water at the centerline within the watershed since the study area has limited downstream capacity.
- **Target 3a:** This solution does not prevent any additional buildings/structures within this area from impacted by the 1% AEP design storm.
- **Target 3b:** There are no enclosed depressions within this area.
- **Target 3c:** There are no greenway crossings within this area.
- **Target 4a:** This solution does not prevent any additional buildings/structures within this area from impacted by the 0.2% AEP design storm.

Project Constraints/Considerations

All of this recommended solution is piped infrastructure, and will be contained within the City right-of-way. The recommended solution is comprised entirely of pipe-replacements, without known major utility conflicts. Additional costs associated with minor utility conflicts that are likely as part of any construction project within developed areas are included in the contingency allowance. There are no other known or potential issues that could impact costs or the ability to construct the improvement.

Anticipated permits

Based on the planning level design, the following environmental permits would be needed:

- City of Madison Erosion Control

Water Quality Benefits

Local storm sewer improvements will not provide water quality benefits.

Additional Notes/Information

Note that **Figures 30-37** show the inundation after all of the improvements have been built. Flood reductions in this area are likely due to a combination of improvements, including the University Ave corridor, N Midvale Blvd, and South Hill Dr, Segoe Rd and Vernon Blvd storm system improvements.

11 Areas where Flood Control Targets are Not Met

Unlike many of the prior watershed studies completed for the City, there are many locations within the Willow Creek Watershed where the City's flood control targets are not met. Much of this is simply limited by topography and a capacity limited outlet along University Ave. In addition, since the watershed is effectively fully developed, there are not any available real estate to create storage in the upper reaches of the watershed (see **Section 9.2.1.2**). One solution that could potential relief the downstream capacity issues would be to add a secondary outlet via "big tunnel", an option that has been considered historically (see **Section 2.5**) and was not included within the final recommended solutions for this study due to feasibility of implementation (see **Section 9.2.1.6**). Finally, all of the recommended improvements within the watershed needed to ensure that flooding issues were not simply transferred from one location to another.

With all of these limitations, the only remaining recommended solutions increased the piped capacity for certain undersized systems to serve the 20% AEP design storm. However, all of the City's targets target even larger storm events. Therefore, the recommended improvements will reduce flooding in some areas of the watershed, but they will not remove the flooding entirely.

This section is included to see how much the recommended improvements reduced flooding with respect to each target, with the understanding that flooding will still occur within the watershed.

11.1 Target 1a: Flooding Storm Sewer (10% AEP)

No surcharging onto the street for up to the 10% AEP design storm; all water shall be contained within the pipes and structures. When using rain-on-grid hydrology, the target is met if there is less than 0.25' of curb depth.

This criteria was evaluated by clipping the edge of pavement to 50-foot segments and intersected with the 10% AEP inundation raster to determine locations where the average water depth was 0.25' or greater along the curb line. The study area has 104.2 miles of road curblines within the City of Madison. Under the existing conditions, 17.3 miles of curbline (16.6%) were classified as potential problem locations. Under the recommended conditions, 15.4 miles (14.8%) were still classified as a potential problem location.

11.2 Target 2a: Street Centerlines (4% AEP)

Centerline of street to remain passable during 4% AEP design storm with no more than 0.5 feet of water at the centerline.

This criteria was evaluated by using a road centerline dataset, split at 50-ft intervals and intersecting them with the 4% AEP inundation raster. Any segment with more than 0.5-feet of water was classified as a 'potential problem location'. The watershed has the 58.1 miles of roads within the City of Madison. Under existing conditions, 7.7 miles were classified as problem locations (13.2%). Under the recommended conditions, 6.4 miles were classified as problem locations (11.0%).

11.3 Target 3a: Homes and Businesses (1% AEP)

No homes or businesses will be flooded during the 1% Annual Exceedance Probability (AEP) design storm.

This criteria was evaluated by buffering all buildings by 5-ft, and intersecting them with the 1% AEP inundation raster. The analysis was further refined to only include regions with 0.5 acres of continuous inundation. Any buffered building with an inundation depth of 0.5-feet or greater was classified as a 'potential problem location'. Note that this analysis does not account for modifications residents take to mitigate flooding on their own properties. There were 5,040, buildings/structures within the watershed within the City of Madison. Under existing conditions, 353 structures could be impacted by the 1% AEP design storm (7.0%). Under the recommended conditions, 322 structures could still be impacted by flooding during the 1% AEP design storm (6.4%).

11.4 Target 3b: Enclosed Depressions (1% AEP)

Enclosed depressions to be served to the 1% AEP design storm (which can include safe overland flow within street, easements, greenways or other public lands).

This criteria was evaluated by identifying all of the enclosed depressions at least 0.25 acres in size, based on the 2017 LiDAR DEM. This was completed using the LiDAR processing GIS tool created by Dr. Qiusheng Wu (<https://github.com/giswqs/lidar>). All depressions were intersected with the 1% AEP inundation raster. Any depression that had a maximum depth of 1-foot or more and touched public land (e.g. street ROW, greenway or SWU lands, etc) was flagged for review. The public lands and private ponds were removed from this subset of enclosed depressions, to determine if the depression also encompassed a portion of privately owned land.

Any enclosed depression that touched public land, included at least 0.25 acres of private land, and had more than 1-foot of inundation depth during the 1% AEP event was classified as a potential problem area. There are forty-eight (48) enclosed depressions within the watershed within the City of Madison. .

Under the existing conditions, modeling predicts that the 1% AEP service levels are not achieved in twelve (12) enclosed depressions classified as a potential problem location. Under the recommended conditions, these twelve (12) enclosed depressions still classified as potential problem locations.

11.5 Target 3c: Greenways (1% AEP)

Greenway crossings at streets to be served to the 1% AEP design storm.

This criteria was evaluated by identifying all of the locations where channelized overland flow enters the piped stormwater system at roadway. Each location was intersected with the 1% AEP inundation raster, to determine the maximum water depth at the road centerline. See **Figure 26**.

The Willow Creek watershed has six (6) greenways: Merlham Drive Section, Regent Street Section, South Owen Drive Section, Hillcrest Drive Section and Robin Drive Sections 1 and 2. Under existing conditions, five (5) of the locations overtop the road during the 1% AEP design storm (only the Regent Street Section does not overtop). Under recommended conditions, these same five (5) greenways are modeled to overtop the road in the 1% AEP design storm.

Water level depths on the road were effectively the same under existing and recommended conditions, as the recommended improvements did not include any upstream storage, which would have reduced the quantity of flow reaching the greenways.

11.6 Target 4a: Safely Convey Stormwater (0.2% AEP)

This criteria was evaluated by buffering all buildings by 5-ft, and intersecting them with the 0.2% AEP inundation raster. The analysis was further refined to only include regions with 0.5 acres of continuous inundation. Any buffered building with an inundation depth of 0.5-feet or greater was classified as a 'potential problem location'. Note that this analysis does not account for modifications residents take to mitigate flooding on their own properties.

The watershed has 5,040 buildings/structures within the City of Madison. Under existing conditions, there are 551 structures (10.9% of all structures) that could be impacted by the 0.2% AEP design storm. Under recommended conditions, 536 structures (10.6%) could still be impacted by the 0.2% AEP design storm.

12 Climate Resilience Analysis

12.1 0.2% Chance Analysis

The following section describes anticipated changes in 0.2% AEP (500-yr) flooding between existing and recommended conditions.

As described in previous sections of the report, storm sewer capacity improvements are recommended along the trunk line starting at Segoe Road and South Hill Drive, running north to Vernon Blvd., then east to Midvale, then north to University, and then east along University to approximately Grand Avenue. These improvements were generally recommended with the intent of balancing storm sewer capacity along the main trunk storm sewer system serving the watershed with a target of providing sufficient capacity to convey 20% AEP peak flow rates. Even so, under 0.2% AEP event conditions, modeling predicts moderate improvements in flooding conditions along this corridor.

- Along Segoe Road from South Hill Drive to Vernon Blvd, 0.2% AEP flood depths are expected to be reduced by an approximate average 0.10 feet
- Along Midvale Blvd. from Vernon Blvd to University Avenue, 0.2% AEP flood depths are expected to be reduced by an approximate average 0.25 feet
- Along University Avenue from roughly Blackhawk Avenue to Walnut Street, 0.2% AEP flood depths are expected to be reduced by an approximate average 0.25 feet. Flood depth reductions reach a maximum depth of 0.5 feet near University Bay Drive.

A discrete comparison of recommended conditions mapped flood depth to existing conditions flood depths do indicate a few isolated instances where recommended conditions 0.2% AEP flood elevations are higher under recommended conditions. These instances are felt to be model results anomalies as they all occur in areas of the watershed upstream from any recommended solution and are discontinuous (in most cases by a long distance) with locations where improvements are recommended.

Across the watershed, with regard to structures at risk of 0.2% AEP event flooding, there is a substantial improvement under recommended conditions. Under existing conditions, 551 structures are anticipated to be affected by 0.2% AEP event flood conditions. Under full-watershed improved conditions, this number is anticipated to be reduced to 536. This is a net reduction of 15 structures.

Figure 20 and **Figure 37** present a comparison of flooding conditions under 0.2% AEP (500-yr) conditions.

12.2 Infrastructure modifications

The Willow Creek watershed is capacity limited at the single downstream outlet. One of the recommended solutions was to increase the piped capacity along University Ave (see **Section 10.1**); however due to the topography limitations within the area, this improvement only serves approximately the 20% AEP design event. Therefore, upsizing any of the upstream infrastructure to serve a larger event (for example, the 0.2% AEP design event) would have negative implications downstream, since the piped infrastructure simply cannot support the increased flows. This could cause more flooding downstream, which violates one of the City's design targets.

To meet the stormwater needs for the 0.2% AEP design storm, alternative solutions that were not recommended due to other concerns (e.g. cost, public feedback, etc) would need to be reconsidered. For example, placing large regional stormwater detention basins on private land (see **Section 9.2.1.2**) could retain water during large events and effectively delay the water from entering the piped system to reduce peak flows. Adding a secondary outlet, such as a deep tunnel from the University/Midvale Blvd intersection (see **Section 9.2.1.6**) would also provide a relief to the downstream system on University Ave. Both of these options could be reevaluated in the future, if the City's design targets change.

13 Cost Estimates

In order to help the City plan for future implementation, planning level cost estimates were developed for each of the stand-alone solutions outlined in **Section 10**. For each solution, cost estimates were prepared by creating a tabulated list of estimated quantities. All of the recommended improvements in Willow Creek were within the street right-of-way, and it was assumed that the pipe replacements would require the entire street to be reconstructed (rather than simply replacing/repairing pavement areas impacted by selectively modifying just the stormwater system).

Since all of the projects are therefore effectively street reconstructions, the City requested approximate costs for street replacements on a per linear foot basis for Local, Collector and Principal Arterial Streets. *Note that streets with boulevards have higher costs, due to the construction of effectively two separate street sections.* The City provided average unit costs for typical stormwater bid items, specifically for pipe materials. The cost of the piped improvements were added to the street-replacement costs, to calculate an estimated cost for each of the recommended projects.

Standard unit costs were adjusted by MSA based on specific project conditions that may result in higher or lower than average unit costs. In these cases, a note was added to justify the rationale for the cost revision. Initial cost estimates were provided to the City for review prior to finalizing them in the report.

The total estimates cost for each of the stand-alone projects is provided in **Table 13.1**. A detailed breakdown for each cost estimate, with quantities, average unit costs, and adjustments is provided in **Appendix G**.

Table 13.1: Stand-Alone Project Cost Estimates for Willow Creek Watershed

Project	Estimated Cost
University Ave Storm System Improvements	Currently under construction
N Midvale Blvd Parallel Storm System Improvements	\$16.84 M
South Hill Dr, Segoe Rd, and Vernon Blvd Storm System Improvements	\$20.90 M
Regent St and Owens Dr Storm System Improvements	\$1.99 M
N Eau Claire Ave, Regent St and Rennebohm Park Storm System Improvements	\$1.15 M
S Segoe Rd Storm System Improvements	\$3.95 M

14 Recommended Implementation Order

14.1 Technical Implementation Needs

Implementing individual improvements in the one part of the watershed can impact other parts of the watershed. For example, increasing the pipe capacity upstream can negatively impact downstream areas without adequate capacity to handle the increase in peak flows. Within the Willow Creek Watershed, there are some known limitations for implementation order that should be considered prior to advancing any of the recommended solutions. The following guidelines are recommended for implementation.

1. In general, improvements should be implemented from downstream end, progressing towards the upstream projects.
2. The University Ave project is slated for construction in the summer of 2022. This improvement was already scheduled by the City, and needed to be completed prior to others. Once this is completed, restoring the connection between the Midvale Blvd storm sewer and the existing 4' x 12' University Ave box is recommended.
3. The N Midvale Blvd Parallel Storm System should be considered prior to improvements along Segoe Rd and further upstream. This is a main trunk line for the system, and will improve conveyance through the area, particularly if upstream improvements are increasing flows through the piped system.
4. The University Bay Relief Sewer was not included as a recommended final solution (see **Section 9.2.1.5**). However, it could provide additional some downstream capacity if additional pipes in the upper portions of the watershed are re-sized to serve anything above the 20% AEP Design Storm.
5. The Deep Tunnel from Midvale Blvd/University Ave to Lake Mendota solution was also not included as a recommended final solution for numerous reasons (see **Section 9.2.1.6**). However, creating a secondary outlet for this watershed could provide substantial flood reductions, and allow for increasing the piped capacity in the upper reaches of the watershed to reduce localized flooding.

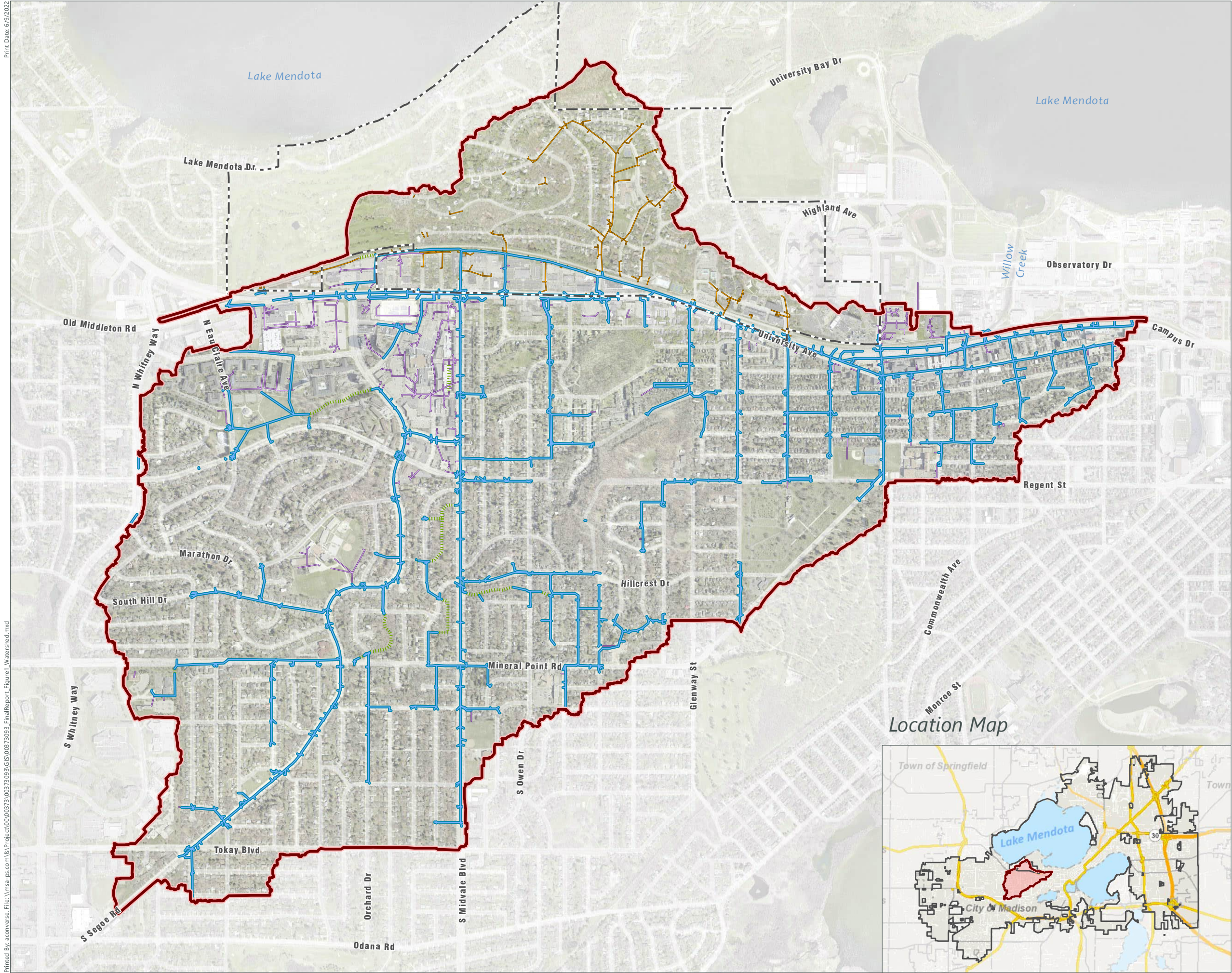
14.2 Citywide Implementation Prioritization

The City is conducting similar studies for all the watersheds in the City, all of which will have numerous recommendations. The City is developing a process to rank and prioritize the order in which the solutions might be implemented if and when funding and public support are obtained. Information on this process will be shared by the City when it is available.

15 Next Steps

At this point, the next steps in the watershed study are to disseminate the findings, for both the existing conditions modeling and the recommended solutions with interested parties. This includes coordinating with City design staff, presenting the information to City Council and other applicable Cities Agencies. Results can also be presented to stakeholders, including local Friends Groups, Neighborhood Organizations, interested Developers and neighborhood residents.

Figures



Watershed Area

FIGURE 1
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison



0 0.125 0.25 Miles



Historic Flooding

FIGURE 2
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow
- Observations by City Engineering Staff
- Priority Inlets
- Operations Flooding Points
- Reported Flooding
- Historic/Observed Flood Points

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Reported Flooding: City's Online Public Reporting (through July 2020)
Historic Flooding, Observations and Priority Inlets: City of Madison
Observations by City Staff: Based on discussions of known flooding concerns with City Engineering Staff and prior Watershed Studies

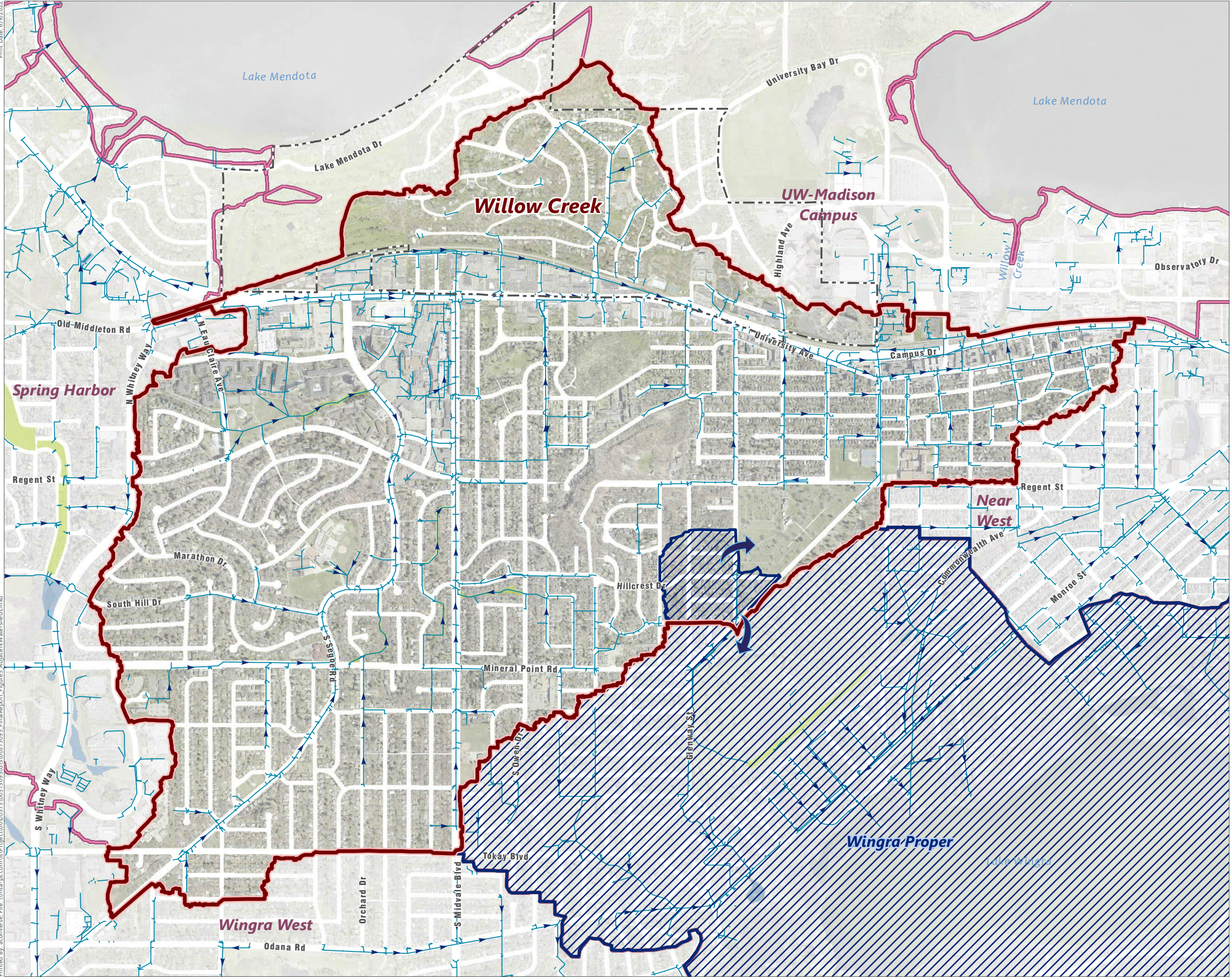


0 0.125 0.25 Miles



Print Date: 5/9/2023

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Adjacent Watersheds

FIGURE 3
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Wingra Proper Watershed
- Other Watershed Study Areas
- Village of Shorewood Hills
- Greenway
- Pond
- Storm System
- Connection/Overflow from Wingra

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison



0 0.125 0.25 Miles



Land Use

FIGURE 4
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

-  Watershed Study Area
-  Village of Shorewood Hills
-  Parcels
-  Public Storm System
-  Private Storm System
-  Shorewood Hills Storm System
-  Open Channel
- Land Use (2015)
 -  Agriculture
 -  Commercial
 -  Institutional
 -  Recreation
 -  Residential
 -  Transportation/Utilities
 -  Open Land
 -  Water
 -  Woodlands

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Land Use: Dane County (2015)

Impervious Areas

FIGURE 5
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Parcels
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel
- Impervious Area**
 - Roof
 - Sidewalk/Other
 - Driveway/Parking
 - Street

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Impervious Areas: MSA

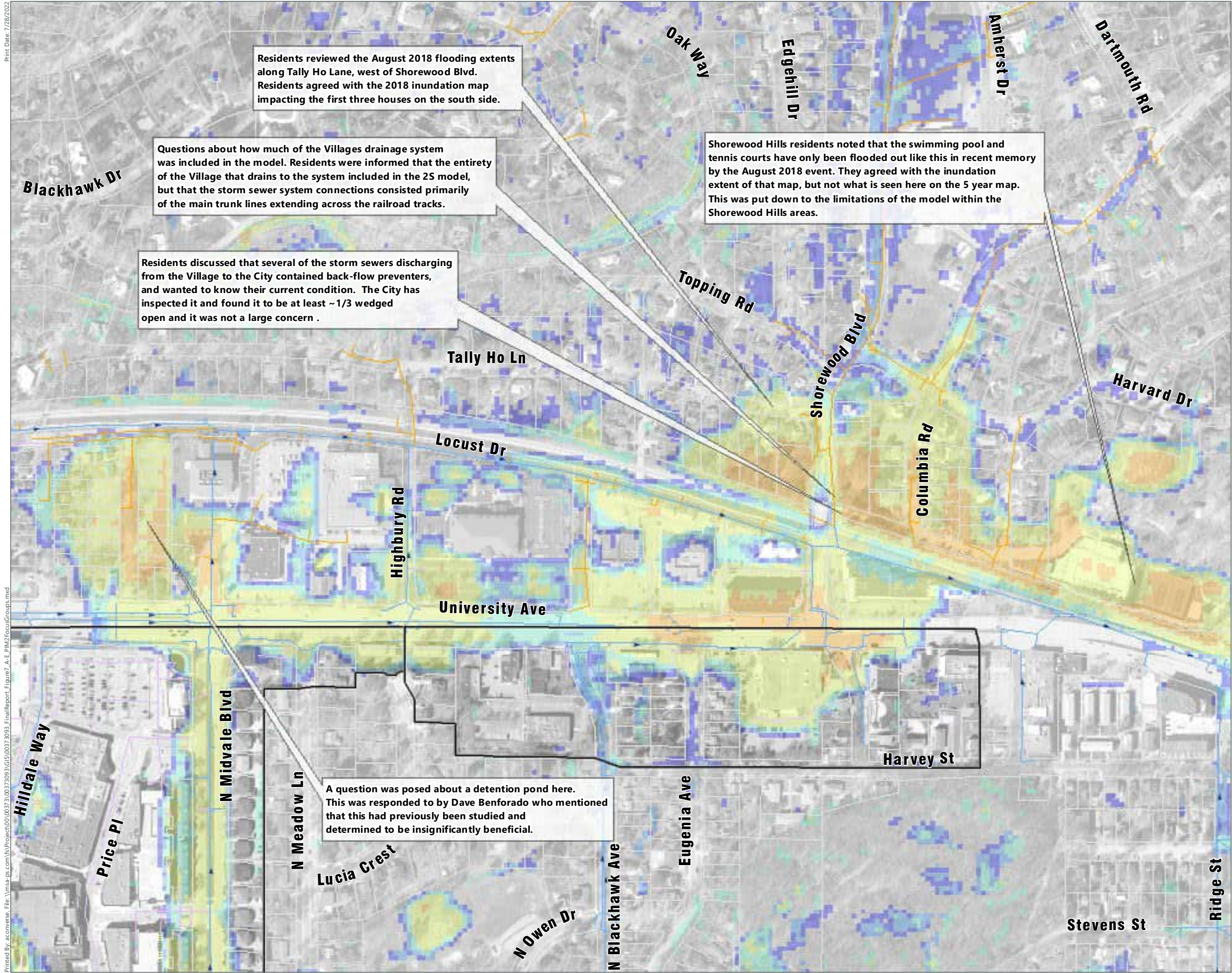
Soils

FIGURE 6
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

-  Watershed Study Area
-  Village of Shorewood Hills
-  Parcels
-  Public Storm System
-  Private Storm System
-  Shorewood Hills Storm System
-  Open Channel
- Modeled Hydrologic Soil Group**
 -  A
 -  B
 -  C
 -  D

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Soils: USDA NRCS (SSURGO, Oct 2020)



PIM #2

Resident Comments

Northern

FIGURE 7A
Willow Creek Watershed
Study Report

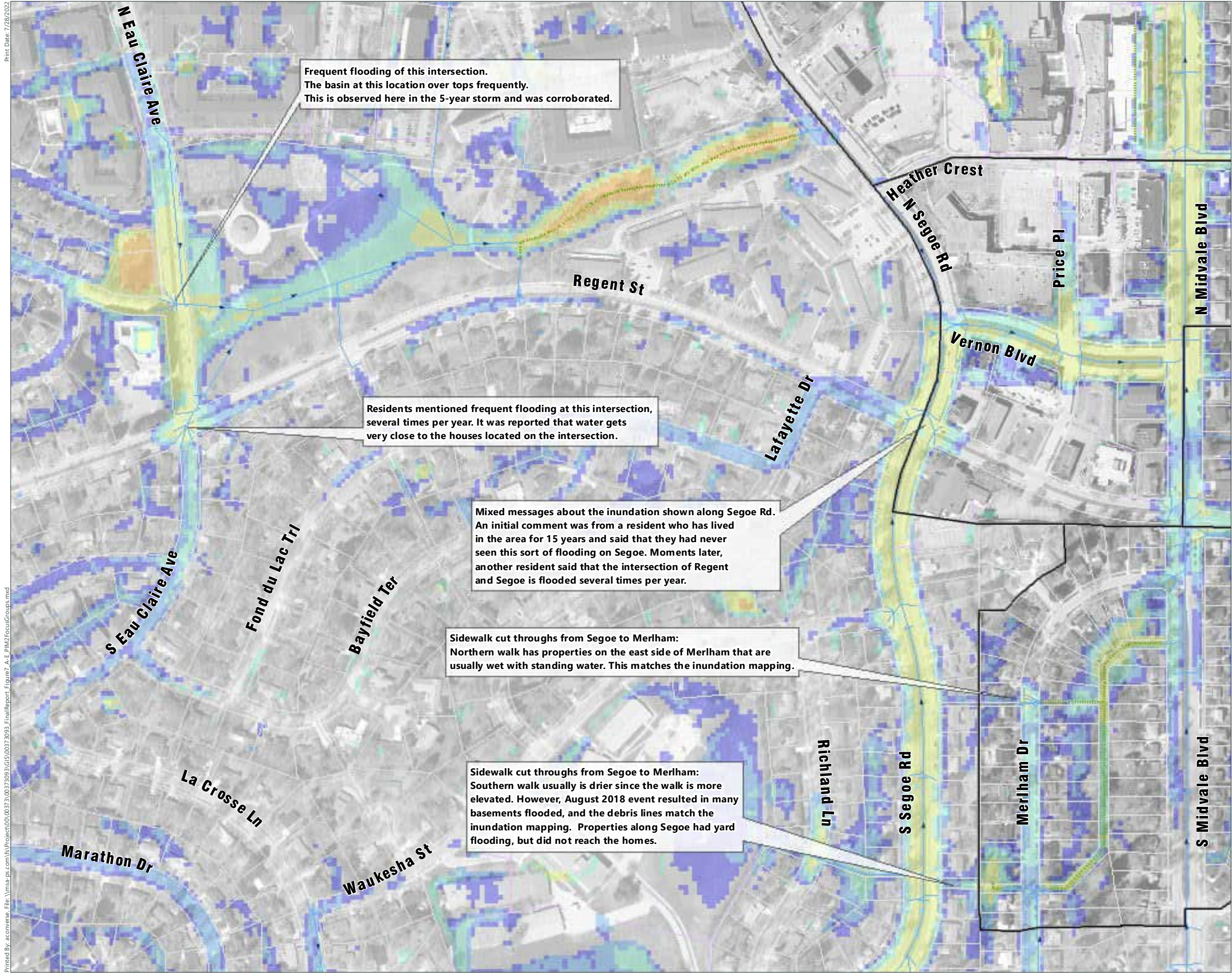
- City of Madison
Dane County, WI
- Focus Group
 - Public Storm System
 - Private Storm System
 - Shorewood Hills Storm System
 - Open Channel Flow
- August 20th, 2018 Storm Event
- Maximum Water Depth (ft)
- 0.1 - 0.25
 - 0.25 - 0.5
 - 0.5 - 1
 - 1 - 3
 - 3 - 6
 - > 6



Data Sources:
Aerial: Madison (2020)
Watershed Boundaries: MSA
Stormwater System: City of Madison

Focus Group Comments: Residential feedback to MSA staff. Flooding extents, ponding, etc are in reference to the August 20th, 2018 rainfall event unless otherwise noted.

Resident comments during the focus group sessions were not confined to the focus group areas. Therefore, all comments are displayed regardless of location within the watershed.



PIM #2

Resident Comments

Western

FIGURE 7B
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Focus Group
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

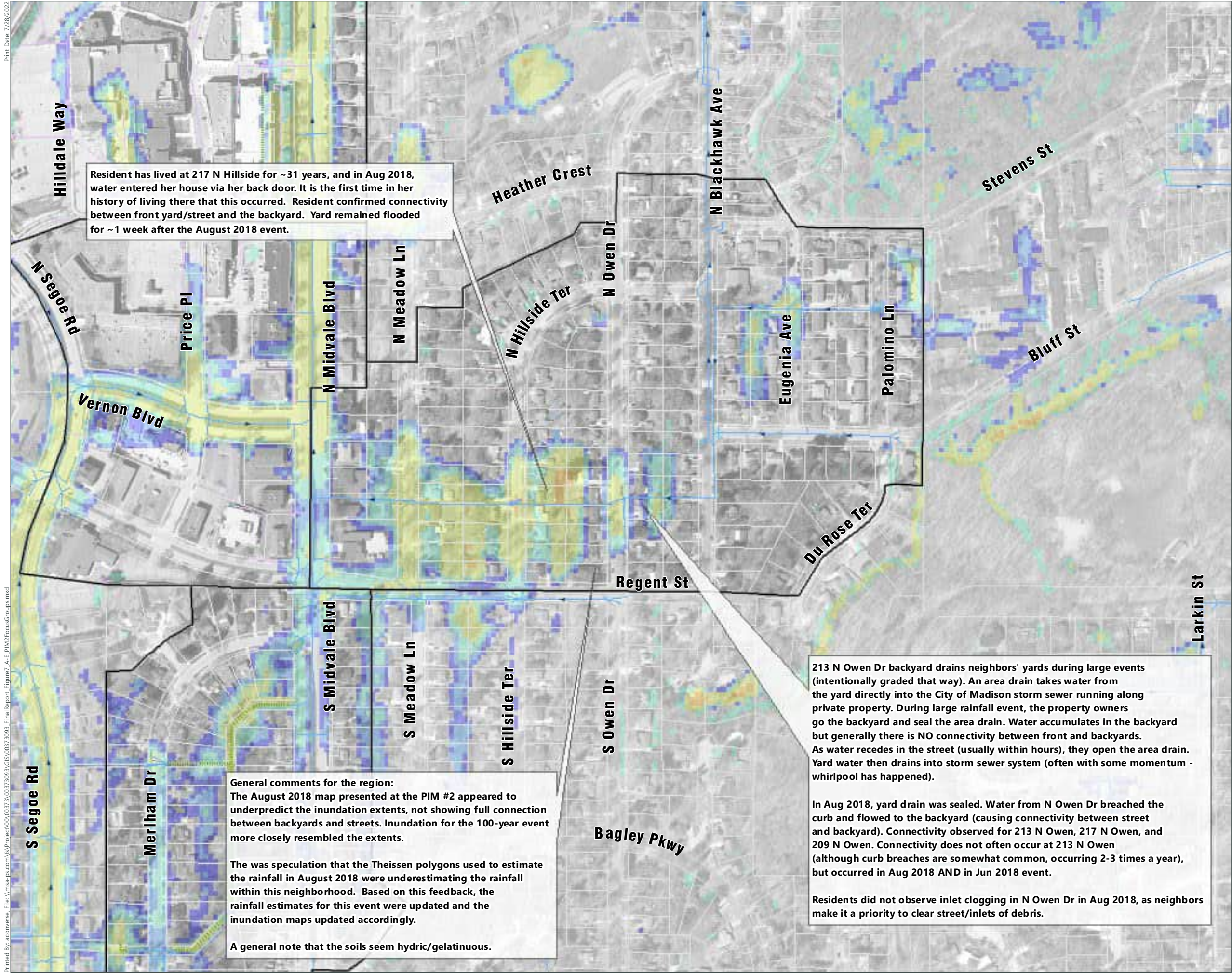
August 20th, 2018 Storm Event

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- > 6



Data Sources:
Aerial: Madison (2020)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Focus Group Comments: Residential feedback to MSA staff. Flooding extents, ponding,
etc are in reference to the August 20th, 2018 rainfall event unless otherwise noted.
Resident comments during the focus group sessions were not confined to the focus
group areas. Therefore, all comments are displayed regardless of location within the
watershed.



PIM #2

Resident Comments

Central

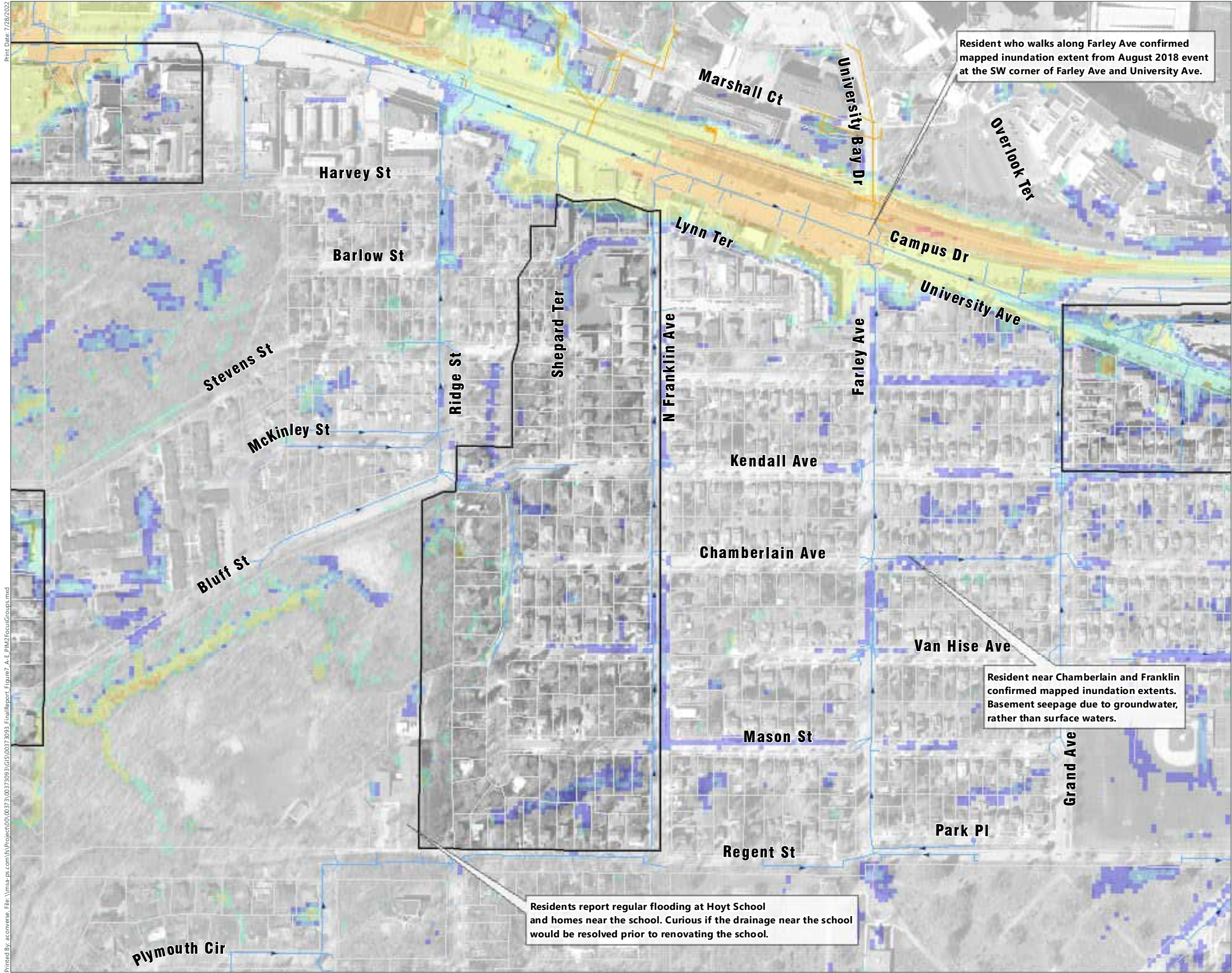
FIGURE 7C
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Focus Group
 - Public Storm System
 - Private Storm System
 - Shorewood Hills Storm System
 - Open Channel Flow
- August 20th, 2018 Storm Event
- Maximum Water Depth (ft)
- 0.1 - 0.25
 - 0.25 - 0.5
 - 0.5 - 1
 - 1 - 3
 - 3 - 6
 - > 6



Data Sources:
Aerial: Madison (2020)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Focus Group Comments: Residential feedback to MSA staff. Flooding extents, ponding, etc are in reference to the August 20th, 2018 rainfall event unless otherwise noted.
Resident comments during the focus group sessions were not confined to the focus group areas. Therefore, all comments are displayed regardless of location within the watershed.



PIM #2

Resident Comments

Eastern

FIGURE 7D
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

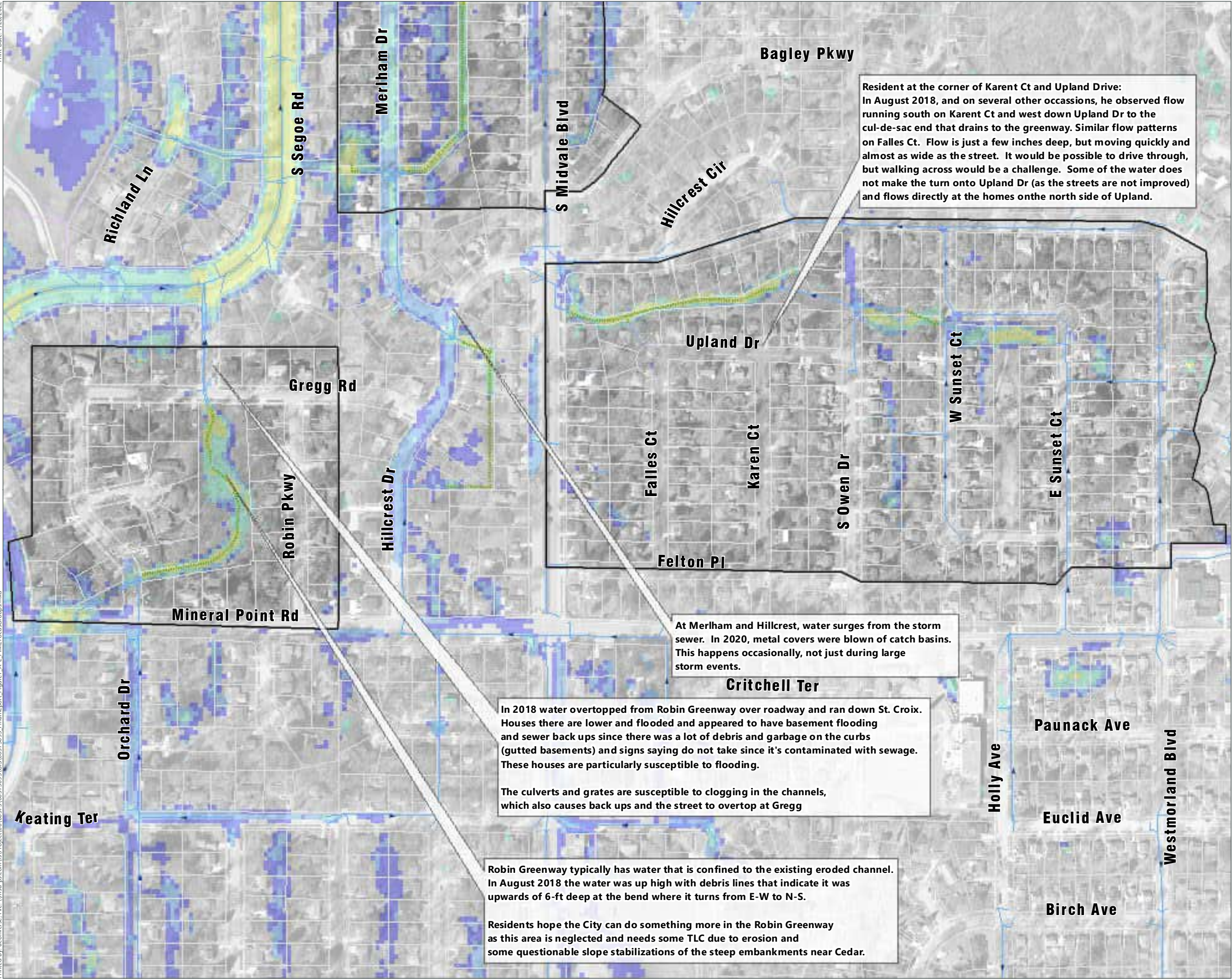
- Focus Group
 - Public Storm System
 - Private Storm System
 - Shorewood Hills Storm System
 - Open Channel Flow
- August 20th, 2018 Storm Event
- Maximum Water Depth (ft)
- 0.1 - 0.25
 - 0.25 - 0.5
 - 0.5 - 1
 - 1 - 3
 - 3 - 6
 - > 6



Data Sources:
Aerial: Madison (2020)
Watershed Boundaries: MSA
Stormwater System: City of Madison

Focus Group Comments: Residential feedback to MSA staff. Flooding extents, ponding, etc are in reference to the August 20th, 2018 rainfall event unless otherwise noted.

Resident comments during the focus group sessions were not confined to the focus group areas. Therefore, all comments are displayed regardless of location within the watershed.



PIM #2

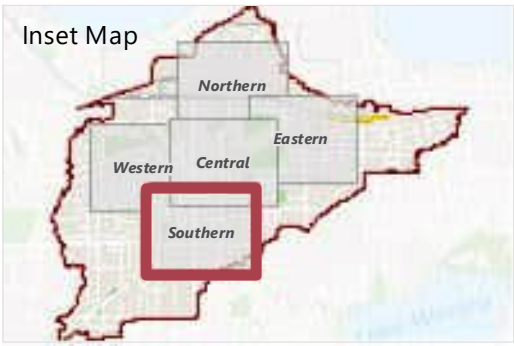
Resident Comments

Southern

FIGURE 7E
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Focus Group
 - Public Storm System
 - Private Storm System
 - Shorewood Hills Storm System
 - Open Channel Flow
- August 20th, 2018 Storm Event
- Maximum Water Depth (ft)
- 0.1 - 0.25
 - 0.25 - 0.5
 - 0.5 - 1
 - 1 - 3
 - 3 - 6
 - > 6

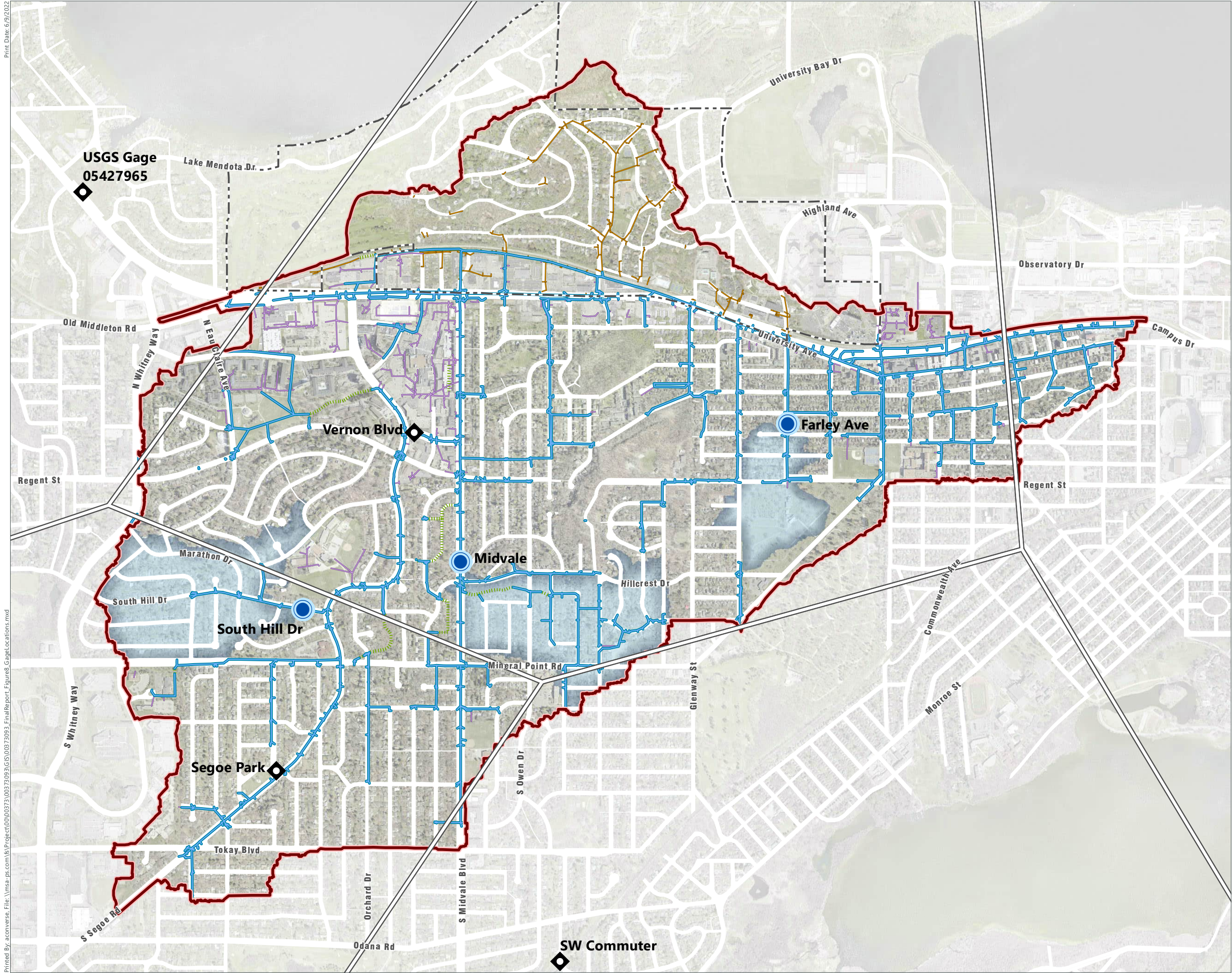


Data Sources:
Aerial: Madison (2020)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Focus Group Comments: Residential feedback to MSA staff. Flooding extents, ponding, etc are in reference to the August 20th, 2018 rainfall event unless otherwise noted.
Resident comments during the focus group sessions were not confined to the focus group areas. Therefore, all comments are displayed regardless of location within the watershed.

Gage Locations

FIGURE 8
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI



- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel
- Remote Monitoring
 - Rain Gage
 - Level Logger (in pipe)
- Thiessen Polygons for Rain Gages
- Metershed for Level Loggers

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Gage Locations: City of Madison and USGS

Model Network

FIGURE 9
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

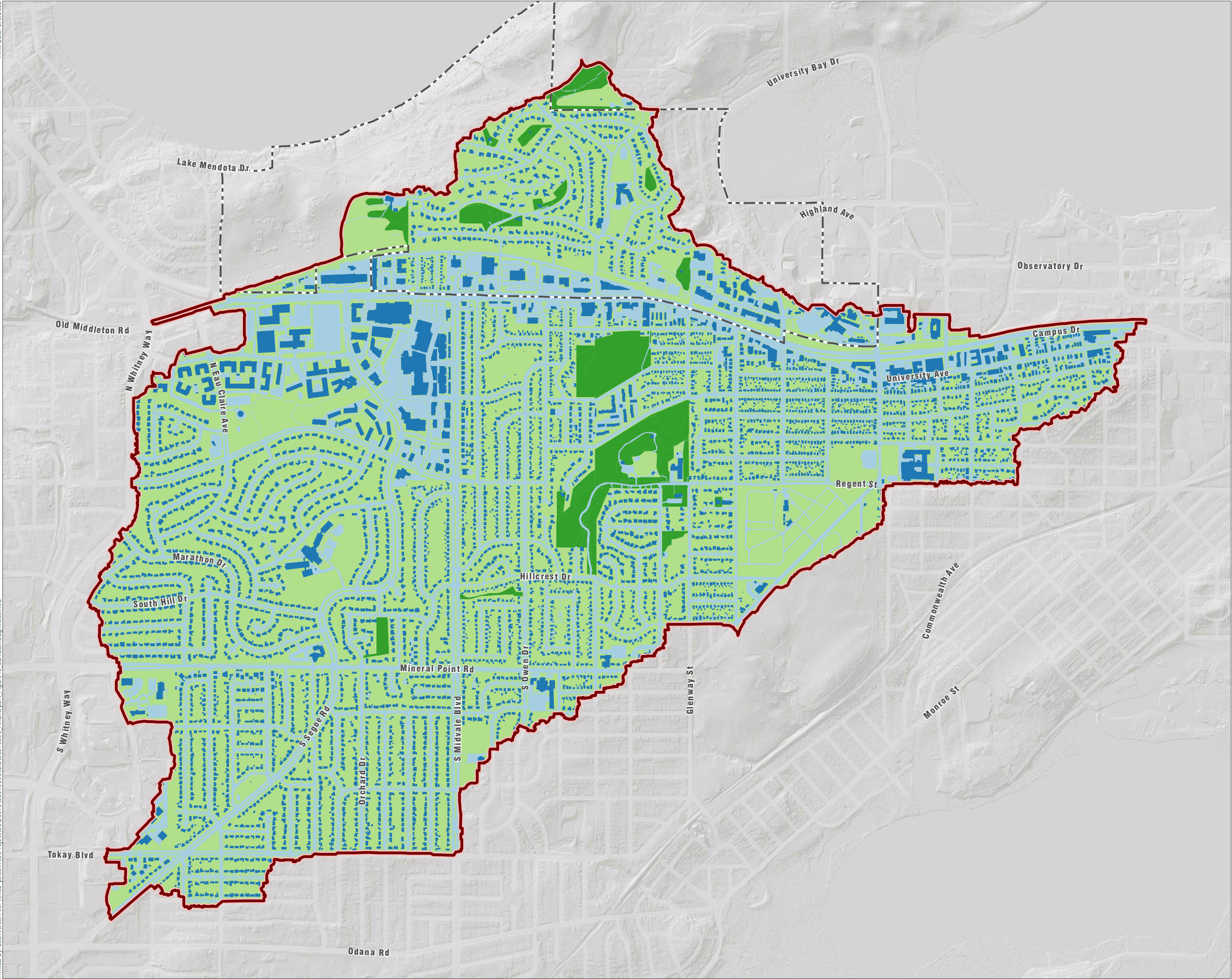
-  Watershed Study Area
-  Village of Shorewood Hills
-  Parcels
-  Modeled Link
-  Modeled Node

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Model Network: MSA



0 0.125 0.25 Miles





Surface Roughness

FIGURE 10
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Surface Roughness (Manning's n)**
 - Streets, Sidewalk, Driveway, Parking = 0.016
 - Buildings, Variable*
 - Wooded, Variable*
 - Turf Grass, Variable*

***Variable Manning's Roughness (n)
based on water depth**

	Depth (ft)	Roughness
Buildings	0 - 0.3	0.01
	0.31 - 10	0.1 - 0.3
Wooded	0 - 1	0.4 - 0.1
	1+	0.1
Turf Grass	0 - 1	0.24 - 0.03
	1+	0.03

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Impervious Areas: MSA



0 0.125 0.25 Miles



2D Land Use

FIGURE 11
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

-  Watershed Study Area
-  Village of Shorewood Hills
-  Public Storm System
-  Private Storm System
-  Shorewood Hills Storm System
-  Open Channel
-  Impervious
-  Pervious, Wooded
-  Pervious, Turf Grass

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Impervious Areas: MSA



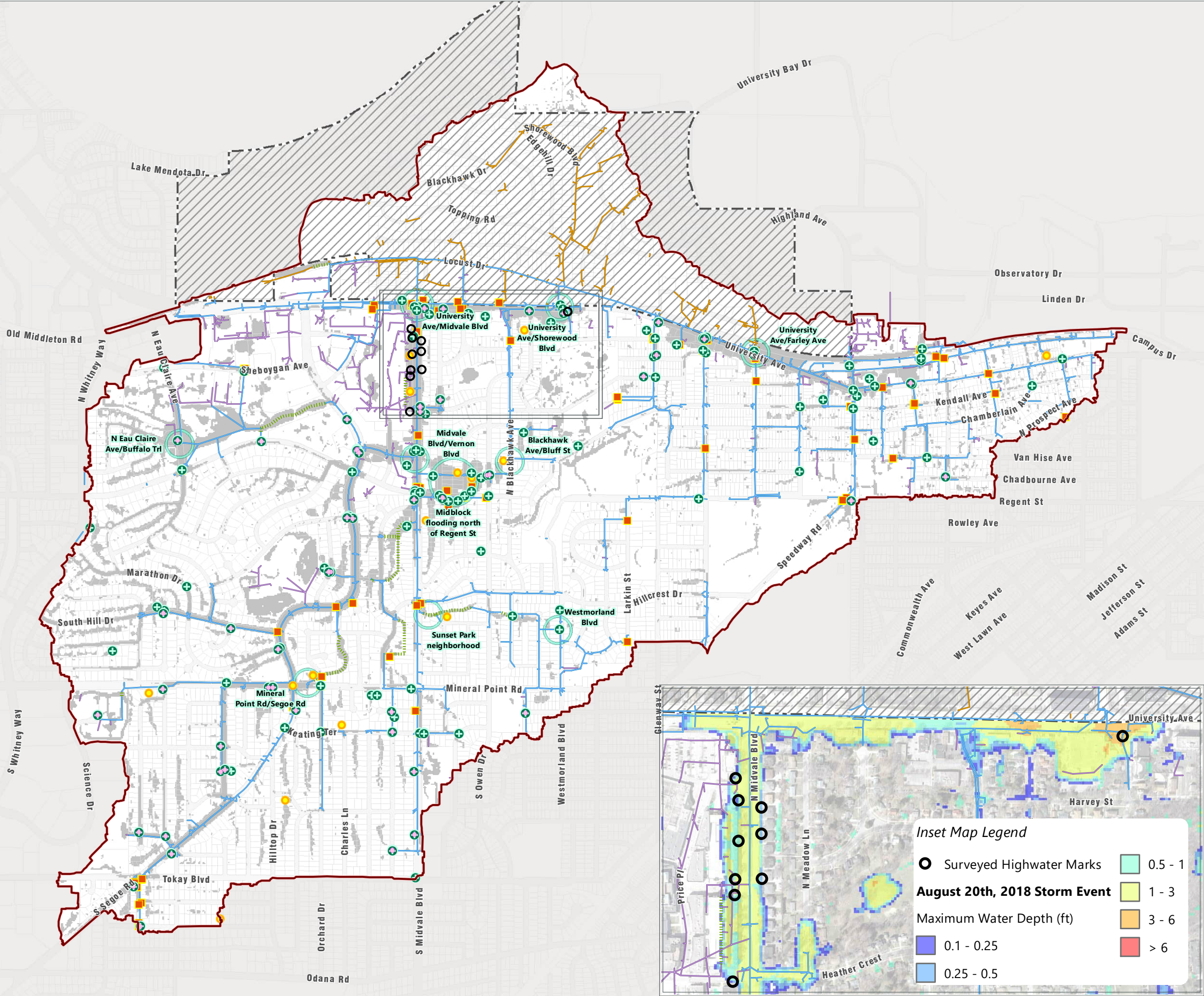
0 0.125 0.25 Miles



Historic Flooding Observations and 8/20/18 Innundation

FIGURE 12
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI



- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow
- Observations by City Engineering Staff
- Priority Inlets
- Operations Flooding Points
- Reported Flooding
- Historic/Observed Flood Points
- Surveyed Highwater Marks (8/20/2018 event)
- August 20th, 2018 Rain Event
- Inundation Extents

Inset Map Legend

- Surveyed Highwater Marks
- August 20th, 2018 Storm Event
- Maximum Water Depth (ft)
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- > 6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Reported Flooding: City's Online Public Reporting (through July 2020)
Historic Flooding, Observations and Priority Inlets: City of Madison
Observations by City Staff: Based on discussions of known flooding concerns with City Engineering Staff and prior Watershed Studies
August 2018 Inundation Extents: MSA modeling using current stormwater system design. Includes system updates from August 2018 - 2021.

50% AEP Inundation

FIGURE 13
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow
- 50% Annual Exceedance Probability Storm
- Maximum Water Depth (ft)
 - 0.1 - 0.25
 - 0.25 - 0.5
 - 0.5 - 1
 - 1 - 3
 - 3 - 6
 - >6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

DISCLAIMER

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20% AEP Inundation

FIGURE 14
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow
- 20% Annual Exceedance Probability Storm
- Maximum Water Depth (ft)
 - 0.1 - 0.25
 - 0.25 - 0.5
 - 0.5 - 1
 - 1 - 3
 - 3 - 6
 - >6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

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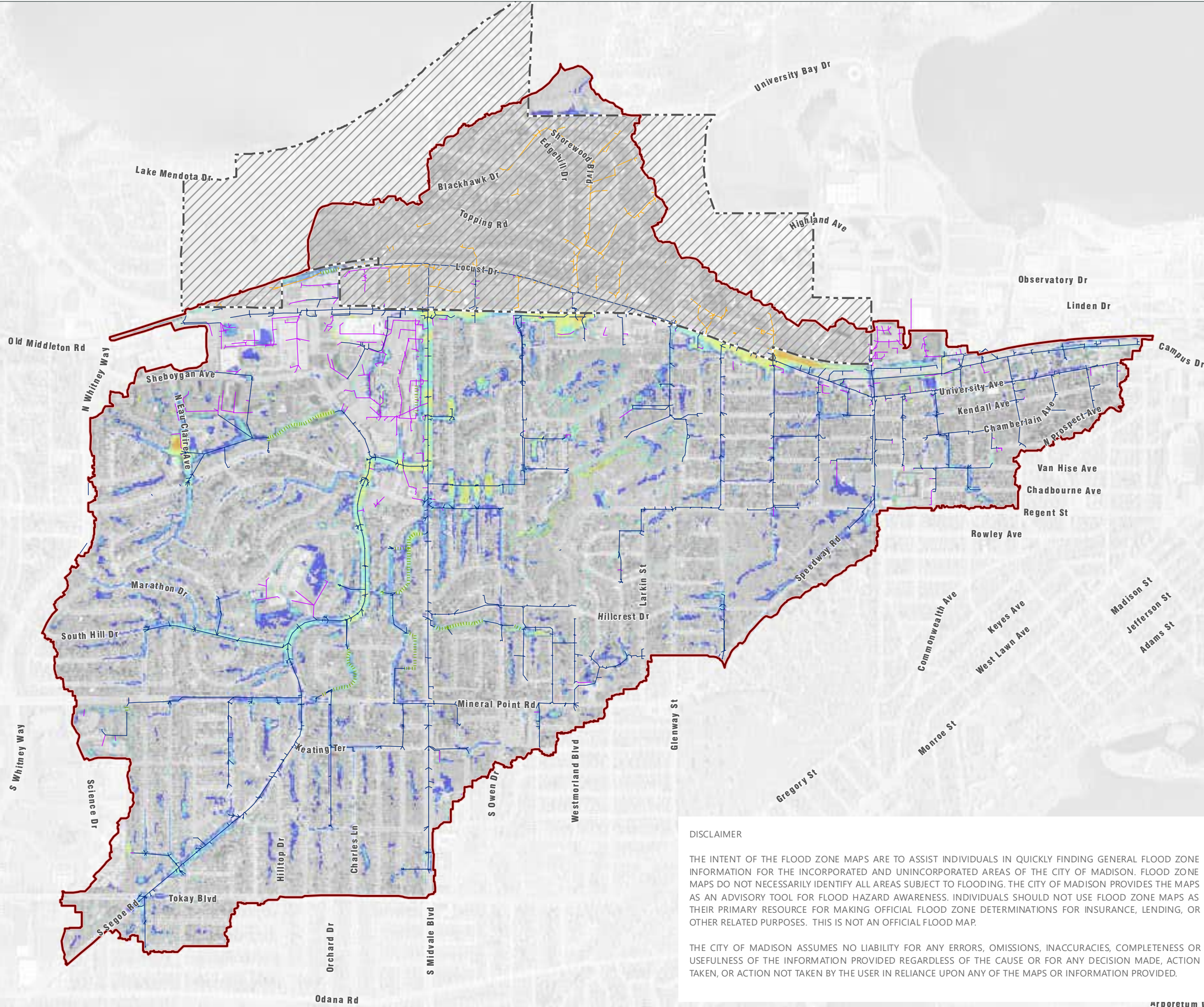
0 0.125 0.25 Miles



10% AEP Inundation

FIGURE 15
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI



- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

10% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- >6

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Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

4% AEP Inundation

FIGURE 16
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow
- 4% Annual Exceedance Probability Storm
- Maximum Water Depth (ft)
 - 0.1 - 0.25
 - 0.25 - 0.5
 - 0.5 - 1
 - 1 - 3
 - 3 - 6
 - >6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

DISCLAIMER

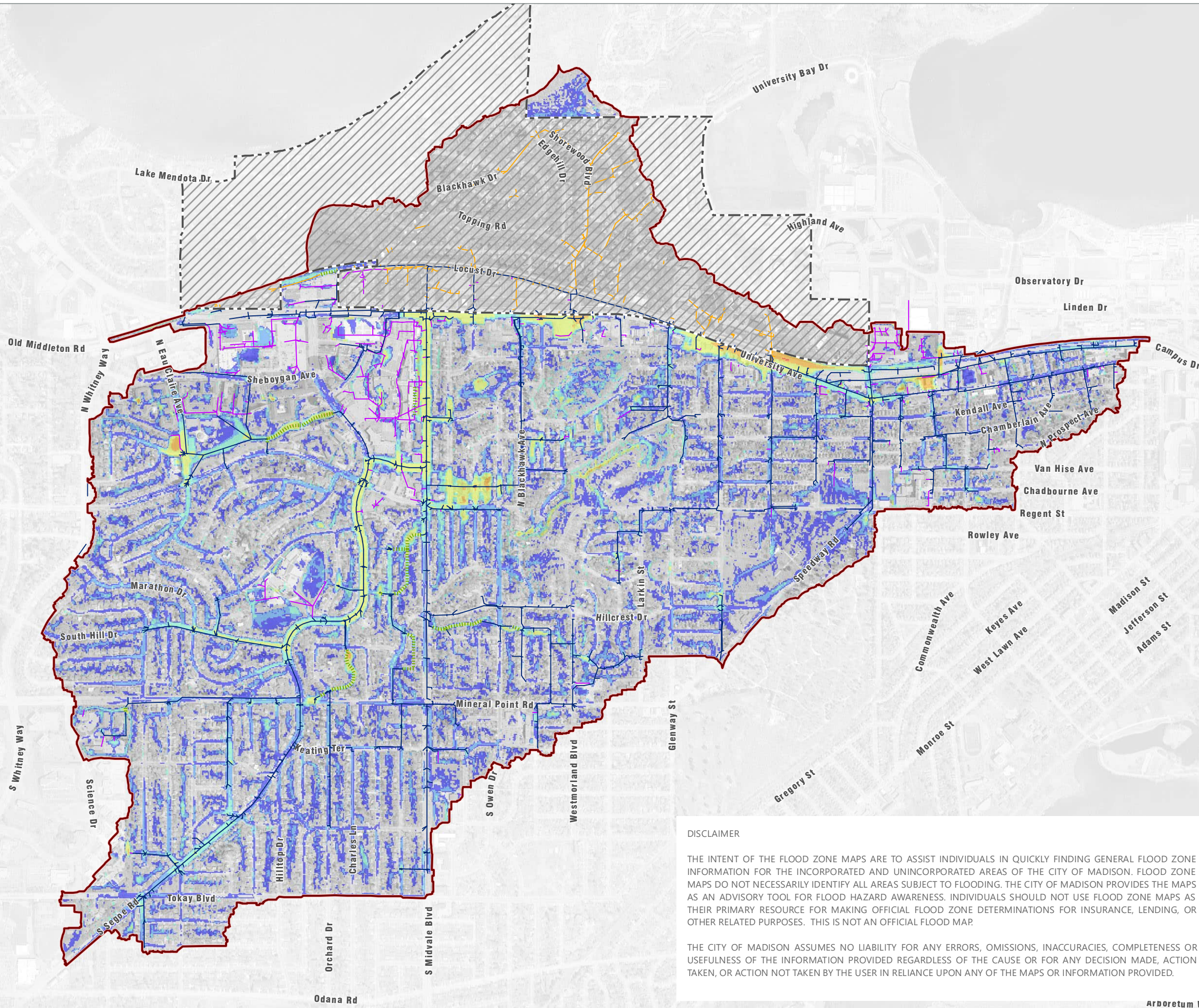
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2% AEP Inundation

FIGURE 17
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI



- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

2% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- >6

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Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

1% AEP Inundation

FIGURE 18
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow
- 1% Annual Exceedance Probability Storm
- Maximum Water Depth (ft)
 - 0.1 - 0.25
 - 0.25 - 0.5
 - 0.5 - 1
 - 1 - 3
 - 3 - 6
 - > 6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

DISCLAIMER

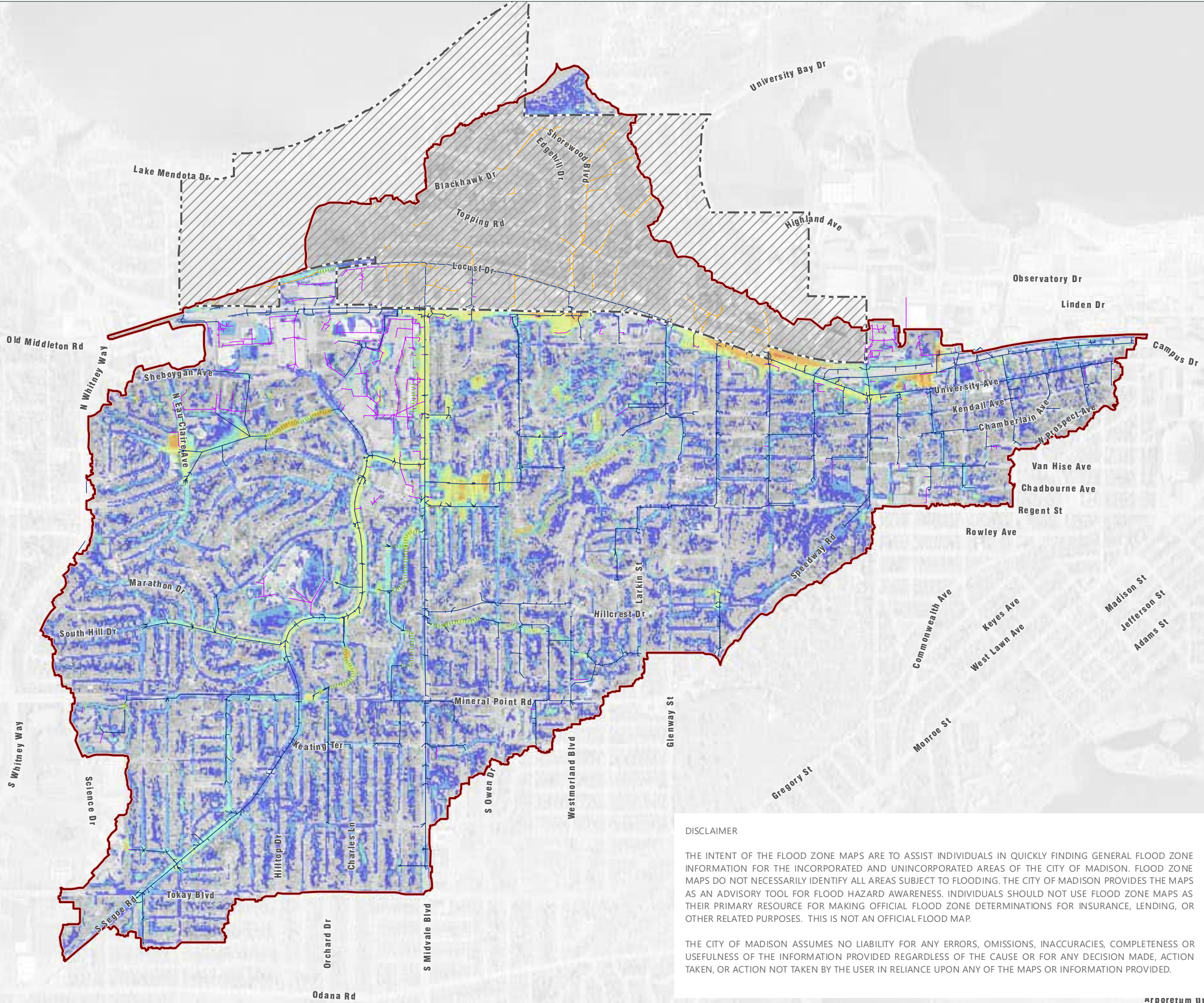
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Long 1% AEP Inundation

FIGURE 19
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI



- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow
- 1% Long AEP Storm
- Maximum Water Depth (ft)
 - 0.1 - 0.25
 - 0.25 - 0.5
 - 0.5 - 1
 - 1 - 3
 - 3 - 6
 - >6

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Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

0.2% AEP Inundation

FIGURE 20
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

0.2% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- > 6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

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0 0.125 0.25 Miles



August 20th, 2018 Inundation

FIGURE 21
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

August 20th, 2018 Storm Event

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- >6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

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Target 1a

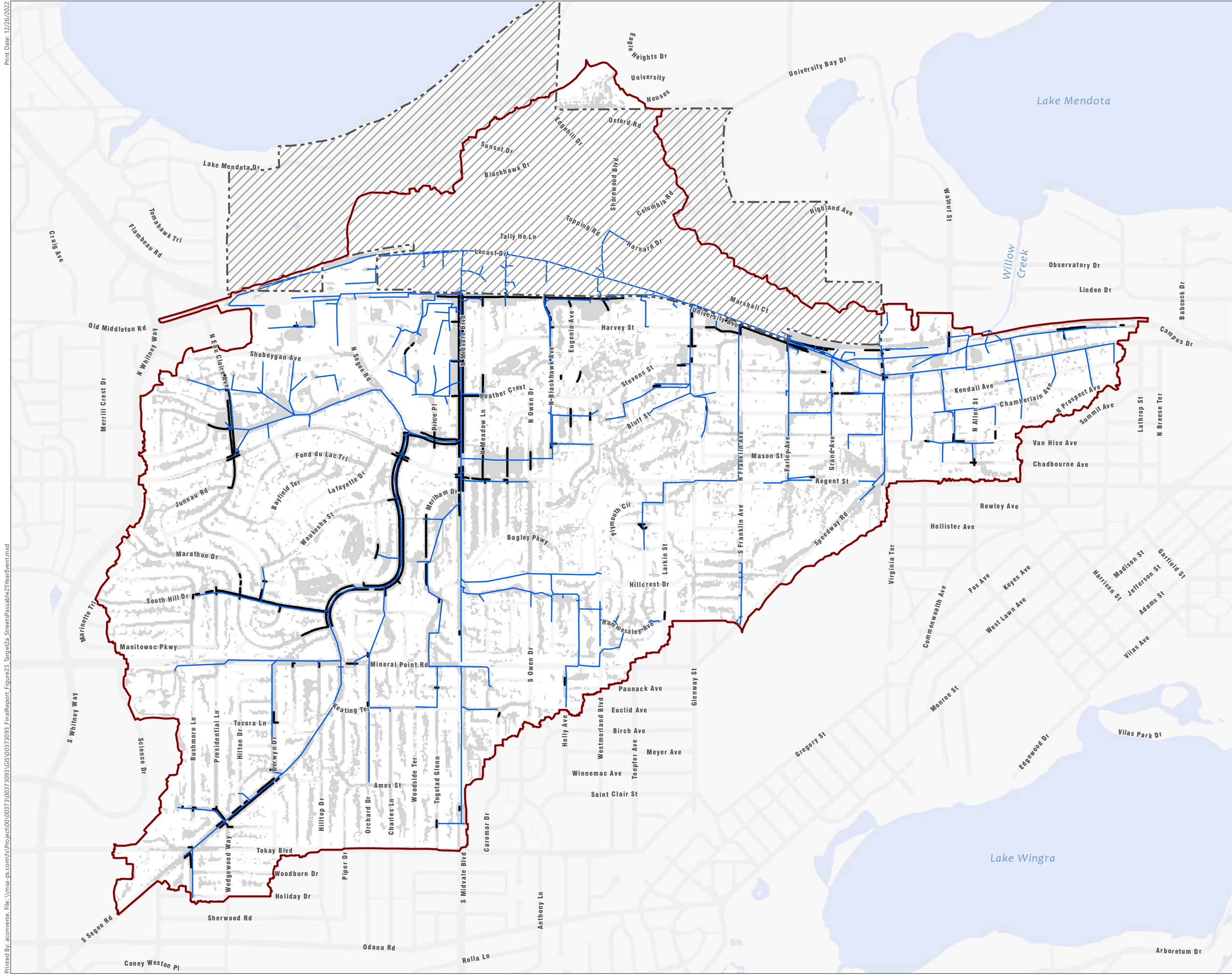
Eliminate flooding from the storm sewer system for the 10% AEP design storm; all water shall be contained within the system, except at low points.

FIGURE 22
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

-  Watershed Study Area
-  Village of Shorewood Hills
-  Modeled Link
-  Inundation Extent, 10% AEP Event
- 0.25" or Greater Inundation at Curbside
-  Sewered
-  Unsewered

Data Sources:
Watershed Boundaries: MSA
Stormwater System: City of Madison



Target 2a

Streets to remain passable during 4% AEP design storm with no more than 0.5-ft of water at the centerline.

FIGURE 23
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Modeled Link
- 0.5" or Greater Inundation at Centerline
- Inundation Extent, 4% AEP Event

Data Sources:
Watershed Boundaries: MSA
Stormwater System: City of Madison

Target 3a

No home or business will be flooded during the 1% AEP design storm.

FIGURE 24
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

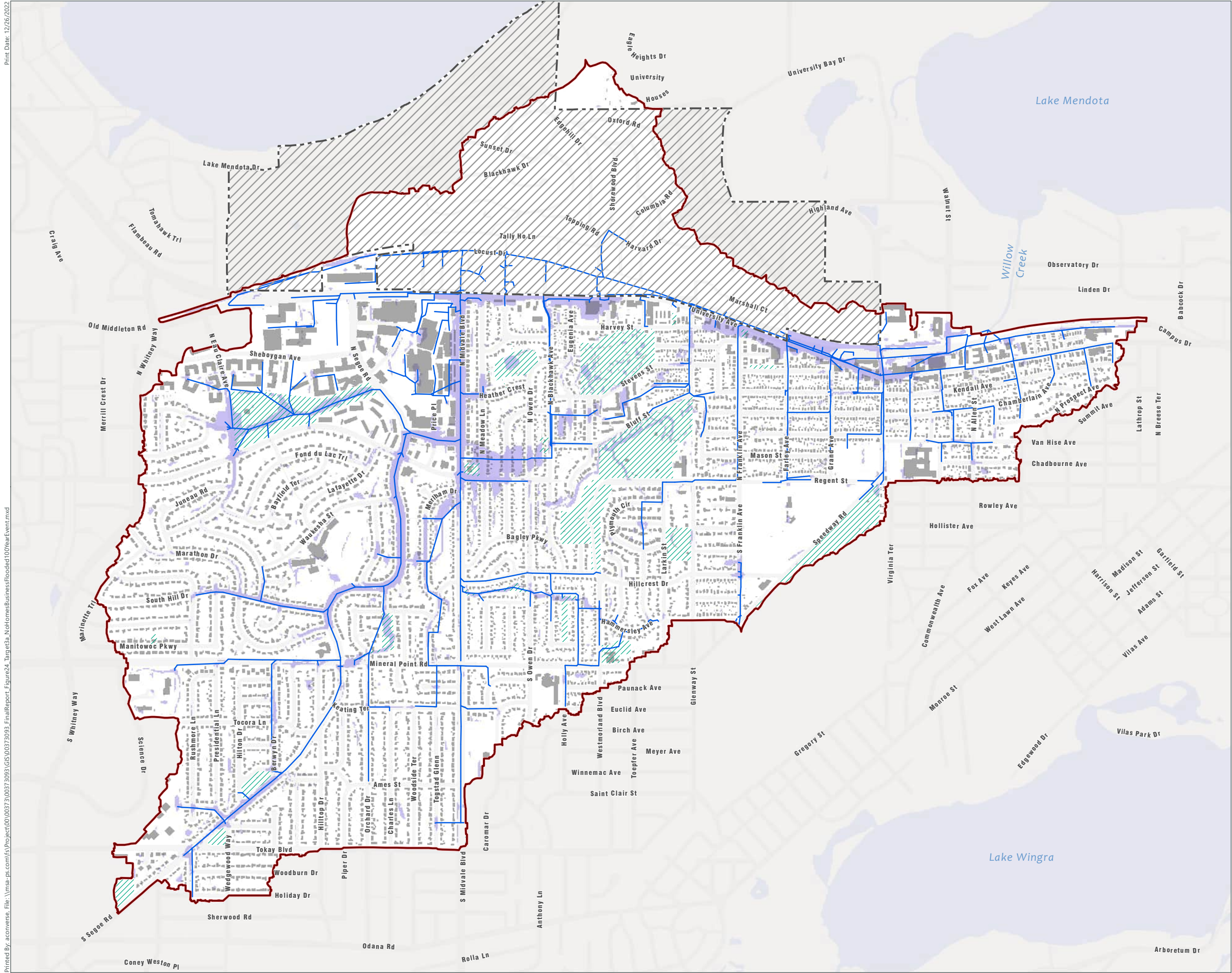
- Watershed Study Area
- Village of Shorewood Hills
- SWU Land/Parks
- Modeled Link
- Building Footprint
- 1% Annual Exceedance Probability Storm
- Inundation >0.5 ft

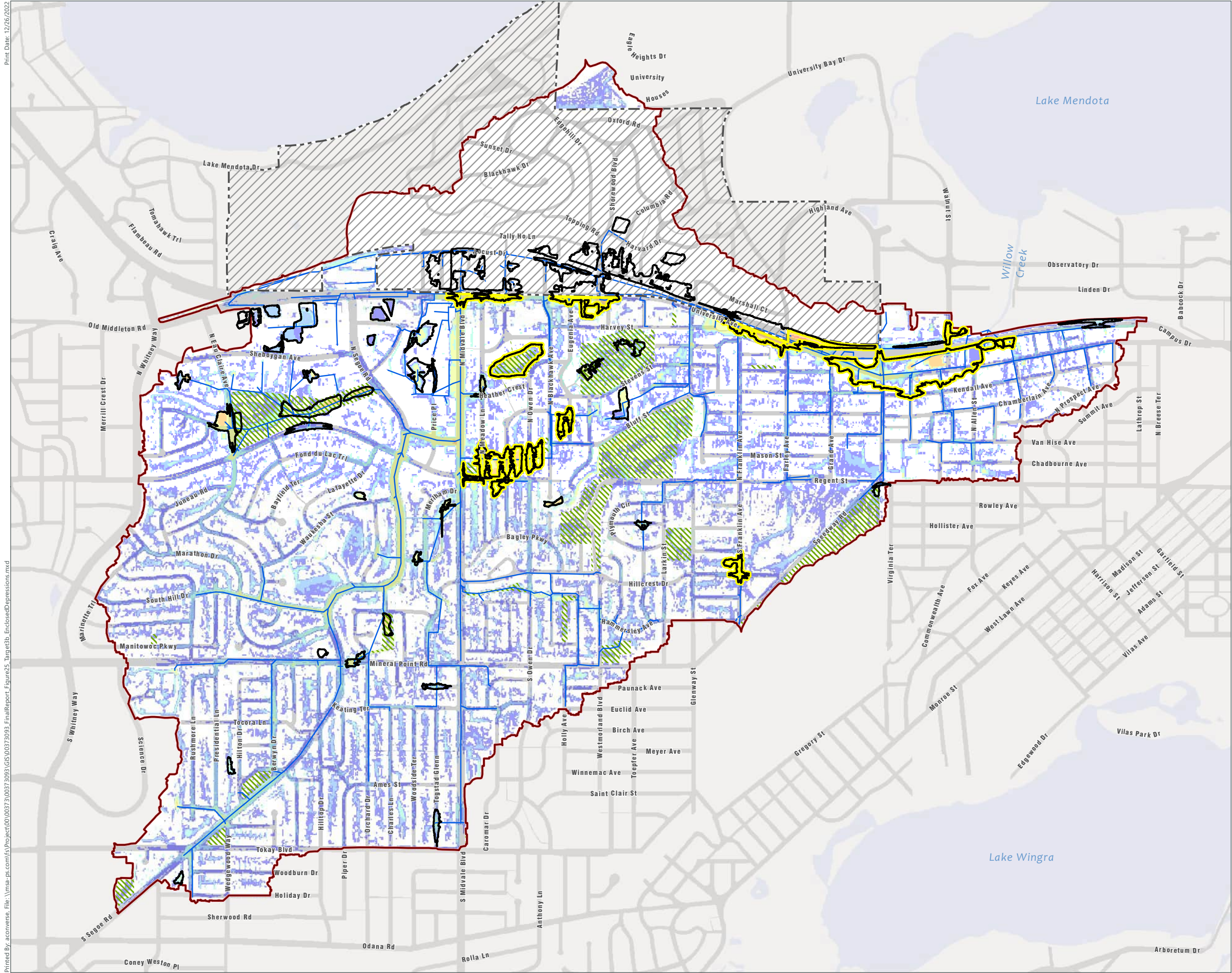
Data Sources:
Watershed Boundaries: MSA
Stormwater System: City of Madison

*Building footprints by >0.1' of water inundation only included if adjacent to a contiguous inundation area greater than 0.5 acres and located within the City of Madison.



0 0.125 0.25 Miles





Target 3b

Enclosed depressions to be served to the 100-year design storm (which can include safe overland flow within street, easements, greenways or other public lands).

FIGURE 25
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

Watershed Study Area
 Village of Shorewood Hills
 SWU Lands and Parks
 Modeled Link

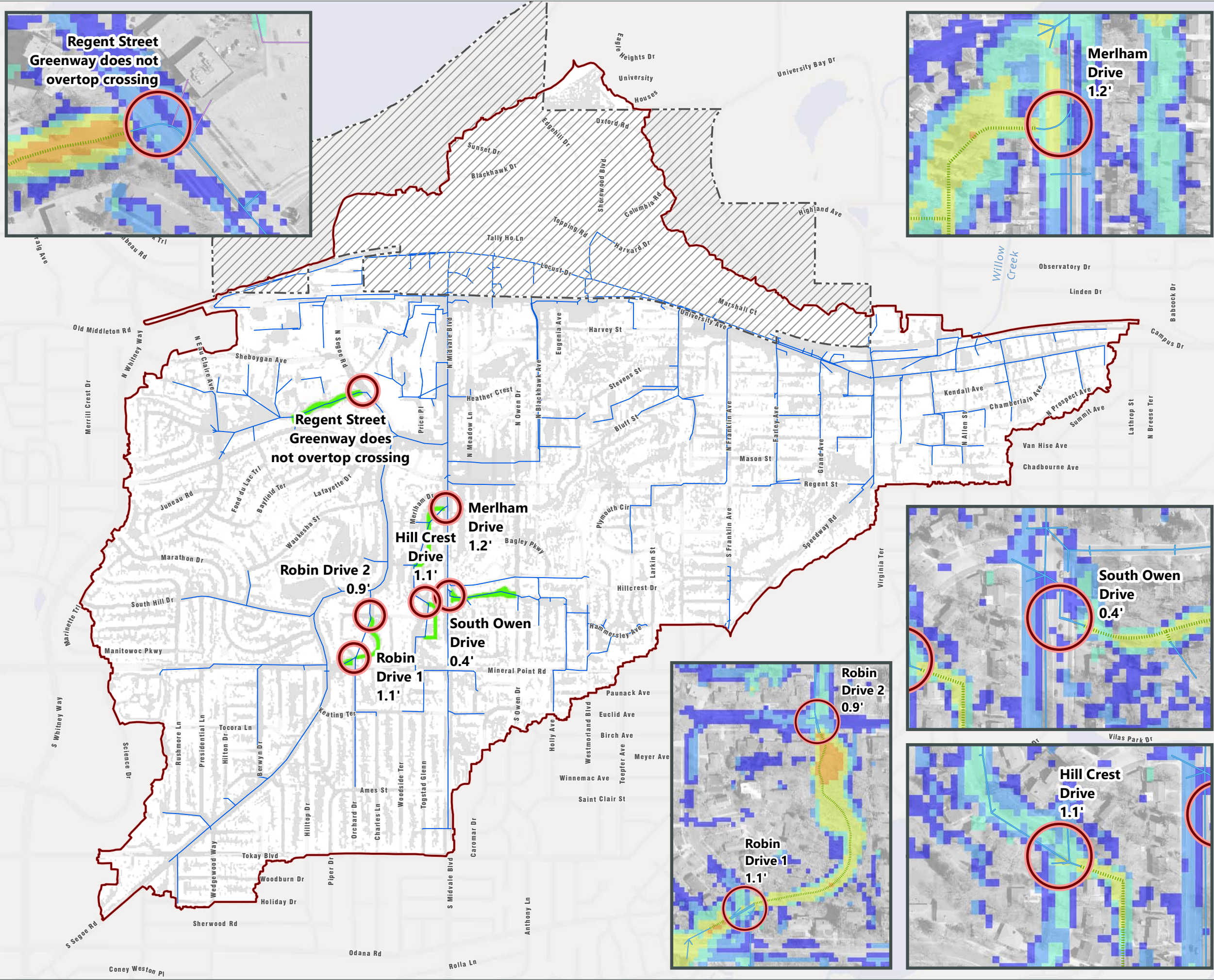
1% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- >6
- Enclosed Depression
- Enclosed Depression Not Meeting Criteria*

Data Sources:
Watershed Boundaries: MSA
Stormwater System: City of Madison
Enclosed Depressions: Derived from 2017 LiDAR DEM, with a minimum size of 0.25 acres. Note that some identified depressions are due to the age of the DEM and recent construction projects.

*Enclosed depressions do not meet the goal criteria if all three of the following are true:
1) The depression touches the public ROW or public lands
2) The residual depression area outside of public lands and street ROW was greater than 0.25 acres
3) The maximum inundation depth is 1' or greater during the 100-year



Target 3c

Greenway crossings at streets to be served to the 1% AEP design storm.

FIGURE 26
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Greenway
- Modeled Link
- Inundation Extent, 1% AEP Event
- Greenway Street Crossing

Inset Maps Legend

- Public Storm System
- Private Storm System
- Open Channel Flow

1% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

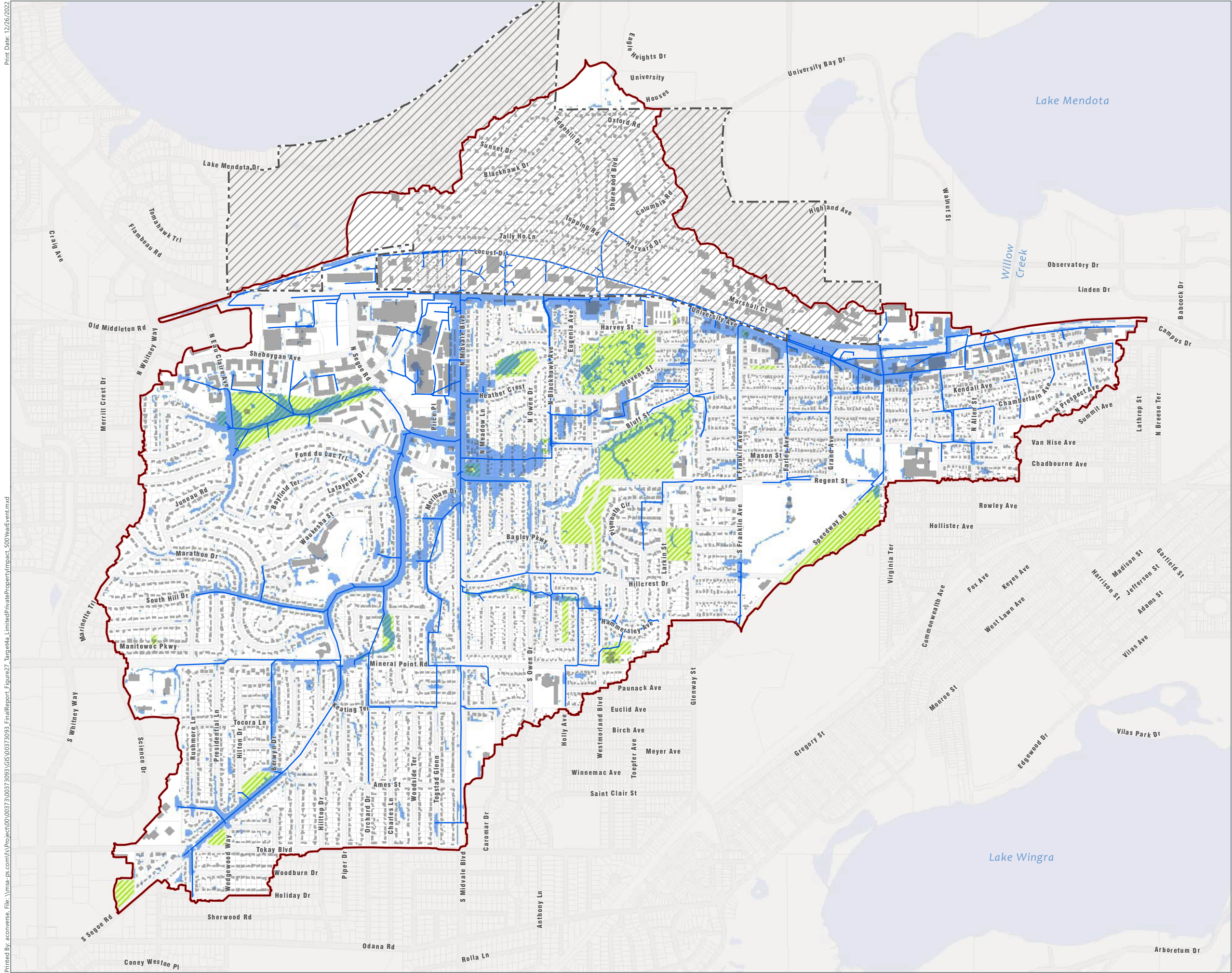
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- >6

Data Sources:
Watershed Boundaries: MSA
Stormwater System: City of Madison
Aerial: City of Madison (2018)



0 0.125 0.25 Miles





Target 4a

Safely convey stormwater with limited impact on private property during the 0.2% AEP design storm.

FIGURE 27
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

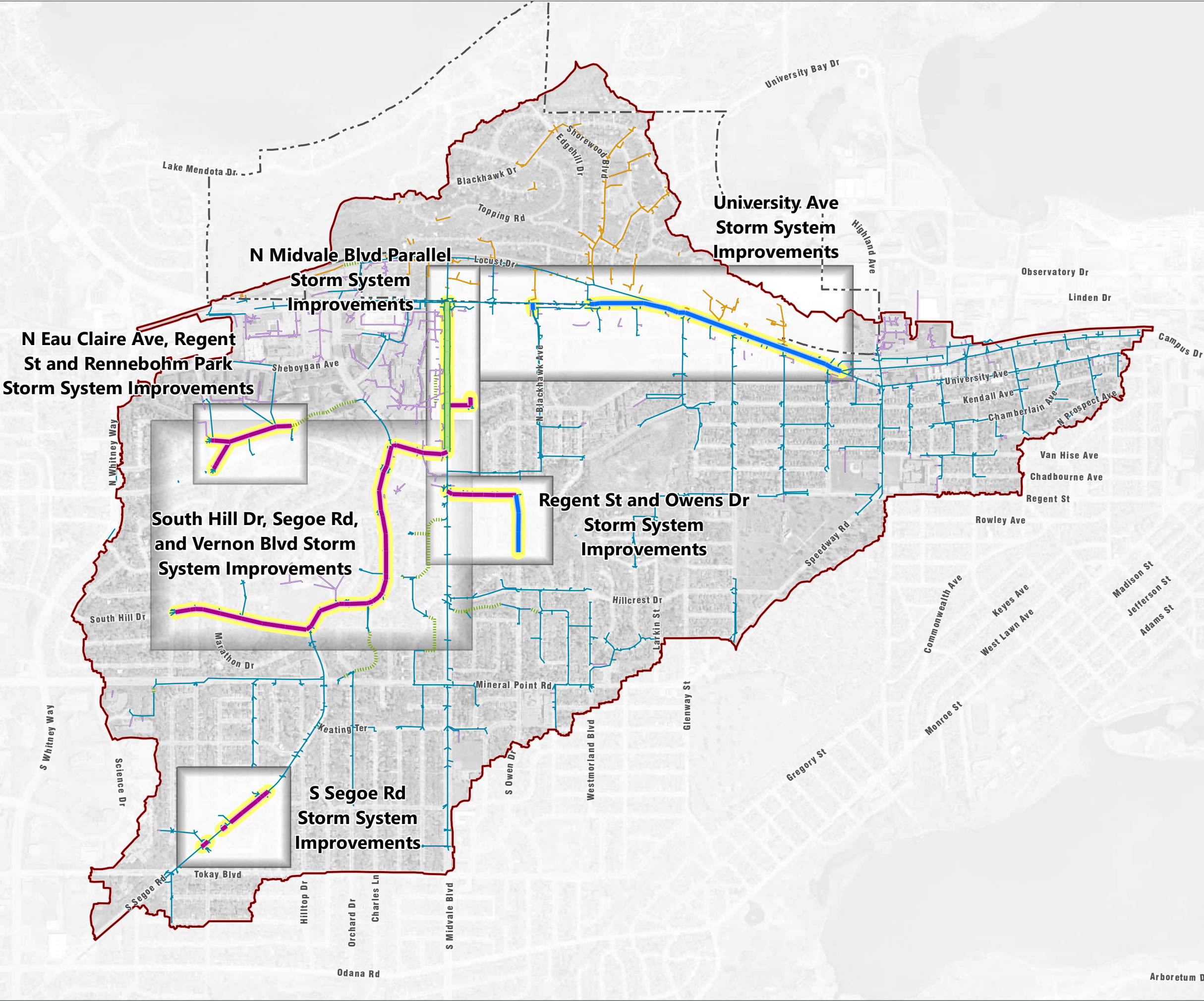
- Watershed Study Area
- Village of Shorewood Hills
- SWU Land/Parks/Private Pond
- Building Footprint
- 0.2% Annual Exceedance Probability Storm**
- Inundation >0.5 ft
- Modeled Link

Data Sources:
Watershed Boundaries: MSA
Stormwater System: City of Madison

Recommended Solutions Index

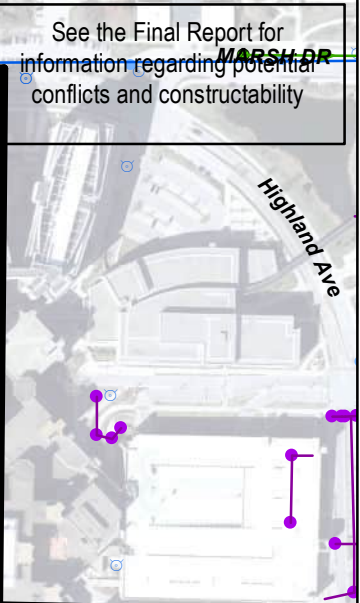
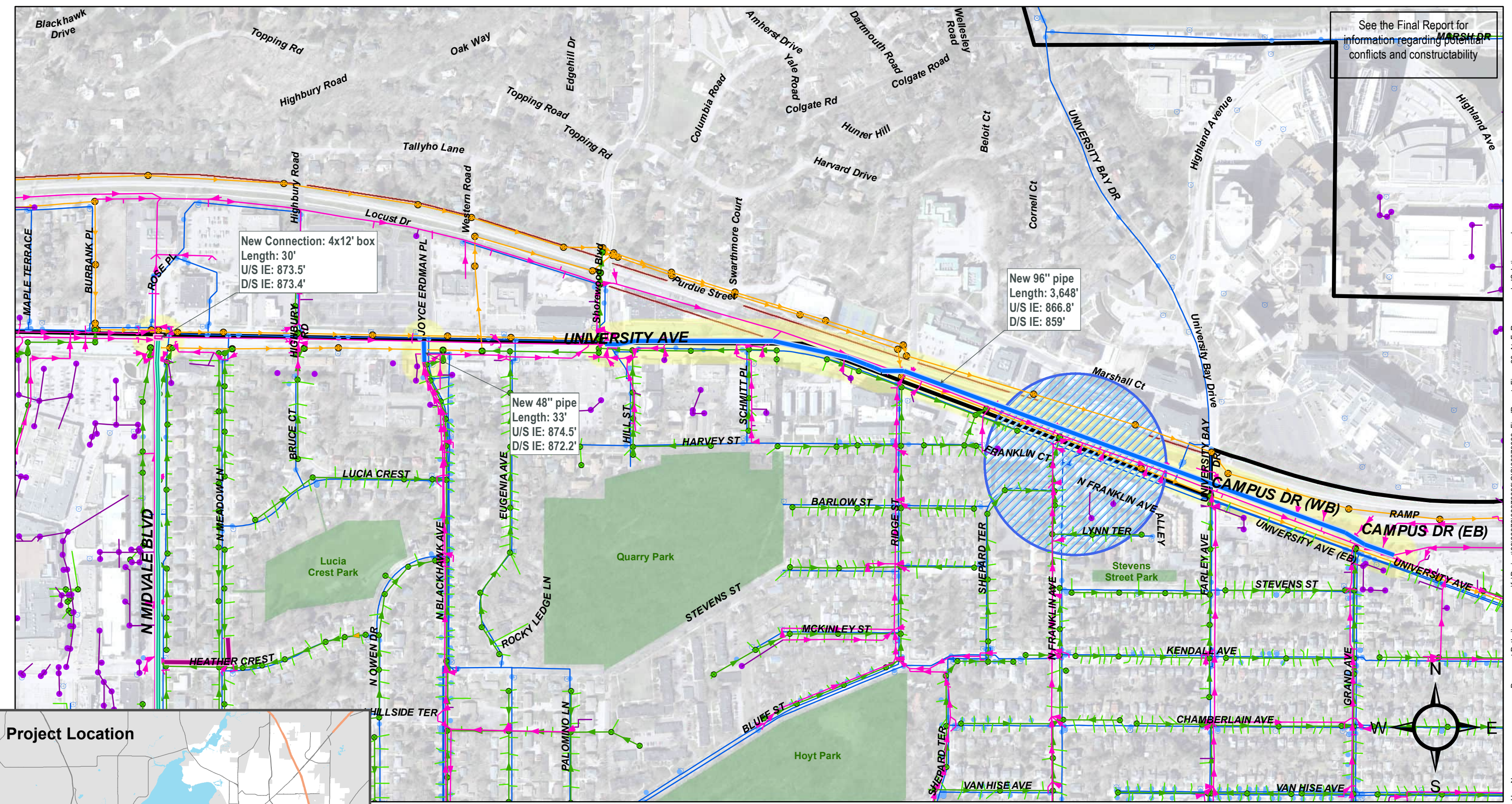
FIGURE 28
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI



- Map Extents (Figures 29 A-F)
- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow
- Improvement Area of Interest
- Recommended Improvements**
 - Replacement Pipe
 - New Pipe
 - New Parallel Pipe

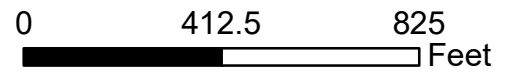
Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison
Reported Flooding: City's Online Public Reporting (through July 2020)
Historic Flooding, Observations and Priority Inlets: City of Madison
Observations by City Staff: Based on discussions of known flooding concerns with City Engineering Staff and prior Watershed Studies



- | | | | |
|-------------------------------------|-------------------|---------------------------------|--------------------|
| Storm Pipe | Sanitary Mains | MMSD SAS | Water Hydrant |
| Private Stormwater Pipes--Approx | SAS | No Wet Pond Within 400' of Well | Municipal Limits |
| Private Stormwater Structures--A... | Sanitary Laterals | Water Main | Park |
| | MMSD Mains | Water Valve | Railroad ROW Lines |
-
- | |
|------------------------------|
| Replacement Pipe |
| New Pipe |
| Replacement Box |
| New Parallel Box |
| Improvement Area of Interest |

University Ave Storm System Improvements

Figure 29 - A

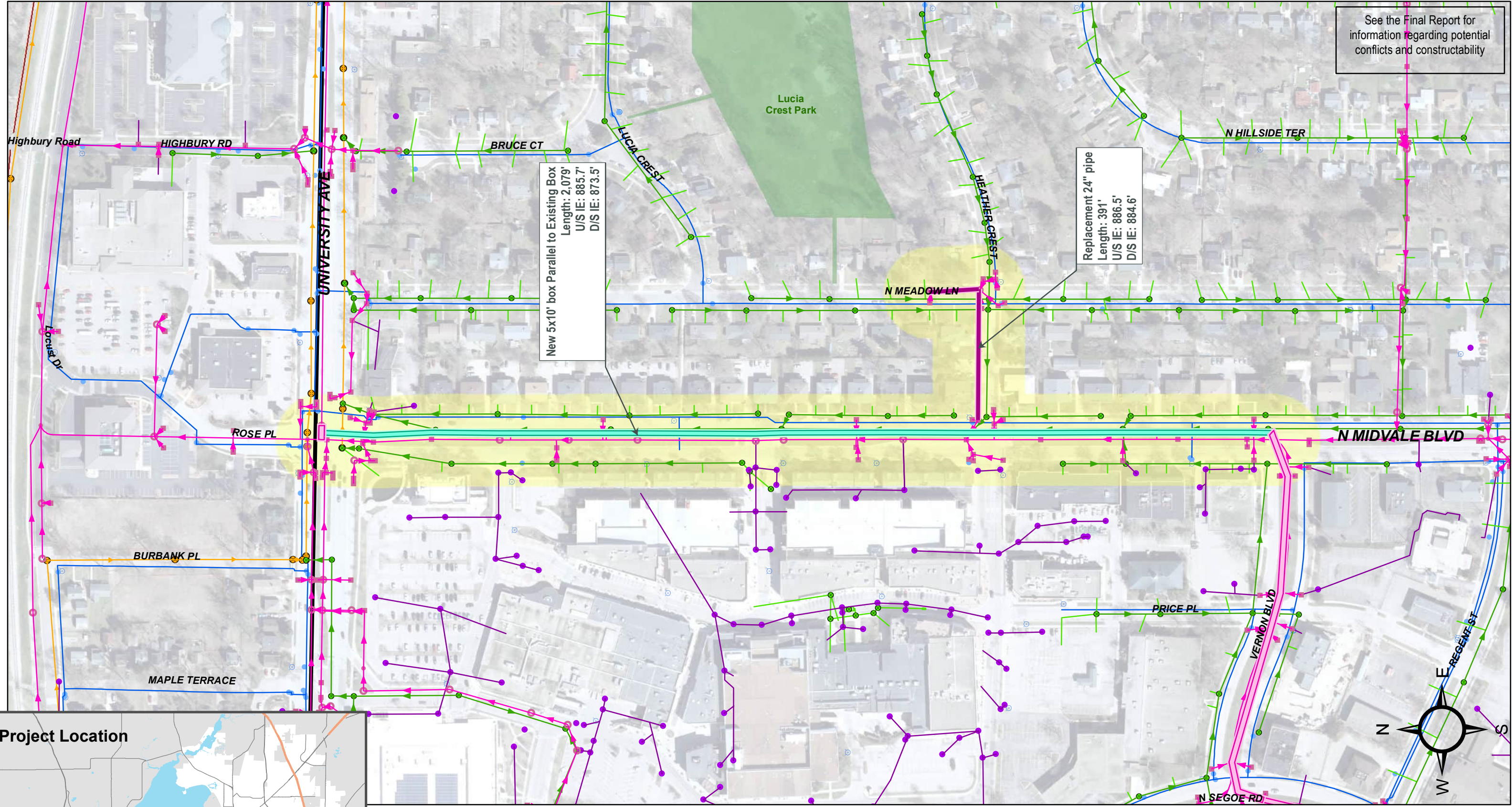


Date: 12/26/2022

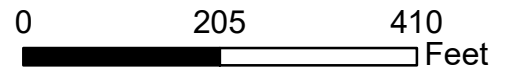


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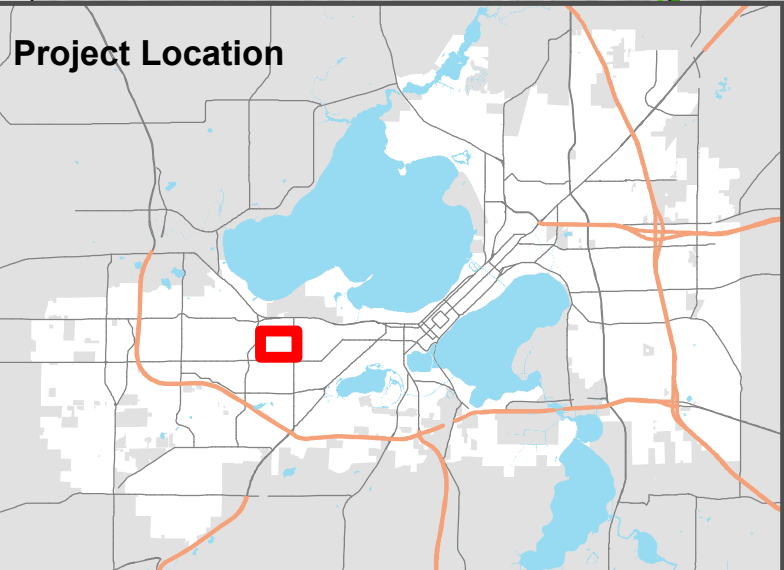
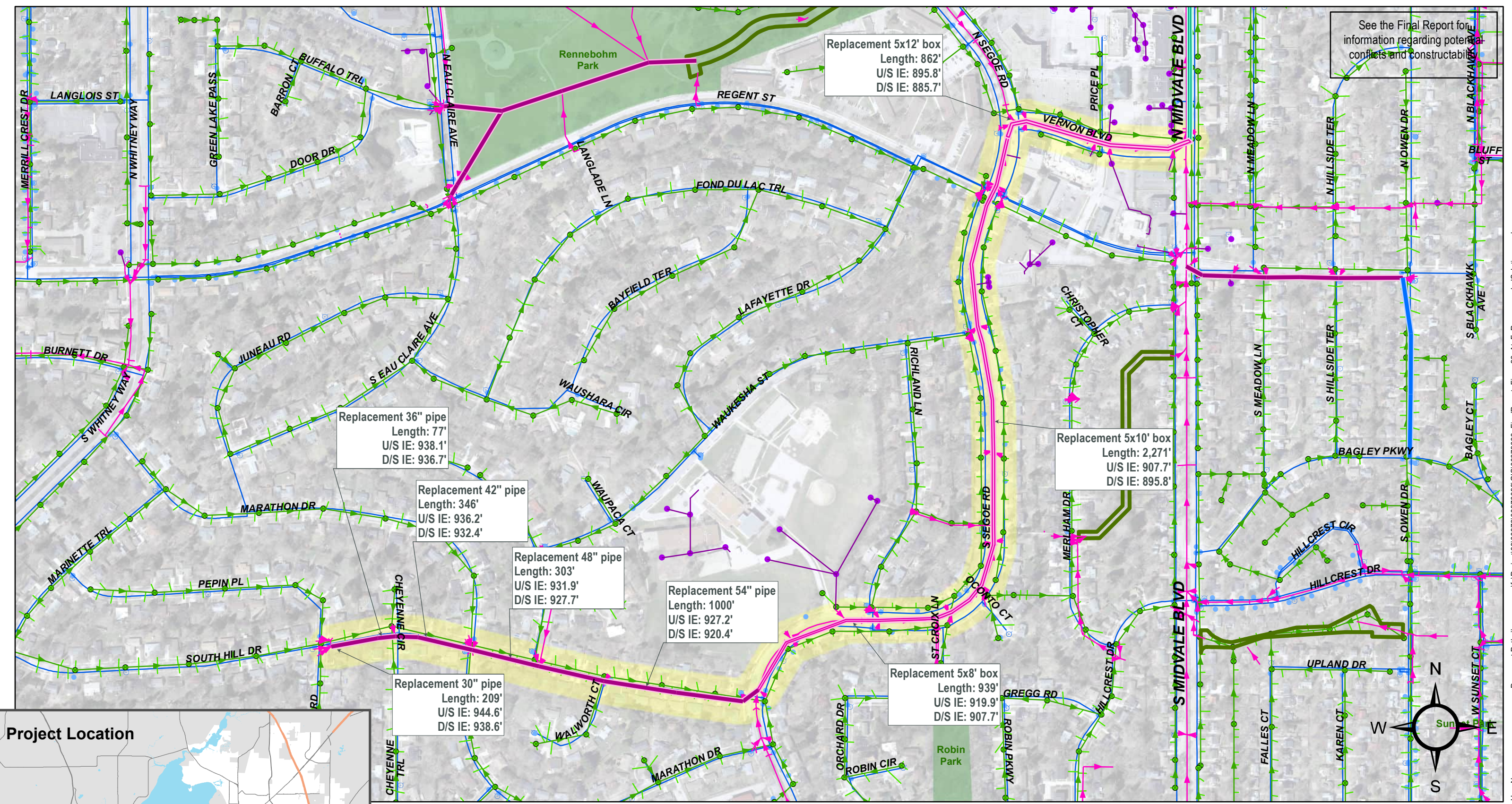
See the Final Report for information regarding potential conflicts and constructability



- | | | | | | |
|-----------------------|-------------------------------------|-------------------|--------------------|---------------------------------|--|
| Storm Pipe | Private Stormwater Pipes--Approx | Sanitary Laterals | Water Hydrant | Recommended Improvements | |
| Other Storm Structure | Private Stormwater Structures--A... | MMSD Mains | Municipal Limits | Replacement Pipe | N Midvale Blvd Parallel Storm System Improvements
Figure 29 - B |
| Access Structures | Sanitary Mains | MMSD SAS | Park | New Pipe | |
| Inlet | Water Main | Water Valve | Railroad ROW Lines | Replacement Box | |
| | SAS | | | New Parallel Box | |
| | | | | Improvement Area of Interest | |



Date: 12/28/2022



- | | | | |
|----------------------------------|---------------------------------------|---------------|---------------------------------|
| Greenway | Private Stormwater Structures--Approx | Water Main | Recommended Improvements |
| Storm Pipe | Sanitary Mains | Water Valve | Replacement Pipe |
| Private Stormwater Pipes--Approx | SAS | Water Hydrant | New Pipe |
| Sanitary Laterals | Park | | Replacement Box |
| | | | New Parallel Box |
| | | | Improvement Area of Interest |

South Hill Dr, Segoe Rd, and Vernon Blvd Storm System Improvements
Figure 29 - C

0 415 830 Feet

Date: 12/26/2022

See the Final Report for information regarding potential conflicts and constructability.

Replacement 5x12' box
Length: 862'
U/S IE: 895.8'
D/S IE: 885.7'

Replacement 36" pipe
Length: 77'
U/S IE: 938.1'
D/S IE: 936.7'

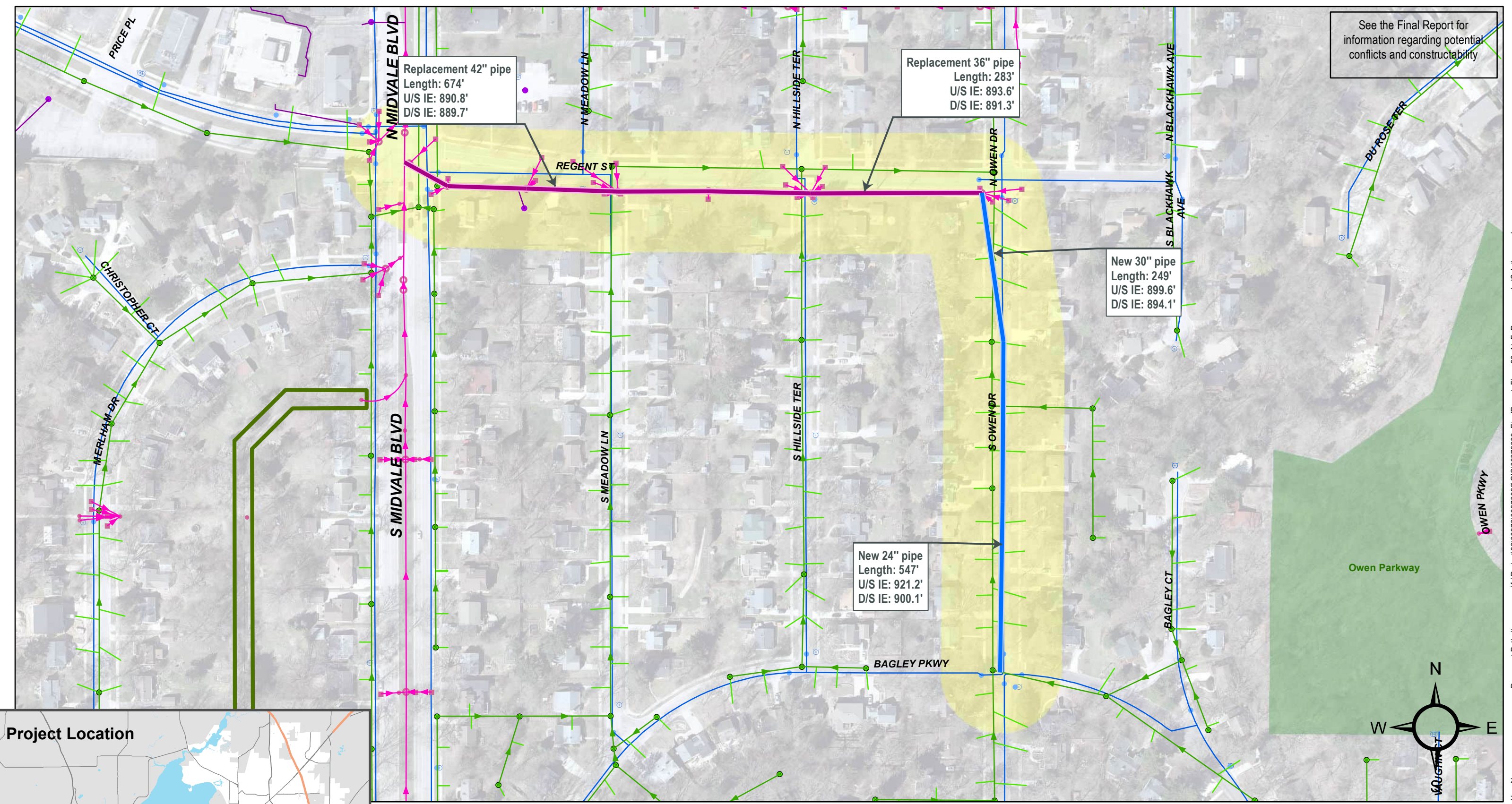
Replacement 42" pipe
Length: 346'
U/S IE: 936.2'
D/S IE: 932.4'

Replacement 48" pipe
Length: 303'
U/S IE: 931.9'
D/S IE: 927.7'

Replacement 54" pipe
Length: 1000'
U/S IE: 927.2'
D/S IE: 920.4'

Replacement 5x10' box
Length: 2,271'
U/S IE: 907.7'
D/S IE: 895.8'

Replacement 5x8' box
Length: 939'
U/S IE: 919.9'
D/S IE: 907.7'



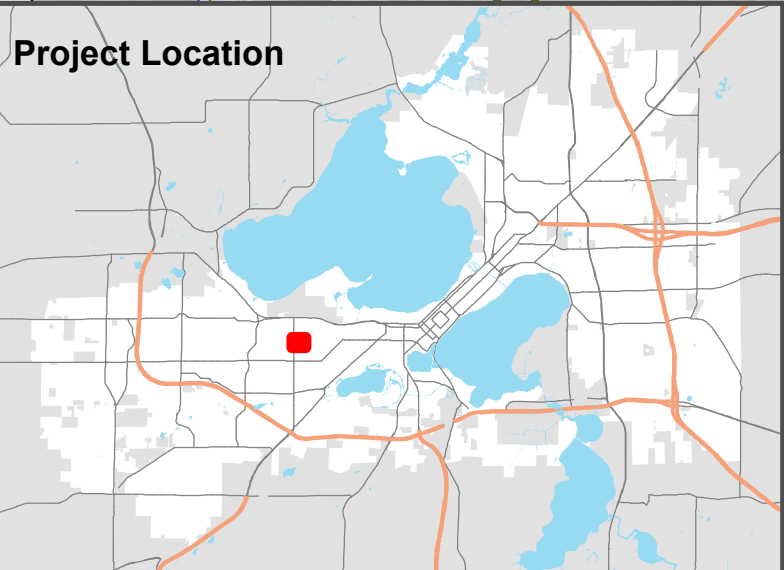
See the Final Report for information regarding potential conflicts and constructability

Replacement 42" pipe
Length: 674'
U/S IE: 890.8'
D/S IE: 889.7'

Replacement 36" pipe
Length: 283'
U/S IE: 893.6'
D/S IE: 891.3'

New 30" pipe
Length: 249'
U/S IE: 899.6'
D/S IE: 894.1'

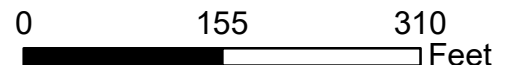
New 24" pipe
Length: 547'
U/S IE: 921.2'
D/S IE: 900.1'



- | | | |
|-----------------------|-------------------------------------|-------------------|
| Greenway | Private Stormwater Pipes--Approx | Sanitary Laterals |
| Storm Pipe | Private Stormwater Structures--A... | Water Main |
| Other Storm Structure | Sanitary Mains | Water Valve |
| Access Structures | SAS | Water Hydrant |
| Inlet | | Park |
- Recommended Improvements**
- Replacement Pipe
 - New Pipe
 - Replacement Box
 - New Parallel Box
 - Improvement Area of Interest

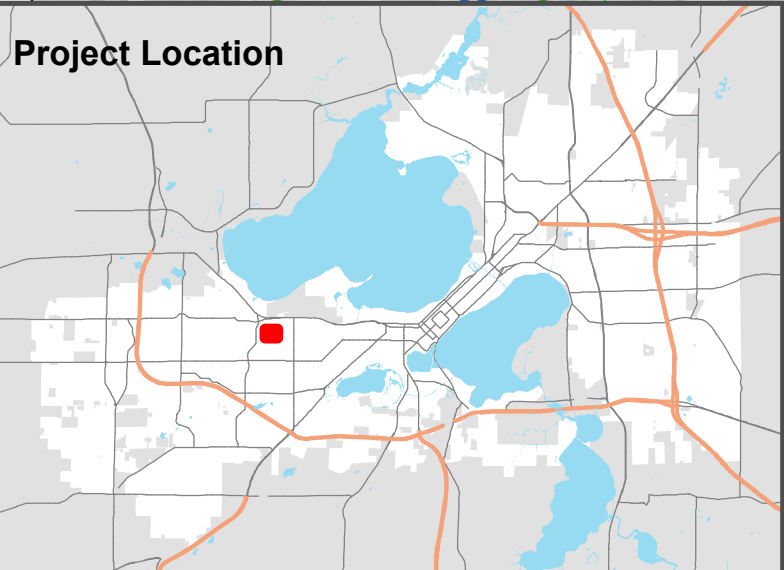
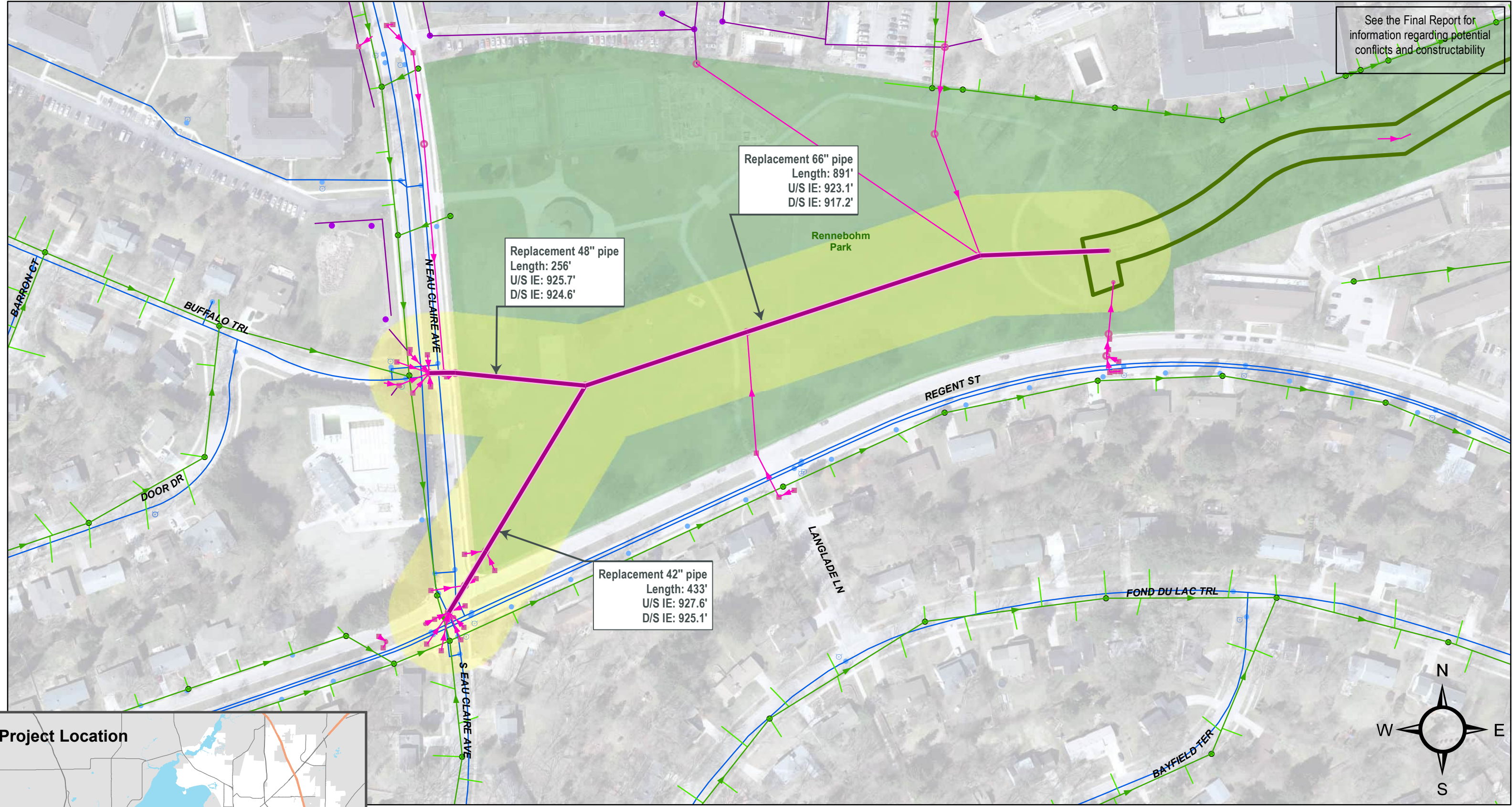
Regent St and Owens Dr Storm System Improvements

Figure 29 - D



Date: 12/26/2022

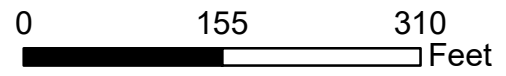
See the Final Report for information regarding potential conflicts and constructability



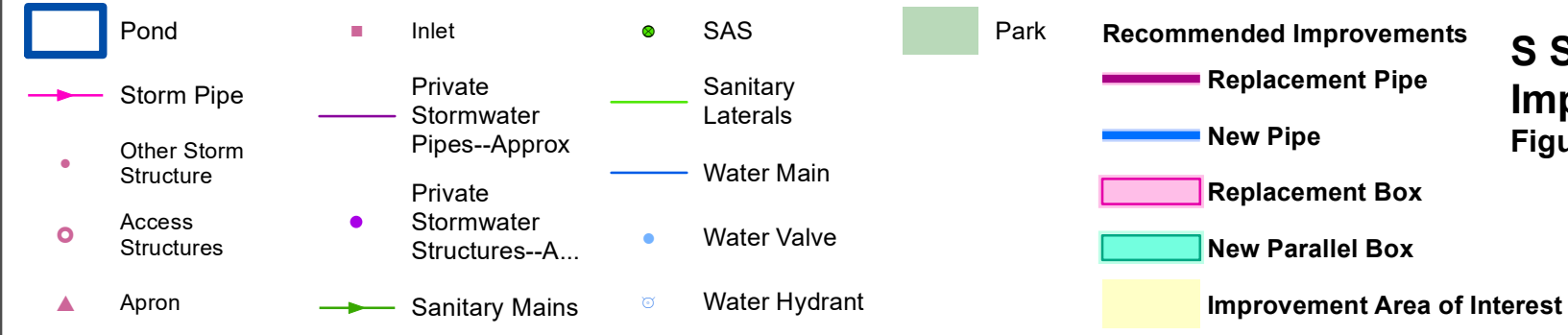
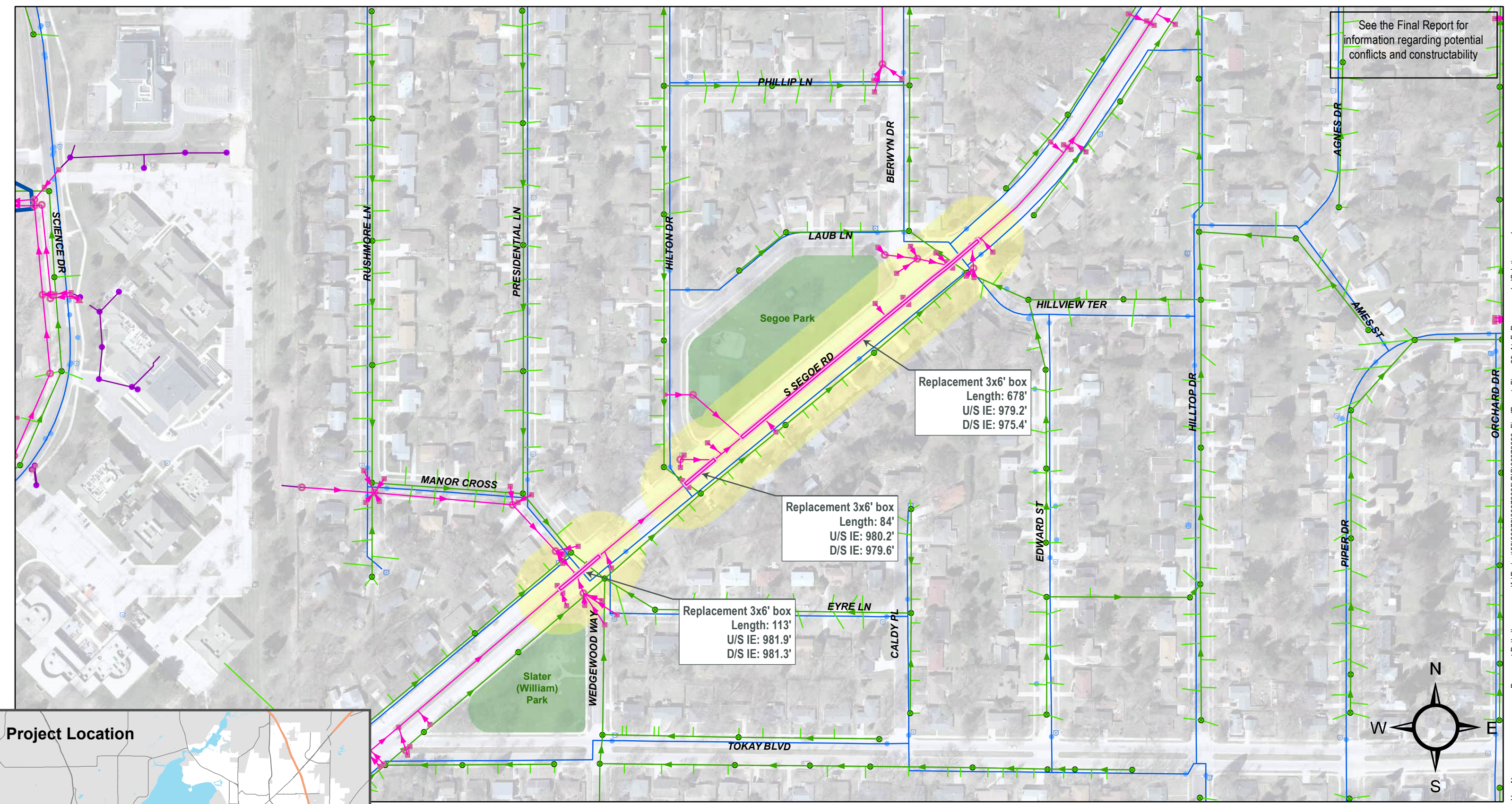
- | | | |
|-----------------------|-------------------------------------|-------------------|
| Greenway | Private Stormwater Pipes--Approx | Sanitary Laterals |
| Storm Pipe | Private Stormwater Structures--A... | Water Main |
| Other Storm Structure | Sanitary Mains | Water Valve |
| Access Structures | SAS | Water Hydrant |
| Inlet | | Park |

- Recommended Improvements**
- Replacement Pipe
 - New Pipe
 - Replacement Box
 - New Parallel Box
 - Improvement Area of Interest

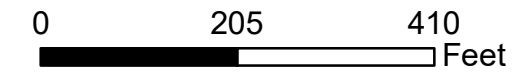
N Eau Claire Ave, Regent St and Rennebohm Park Storm System Improvements
Figure 29 - E



Date: 12/26/2022



S Segoe Rd Storm System Improvements
Figure 29 - F



Date: 12/26/2022

50% AEP Inundation Recommended Conditions

FIGURE 30
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

50% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- >6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

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20% AEP Inundation Recommended Conditions

FIGURE 31
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

20% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- >6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

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0 0.125 0.25 Miles



10% AEP Inundation Recommended Conditions

FIGURE 32
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

10% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

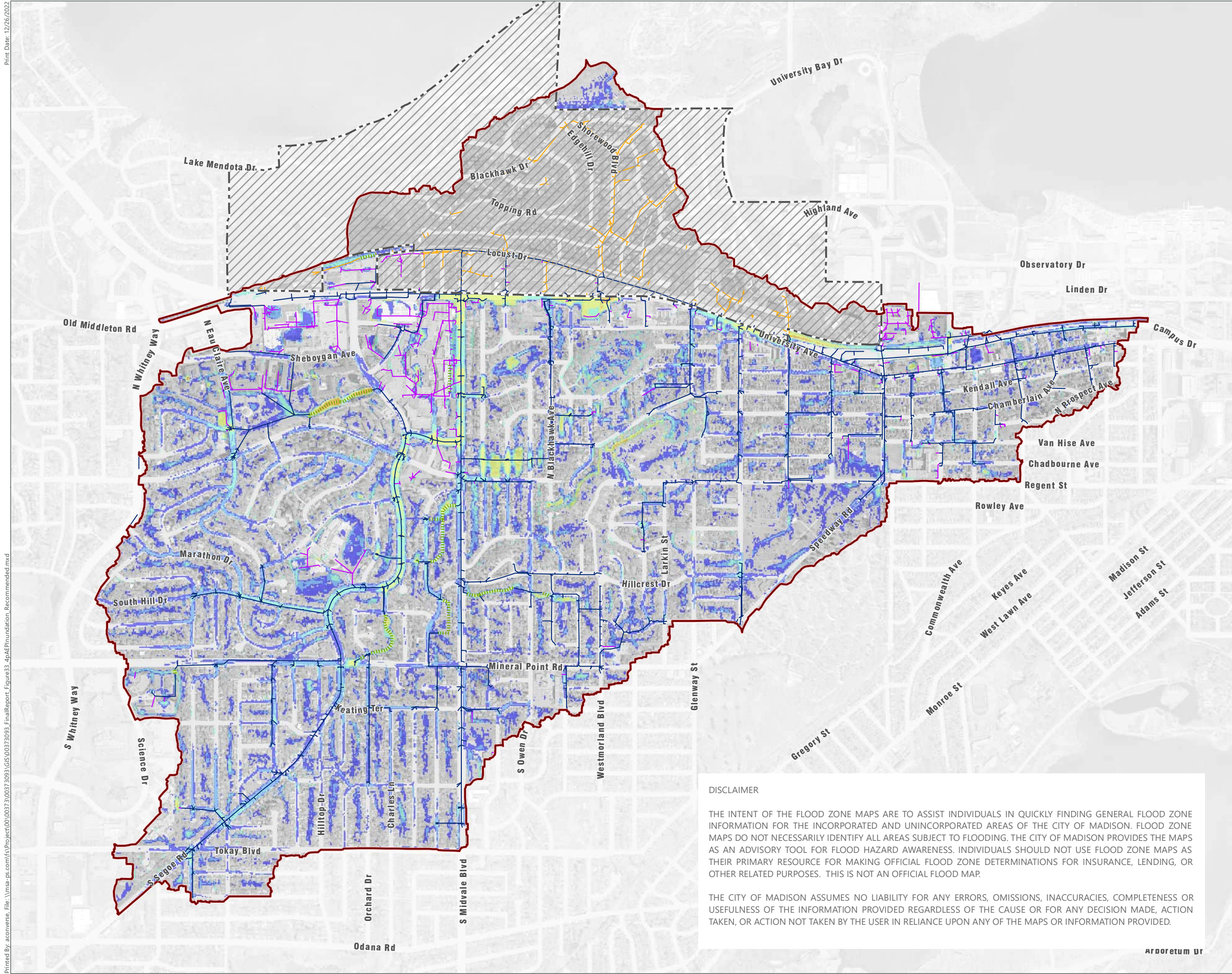
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- >6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

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4% AEP Inundation Recommended Conditions

FIGURE 33
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

4% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- >6

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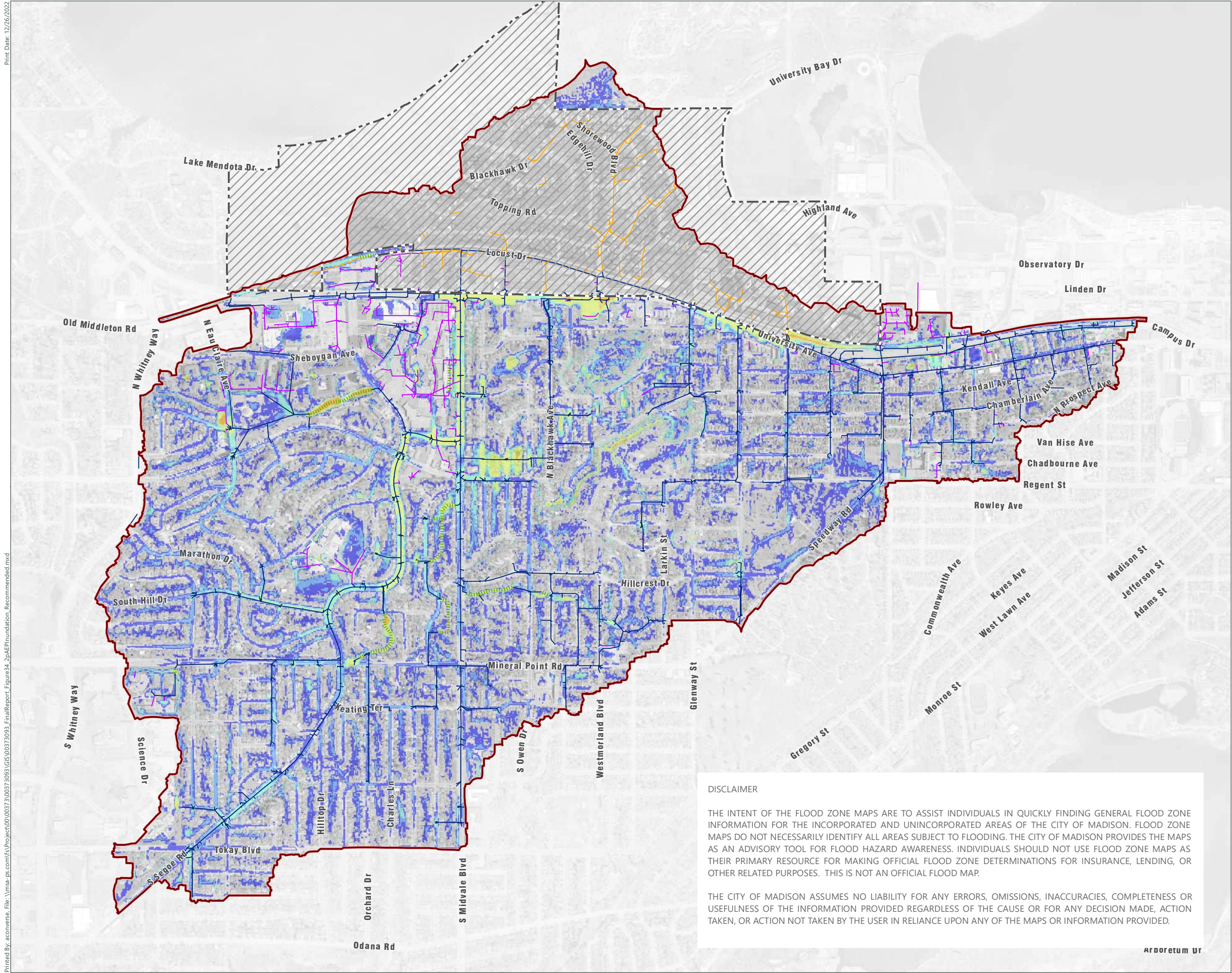
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Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison



0 0.125 0.25 Miles





2% AEP Inundation Recommended Conditions

FIGURE 34
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

2% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6

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Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison



0 0.125 0.25 Miles



1% AEP Inundation Recommended Conditions

FIGURE 35
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

1% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- > 6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

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0 0.125 0.25 Miles



Long 1% AEP Inundation Recommended Conditions

FIGURE 36
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow
- 1% Long AEP Storm
- Maximum Water Depth (ft)
 - 0.1 - 0.25
 - 0.25 - 0.5
 - 0.5 - 1
 - 1 - 3
 - 3 - 6
 - > 6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

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0 0.125 0.25 Miles



0.2% AEP Inundation Recommended Conditions

FIGURE 37
Willow Creek Watershed
Study Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow

0.2% Annual Exceedance Probability Storm

Maximum Water Depth (ft)

- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 6
- > 6

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison

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Appendix A: Modeling Guidance

MODELING GUIDANCE

Version 2021_08_27 (DRAFT)

Round 4 Watershed Studies

The City recognizes that an important aspect of modeling is professional judgement; and it will be up to the Consultant to appropriately define parameters, variables, and methodology. However, it is in the City's best interest to have relative uniformity amongst City models. This guidance document was developed to provide uniformity. Where inputs and assumptions differ from those outlined in this document, the Consultant will be expected to justify and document the differences and reasons for the differences.

The purpose of the watershed modeling is to construct planning-level models of the watershed to identify locations with significant conveyance system deficiencies. The identified solutions will be conceptual solutions, not design-level solutions.

City of Madison Flooding Level of Service Goals

1. 10-year design storm event:
 - a. No surcharging onto the street for up to the 10-year design storm; water shall be contained within the pipes and structures.
 - i. When using rain-on-grid hydrology, the goal is met if there is less than 0.25' of curb depth using the FHA method.
 - b. There are locations within the City where low points exist that pond water; these low points are excluded from this goal and will be addressed as streets are redesigned.
 - c. For locations limited by known inlet capacity, allow no more than 0.5 feet of water above storm sewer inlet rim.
2. 25-year design storm event:
 - a. Street to remain passable for emergency vehicles during 25-year design storm.
 - i. This is defined as no more than 0.5 feet of water on the centerline of the street for a length of 100-feet using the depth raster.
 - ii. To define the centerline of street, the County's centerline data (Dane County SDE – GISdw.DCL.RoadCenterline) should be used.
 - b. Note that the Watershed Study modeling approach will not explicitly account for cross flow conditions where more gutter flow on one side of the street can overtop the crown.
3. 100-year design storm event:
 - a. No home or business will be flooded during the 100-year design storm.
 - i. This is defined as no more than 0.5 feet of water at the 5-foot buffer around a structure.
 - b. Enclosed depressions to be served to the 100-year design storm (which can include safe overland flow within street, easements, greenways or other public lands).
 - i. For purposes of the watershed studies, enclosed depressions are defined as depressions in public right-of-way where stormwater needs to reach private property to overflow from the depression.
 - ii. Solutions will also be developed for enclosed depressions where the stormwater collected is solely from private property. In these cases, the solutions may be implemented thru public-private cooperation or solely by the private property owners.
 - c. Greenway crossings at streets to be served to the 100-year design storm.
4. 500-year design storm event:
 - a. Safely convey stormwater; i.e. limited impact on private property.
 - b. Limited impact is defined as no more than 0.5 feet of water at the 5-foot buffer around a structure.
5. Provide flooding solutions that do not negatively impact downstream properties.

Due to the inherent variability and complexity of stormwater conveyance systems, it is understood it may not be practical to meet the above level of service goals in all areas of the City.

Guidance for Solutions

1. For the purpose of the watershed studies "deficiencies" in the system shall be defined as existing infrastructure, drainage capacity, or system limitations that fail to meet the goals stated in 1-5 above.
2. Watershed deficiencies will be reviewed, and solutions will be provided up to, the 100-yr design storm.
3. In areas where flooding occurs in events exceeding the 100-year storm, those areas will not be prioritized for engineering solutions, but will be identified in existing conditions model for 500-year event storms.
4. Proposed solutions will be identified for only the publicly owned drainage system.
5. Drainage issues that are private (water from the public infrastructure such as streets, greenways, ponds and/or easements is not the cause of the drainage issue) will not require modeling solutions but should be noted, where possible, in the existing conditions analysis so staff may work with property owners if necessary. (See Also Hydraulics section of Modeling Guidance for discussion on private system existing conditions modeling.)

Emergency Vehicle Allowable Flood Depths (email from Fleet on 5/12/2020)

1. SUVs – up to 6-inches
2. Large Trucks – up to 3-feet
3. Ambulances, vans, and pick-up trucks – between 6-inches and 3-feet

MODELING PARAMETERS:

Initial model parameters are the following items:

1. Include storm sewers and culvert segments for the trunk line drainage system and major conveyance to that system. Additional conveyance components may be included if felt necessary by the modeler to understand the conveyance system drainage.
2. Inlet capacity will not be included in the model. It is assumed that sufficient inlets are present to accommodate stormwater. In areas where there is known chronic flooding that has been reported to Engineering, additional detail may be requested.
3. Incorporate significant existing storm water management facilities (public and private) into the model.
4. Subdivide provided outfall basins into smaller watersheds as needed in order to properly execute the model.
5. Coordinate System and Vertical Datum
 - a. Horizontal Coordinate System: NAD 1983 HARN WISCRS Dane County Feet (WKID 103412).
 - b. Vertical Datum: NAVD88 (pre 2007 adjustment) ft (City of Madison Datum + 845.6)
 - c. Various data sources have different horizontal and vertical datums, check datum for each data source prior to use.
 - d. When setting up PC-SWMM Models, the default coordinate system that looks like it matches the City's preferred coordinate system is not the same. PC-SWMM's default coordinate system is State Plane and the exact coordinate system the City uses is not in PC-SWMM's database. To create a PC-SWMM model with the same coordinate system:
 - i. Open up a new, blank model.
 - ii. Add one of the City's shapefiles with the preferred coordinate system.
 - iii. Then, in PC-SWMM, select that coordinate system as the default.
6. Monitoring Data Time Zone: Different sources of monitoring data use different time zones. Also, some adjust for daylight savings time whereas others do not. When using the monitoring data, check both the time zone and if the data is adjusted for daylight savings time.
7. Monitoring Data Review: Familiarize yourself with the location of the monitoring gage at each site. Also, visit the monitoring site following a rain event to review the site conditions for things that would

impact the measurements. For example, is there debris clogging anything?

8. Naming convention

- a. Names are limited to 20 characters where possible. Both PC-SWMM and XP-SWMM can take lengthy names but both indicate shorter is better for avoiding truncating names.
- b. Subcatchments:
 - i. Begin with Subcatchments naming convention provided by the City in the Outfall Basin feature class.
 1. Add a three-digit designator to the end of the name, beginning with 000
 2. As subcatchments are subdivided, increase the added designator by 1.
 3. Example: ME04-A-0014-H (*Provided by City*) → ME04-A-0014-H-MAD-C-000 (*For the original basin*) → ME04-A-0014-H-001 (*For first subdivision*)
 - ii. Final outfall basin feature class file, including supporting files used to compute runoff timing and volume parameters shall be part of the deliverables provided to the City of Madison.
 - iii. Note first downstream stormwater control practice as attribute in subcatchment feature class.
- c. Structures and Junctions:
 - i. Node (Junction/Storage/Outfall) names for existing structures shall retain the asset identification provided by the City.
 - ii. Proposed Structure names are to be determined by the Consultant but shall be given a "logical" name that reflects general location, function, or other.
 - iii. For junctions that need to be added that are storm sewer tees as constructed, use the downstream manhole / structure with "_01" added in increasing order moving from downstream to upstream. For example, the first junction added for a tee upstream of MI3350-001 would be MI3350-001_01
- d. Pipes:
 - i. Conduit names for existing pipes shall retain the asset identification provided by the City, except that:
 1. The first two letters (i.e AE, IN, etc) can be removed
 2. Leads with an asset ID that takes up all 20 characters can be shortened to the corresponding assigned ID. For example, IN3350-032_AS3350-007_3350-001 can be changed to 3350-032_3350-001_001
 - ii. Proposed Pipe names are to be determined by the Consultant but shall be named in a manner similar to the City pipe naming convention, which includes the upstream and downstream structure names.
- e. Channel/Street Flow Segments:
 - i. Conduit names for drainage-ways shall be named in a manner that identifies the greenway segment it represents by Greenway Node Number and the distance from the upstream end. Example: GR7541-062_125 would represent a channel segment that begins 125 feet into the North Door Creek Greenway – Sprecher Road Section.
 - ii. Conduit names for streets shall be named with "Rd_"[US_Node_Name]_[DS_Node_Name] and remove the first two letters in the node name similar to how pipes are named.
- f. Natural Channels:
 - i. Natural channel transects shall be named with the same ID as the conduit name.
 - ii. Street models as natural channels shall be named in a manner that is easily identifiable for the street or street type it represents.
 - iii. A shapefile shall be created documenting where natural channel transects are cut.
- g. Other SWMM Features (Weirs, orifices, etc)
 - i. Other SWMM features shall have readily identifiable names corresponding to the type of feature they are trying to model. For example, an orifice for a detention pond should have an ID that is "<Detention Pond ID>_ORIF_01", keeping within a 20 character limit.
- h. Ponds
 - i. Use the pond name identifier from GT-Viewer combined with a common name.

For example, the ponds at Odana Hills Golf Course would be "PD3461-001_OdanaHills"

- ii. Use abbreviation of name if unofficial full name creates a model name longer than 20 characters.
- i. Non-City owned infrastructure
 - i. Consultant may choose name if consistent naming convention is not created by entity that owns infrastructure
 - ii. If Consultant chooses name, all infrastructure owned by another entity shall start with the same few characters. For example, DOT infrastructure could all start with "DOT-" or Fitchburg owned infrastructure could start with "Fit-"

9. Data Notation

The GIS data describing the conveyance system is not complete. In some instances the modeler will be able to make assumptions based on available data. In other locations, the data will require survey. The City is tracking the accuracy of the data with the ultimate goal of having a complete record.

When the modeling is creating the GIS data describing the structures and pipes, they shall create a new attribute in their GIS data and categorize the data as the following:

- a. Structures:
 - Source_IE
 - Source_Rim
- b. Pipes:
 - Source_ToIE
 - Source_FromIE
- c. Private:
 - Notes
- d. Source –enter Number and text in bold in attribute
 0. **Converted:** legacy EI's taken from the structure, all EI's received the structures outgoing EI by default when converted in 2020. *This does not mean this data is ***better*** than the survey data, if it looks suspect, you should investigate and try to clarify the source (especially for pre-2005 data, or structures/pipes within ponds/gwys)*
 1. **Survey:** Survey data (current)
 2. **AsBuilt >2004:** As-Built (2005-present) since City used GPS-Survey Grade to set control improving consistency citywide
 3. **AsBuilt pre-2005:** As-Built (pre-2005)
 4. **ConstPlan:** Construction plans
 5. **GTV:** GTV in-line text, no plans to support
 6. **Interpolate:** interpolated (saddled structure had inverts on either side and interpolated—should eventually be surveyed)
 7. **Inferred:** best guess, (can't get survey now or is pulled from LiDAR, but should eventually be surveyed)
 8. **No data:** Needs survey (searched and unable to find—should eventually be surveyed, but a higher priority)
- e. When creating a model, Engineers will verify/update:
 - i. Structures:
 - Source_IE
 - Source_Rim
 - Project_No
 - ii. Pipes:
 - Source_ToIE
 - Source_FromIE
 - Project_No
 - iii. Private:
 - Notes
 - PLP_address
 - GTV

- Survey (survey will need to confirm all fields)

10. Rainfall

a. MSE4 24-hour Distribution and NOAA Atlas 14 Depths

Recurrence Interval (years)	Rainfall Depth (inches)
1	2.49
2	2.84
5	3.45
10	4.09
25	5.02
50	5.74
100	6.66
200	7.53
500	8.94

- ##### b. Long-Duration Storm – Two 24-hour, 100-year MSE4 storm events with the time between peak rainfalls shorted from 24 hours to 12 hours.

11. Hydrology (SWMM Method with Horton Infiltration) (References: A, B, C, J, L)

- Parameters listed are default parameters and may need to be adjusted based on calibration data.
- a. Subcatchment Detail for Street Drainage
 - i. Contributing area to the existing storm sewer system that is to be modeled (Determined on a watershed by watershed basis)
- b. SWMM Routing Parameters (if calibration is not available to adjust parameters)
 - i. Percent Impervious:
 - 1. In areas where impervious areas are delineated:
 - a. Use impervious/Pervious areas from City provided shapefile.
 - 2. In areas where Impervious areas are not delineated:
 - a. Use City provided WinSLAMM land use file and the “HowTo_CalculateCN” Document.
 - b. Areas not delineated in City Provided WinSLAMM land use file shall defer to Dane County Land Use Map.
 - c. Match WinSLAMM land uses with Dane County Land Use.
 - 3. Note: Impervious/Pervious layer has been developed by a consultant and has gone through their internal QC process. Consultants for each study should review the data in their project area to check that all data is available.
 - a. Data based on 2018 aerial photo and 2016 LiDAR coverage
 - ii. DCIA
 - 1. In areas where impervious areas are delineated:
 - a. Use impervious/Pervious areas from City provided shapefile.
 - 2. In areas where Impervious areas are not delineated:
 - a. Reference WinSLAMM Standard Land Use DCIA Spreadsheet
 - iii. Width – Estimated based on subcatchment shape. Estimation methodology shall be documented.

A single width shall be calculated for the entire subcatchment and used for all three sub-areas.

It is expected Width is one of the first calibration parameters for peak flow.
 - iv. Slope – Computed manually or estimated based on LiDAR. Computation or estimation methodology shall be documented.
 - v. In XP-SWMM, each subcatchment is to be split into area of (1) DCIA, (2) non-DCIA, and (3) pervious area. Within the model, the non-DCIA shall be routed to

the pervious area.

- vi. In PC-SWMM, indicate the percent being routed to pervious in the subcatchment attribute.

c. Horton Infiltration

- i. For typical urban pervious area (Based on range of values for different soil types, moisture conditions, and vegetation conditions found in Reference A):

HSG Group ^a	Max Infil. Rate (in/hr)	Min Infil. Rate (in/hr)	Decay Rate (1/hr)	Dry Days ^b	Maximum Infiltration Volume (in)
A	4.0	1.0	4.0	3.1	
B	2.0	0.5	4.0	4.4	
C	1.0	0.2	4.0	7.0	
D	0.5	0.1	4.0	9.9	
Water	0	0	0	0	

^aFor HSG listed as A/D, B/D, C/D, the default approach will be to assume the HSG associated with the lower infiltration rate (HSG D).

^bUse equation 4-12, pg 99, SWMM Reference Manual Volume 1 – Hydrology (Revised), January 2016

- ii. Impervious Manning's n – 0.016
 - iii. Pervious Manning's n – 0.20
 - iv. Depression Storage for Impervious – 0.05 inches
 - v. Depression Storage for Pervious – 0.15 inches
 - vi. Zero Depression Storage – 25 percent
 - vii. Factors for adjusting (L)
 - 1. Forest – Multiply max and min infiltration rates by 2.
 - 2. Farmland (row crops) – Multiply max and min infiltration rates by 1.2.
 - 3. Farmland (close crops) - Multiply max and min infiltration rates by 1.8.
 - 4. Other land uses – discuss with City staff
 - viii. Area-weight the Horton Infiltration parameters for each subcatchment based on the area of each soil type within a subcatchment. Remove impervious area from area-weighting.
 - ix. It is understood the NRCS/SCS updates the soil mapping at various times. The project teams will identify a date the soils data will be downloaded and that will be the data used for the duration of the project.
- d. Evaporation: Turn off evaporation from calibration and design storm event runs.

12. Hydrology (SCS CN Hydrology – ONLY USE WHERE DESIGNATED BY CITY) (References B, K)

- a. Runoff Curve number, Percent Impervious, Directly Connected impervious Area
 - i. In areas where impervious areas are delineated:
 - 1. Use impervious/Pervious areas from City provided shapefile.
 - 2. Impervious areas shall use a runoff curve number of 98.
 - 3. Urban pervious areas that are mowed and maintained can assume the area is Open Space in good condition listed in Table 4-9 of Reference B.
 - 4. All other pervious land uses shall match descriptions listed in Table 4-9 of Reference B.
 - 5. Create a composite subbasin runoff curve number that incorporates both impervious and pervious areas.
 - ii. In areas where Impervious areas are not delineated:
 - 1. Use City provided WinSLAMM land use file and the “HowTo_CalculateCN” Document.
 - 2. Areas not delineated in City Provided WinSLAMM land use file shall defer to Dane County Land Use Map.
 - 3. Match WinSLAMM land uses with Dane County Land Use and repeat item “i.” of this section.
 - 4. Impervious areas shall use a runoff curve number of 98.
 - 5. Urban pervious areas that are mowed and maintained can assume Open

Space in good condition listed in Table 4-9 of Reference B.

6. All other pervious land uses shall match descriptions listed in Table 4-9 of Reference B.
7. Create a composite subbasin runoff curve number that incorporates both impervious and pervious areas.

b. Routing Parameters

- i. Width - In PC-SWMM only, Estimated based on subbasin shape. Estimation methodology shall be documented. It is expected that width is one of the first calibration parameters to be adjust for peak flow.
- ii. Slope - In PC-SWMM only, computed manually or estimated based on LiDAR. Computation or estimation methodology shall be documented.
- iii. Time of Concentration - In XP-SWMM only, calculate each watershed time of concentration based on equations listed in SCS Urban Hydrology for Small Watershed, 2nd Ed., (TR-55), June 1986 (Reference K). The max flow length for sheet flow is 75 feet in urban areas and 150 feet in agricultural/natural areas.
- iv. In XP-SWMM and PC-SWMM, the percent impervious shall be zero and the composite runoff curve number shall incorporate impervious and pervious areas.

13. 1D Hydraulics (References: A, B, D, E, F, G)

- Dynamic mode with constant / variable timestep sufficient to model system accurately.
 - Conduit lengthening shall not be used unless prior approval from City on reason.
 - Parameters are default parameters and may need to be adjusted based on calibration data.
 - This list is not intended to be exhaustive.
- a. System to be Modeled
- i. Public
 1. Standard: Trunk line and major conveyance components to trunk line.
 2. Process for Exceptions: Provide justification for conveyance components not included.
 3. Use engineering judgement for inclusion of additional detail beyond this standard.
 - ii. Private
 1. Standard: Not included
 2. Process for requiring inclusion of private pipes:
 - a. Stormwater management detention facilities providing significant detention
 - b. When necessary to understand the functioning of the public system. For example, the West Towne Mall parking lot drainage system.
 - iii. Greenways and major surface drainages
 - iv. Significant stormwater detention facilities (public and private).
 1. Private systems may be simplified if serving a single site.
 2. Provide justification for detention facilities not included.
- b. Loss Coefficients (see drawing at end of document)
- i. Entry
 1. Culverts – Select Inlet Type based on the Help File or HEC-RAS Hydraulic Reference Manual
 2. Storm Sewer (internal at MHs) = 0.05
 3. Storm Drainage Structures (MH) at 45 degree bend = 0.25
 4. Storm Drainage Structures (MH) at 90 degree bend = 0.5
 5. For culverts and entrances to storm sewer from an open channel or pond, both the energy loss coefficient and the inlet control (culvert code) shall be used.
 - ii. Exit
 1. Culverts –
 - a. Exit closed conduit to open channel = 0.5
 - b. Exit closed conduit to lake or pond = 1.0

2. Storm Sewer (internal at MHs) = 0.05
 3. Storm Drainage Structures (MH) at 45 degree bend = 0.25
 4. Storm Drainage Structures (MH) at 90 degree bend = 0.5
 - c. Coefficient of Discharge
 - i. Weirs
 1. Sharp Crested – 3.0
 2. Roadway embankment – 2.6
 3. Flatter overflow – Use engineering judgment
 - ii. Orifices
 1. 0.6
 - d. Manning's n
 - i. Pipes
 1. Concrete Pipe: 0.013
 2. Other n values shall be chosen within generally acceptable ranges.
 - ii. Channels
 1. Use Chow's Open Channel Hydraulics, Reference E
 - iii. Bank Flow, including developed urban areas
 1. Use Chow's Open Channel Hydraulics, Reference E
 - e. Transect Placement and Modifiers
 - i. Splitting long open channels
 1. Changes in cross section
 2. Significant changes in slope and roughness
 3. Overflow points
 - ii. Segment Lengths
 - iii. Channel Geometry
 - iv. Provide shapefile where natural channel transects are selected along with XS Identifier
 - f. Tailwater Conditions:
 - i. Lake Mendota: one foot over Summer Maximum – 851.10
 - ii. Lake Monona: TBD
 - iii. Lake Wingra (100-year WSE): 848.0
 - iv. Yahara River between Lakes Mendota and Monona: TBD
 - g. Inlet Clogging Factors
 - i. Continuous Slopes
 1. Street slope < 1% - 25% Clogging
 2. Street slope >= 1% - No Clogging
 - ii. Sags – 50% Clogging
14. 2D Data (References: A, G, H, I)
- a. Surface Roughness – The average Manning's n may vary by land cover / land use. Referencing TR-55, the following roughness can be used for sheet flow conditions. Choose based on professional judgement and document in the report.
 - i. Impervious areas - 0.1
 - ii. Turf grass areas - 0.24
 - iii. Wooded – 0.4
 - iv. Prairie – 0.15
 - v. Other – reference TR-55
 - b. Channel Roughness: Where the 2D surface experiences channel flow, rather than sheet flow, utilize the Manning's n values for open channels
 - c. There is not currently a city-wide impervious area layer. The consultant may choose to delineate the impervious area for the watershed.
Or, the existing data may be utilized. The following assumptions can be made using the existing land use data:
 - i. For non-residential parcels, impervious and pervious area is available, therefore, that shall be used.
 - ii. A percent impervious is available for residential parcels. Calculate a composite

roughness using the percent impervious area. Remove roofs from the composite roughness calculation – reference the Dane County land use for residential roofs. (roofs will be entered as blocked obstructions)

- iii. Average the roughness within the ROW based impervious and pervious area.
- d. Blocked Obstructions – enter roofs as Inactive Areas in XP-SWMM and Obstructions in PC-SWMM
 - i. Non-residential – use City impervious area data for roofs
 - ii. Residential – use Dane County roof layer
- e. Grid cell/mesh size: Use size that balances model run time and sufficient 2D overland flow detail.
- f. Grid/mesh orientation: Where possible, align grid/mesh with major channel flow direction. If not practical, then use orientation that minimizes run time.

15. Rain-on-Grid Analysis (Do not use without discussion with City)

a. Hydrology

For a full study area Rain-on-Grid model, no nodes or pipes should be active within the Runoff Mode.

- i. Rainfall - All runoff is generated using Rainfall / Flow Area layers. Individual layers shall be created for each rainfall event, with only the applicable one active during each scenario. Rainfall distributions stated above in Section 9 shall be used.
- ii. Landuse – Layers for the following land uses must be created: Buildings, Impervious, Turf Grass, Wooded, Prairie, Water and any other applicable layers. Land use layers for Turf Grass, Wooded, Prairie, and any other pervious land coverage, shall be additionally divided up into Hydrologic Soil Groups A, B, C, and D. These layers should cover the entire study area. Under the Land use data tab, inputs for Manning's Roughness, Rainfall Abstraction, and Infiltration must be completed.

1. Manning's Roughness:

- a. Buildings – Variable roughness must be used. A Depth-Roughness relationship as follows is appropriate:

Depth (ft)	Roughness
0.00	0.01
0.30	0.01
0.31	0.1
10.0	0.3

- b. Impervious – A constant roughness of 0.016
- c. Turf Grass, Prairie, Wooded, and other Pervious – Variable roughness must be used to account for sheet flow at low flow depths. The consultant shall use roughness coefficients stated above in Sections 10.c and 12.a to develop these roughness curves.
- d. Water – A constant roughness of 0.01.

2. Rainfall Abstraction:

- a. Buildings and Impervious – Initial Abstraction of 0.04 inches (XP-SWMM Default). Continuing loss should remain 0.0.
- b. Pervious - This shall remain unchecked, as Initial and Continuing losses will be accounted for via the Horton Infiltration parameters.

3. Infiltration:

- a. Buildings and Impervious – This shall remain unchecked
- b. Pervious – Horton Infiltration as described above in Section 10.c shall be created for each pervious land use layer.

b. 2D Model Settings

- i. Grid extent shall cover the entire study area.
- ii. Default area type shall be set to Active Area. There should not be any inactive areas within the model.

- iii. Default land use should be set to one of the pervious layers (suggested to use layer with largest total area). However, this should not have any impact on the modeling if there is full coverage of land use layers.
 - iv. Head boundaries shall be set anywhere where surface flow is able to leave the study area.
- c. 1D Model Network
 - i. The 1D storm sewer network shall be extensive enough to include enough inlets throughout the watershed so that surface water can adequately pass from the 2D surface into the 1D model. Multiple inlets at the same location may be combined to a single node. Inlets either side of the street shall remain separate nodes.
 - ii. Each inlet node must have Link Spill Crest to 2D checked. Each culvert inlet/outlet must have Link Invert to 2D checked. If calibration shows not enough flow is entering each inlet node, Spill Crest elevations may be lowered below the 2D cell elevation (0.5 ft is an acceptable initial lowering value)
- d. 1D/2D Interface Lines at Intersections
 - i. In steeper watersheds, the water on the grid may not enter the pipe due to the limitations of the xp2d grid module. Pipes should be reviewed after a simulation for this occurrence. Where this occurs, add 1D/2D interface lines to connect the flow at appropriate intersections to the 1D node.

16. Suggested Proposed Solutions Organization

- a. The Proposed Solutions simulations should be set up in the following way (unless discussed with City staff first). The purpose is to have a model with just the proposed storm sewer improvements, just the regional improvements, and then both.
 - i. Add the proposed storm sewer to the Existing Conditions Model as a Scenario.
 - ii. Once complete, save the model file with a new name. Add the regional solutions in the Base Scenario, keeping the proposed storm sewer as a scenario.

17. Non-Modeling Data

- a. When utilizing XP-SWMM, provide attributed describing the source of data in the representative GIS feature classes
- b. When utilizing PC-SWMM, also add attributes to the entities describing their data sources.

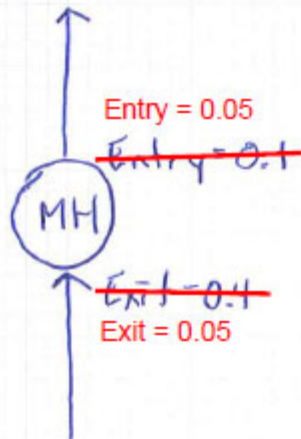
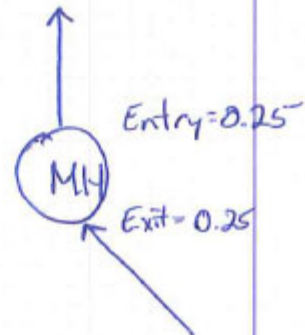
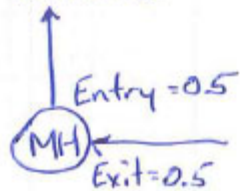
18. Solutions

- a. Analysis – what are the underlying causes of flooding in:
 - i. Areas reported in the “Flood Download” from City staff
 - ii. Other flooded areas in the modeling not identified in the “Flood Download”
 - 1. If more than 10 total areas, work with City staff to prioritize locations to evaluate
 - iii. City to identify suggested solutions and provide to Consultant for consideration
 - iv. Consultant to identify solutions independently and take lead on overall solutions for watershed
- b. Prioritize Solutions
 - i. Property Damage
 - ii. Major arterials where emergency vehicles cannot get through
 - iii. More criteria - TBD
- c. Displaying solutions/Order of solutions
 - i. Show each solution independently and then combined
 - ii. Order
 - 1. Property/pipe owned by Stormwater Utility
 - 2. Pipe size needed to solve remainder of issues
 - 3. Other public properties
 - a. Janet will provide areas where there are non-starters in Parks
 - 4. Private properties
 - iii. Show structures removed from the 100-yr event

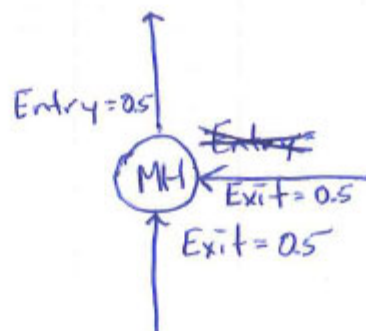
1. Intersect the flood raster with the building outlines
 2. Buffer buildings by 5-feet to account for inaccuracies of building footprint layer
 3. Any building outline that intersects the buildings is considered “flooded”, if depth of intersection is 6 inches or greater.
- d. In SWU-owned land all proposed grading must have the following conditions for maintenance access:
- i. be offset from the property line on 1 side by 15 feet (parallel to channel flow, from Pond access to pond outlet)
 1. Shall be extended to reach all priority inlets or sanitary access structures within greenway
 - ii. All proposed berms must be 10 feet wide @ top of berm
 - iii. Slopes no steeper than 4:1
- e. Overlay TIP map with inundation mapping to understand where immediate future project opportunities are
- f. Freeboard – City does not have a minimum freeboard requirement
- g. Properties adjacent to greenway and new greenway crossings – Current ordinance states property low building opening must be 4’ above invert of downstream greenway street structure crossing. Therefore, may need to make structures wider, instead of deeper, to not flood upstream properties

REFERENCES

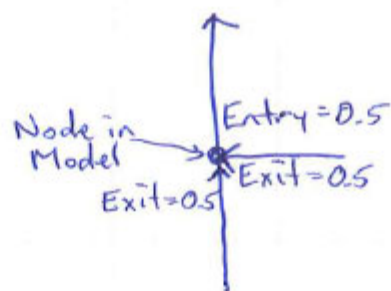
- A. Model Help Files and User Forums
- B. Storm Water Management Model version 5.1 User’s Manual. (Available at: <https://www.epa.gov/water-research/storm-water-management-model-swmm-version-51-users-manual>)
- C. SWMM reference manual volume I – hydrology (Available at: <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockkey=P100NYRA.txt>)
- D. SWMM reference manual volume volume II – hydraulics (Available at: <https://nepis.epa.gov/Exe/ZyPDF.cgi/P100S9AS.PDF?Dockkey=P100S9AS.PDF>)
- E. Chow, Open Channel Hydraulics, 1959
- F. HEC-RAS Hydraulic Reference Manual. (Available at: <https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%205.0%20Reference%20Manual.pdf>)
- G. ASCE Two-Dimensional Modeling Using HEC-RAS, Lecture 8 – Troubleshooting and Reviewing, Page 31; 2017.
- H. Australian Rainfall & Runoff Revision Projects, Project 15: Two Dimensional Modeling in Urban and Rural Floodplains, November 2012.
- I. FLO-2D Reference Manual, FLO-2D Software, 2012.
- J. ASCE Manual of Engineering Practice No 28.
- K. SCS Urban Hydrology for Small Watershed, 2nd Ed., (TR-55), June 1986
- L. Found during calibration in the Pheasant Branch Watershed. Area underlain with Prairie du Chein geology. Areas with other geology will need to select appropriate multipliers.

Straight-Through
Manhole45° Bend
Manhole90° Bend
Manhole

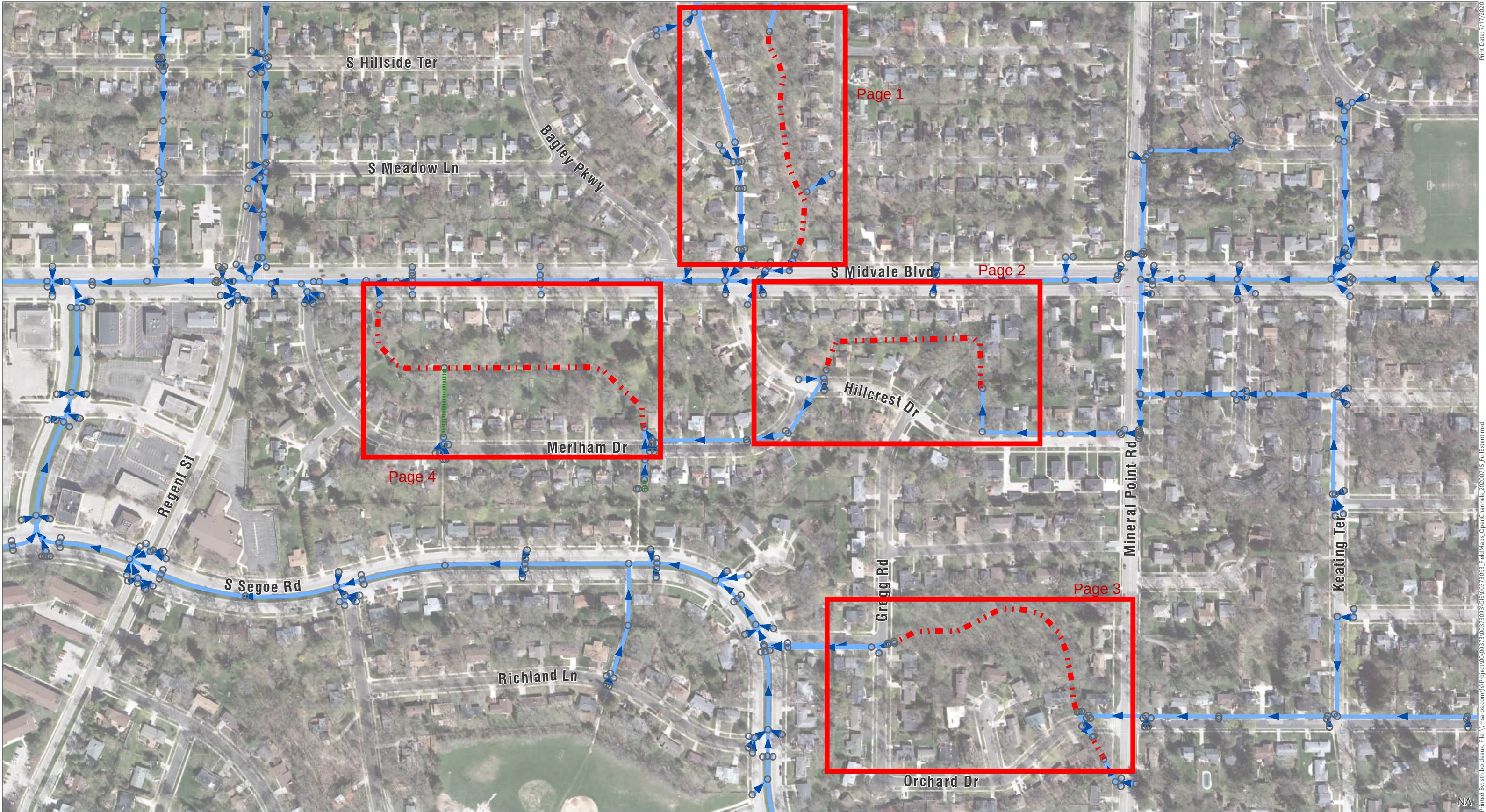
TEE Manhole



TEE (No Manhole)



Appendix B: Greenway/Channel Inspection Photolog 2020



Data Sources:
 Storm System, Open Channels, Lakes & Rivers:
 City of Madison
 Road Centerlines & Aerial: Dane County



- Storm Sewer Structures
- ▶ Stormwater Pipe
- ▬ Ditch/Swale
- ▬ Open Channel
- ▬ Lakes and Rivers

Open Channels

Willow Creek Watershed

City of Madison
 City of Madison, Dane County, WI



Data Sources:
 Storm System, Open Channels, Lakes & Rivers:
 City of Madison
 Road Centerlines & Aerial: Dane County

0 50 100 Feet

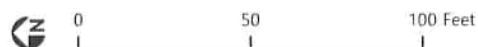
- Storm Sewer Structures
- Stormwater Pipe
- Ditch/Swale
- Open Channel
- Lakes and Rivers

Open Channels
Willow Creek Watershed
 City of Madison
 City of Madison, Dane County, WI

Print Date: 7/15/2020
 Printed By: smorison, File: \\msa-pc.com\15\Project\00373\00373093\00373093_Fields\Maps_OpenChannels_20200715.mxd



Data Sources:
Storm System, Open Channels, Lakes & Rivers:
City of Madison
Road Centerlines & Aerial: Dane County



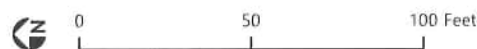
- Storm Sewer Structures
- ➡ Stormwater Pipe
- Ditch/Swale
- - - Open Channel
- Lakes and Rivers

Open Channels Willow Creek Watershed

City of Madison
City of Madison, Dane County, WI



Data Sources:
 Storm System, Open Channels, Lakes & Rivers:
 City of Madison
 Road Centerlines & Aerial: Dane County



- Storm Sewer Structures
- ➡ Stormwater Pipe
- Ditch/Swale
- Open Channel
- Lakes and Rivers

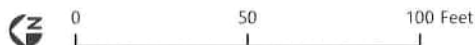
Open Channels

Willow Creek Watershed

City of Madison
 City of Madison, Dane County, WI



Data Sources:
Storm System, Open Channels, Lakes & Rivers:
City of Madison
Road Centerlines & Aerial: Dane County



- Storm Sewer Structures
- Open Channel
- Stormwater Pipe
- Lakes and Rivers
- ... Ditch/Swale

Open Channels
Willow Creek Watershed
City of Madison
City of Madison, Dane County, WI



Photo 1
Channel outlet
42" RCP FES w/Grate
Debris and heavy vegetation



Photo 1a
Looking down at erosion near culvert inlet
Debris and heavy vegetation



Photo 2
Channel looking downstream.
Becoming overgrown



Photo 3
Outfall on left side of channel.
18" CMP



Photo 3a
18" CMP
Corrosion on bottom



Photo 4
Channel looking downstream.



Photo 5
Primary outfall
36" RCP
FES



Photo 6
Raised sidewalk
exposed rebar on left side
6' w x 12" h at edge, 13" h at midpoint



Photo 7
Channel outlet
42" RCP heawall, socket end
7' x 30" Rectangular channel



Photo 8
First bend in channel upstream of outlet
Note cantilever for bridge abutment



Photo 9
7'w x 20" h channel with two wooden bridges



Photo 10
Channel outfall
48" RCP



Photo 10a
48" RCP outfall
Missing concrete in invert



Photo 11
Dual 42" CMPs
Square Headwall



Photo 11a
Some Corrosion on Left channel outlet



Photo 11b
Sediment build-up on right channel outlet

Photo 12

No defined channel
Evidence of substantial sediment movement



Photo 13





Photo 14
Outfalls into channel
Left - 36" CMP
Middle - 36" CMP
Right - 24" RCP (end sleeved CMP)



Photo 14a
Left outfall - 36" CMP
Downward bend along length



Photo 14b
Middle outfall - 36" CMP
Bend along length



Photo 14c
Right outfall- 24" RCP
Concrete pipe with CMP sleeve extension



Photo 15

Box Culvert with chamfered top edge
30" tall x unknown width
Culvert necks down ~5' going under Midvale Blvd
7' w x 30" h rectangular channel



Photo 16

Outfall coming into the side of channel
~43" x ~26" CMPA (42" x 29" = likely standard size)
Heavy vegetation surrounding
Large rocks within culvert



Photo 16a
~43" x ~26" CMPA (42" x 29" = likely standard size)
Rocks and sediment build-up within culvert



Photo 17
7' w x 30" h rectangular channel
Clean and very good condition



Photo 18

Outfall into channel

Left- ~57" x ~37" CMPA (57" x 38" = likely std size)

Middle- ~54" x ~38" CMPA (57" x 38" = likely std size)

Right- 36" RCP

* Directions are referenced to channel flow

Appendix C: Inlet Capacity Discussion

Appendix C: Inlet Capacity Discussion

The Willow Creek watershed model was constructed using the rain-on-grid approach, and as per the scope of work for this specific study, inlet capacity analysis was not included in this watershed study. MSA is worked with City staff to evaluate inlet capacity against drainage capacity at several areas of interest but it was not formally documented by MSA. Communication on this topic was conducted via email with City Staff, and the pertinent information related to that discussion is included below.

Intersections Identified by City Staff as Potentially Inlet Restricted

(Email from Greg Fries, 07/15/2021)

1. "Intersection of Buffalo and Eau Clarie
2. Intersection of Hillcrest and S Franklin (sorry this is Wingra)
3. Enclosed depression on McKinley Street
4. Enclosed depression on Bluff St West of Ridge
5. Enclosed depression on Palomino Ln
6. Enclosed depression on Eugenia Ave

I looked over the rest of the watershed and it really looks pipe limited to me in pretty much every case."

Direction provided to MSA by the Project Manager

(Email from Lauren Striegl, 08/13/2021)

"...we had discussed that, while one of the 10-yr flood goals involves inlet capacity, we actually wrote inlet capacity evaluation out of the scope of the Willow Creek watershed study. That said, I reached out to Greg and asked him if he could ID areas that he thought might be inlet-limited vs pipe-limited, particularly in smaller events. He came back with the following, and indicated he'd like a rough analysis of whether these are indeed inlet-limited.

My gut feeling is that your model is really not set up to evaluation inlet capacity... I feel like the best approach to this would be a combination of work from both of us. My proposal would be that Alistair would provide the capacity of the pipes downstream of each of these from his model (I'd assume that the 10-yr event is enough to fill them up, but if not, whatever event is), and I could take a look at the inlet configuration at each low point and use some back-end spreadsheet math to calculate out the inlet capacity..."

Recommended methodology provided to the City by MSA

(Email from Eric Thompson, 08/16/2021)

“... I think we can summarize what you are asking for somewhat simply – although I think we could use a little more input from the City. I would envision that this will come in the form of a series of maps where you’ve circled the pipe lengths in question. This will allow us to focus on just these areas rather than dump out a potentially confusing mass of data that will be hard to sift through. I think we (Amber) can provide the base maps

I’d envision for each intersection of concern (the reach of pipes in question) we’d export the following:

1. Manning full-flow capacity (probably this will be calculated from raw input data)
2. Q2, Q5, Q10, Q25
3. Upstream MH rim
4. Z2, Z5, Z10, Z25 for Upstream MH

I think between all this data we should be able to determine whether any pipe is flowing less than full, surcharged but not to street level, or surcharged to street level. “

Direction provided to MSA by the Project Manager

(Email from Lauren Striegl, 10/08/2021)

“... I would like your group to pull the data Eric describes in (2)(a-d) below for each of the pipes shown in yellow in the attached Word doc (complete with really official screenshots). Go ahead and just provide that information in a simple table, with each pipe IDed by upstream structure ID, downstream structure ID, and pipe size. That will give me just enough material to make sure I have the correct pipe. An email with this information is just fine. I will then look at our maps and records and figure out how many inlets there are at each location of concern, what types they are, and their rough capacity, and compare to the pipe info you give me. I’ll clean everything up and present the analysis to Mr. Fries.

For now, please do not feel the need to document this in your existing conditions report. If this ends up being included, my preference would be to have you just note that the City did some inlet capacity stuff, but for now let’s just assume they’re separate....”

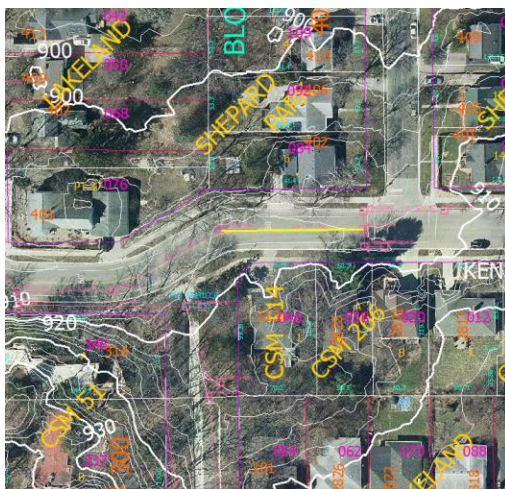
Buffalo Tr/N Eau Claire Ave



Enclosed depression on McKinley



Enclosed Depression on Bluff St



Enclosed Depressions on Palomino Ln/Eugenia Ave (two spots, but in one map)



Inlet Capacity Analysis by MSA at Select Locations

(Email from Alistair Hancox, 11/19/2021)

Please see the table below for the data pertaining to the inlet capacity analysis.

Location	Name (US-Node_DS-Node)	Diameter	Design Flow (cfs)	US Ground Elevation (ft)	AEP 50% (2-year)		AEP 20% (5-year)		AEP 10% (10-year)		AEP 4% (25-year)	
					Peak Flow (cfs)	Maximum US Water Elevation (ft)	Peak Flow (cfs)	Maximum US Water Elevation (ft)	Peak Flow (cfs)	Maximum US Water Elevation (ft)	Peak Flow (cfs)	Maximum US Water Elevation (ft)
Eugenia Ave	AS3851-006_AS3851-001	18"	3.01	897.67	9.91	899.40	10.15	900.16	10.36	900.17	10.45	900.20
Palomino Ln	AS3851-007_AS3851-006	18"	6.70	900.59	6.55	900.26	8.17	901.13	8.11	901.39	7.76	901.61
McKinly St	AS3951-017_AS3951-014	24"	10.16	894.62	3.73	893.22	9.03	894.86	7.90	894.95	7.65	895.05
Buffalo Tr/N Eau Claire Ave	AS3552-014_AS3552-015	21"	10.39	931.58	20.09	932.39	22.17	933.96	22.16	933.96	22.08	933.72
Kendall Ave/Shepard Ter	AS4051-044_CB4051-042	18"	6.17	907.36	2.54	902.53	3.99	903.65	4.79	904.06	6.08	904.43

Bold text indicates a Peak Flow greater than the Design Flow (**HGL slope greater than physical slope**) or a Maximum Upstream Water Elevation greater than the Ground Elevation (**node surcharged**).

Below is a description of what's occurring at each location, to provide a little more context.

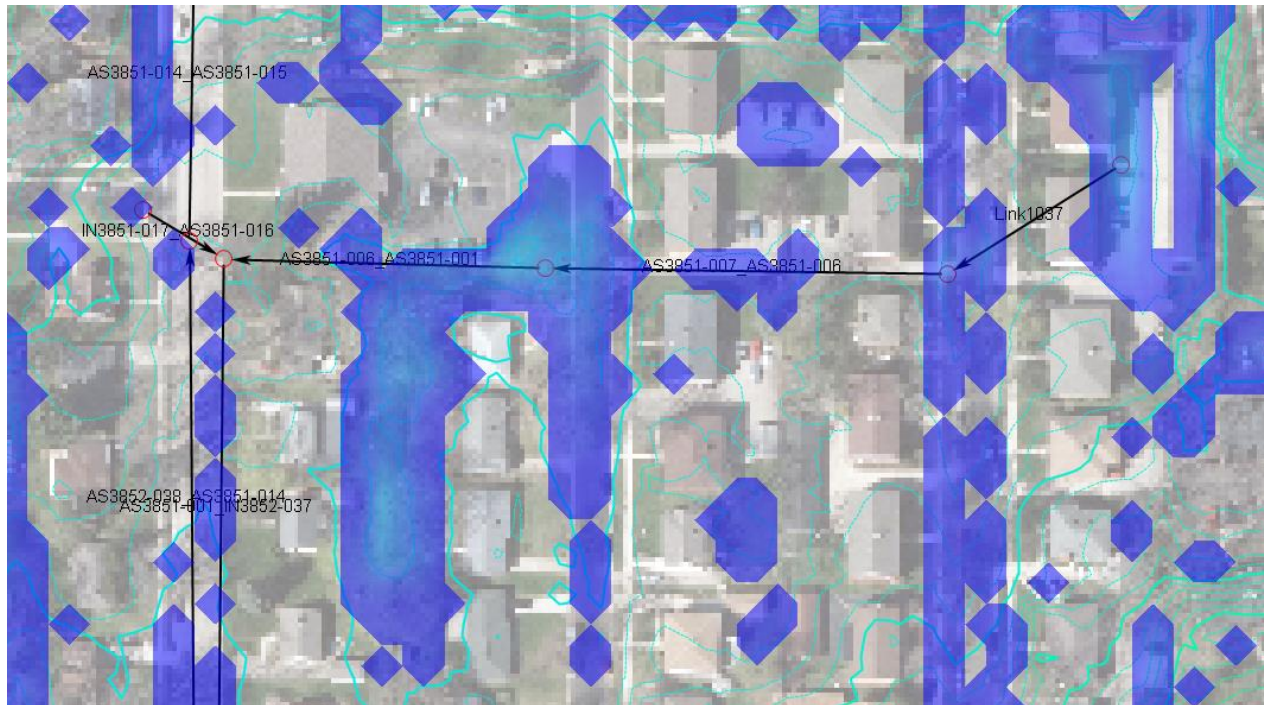
Eugenia Ave

Water is ponding at this location. Flow in the pipe will be driven by the headwater built up at this location, for all storm events. Due to the multiple links upstream of this location and the head build up at the node, it's unlikely there are any inlet limiting factors associated with this location.

Palomino Ln

From the 5-year event and greater, this pipe appears to be at capacity. There is ponding on the surface here, but it doesn't have as great an affect on flows due to the tailwater condition on Eugenia Ave. If the inlet capacity of this sag point plus the upstream node are less than 8 cfs, there could be inlet capacity limitations to the system here.

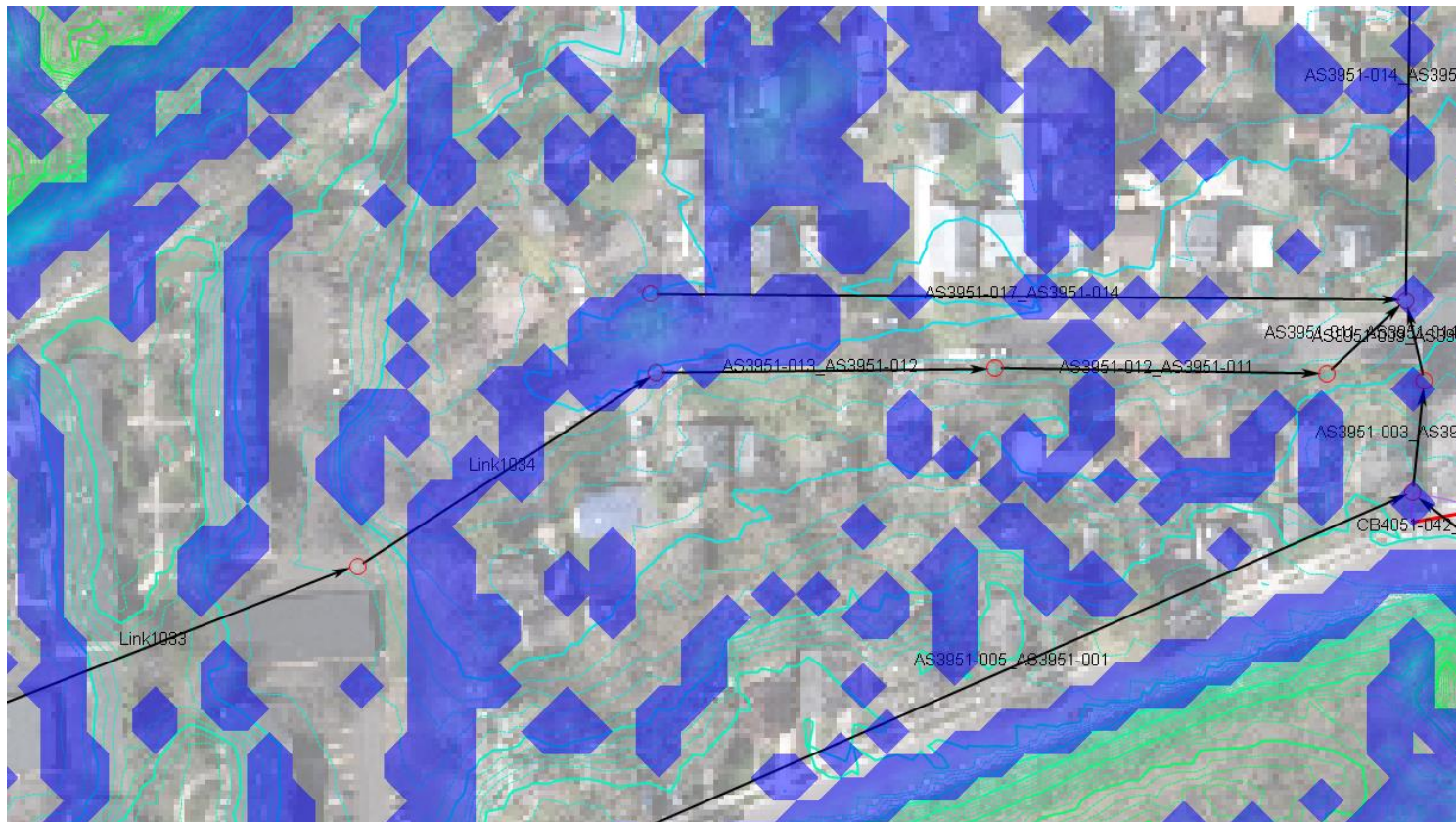
Eugenia Ave – Palomino Ln (10-year Inundation)



McKinly St

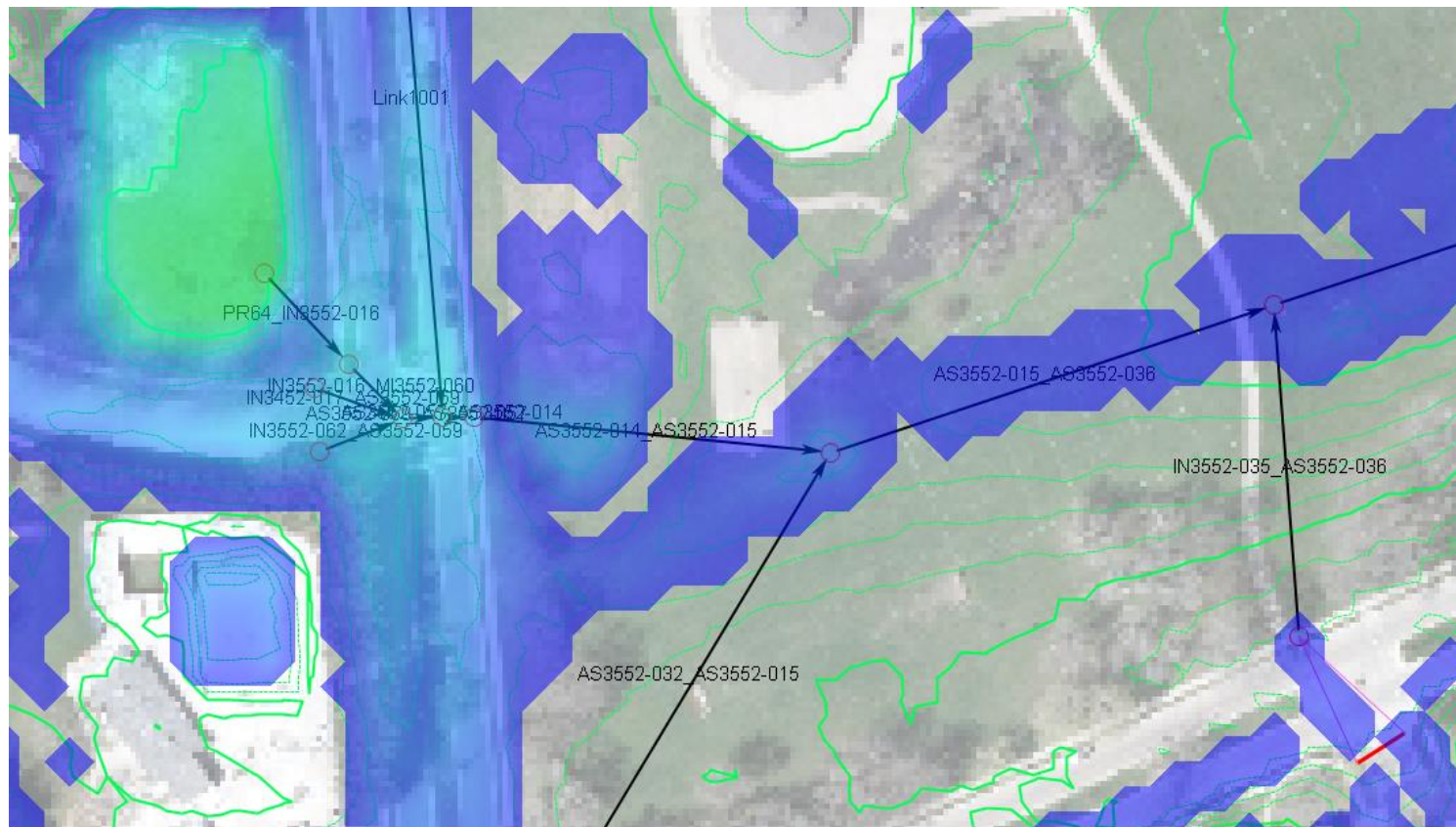
There's a decent sized watershed draining here, with a significant amount of impervious. Ponding occurs during the 5-year and greater. The system is barrel limited from the 5-year, with a tailwater condition occurring during the 10- and 25-year events. May be inlet limited during the smaller events, but unlikely at the 10-year or greater.

McKinly St (10-year inundation)



Buffalo Tr/N Eau Claire Ave

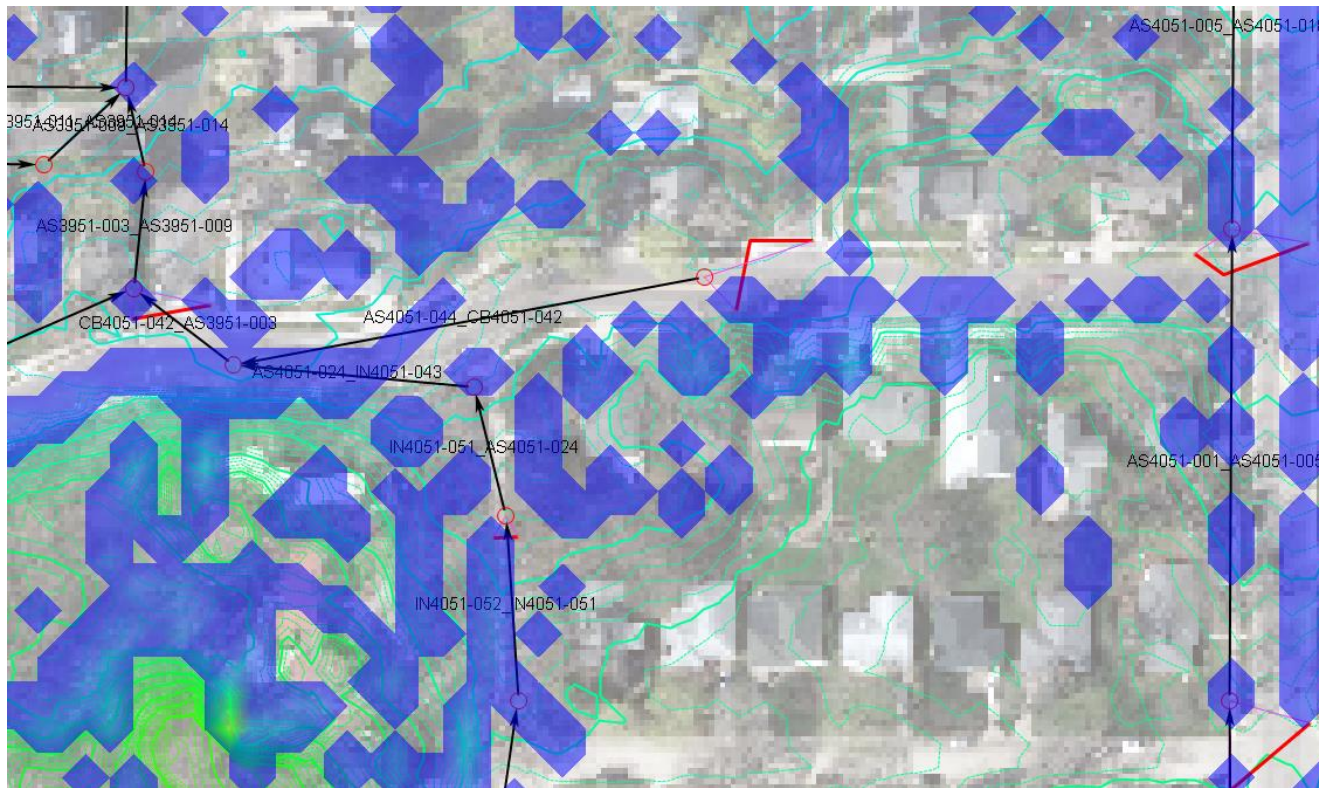
There's significant inundation at this location during all events. The drainage area here is large and the design flow is low. The head build up at the intersection provides a relatively consistent flow for all events. There's unlikely any inlet limiting factors at play here due to the large drainage area and relatively low pipe flow.

Buffalo Tr/N Eau Claire Ave (10-year inundation)

Kendall Ave/Shepard Terrace

The watershed at this location is surprisingly small. It appears as though even the 25-year can be captured and routed through the pipe. This location doesn't appear to be inlet or pipe limited until an event greater than the 25-year, simply because there is not enough area draining to this location (approximately 1.0 acre).

Kendall Ave/Shepard Terrace (10-year inundation)



Let us know your thoughts on this breakdown and if you're after any further information. Happy to talk any or all of this through if I haven't done a good enough job explaining the intricacies in this email.

Appendix D: Calibration Memo

To: Lauren Striegl, P.E. – City of Madison
From: Alistair Hancox and Eric Thompson, P.E.
Subject: Willow Creek Watershed Study – Existing Conditions Model Calibration
Date: December 24, 2020

INTRODUCTION

The memorandum presents the results of MSA's efforts to calibrate the 1D/2D XP-SWMM model for the Willow Creek watershed. Monitoring equipment consisting of two rain gauges, and three level loggers within storm sewer structures were installed and operational from Spring until Fall 2020. The location of these can be seen in the attached map. Each level logger was installed to monitor isolated parts of the overall Willow Creek watershed. Since each was independent of the others, MSA took the uncalibrated Existing Conditions Model and reduced it down to only the areas contributing to each meter. A buffer of approximately 100 ft from each metershed boundary was used to create Rain-on-Grid surges. This truncated calibration model assumes no tailwater condition at each of the meter locations during the three calibration rainfall events.

CALIBRATION RAINFALL EVENTS

Three rainfall events were chosen, each with varying duration and intensity. Only the two rain gauges within the Willow Creek Watershed were used for calibration purposes.

Table 1 – Calibration Storms

Name	Start	End	Duration	Total Rainfall Depth		5-Day Antecedent Rainfall	
				Vernon	South Hill	Vernon	South Hill
Sept 8	01:00, 09/08/20	01:00, 09/11/20	72.0 hours	1.85"	1.82"	0.59"	0.56"
Oct 21	19:50, 10/21/20	13:50, 10/23/20	44.0 hours	3.17"	3.20"	0.20"	0.22"
Nov 10	12:00, 11/10/20	17:30, 06/25/20	5.5 hours	1.05"	1.00"	0.00"	0.00"

As shown in the table above, rainfall captured as these two gauges was fairly consistent during and preceding the calibration events chosen.

MODEL PARAMETERS

The Willow Creek Existing Conditions model was built following the City of Madison Modeling Guidance documentation. The only exception to this was the use of depth variable roughness coefficients for each pervious 2D Land Use layer. Variable roughness was used to estimate both sheet flow and concentrated flow conditions.

Table 2 – Depth-Roughness Chart

Surface Water Depth (ft)	Manning's Roughness	
	Turf Grass	Wooded
0	0.24	0.40
1	0.03	0.10
15	0.03	0.10

UNCALIBRATED MODEL

See attached comparative charts for Modeling Calibration Results. The results of the initial comparison of the Uncalibrated Model to the Metered data can be summarized by three main findings:

1. There was very good correlation between the modeled and metered data at the South Hill Drive Level Logger for all three storm events.
2. The modeled results for Midvale Blvd Level Logger and the Farley Ave Level Logger both appeared to be under predicting the metered levels.
3. The Midvale Blvd meter appeared to cap out around 0.3 ft for each of the calibration storm events, therefore metered results at this level, when consistent rainfall was recorded, were considered unreliable as far as peak depth is concerned.

Because the results in the South Hill Drive metershed were so well matched, differences in the characteristics of all three metersheds were looked at to determine the cause. We found that the Midvale Blvd and Farley Ave metersheds both had much steeper average ground slopes than the South Hill Dr metershed. Comparison of surface flows to pipe flows indicates unrealistic bypass of storm sewer inlets. Further investigation showed that Node Spill elevations vs. Grid surface elevation sampling played a crucial role in determining the 2D inflow throughout the 1D network.

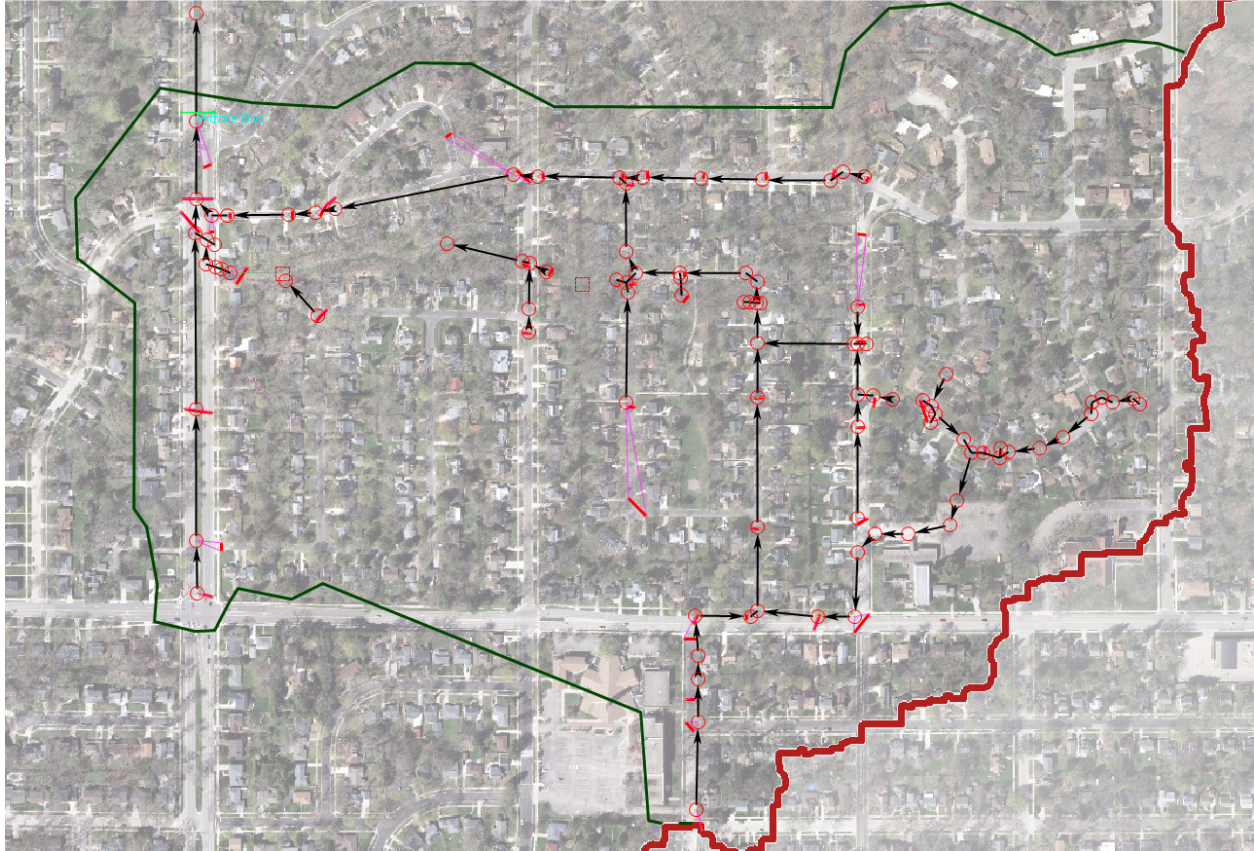
(Note: The displayed grid surface elevation at each cell center is an average of the four corner elevations. This is the process of "sampling" mentioned above.)

CALIBRATED MODEL

The solution to the above problem was to build 1D/2D Interface lines at every storm sewer inlet location across all three metersheds (Although not specifically required for South Hill, this was done for consistency). See Image 1 below of the Midvale Blvd metershed as an example of the model modifications. These additions to the model link all surface water on the 2D cells, touched by the interface lines, to the connecting nodes. The connection at the 1D node to 2D surface now

behaves similarly to that of a traditional 1D hydrologic model, where hydrology is loaded to specific watershed delineation points.

Image 1 – Calibrated XP SWMM Model – Midvale Blvd Metershed



The abovementioned changes to the model resulted in greater flows within the 1D network for the Midvale Blvd and Farley Ave metersheds, and had negligible impact on the South Hill Dr metershed.

South Hill Drive Level Logger

Modeling results, for both intensity and volume, at the South Hill Drive level logger match extremely well with the metered data for all three events. The addition of the 1D/2D Interface lines at each inlet cluster had minimal impact on the modeled water elevations at this structure.

MSA also conducted a quick assessment on the USGS gauge installed almost immediately downstream of the City's South Hill Drive meter. Flow data collected at that meter also correlated very well with that of the calibrated model.

Midvale Boulevard Level Logger

Results at this meter appear to be inconsistent any time the modeled results predict a flow depth above 0.3 ft. MSA decided to ignore the results recorded during the September 8th event because the repeated pattern of consistent depths slightly below 0.4 ft for long durations suggest a systematic malfunction.

During the October 21st event, there is good correlation of shape and timing until the peak of the rainfall intensity at 12:00 AM 10/23. The metered data shows a slight downturn in flow depth at this time. The same thing occurs during the first intense peak of the November 10th rainfall. For this reason, MSA determined that this meter did not accurately measure flow depth during intense rainfall periods.

Because of the inconsistencies identified in these results, correlation at the South Hill Drive and Farley Ave Level Loggers were given more significance.

Farley Ave Level Logger

This watershed saw a noticeable benefit with the addition of the 1D/2D interface lines. The shape of the modeled flow elevation graph does not match that of the metered data perfectly, but it does appear to be over predicting as much as it is underpredicting.

All three events display a slight misalignment of peak elevations. This could suggest an error in the raw data processing by the meter. A worm was discovered and removed from this meter on September 11th. Given these issues experienced at this location, correlation is good throughout each event with peak flow depths matching up well.

1D/2D INLET CONNECTION SENSITIVITY

So as to not exaggerate inlet capacity in unmetered areas while also considering model development effort and solution run times, MSA modeled the 5-Year design storm within the truncated Calibration model and again within the current Existing Conditions Model (ECM) of the entire study area.

Images 1, 2, and 3 are screen shots displaying this comparison for the Midvale Boulevard metershed. The inundation mapping is very consistent across both, until flow accumulates on the surface at Midvale Boulevard and flows north. There is clearly more water shown on the ECM model surface, suggesting that inlet capture is not adequate for this event at this location. Peak flow results in the downstream network confirm that not enough runoff is entering the 1D network in the current ECM for this metershed.

This same comparison for the South Hill Drive and Farley Ave metersheds showed no such discrepancies and consistent pipe flow rates across both models. This finding supports the proposed method that MSA focus efforts on inlet capture at locations experiencing observed surface flow with pipe flow less than capacity.

Image 2 – Midvale Blvd: Current ECM (5-Year Inundation)

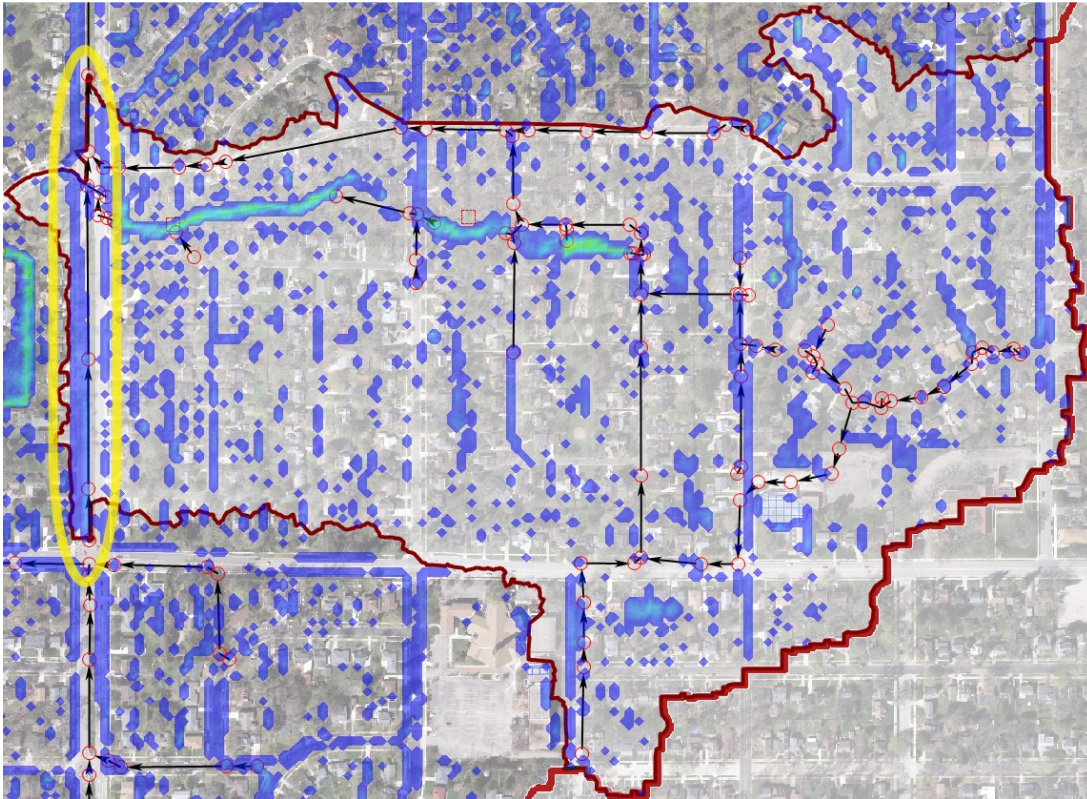
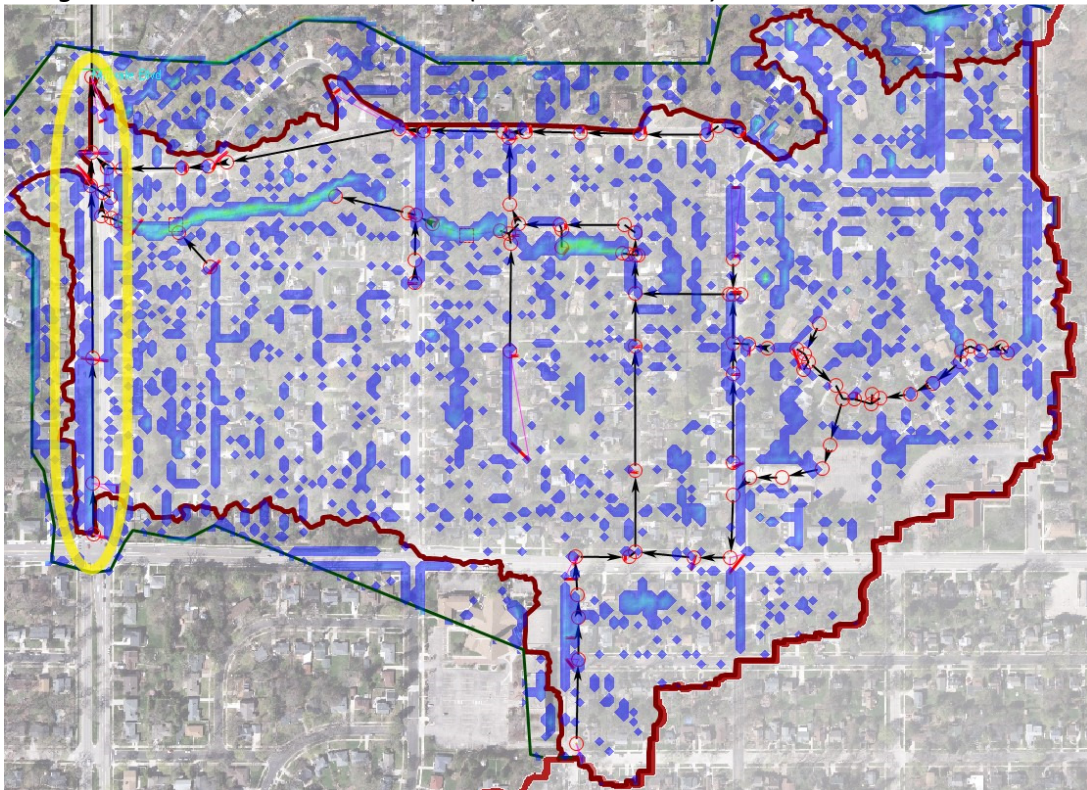


Image 3 – Midvale Blvd: Calibrated (5-Year Inundation)



CONCLUSION

Given that the results shown at the South Hill Drive and Farley Ave Level Loggers were well matched, MSA decided not to alter the model hydrologic parameters any further. These watersheds are representative of much of the Willow Creek study area, with the exception of not containing any commercial land.

MSA is now working to update the entire Existing Conditions Model with the 1D/2D Interface lines at all locations where inlet bypass appears to exceed what would be expected. This will likely be focused in the upper watershed areas where shallow flows were not appearing to enter the 1D storm sewer network. This modification will not be required where nodes are shown to experience frequent and deep inundation. The calibration process showed that these modifications were required in steeper areas like Midvale Boulevard and Farley Ave, but not in the gradual sloped areas like South Hill Drive.

 Willow Creek Watershed

 Farley Ave Level

 South Hill Dr Level

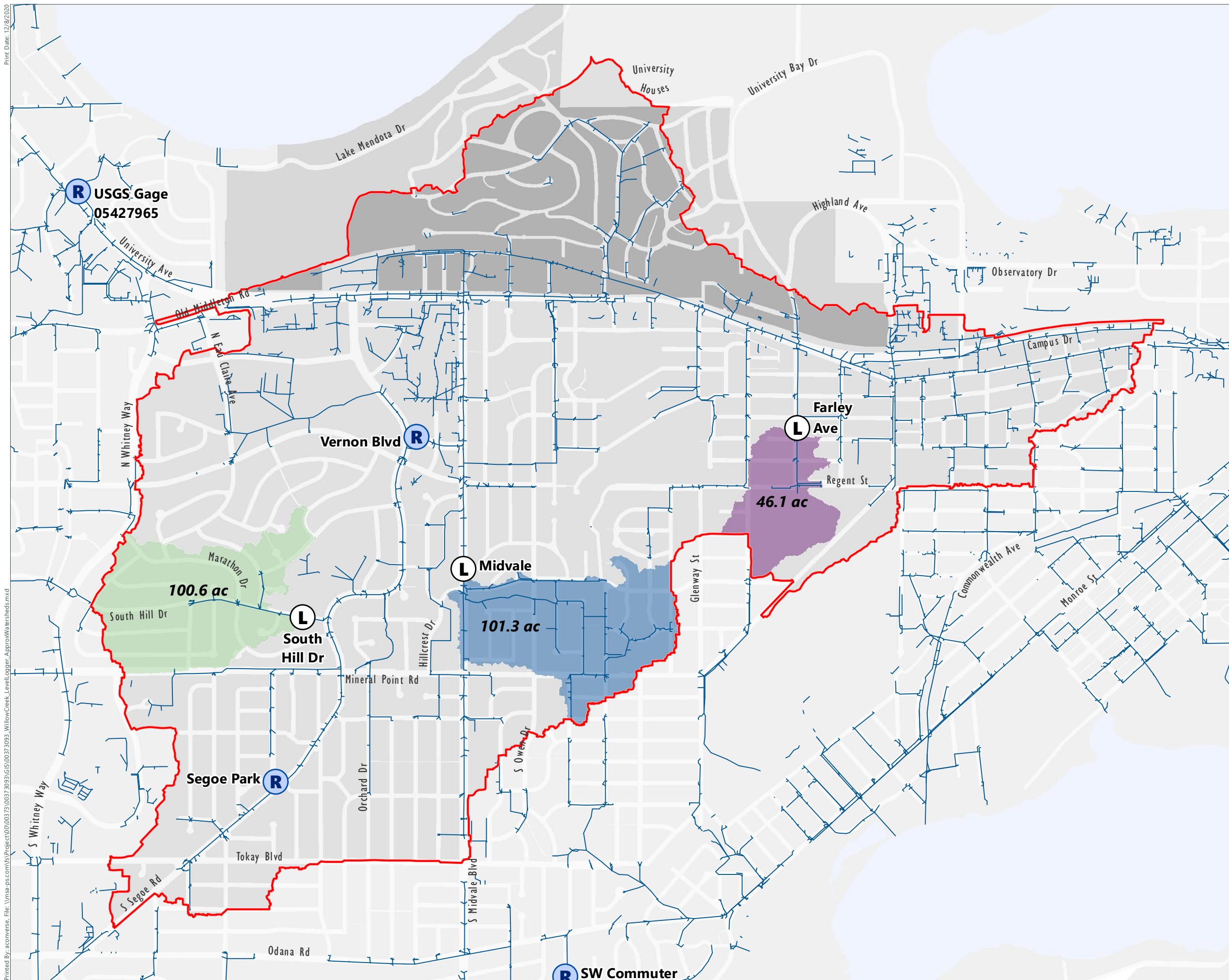
 Midvale Level

— Stormwater Pipe

 Rain Gauge

L Level

Data Sources:
Aerial: City of Madison (2018)
Stormwater System: City of Madison

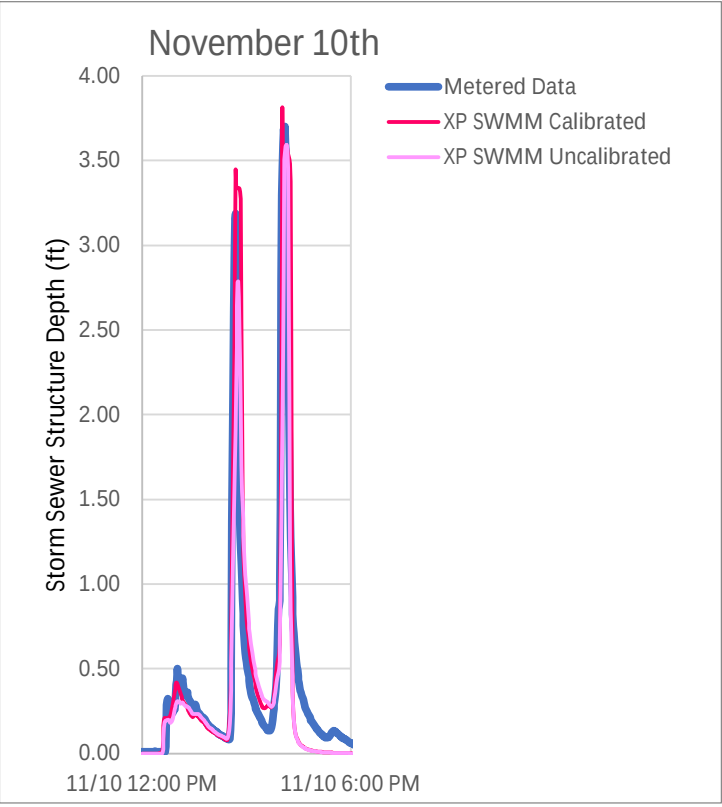
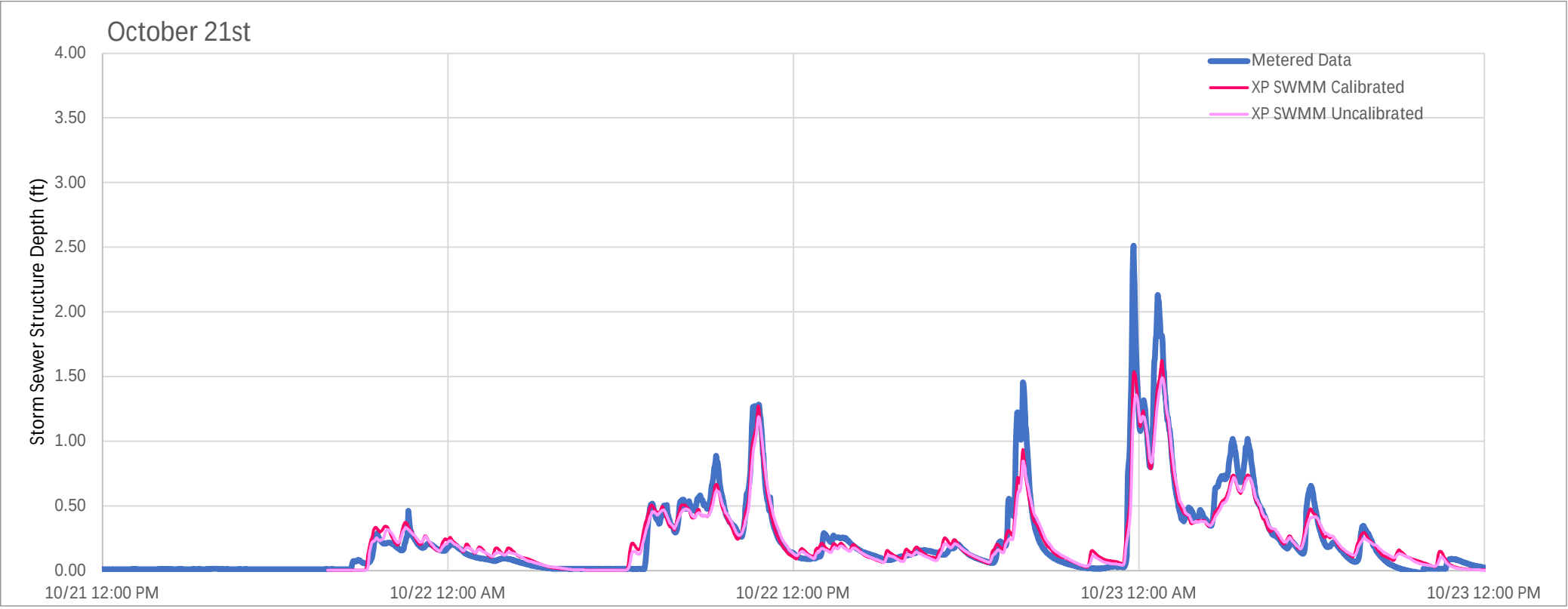
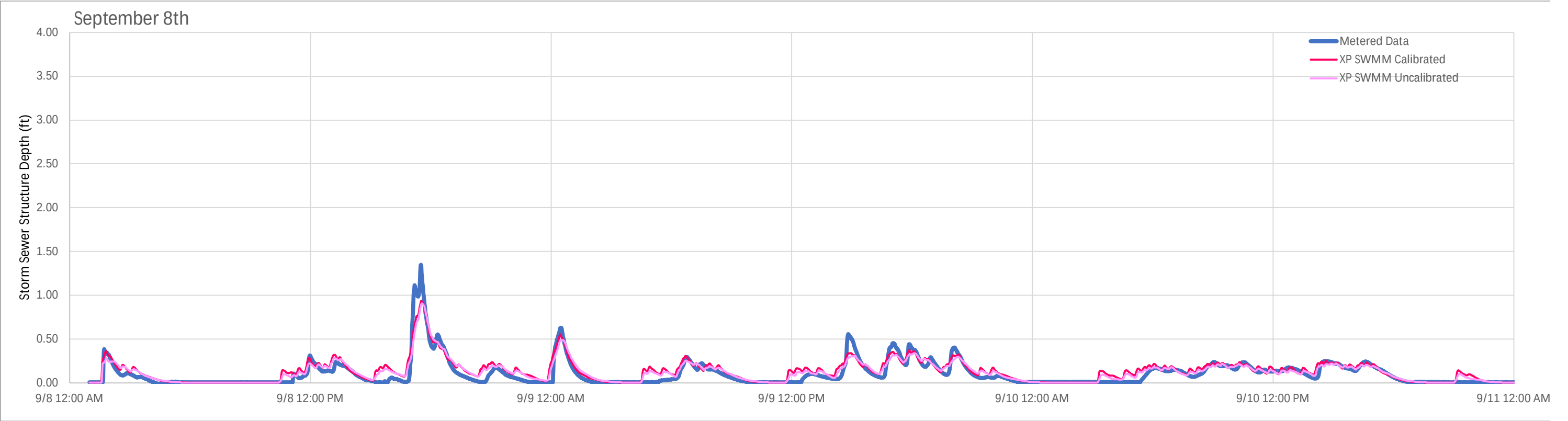


Model Calibration Results

South Hill Dr Level Logger

Metershed Area = 100.6 acres

Downstream Pipe = 30" Circular @ 1.0%

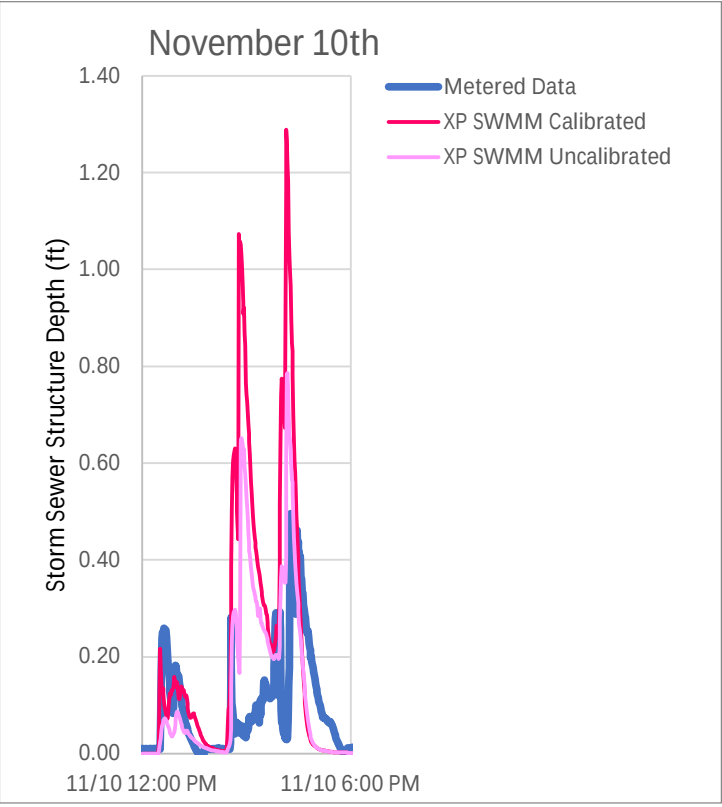
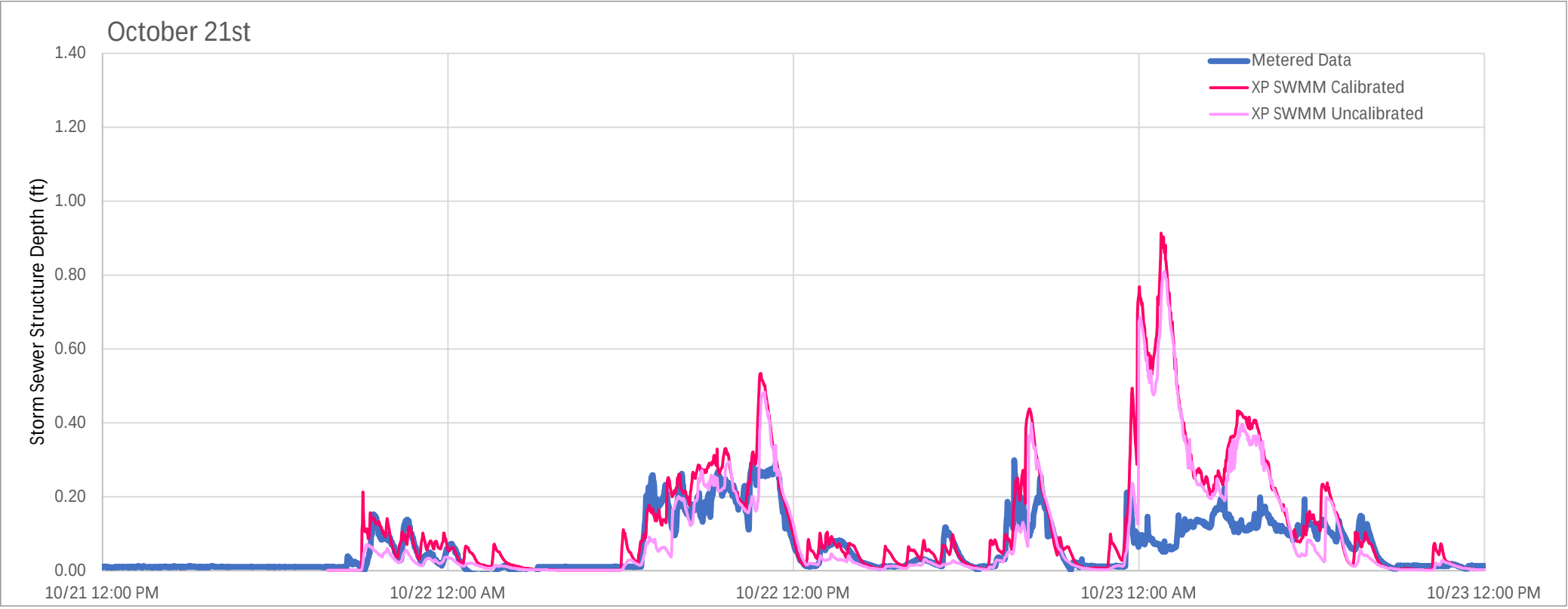
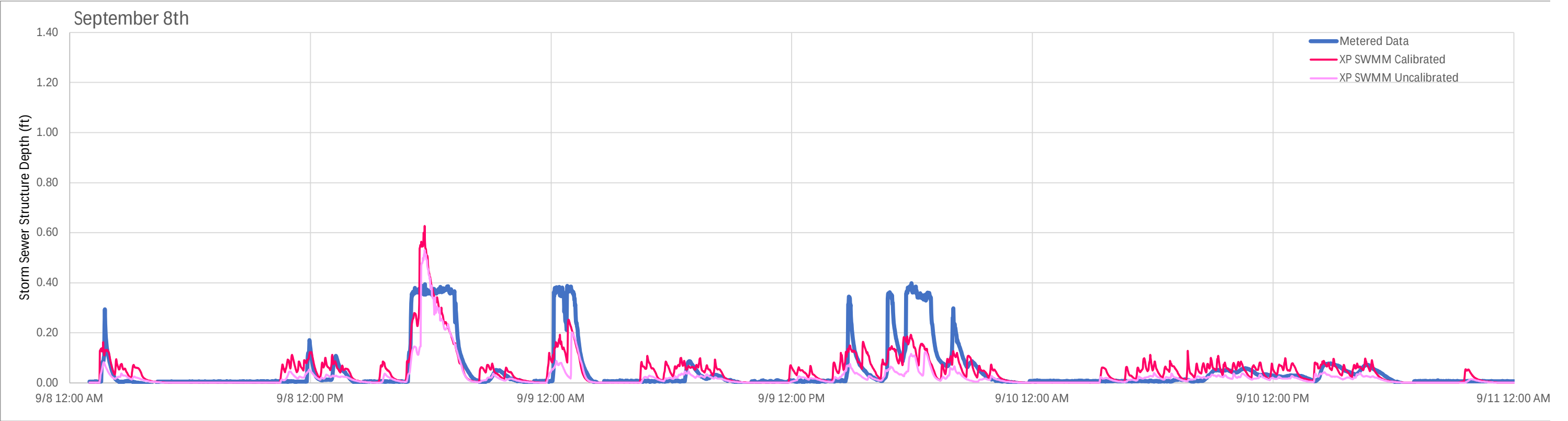


Model Calibration Results

Midvale Blvd Level Logger

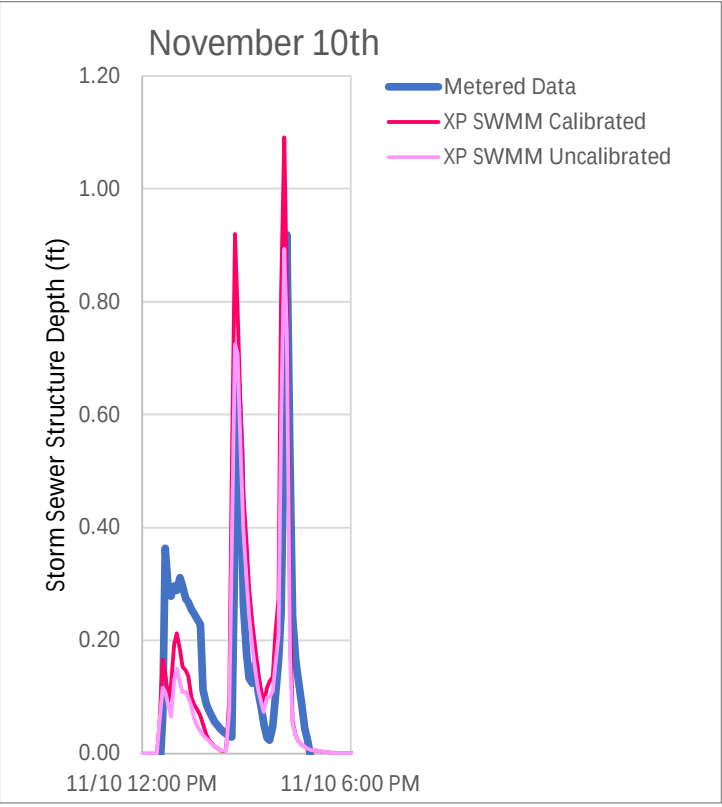
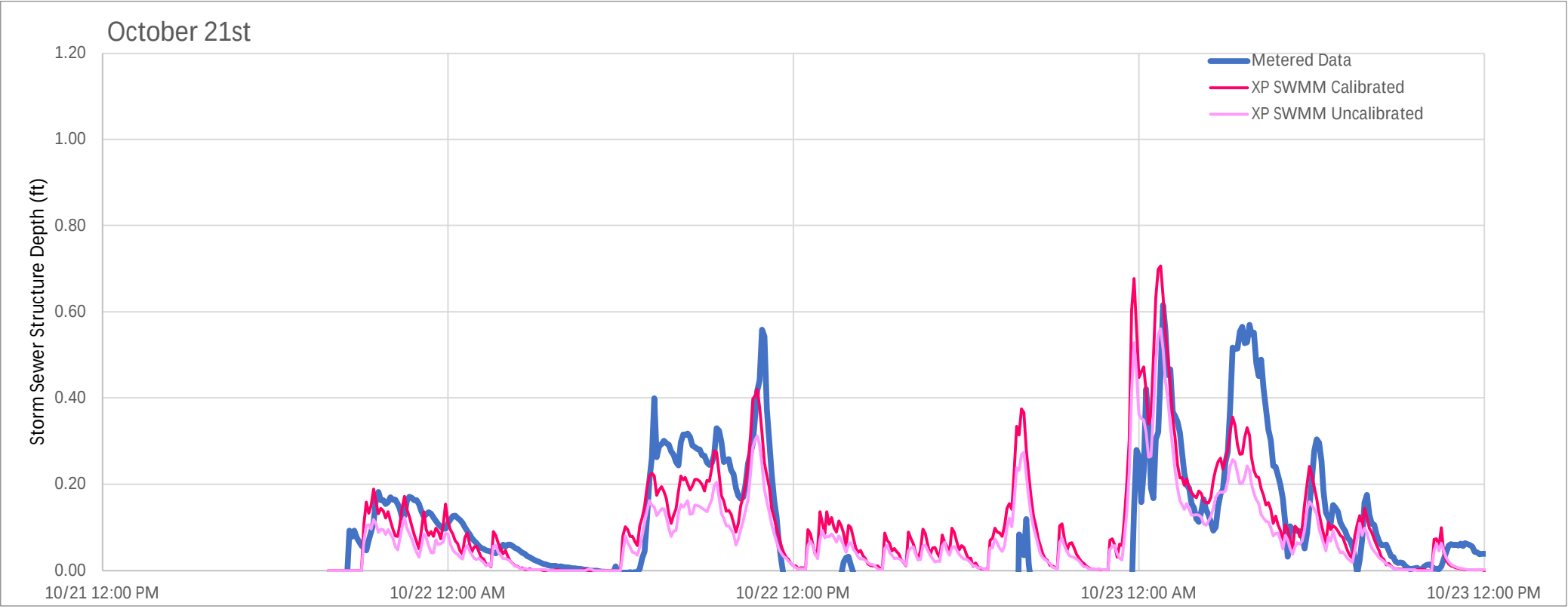
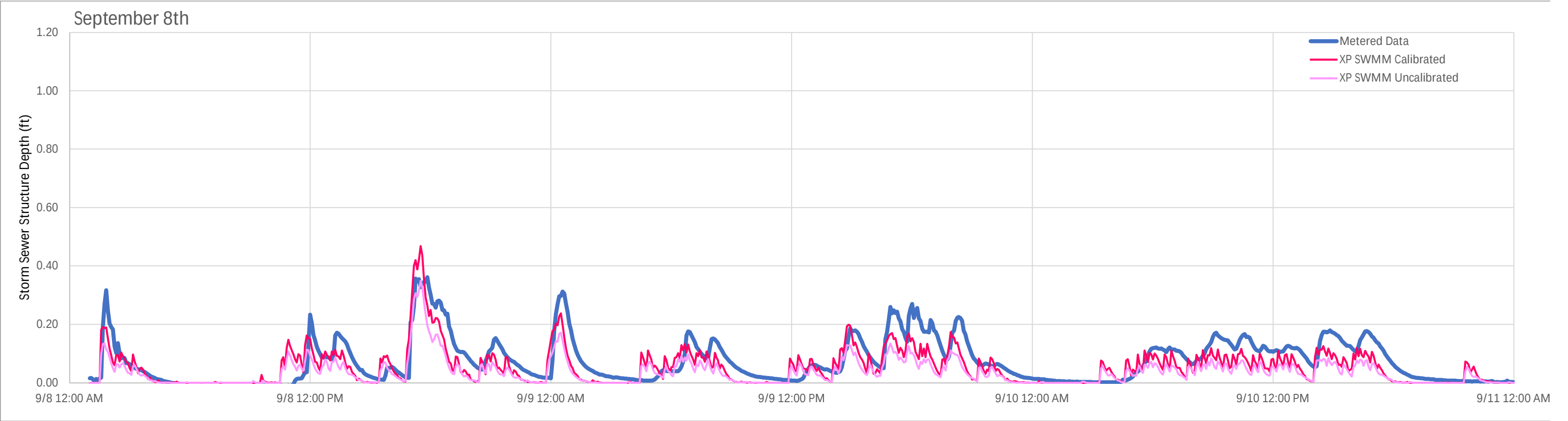
Metershed Area = 101.3 acres

Downstream Pipe = 42" Circular @ 2.7%



Model Calibration Results
Farley Ave Level Logger

Metershed Area = 46.1 acres
Downstream Pipe = 24" Circular @ 4.0%



Appendix E: Select Locations: Flooding Depth & Duration

Appendix E: Select Locations Flooding Depth & Duration

Flood report locations were selected with help from the City. Locations where preliminary modeling showed structure damage was possible were prioritized. 27 locations in total were originally selected. However, this number was reduced to 8 key locations for a more thorough analysis. Because it was determined that the proposed 96" storm sewer along University Ave would provide close to the 5-year event level of service, flooding depths and durations have been summarized for the 5-, 10-, and 100-year events to demonstrate the range of improvement expected.

The 1D results at the summarized locations for Max Water Level and Flooding Duration were recorded for the abovementioned events.

Locations for Analysis

APPENDIX E
Willow Creek Watershed Study
Existing Conditions Report

City of Madison
Dane County, WI

- Watershed Study Area
- Village of Shorewood Hills
- Public Storm System
- Private Storm System
- Shorewood Hills Storm System
- Open Channel Flow
- Locations for Analysis

Data Sources:
Aerial: City of Madison (2018)
Watershed Boundaries: MSA
Stormwater System: City of Madison



0 0.125 0.25 Miles



Proposed Solution Comparison - Willow Creek Watershed Study

5-Year Flood Elevation Results

Node	Location Descriptoin	Ground Elevation	Existing		Proposed	
			Depth (ft)	Duration (mins)	Depth (ft)	Duration (mins)
AS3552-059	N Eau Claire Sag	931.16	1.84	123	0.00	0
AS3752-018	Residential north of Regent	893.84	1.30	53	0.76	27
AS3752-005	Vernon Blvd	893.09	2.19	49	1.98	27
TEE3	Midvale/University	884.74	2.11	178	2.96	62
BQ7	Garden Homes	883.35	3.43	183	3.27	95
AS3950-001	Shorewood/University	879.30	3.02	197	2.33	66
IN4050-040	University Bay Dr Sag	874.68	1.78	81	1.69	0
IN4250-014	Highland Ave Sag	857.08	0.00	0	0.00	0

10-Year Flood Elevation Results

Node	Location Descriptoin	Ground Elevation	Existing		Proposed	
			Depth (ft)	Duration (mins)	Depth (ft)	Duration (mins)
AS3552-059	N Eau Claire	931.16	2.24	152	0.00	0
AS3752-018	Residential north of Regent	893.84	1.98	70	1.21	47
AS3752-005	Vernon Blvd	893.09	2.42	56	2.35	37
TEE3	Midvale/University	884.74	2.44	201	2.74	75
BQ7	Garden Homes	883.35	3.82	198	3.94	133
AS3950-001	Shorewood/University	879.30	3.28	200	3.71	86
IN4050-040	University Bay Dr Sag	874.68	4.69	124	2.10	12
IN4250-014	Highland Ave	857.08	0.00	0	0.59	7

100-Year Flood Elevation Results

Node	Location Descriptoin	Ground Elevation	Existing		Proposed	
			Depth (ft)	Duration (mins)	Depth (ft)	Duration (mins)
AS3552-059	N Eau Claire	931.16	2.89	196	2.30	40
AS3752-018	Residential north of Regent	893.84	3.17	141	2.98	123
AS3752-005	Vernon Blvd	893.09	3.34	87	3.29	67
TEE3	Midvale/University	884.74	3.48	216	3.31	113
BQ7	Garden Homes	883.35	4.87	212	5.09	184
AS3950-001	Shorewood/University	879.30	3.87	209	3.78	154
IN4050-040	University Bay Dr Sag	874.68	5.39	199	5.29	141
IN4250-014	Highland Ave	857.08	7.18	150	6.25	56

Appendix F: University Bay Relief Pipe and the Deep Tunnel

Appendix F: University Bay Relief Pipe and Deep Tunnel

University Bay Relief Pipe

The University Bay Relief Pipe was a drainage solution originally proposed in the 2003 “Willow Creek Watershed Drainage Evaluation” report by Strand. MSA followed the alignment and connectivity of the pipe proposed within this report for analysis. The Strand report looked at running a 6’ x 8’ box transitioning to a 6’ x 12’ box along this length; however, it was the City’s opinion based on current conditions within the corridor that construction limitations would require installation of a circular pipe. For this reason, MSA kept the conduit height of 6’ and analyzed the effects of a proposed 72” circular pipe for the entire alignment described in the 2003 report. Model results showed significant improvement to inundation levels along the University Ave corridor, with the greatest benefits observed at the University Bay Dr intersection. This solution was ultimately deemed impractical, given the significant complications of trying to install a pipe that large in a heavily developed area.

Deep Tunnel

As introduced in section 2.5 of this report, there are records (although not necessarily copies in existence) of drainage studies within Willow Creek watershed dating back to as long ago as 1945 that evaluated flooding conditions at/near the intersection of University Avenue and Midvale Boulevard. It was with these earlier studies that the concept of the relief sewer (deep tunnel) outlet directly to Lake Mendota appears to have been first introduced.

The alignment of the tunnel varied slightly within those reports, where alignment maps were available, but the alignments were fairly consistent in that the tunnel began near the intersection of Midvale Boulevard and University Avenue and it ran northwest through the Blackhawk Golf Course to the Lake Mendota. Similarly the size of the tunnel varied between the different reports, but the sizes were all large, ranging from 78 inches to 108 inches in diameter.

While studies have shown the tunnel to be quite effective at reducing flooding in the Willow Creek watershed, to date the tunnel project has not been found to be feasible. A significant basis of this finding is the estimated construction cost of the project, but another important reason is the engineering challenge associated with providing the necessary inlet capacity at the upstream end of the tunnel. This study estimates that the existing conditions 100-yr peak flow rate flowing north in the street along Midvale Boulevard is 1,447 cfs. Even assuming high capacity terrace inlets could be installed in close succession, this would require roughly 100 inlets and between the inlets themselves and the necessary connections to the tunnel there isn’t enough physical space.

As part of this study, MSA analyzed several proposed conditions alternatives. Two of those alternatives included construction of a deep tunnel option, one utilized a 9-foot diameter pipe and the other a 12-foot diameter pipe. Both options also incorporated other systemic improvements, most importantly other storm sewer system upgrades immediately upstream from the intersection of University Avenue and Midvale Boulevard. Even though these storm sewer upgrades were only intended to bring the capacity of the upstream system to approximately 5-yr capacity to balance that of University Avenue

downstream (with other recommended improvements) this resulted in a substantial reduction in overland flow on Midvale Blvd. With the upstream storm sewer improvements (pipe and inlet capacity) 100-yr peak flow in the street were reduced to 584 cfs. While this is a substantial reduction in overland flow relative to existing conditions, for the deep tunnel option to be physically feasible it will still require a very large amount of inlet capacity.

Construction of the deep tunnel was still not considered feasible by the City as of the date of this report; however, if in the future the deep tunnel option were to be revisited, it was felt important that this report include some documentation as to how currently planned systemic storm sewer system improvements could affect the constructability of the tunnel. Specifically, that additional increases in upstream system inlet and pipe capacity could affect the needs for the same at the intersection of University Ave and Midvale Blvd.

Appendix G: Detailed Cost Estimates Stand-Alone Recommended Solutions

Willow Creek Solution B

N Midvale Blvd Parallel Storm System Improvements

(1) Midvale Blvd from University Ave to Vernon Blvd. (2) Heather Crest from N Meadow Ln to Midvale Blvd. (3) N Meadow Lane 200' south to Heather Crest.

Conceptual Cost Estimate

6/23/2022

DRAFT

Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	10,000.00	\$ 10,000	
10911	MOBILIZATION	1	LUMP SUM	185,000.00	\$ 185,000	1.5% of other bid items with a minimum of 50K
	LOCAL STREET	488	L.F.	400.00	\$ 195,200	Cost per L.F. provided by City of Madison Streets: \$300-500 per LF
	COLLECTOR STREET	0	L.F.	1,000.00	\$ -	Cost per L.F. provided by City of Madison Streets: \$1,000 per LF
	PRINCIPAL ARTERIAL STREET	4,275	L.F.	2,000.00	\$ 8,550,000	Cost per L.F. provided by City of Madison Streets: \$2,000 - 4,000 per LF
50405	24 INCH TYPE I RCP STORM SEWER PIPE	395	L.F.	0.00	\$ -	Cost for typical storm sewer incidental to applied street unit cost
WW11	5'x10' BOX CULVERT	2,079	L.F.	1,700.00	\$ 3,534,300	
				Subtotal	\$ 12,474,500	
				Contingency 25%	\$ 3,118,625	
				Design 10%	\$ 1,247,450	
				Total	\$ 16,840,575	
				Land Acquisition	\$ -	
				Wetland Mitigation	\$ -	
				Total Total	\$ 16,840,575	

Willow Creek Solution C

South Hill Dr, Segoe Rd, and Vernon Blvd Storm System Improvements

(1) South Hill Dr from Racine Rd to S Segoe Rd. (2) S Segoe Rd from South Hill Dr to Vernon Blvd. (3) Vernon Blvd from S Segoe Rd to N Midvale Blvd.

Conceptual Cost Estimate

6/23/2022

DRAFT

Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	10,000.00	\$ 10,000	
10911	MOBILIZATION	1	LUMP SUM	230,000.00	\$ 230,000	1.5% of other bid items with a minimum of 50K
	LOCAL STREET	3,436	L.F.	400.00	\$ 1,374,400	Cost per L.F. provided by City of Madison Streets: \$300-500 per LF
	COLLECTOR STREET	6,644	L.F.	1,000.00	\$ 6,644,000	Cost per L.F. provided by City of Madison Streets: \$1,000 per LF
	PRINCIPAL ARTERTIAL STREET	0	L.F.	2,000.00	\$ -	Cost per L.F. provided by City of Madison Streets: \$2,000 - 4,000 per LF
50407	30 INCH TYPE I RCP STORM SEWER PIPE	209	L.F.	0.00	\$ -	Cost for typical storm sewer incidental to applied street unit cost
50409	36 INCH TYPE I RCP STORM SEWER PIPE	77	L.F.	0.00	\$ -	Cost for typical storm sewer incidental to applied street unit cost
50410	42 INCH TYPE I RCP STORM SEWER PIPE	346	L.F.	185.00	\$ 64,010	
50411	48 INCH TYPE I RCP STORM SEWER PIPE	303	L.F.	200.00	\$ 60,600	
50412	54 INCH TYPE I RCP STORM SEWER PIPE	997	L.F.	250.00	\$ 249,250	
WW11	5'x8' BOX CULVERT	928	L.F.	1,500.00	\$ 1,392,000	
WW11	5'x10' BOX CULVERT	2,263	L.F.	1,700.00	\$ 3,847,100	
WC1	5'x12' BOX CULVERT	848	L.F.	1,900.00	\$ 1,611,200	
Subtotal					\$ 15,482,560	
Contingency 25%					\$ 3,870,640	
Design 10%					\$ 1,548,256	
Total					\$ 20,901,456	
Land Acquisition					\$ -	
Wetland Mitigation					\$ -	
Total Total					\$ 20,901,456	

Willow Creek Solution D

Regent St and Owens Dr Storm System Improvements

(1) S Owen Dr 810' north to Regent St. (2) Regent St from S Owen Dr to N Midvale Blvd.

Conceptual Cost Estimate

6/23/2022

DRAFT

Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	10,000.00	\$ 10,000	
10911	MOBILIZATION	1	LUMP SUM	50,000.00	\$ 50,000	1.5% of other bid items with a minimum of 50K
	LOCAL STREET	811	L.F.	400.00	\$ 324,400	Cost per L.F. provided by City of Madison Streets: \$300-500 per LF
	COLLECTOR STREET	964	L.F.	1,000.00	\$ 964,000	Cost per L.F. provided by City of Madison Streets: \$1,000 per LF
	PRINCIPAL ARTERTIAL STREET	0	L.F.	2,000.00	\$ -	Cost per L.F. provided by City of Madison Streets: \$2,000 - 4,000 per LF
50405	24 INCH TYPE I RCP STORM SEWER PIPE	547	L.F.	0.00	\$ -	Cost for typical storm sewer incidental to applied street unit cost
50407	30 INCH TYPE I RCP STORM SEWER PIPE	249	L.F.	0.00	\$ -	Cost for typical storm sewer incidental to applied street unit cost
50409	36 INCH TYPE I RCP STORM SEWER PIPE	283	L.F.	0.00	\$ -	Cost for typical storm sewer incidental to applied street unit cost
50410	42 INCH TYPE I RCP STORM SEWER PIPE	682	L.F.	185.00	\$ 126,170	
				Subtotal	\$ 1,474,570	
				Contingency 25%	\$ 368,643	
				Design 10%	\$ 147,457	
				Total	\$ 1,990,670	
				Land Acquisition	\$ -	
				Wetland Mitigation	\$ -	
				Total Total	\$ 1,990,670	

Willow Creek Solution E

N Eau Claire Ave, Regent St and Rennebohm Park Storm System Improvements

(1) From Buffalo Trail and N Eau Claire Ave intersection to Rennebohm Park. (2) From N Eau Claire Ave and Regent St intersection to Rennebohm Park. (3) Rennebohm Park storm system to open channel.

Conceptual Cost Estimate

6/23/2022

DRAFT

Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	10,000.00	\$ 10,000	
10911	MOBILIZATION	1	LUMP SUM	50,000.00	\$ 50,000	1.5% of other bid items with a minimum of 50K
	LOCAL STREET	257	L.F.	400.00	\$ 102,800	Cost per L.F. provided by City of Madison Streets: \$300-500 per LF
	COLLECTOR STREET	166	L.F.	1,000.00	\$ 166,000	Cost per L.F. provided by City of Madison Streets: \$1,000 per LF
	PRINCIPAL ARTERTIAL STREET	0	L.F.	2,000.00	\$ -	Cost per L.F. provided by City of Madison Streets: \$2,000 - 4,000 per LF
20314	REMOVE PIPE	1,581	L.F.	25.00	\$ 39,525	
21073	EROSION MATTING CLASS 11, TYPE C - ORGANIC	8,783	S.Y.	6.25	\$ 54,896	Assuming 50-ft construction corridor
	SEEDING	8,783	S.Y.	3.00	\$ 26,350	Assuming 50-ft construction corridor
50410	42 INCH TYPE I RCP STORM SEWER PIPE	433	L.F.	185.00	\$ 80,105	
50411	48 INCH TYPE I RCP STORM SEWER PIPE	256	L.F.	200.00	\$ 51,200	
WC2	66 INCH TYPE 1 RCP STORM SEWER PIPE	891	L.F.	300.00	\$ 267,300	
				Subtotal	\$ 848,176	
				Contingency 25%	\$ 212,044	
				Design 10%	\$ 84,818	
				Total	\$ 1,145,037	
				Land Acquisition	\$ -	
				Wetland Mitigation	\$ -	
				Total Total	\$ 1,145,037	

Willow Creek Solution F

S Segoe Rd Storm System Improvements

(1) Portions of S Segoe Rd near the intersection of Manor Cross and Hillview Ter.

Conceptual Cost Estimate

6/23/2022

DRAFT

Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	10,000.00	\$ 10,000	
10911	MOBILIZATION	1	LUMP SUM	50,000.00	\$ 50,000	1.5% of other bid items with a minimum of 50K
	LOCAL STREET	0	L.F.	400.00	\$ -	Cost per L.F. provided by City of Madison Streets: \$300-500 per LF
	COLLECTOR STREET	2,169	L.F.	1,000.00	\$ 2,169,000	Cost per L.F. provided by City of Madison Streets: \$1,000 per LF
	PRINCIPAL ARTERTIAL STREET	0	L.F.	2,000.00	\$ -	Cost per L.F. provided by City of Madison Streets: \$2,000 - 4,000 per LF
WC3	3'x6' BOX CULVERT	875	L.F.	800.00	\$ 700,000	
				Subtotal	\$ 2,929,000	
				Contingency 25%	\$ 732,250	
				Design 10%	\$ 292,900	
				Total	\$ 3,954,150	
				Land Acquisition	\$ -	
				Wetland Mitigation	\$ -	
				Total Total	\$ 3,954,150	

Appendix H: Green Infrastructure Assessment

To: Caroline Burger, PE – City of Madison
From: Alistair Hancox, PE and Eric Thompson, PE – MSA Professional Services
Subject: Willow Creek – Green Infrastructure Assessment
Date: September 21, 2021

PURPOSE

This memorandum summarizes results of modeling simulations of the installation of Distributed Green Infrastructure (DGI) uniformly throughout the Willow Creek watershed for purposes of reducing the frequency and/or severity of flooding. Specific to this evaluation, DGI means installation of practices designed to reduce runoff volumes during rainfall events. While this implies infiltration of runoff, for this event-based study, the target volumes were simply retained in the upper watershed areas and not allowed to pass downstream.

METHODOLOGY

The City of Madison, in conjunction with other consultants, had conducted green infrastructure assessments in studies predating MSA's work in the Willow Creek Watershed. These prior studies all utilized a traditional hydrology model which divided each sub-watershed up into Directly Connected Impervious Area (DCIA), Unconnected Impervious Area (UCIA), and Pervious Area. To estimate the benefits of green infrastructure, and simulate the interception of flow from impervious areas and the subsequent diversion of these flows to pervious areas where they were allowed a chance to infiltrate, a fraction of the estimated existing DCIA was converted to UCIA (10% and 25%, for the respective simulations).

The Willow Creek Watershed Study model was built using a Rain-on-Grid hydrologic method which generates runoff everywhere throughout the catchment simultaneously, depending on the unique ground cover and infiltration parameters of each individual grid cell. Impervious areas cannot be designated by the user as either DCIA or UCIA and so allocations could not be reapportioned as they were with the prior studies. To estimate the effects of a 10% and 25% reduction in DCIA, MSA built a greatly simplified version of the watershed model, reducing all input to a single traditional-hydrology 1-D node representing the entire 1,913-acre watershed. This model was calibrated by adjusting the subcatchment width parameter until runoff volumes matched, within reason, those of the full detail calibrated rain-on-grid Existing Conditions model. The single 1-D node model was then adjusted to convert 10% and 25% of DCIA to UCIA and solved to determine the resulting reduction in total watershed runoff volume for the 50% AEP, 10% AEP, and 1% AEP (a total of six scenarios). The single 1-D node model was then set aside from this study and the full detail rain-on-grid model was modified to include distributed 1-D hydraulic storage nodes distributed proportionately throughout the study area such that their cumulative volume equaled the volume reduction reported for each scenario evaluated using the single 1-D node model.

MEMO

September 23, 2021

RESULTS

Attached are detailed tabulated results for peak elevation and peak flow rates at 28 selected locations within the rain-on-grid Willow Creek model. The locations were chosen to provide an even distribution throughout the watershed, as well as at key locations where known flooding occurs.

The Willow Creek XP-SWMM model results did show some instabilities in 1D results at some of the nodes and links analyzed during this assessment. The result of such instabilities was for some nodes to show greater flood depths during the greater DCIA disconnected scenarios. These instances were reviewed, and it was determined that these conditions result from specific issues associated with flood conditions occurring within the model during selected flood event resulting from specific physical conditions that the model is predicting to occur and are independent of the DGI analysis. An unfortunate effect of these instabilities is that without interpretation they provide misleading results. For purposed of this study, those nodes should be ignored.

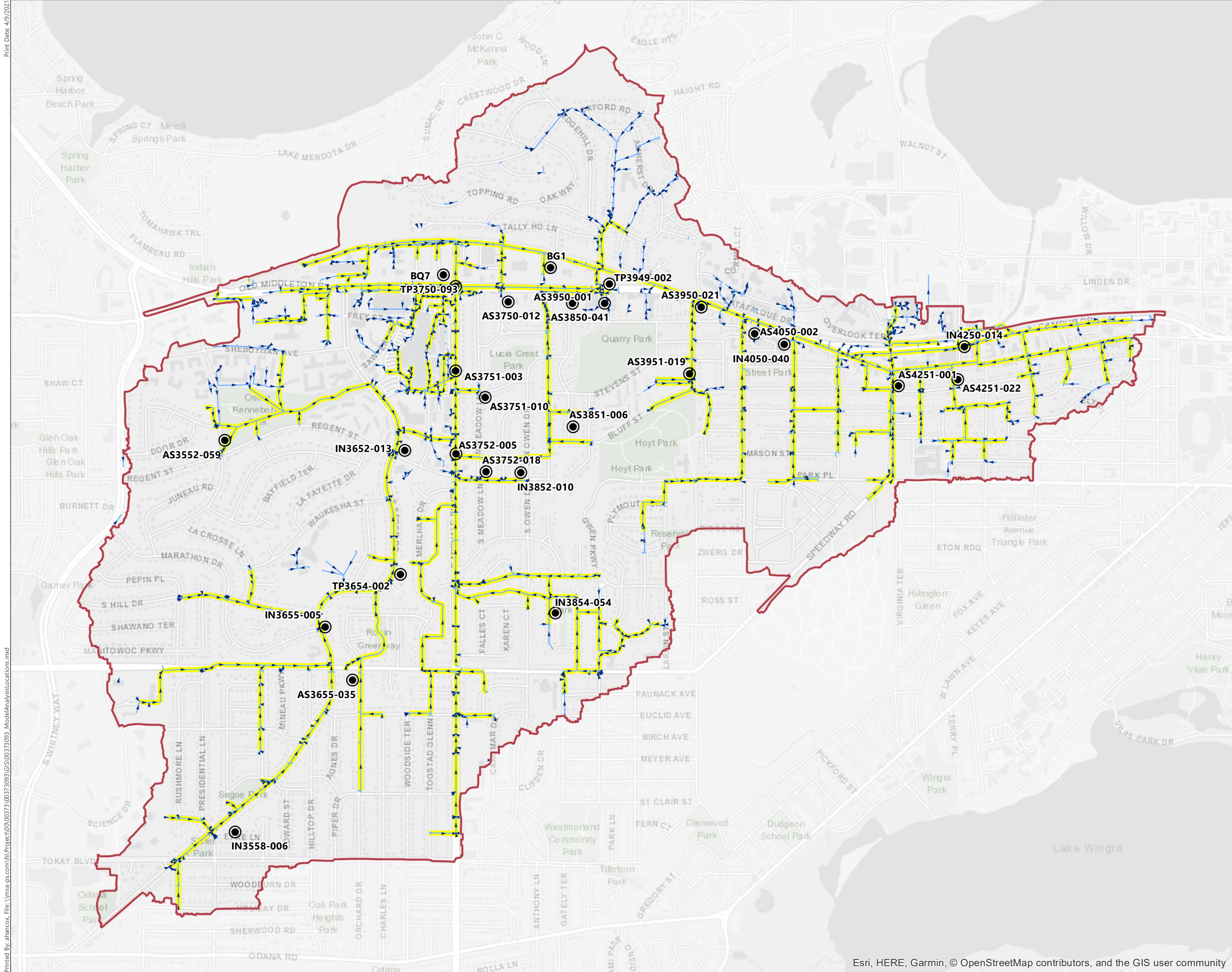
In general, the Flood Elevation Results show minor improvements throughout the watershed for 10% DCIA disconnection and slightly greater improvements for 25% DCIA disconnection. Improvements were most evident during the 50% AEP (smaller) event and were somewhat negligible for the 1% AEP (large) event.

Model Analysis Locations

Willow Creek Watershed Study

City of Madison

-  Willow Creek Watershed
-  Existing Stormwater Pipe
-  Modeled Pipes in XPSWMM
-  Proposed Analysis Location (27)



Data Sources:
Storm System: City of Madison
Proposed 96" Pipe: KL Engineering

Green Infrastructure Analysis - Willow Creek Watershed Study

Flood Elevation Results

Node	Ground Elevation	Existing						10% DCIA Disconnected						25% DCIA Disconnected					
		2-Year		10-Year		100-Year		2-Year		10-Year		100-Year		2-Year		10-Year		100-Year	
		Elevation	Depth	Elevation	Depth	Elevation	Depth	Elevation	Change	Elevation	Change	Elevation	Change	Elevation	Change	Elevation	Change	Elevation	Change
IN3854-054	986.74	984.43	0.00	986.75	0.01	988.09	1.35	984.21	0.0	986.18	0.0	988.10	0.0	983.83	0.0	984.66	0.0	988.02	-0.1
IN3558-006	983.90	983.16	0.00	985.48	1.58	985.98	2.08	983.08	0.0	985.43	-0.1	985.98	0.0	983.01	0.0	985.40	-0.1	985.94	0.0
AS3655-035	938.30	937.13	0.00	939.80	1.50	940.66	2.36	937.14	0.0	939.80	0.0	940.65	0.0	937.16	0.0	939.63	-0.2	940.62	0.0
AS3552-059	931.16	932.51	1.35	933.52	2.36	934.17	3.01	932.37	-0.1	933.42	-0.1	934.13	0.0	932.23	-0.3	933.16	-0.4	934.07	-0.1
IN3655-005	926.50	925.52	0.00	927.34	0.84	928.03	1.53	925.31	0.0	927.31	0.0	928.04	0.0	925.05	0.0	927.31	0.0	927.85	-0.2
TP3654-002	911.21	911.66	0.45	912.25	1.04	912.94	1.73	911.54	-0.1	912.26	0.0	912.94	0.0	911.33	-0.3	912.01	-0.2	912.81	-0.1
IN3652-013	901.54	903.23	1.69	904.40	2.86	904.92	3.38	903.06	-0.2	904.24	-0.2	904.92	0.0	902.65	-0.6	903.62	-0.8	904.76	-0.2
AS3851-006	897.67	899.55	1.88	899.98	2.31	900.71	3.04	899.54	0.0	899.98	0.0	900.70	0.0	899.50	0.0	899.94	0.0	900.67	0.0
AS3752-018	893.84	894.77	0.93	896.15	2.31	897.14	3.30	894.51	-0.3	896.04	-0.1	897.14	0.0	891.85	-0.9	893.57	-2.3	896.76	-0.4
IN3852-010	893.63	894.72	1.09	896.07	2.44	897.14	3.51	894.54	-0.2	895.87	-0.2	897.15	0.0	893.77	-1.0	894.85	-1.2	896.76	-0.4
AS3752-005	893.09	894.76	1.67	895.73	2.64	896.76	3.67	894.58	-0.2	895.69	0.0	896.74	0.0	888.79	-1.7	889.12	-2.6	896.29	-0.5
AS3751-003	890.10	891.16	1.06	891.90	1.80	892.65	2.55	891.01	-0.2	891.86	0.0	892.64	0.0	884.90	-1.1	887.61	-1.8	892.29	-0.4
AS3751-010	889.77	891.69	1.92	892.48	2.71	893.34	3.57	891.49	-0.2	892.43	0.0	893.32	0.0	890.69	-1.0	891.30	-1.2	892.93	-0.4
AS3951-019	889.35	890.69	1.34	890.87	1.51	891.09	1.74	890.70	0.0	890.86	0.0	891.09	0.0	890.68	0.0	890.87	0.0	891.09	0.0
TP3750-093	884.99	889.25	4.26	890.61	5.62	889.31	4.32	890.71	1.5	888.23	-2.4	891.63	2.3	879.34	-4.3	887.50	-3.1	889.15	-0.2
AS3750-012	884.20	886.62	2.42	887.21	3.01	887.92	3.72	886.46	-0.2	887.16	0.0	887.92	0.0	880.80	-2.4	882.23	-3.0	887.62	-0.3
BQ7	883.35	886.61	3.26	887.48	4.13	888.56	5.21	885.89	-0.7	887.45	0.0	888.51	0.0	881.10	-3.3	884.34	-3.1	888.10	-0.5
BG1	881.57	881.88	0.31	883.36	1.79	883.83	2.26	881.67	-0.2	883.05	-0.3	883.83	0.0	876.46	-0.3	881.69	-1.7	883.56	-0.3
TP3949-002	880.18	880.45	0.27	882.35	2.17	882.77	2.59	880.80	0.4	882.31	0.0	882.77	0.0	874.69	-0.3	880.49	-1.9	882.55	-0.2
AS3950-021	879.78	880.94	1.16	882.46	2.68	881.86	2.08	881.04	0.1	882.22	-0.2	882.10	0.2	873.43	-1.2	880.92	-1.5	882.53	0.7
AS3950-001	879.30	881.07	1.77	882.71	3.41	883.32	4.02	880.22	-0.8	882.64	-0.1	883.29	0.0	876.56	-1.8	880.12	-2.6	882.91	-0.4
AS3850-041	879.03	881.07	2.04	882.76	3.73	883.34	4.31	880.24	-0.8	882.69	-0.1	883.37	0.0	876.53	-2.0	880.14	-2.6	882.98	-0.4
AS4050-002	875.54	876.40	0.86	878.10	2.56	880.08	4.54	874.45	-0.9	877.93	-0.2	879.59	-0.5	873.00	-0.9	876.43	-1.7	878.78	-1.3
IN4050-040	874.68	873.98	0.00	878.04	3.36	880.02	5.34	873.84	0.0	877.29	-0.7	879.48	-0.5	872.66	0.0	873.44	-3.4	878.69	-1.3
AS4251-001	871.38	868.24	0.00	870.93	0.00	874.45	3.07	867.81	0.0	870.44	0.0	873.67	-0.8	866.85	0.0	868.23	0.0	872.80	-1.7
AS4251-022	870.26	866.59	0.00	869.74	0.00	871.00	0.74	866.26	0.0	868.32	0.0	870.28	-0.7	865.09	0.0	866.72	0.0	870.26	-0.7
IN4250-014	857.08	859.28	2.20	860.14	3.06	865.60	8.52	859.19	-0.1	859.83	-0.3	864.48	-1.1	858.75	-0.5	859.59	-0.5	861.36	-4.2

- * Denotes a node were minor instabilities have occurred in the 1D model results.
- * Flood Depths Reduced due to DCIA Reduction.
- * Flood Depths Increased due to DCIA Reduction.

Green Infrastructure Analysis - Willow Creek Watershed Study

Pipe Flow Results

Pipe	Existing			10% DCIA Disconnected						25% DCIA Disconnected					
	2-Year Flow (cfs)	10-Year Flow (cfs)	100-Year Flow (cfs)	2-Year Flow (cfs)	Change	10-Year Flow (cfs)	Change	100-Year Flow (cfs)	Change	2-Year Flow (cfs)	Change	10-Year Flow (cfs)	Change	100-Year Flow (cfs)	Change
IN3558-006_IN3558-001	100.9	132.2	132.0	89.3	-11%	129.4	-2%	128.7	-3%	86.7	-14%	129.0	-2%	130.1	-1%
IN3854-054_DT3854-006	60.2	90.4	102.3	56.3	-6%	83.8	-7%	102.3	0%	49.9	-17%	63.2	-30%	101.7	-1%
AS3655-035_DT3655-036	9.3	20.0	20.4	9.3	0%	20.0	0%	20.3	-1%	9.4	1%	19.9	0%	20.2	-1%
AS3552-059_AS3552-057	15.6	15.9	16.0	14.8	-5%	15.9	0%	15.7	-2%	12.3	-21%	15.5	-3%	16.1	1%
IN3655-005_IN3654-041	317.4	350.2	349.6	308.7	-3%	351.5	0%	351.3	0%	296.0	-7%	349.4	0%	353.4	1%
TP3654-002_IN3653-012	267.7	266.7	264.5	266.7	0%	265.9	0%	260.8	-1%	271.7	2%	264.7	-1%	261.1	-1%
IN3652-013_TEE5	312.1	324.8	288.7	303.5	-3%	313.8	-3%	279.5	-3%	290.1	-7%	332.8	2%	362.2	25%
AS3851-006_AS3851-001	9.8	10.3	10.6	9.9	1%	10.3	0%	10.6	0%	11.5	17%	12.1	18%	10.7	0%
AS3752-018_AS3752-056	29.6	49.9	51.9	30.2	2%	48.9	-2%	51.1	-1%	31.0	5%	38.3	-23%	51.1	-1%
IN3852-010_AS3752-022	18.2	22.0	22.5	18.7	3%	21.9	-1%	22.8	1%	18.9	4%	22.1	0%	22.8	1%
AS3752-005_TP3752-004	387.6	368.4	363.9	338.8	-13%	380.3	3%	399.0	10%	106.1	-73%	69.0	-81%	264.8	-27%
AS3751-003_AS3751-002	555.7	539.7	552.7	539.7	-3%	540.9	0%	552.7	0%	183.9	-67%	316.7	-41%	550.3	0%
AS3751-010_AS3751-017	9.5	9.2	8.5	9.4	-1%	9.3	1%	8.6	1%	8.5	-11%	9.1	-1%	9.0	5%
AS3951-019_AS3951-018	3.5	2.8	2.9	3.4	-2%	2.8	0%	3.0	1%	3.4	-3%	3.4	19%	3.0	0%
TP3750-093_TP3750-058	483.2	472.6	423.9	482.1	0%	457.3	-3%	464.0	9%	233.6	-52%	400.6	-15%	284.4	-33%
AS3750-012_AS3849-026	69.7	65.8	41.6	75.4	8%	50.0	-24%	54.7	32%	15.7	-78%	31.5	-52%	53.3	28%
BQ6_BQ5	39.6	38.5	37.7	38.0	-4%	38.5	0%	37.9	0%	6.3	-84%	20.4	-47%	37.9	1%
BG1_TP3849-005	440.9	431.5	428.6	489.5	11%	434.8	1%	430.8	1%	331.0	-25%	442.1	2%	441.8	3%
TP3949-002_TP3949-001	540.5	498.2	517.0	515.0	-5%	501.9	1%	528.0	2%	354.0	-35%	475.3	-5%	502.1	-3%
AS3950-021_TP4050-008	586.2	659.1	646.4	547.8	-7%	640.8	-3%	674.1	4%	370.7	-37%	484.2	-27%	658.4	2%
AS3950-001_IN3949-010	30.8	30.8	31.0	25.4	-18%	30.1	-2%	30.1	-3%	20.6	-33%	30.4	-1%	30.4	-2%
AS3850-041_IN3850-036	102.0	123.0	84.9	102.3	0%	117.9	-4%	89.4	5%	21.2	-79%	106.8	-13%	135.6	60%
AS4050-002_TP4150-004	585.3	560.7	537.5	525.3	-10%	667.1	19%	589.6	10%	404.7	-31%	571.9	2%	540.2	1%
AS4050-002_TP4150-004.1	542.8	769.9	717.4	536.8	-1%	764.7	-1%	721.5	1%	424.2	-22%	512.4	-33%	713.3	-1%
AS4251-001_AS4251-033	597.1	746.8	817.6	570.6	-4%	680.8	-9%	820.1	0%	451.8	-24%	571.5	-23%	743.2	-9%
AS4251-022_AS4251-016	643.9	731.2	846.2	612.0	-5%	715.6	-2%	837.4	-1%	479.9	-25%	641.3	-12%	796.9	-6%
IN4250-014_IN4250-013	4.8	4.1	6.3	6.1	27%	4.6	11%	6.4	2%	4.8	-1%	5.4	31%	6.3	0%

- * Denotes a pipe were minor instabilities have occurred in the 1D model results.
- * Flows Reduced due to DCIA Reduction.
- * Flows Increased due to DCIA Reduction.