East Badger Mill Creek Watershed Study
Draft Final Report

City of Madison, WI
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List of Abbreviations

1D	One-dimensional
2D	Two-dimensional
AEP	Annual Exceedance Probability
CMP	Corrugated metal pipe
cfs	Cubic feet per second
CIP	Capital Improvement Plan
City	City of Madison
CLOMR	Conditional Letter of Map Revision
DCIA	Directly Connected Impervious Area

ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
H&H	Hydrologic and hydraulic
GI	Green Infrastructure
GIS	Geographic Information System
gpm	Gallons per minute
HERCP	Horizontal elliptical reinforced concrete pipe
HSG	Hydrologic soil group
LiDAR	Light detecting and ranging
LOMR	Letter of Map Revision
MG&E	Madison Gas and Electric
MPO	Metropolitan Planning Organization
MSE	Midwest/Southeast States
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanographic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
PCSWMM	Computational Hydraulics International's Stormwater Management Model Software
PFCI	Peak Flow Control Infrastructure
PIM	Public Information Meeting
RCP	Reinforced concrete pipe
ROW	Right-of-way
SAS	Storm access structure
SLU	Standard land use
STH	State Trunk Highway
SWMP	Stormwater management plan
TIN	Triangular irregular network
USGS	United States Geological Survey
UW	University of Wisconsin
WDNR	Wisconsin Department of Natural Resources
WSE	Water Surface Elevation
WisDOT	Wisconsin Department of Transportation

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 multifaceted 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 comprehensive watershed studies are conducted in two phases. Throughout both phases, the City incorporates multiple opportunities for public involvement and interaction.

Phase 1: Development of a hydrologic and 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: Using the model, alternative methods and/or infrastructure improvements are evaluated 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 evaluated further, and if they move to the point they are considered for programming, then projects will then go into a more detailed design phase. This project phase includes collection of detailed data to aid design and focuses on refining design details, permitting, and environmental issues associated with the particular project.

This document reports the methods, procedures, and results that comprise the East Badger Mill Creek Watershed Study. The project area covers approximately 1,297 acres (2.0 square miles). The watershed is unique in the City of Madison in that a constructed stormwater greenway channel runs from the northern extent of the watershed to the southern extent where the watershed discharges.

Figure 1-1 shows the extent of the watershed area.

City's Flood Reduction Targets

The analyses conducted for the watershed studies referred back to the City's flood reduction targets to understand where targets were being met and where there is room for improvement. The City has the following flood reduction targets. Please note, these targets may change in the future as more information becomes available.

1. No home or business flooding during the 1-percent chance, 24-hour design storm event (6.66 inches).
2. Eliminate flooding (surcharging of the storm sewer system onto the municipal streets) for up to the 10-percent chance, 24-hour design storm event (4.09 inches), with the exception of road low points.
3. Allow no more than 0.5 feet of stormwater ponding above storm sewer inlet rim elevations at inlet-restricted low points during the 10-percent chance, 24-hour design storm event (4.09 inches).
4. Maintain drivability of municipal streets (center of the street with water depth no greater than 0.5 feet) during the 4-percent chance, 24-hour design storm event (5.02 inches).

5. Enclosed depressions should provide safe storage, or overflow, of stormwater during the 1-percent chance, 24-hour design storm event (6.66 inches). Flooding should be contained within public lands (streets, greenways, easements, etc.).
6. Where greenways cross streets, there should be no road overtopping during the 1-percent chance, 24-hour design storm event (6.66 inches).
7. Flooding solutions should not negatively impact downstream properties.

Existing Conditions Results

The results of the existing conditions analysis indicates there are numerous locations where the City's flood reduction targets are not met:

1. 10-percent chance storm event (10-year design storm)
    a. 6.6 miles out of the 35.9 street miles in the watershed do not meet the target. This is 18 percent of the streets in the watershed.
2. 4-percent chance storm event (25-year design storm)
    a. 2.5 miles out of the 35.9 street centerline-miles in the watershed do not meet the target. This is 7 percent of the streets in the watershed.
3. 1-percent chance storm event (100-year design storm)
    a. 70 structures out of 3,089 structures in the watershed do not meet the target. This is 2 percent of the structures in the watershed.
    b. 3 out of 10 greenway crossings in the watershed do not meet the target. This is 30 percent of the greenway crossings in the watershed.

Figure ES-1 shows surface flooding locations under the 4 percent chance storm event and how the performance of the stormwater conveyance system compares to the City's flood reduction targets.

In this watershed, homes near the intersection of Frisch Road and Tottenham Road have experienced recurring flooding, including some of the most severe flooding observed in the watershed. The direct source of inundation at this location is the adjacent greenway that runs through Pilgrim Park, which is drained by existing pipe culverts underneath McKenna Boulevard. This leads to both frequent flooding that cuts off access to residences as well as severe flooding which results in significant property damage, as was the case in August 2018. While structure inundation in the 4-percent chance storm event is not an established flood reduction target, a significant improvement can be made for this event that should be quantified. The recommended solutions included in this report can reduce high water elevation in the 4-percent chance storm event by as much as 1.4 feet at this location. In the 4-percent chance storm event under existing conditions 17 homes flood 0.5 feet or more, but if all recommended solutions are implemented, this would be reduced to 3 homes. In the 10-percent chance storm event under existing conditions 12 homes flood 0.5 feet or more, but if all recommended solutions are implemented, all of these homes would be removed from flooding.

Recommended Solutions and Cost

Following the existing conditions analysis, an extensive process was conducted to brainstorm, evaluate, and ultimately identify solutions to meet the City's flood reduction targets. **Table ES-1** lists the solutions that were recommended along with the total estimated design and construction cost for each. Figures depicting each solution can be found later in this report.

Table ES-1. Recommended Solutions Design and Construction Costs

Project Name	Design & Construction Cost
McKenna Boulevard-Raymond Road Reconstruction	$4,273,439
Riva Road Reconstruction	$1,164,407
Raymond Road-Cameron Drive-Barton Road-Whitney Way Reconstruction	$2,526,520
East Pass Relief Box Culvert Replacement	$420,103
McKee Road Relief Box Culvert Replacement	$681,113
Carnwood Road Box Culvert Replacement	$860,305
Lancaster Lane Box Culvert Replacement	$981,021
Canterbury Road Box Culvert Replacement	$766,385
McKenna Boulevard-Pilgrim Road Box Culvert Replacement	$2,666,682
Westbrook Lane Box Culvert Replacement	$742,922
Lucy Lincoln Hiestand Park Culvert and Frisch Road Storm Sewer	$1,255,896
Prairie Road Box Culvert and Theresa Terrace Storm Sewer	$1,039,724
Total	$17,378,517

Recommended Solutions Results

During evaluation of the recommended solutions, benefits were quantified relative to the flood reduction targets. The proposed conditions analysis show the following flood reduction benefits:

1. 10-percent chance storm event
    a. 0.7 miles out of the 35.9 street miles in the watershed do not meet the target. This is 2 percent of streets in the watershed; a 90 percent reduction from existing conditions.
2. 4-percent chance storm event
    a. 0.6 miles out of the 35.9 street centerline miles in the watershed do not meet the target. This is 2 percent of street centerline miles in the watershed; a 76 percent reduction from existing conditions.
3. 1-percent chance event
    a. 29 structures out of 3,089 structures in the watershed do not meet the target. This is 1 percent of structure in the watershed; a 57 percent reduction from existing conditions.
    b. 0 out of 9* greenway crossings in the watershed do not meet the target. This is 0 percent of the greenway crossings in the watershed and is a 100 percent reduction from the existing conditions. **The existing Pilgrim Road and McKenna Boulevard greenway crossings are combined into one crossing under the recommendations of this study.*

There are still locations where the flood reduction targets are not met. The targets cannot be met for various reasons including lack of physical space, topographic relief limitations, and avoiding increased flooding downstream. Additional information can be found in Section 11 of this report.

Figure ES-2 depicts the flood reduction summary within the watershed with the recommended solutions implemented. It shows surface flooding locations under the 4-percent chance storm event and how the performance of the improved stormwater conveyance system compares to City's flood reduction targets with the recommended solutions in place.

Section 1 Introduction

1.1 Project Background and Purpose

The City of Madison has experienced increased frequency and intensity of rainfall events over the past ten to fifteen years. On August 20th and 21st, 2018, an unprecedented rainfall event occurred on the city of Madison's west side. A nearby United States Geological Survey (USGS) rain gauge recorded 10.5 inches of rain over a 12-hour period. For reference, NOAA Atlas 14 rainfall 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.

This process began with watersheds hardest hit by 2018 flooding. The East Badger Mill Creek watershed is part of the second round of watershed studies undertaken by the City, which began in July 2019.

The overall purpose of this study is to develop a comprehensive stormwater management plan (SWMP) for the East Badger Mill Creek watershed that will guide the City in meeting its flood reduction targets. This document describes study's methodology, approach, and results. It documents the: (1) development of input parameters for the watershed's hydrologic and hydraulic (H&H) model, (2) construction of the stormwater H&H model, (3) calibration process for that model, (4) modeling results showing flooding under the watershed's existing physical conditions, (5) analyses of alternative flood mitigation measures, (6) flood reductions that can be expected from those mitigation measures, and (7) specific recommendations for flood reduction actions.

Figure 1-1 shows the location of the study area within the City. **Figure 1-2** provides a more detailed view of the watershed.

1.2 Historic Flooding in the Watershed

Within the East Badger Mill Creek watershed, there are several areas that have experienced flooding in the past. Figure 1-3 depicts areas that have previously experienced flooding and reported it to the City within this watershed. Known flooding locations include flood reports from a variety of data sources including resident reports, emergency services reports, and City of Madison Building Inspection. Documented areas that have previously experienced flooding are only included within City of Madison limits.

Known flooding locations from the August 2018 storm event, as well as areas with chronic drainage and flooding issues, were discussed with City of Madison Engineering Division staff at a meeting on May 18, 2020. **Figure 1-4** identifies the locations that were discussed during the meeting, in addition to Engineering Division Operations staff flood reports. A summary of the flooding locations discussed at the meeting are described below:

1. East Pass and Stonecreek Drive intersection floods frequently during smaller storms, sometimes spilling over into a driveway to apartment underground parking garage off of Stonecreek Drive.
2. Along the west side of the greenway just upstream of McKee Road several homes have low basement exposures that flooded on multiple occasions. This primarily occurred before CMPA culverts under McKee Road were replaced by the existing box culverts. This section of greenway

didn’t overtop the road or cause flooding in adjacent homes in August 2018 to the best of City staff’s knowledge.

3. Along the greenway channel between McKee Road and Lancaster Lane there are pipes and graded areas in easements between some homes. Based on past experience it appears many of these may be undersized.
4. At Maple Grove Road and Stratford Drive runoff comes from the east, upslope, and causes icing at intersection and all the way down Stratford Drive to McKenna Boulevard.
5. Sizing of the greenway crossings does not increase progressively moving downstream as flows increase. Culverts at Lancaster Lane overtopped in August 2018.
6. Wooded greenway between McKenna Boulevard and Pilgrim Road pipe culverts. This crossing doesn’t overtop, but is a constriction that causes upstream flooding.
7. Frisch Road cul-de-sac end near Tottenham Road has flooded historically. A terrace inlet was installed at the end of Frisch Road around 2011 according to City records. Driveway of 2210 Frisch sits lower than the overflow elevation at inlet out to the greenway. The water was several feet deep along Frisch Road in August 2018 and got into homes.
8. Low point on McKenna Boulevard just south of Tottenham Road. When McKenna Boulevard was most recently reconstructed the City hadn’t observed flooding at this location and didn’t receive a report of previous flooding from a resident until the project was being paved. Pipe size and inlet capacity issues were not addressed with the project since the City wasn’t aware.
9. Low point on Raymond Road just east of McKenna Boulevard experiences ponding in frequent rainfall roughly equivalent to 20-percent chance storm event, likely limited by pipe size and inlet capacity. When ponding gets deep enough it overflows through both driveways just to the south. This contributes to flooding of underground garages at the McKenna Townhomes complex.
10. Under the Riva Road grass median starting at Prairie Road and running to the east (upstream) there’s a large box culvert that may or may not be adequately sized. Water ponds in the street here, but the specific cause was unknown before this study was undertaken.
11. When Riva Road was last resurfaced between Prairie Road and Thrush Lane, box culvert sections sized to match the existing boxes under the medians could not be fabricated and delivered in time. A decision was made to use an available pipe size (48”x76” HERCP) at each street opening along the median. Alternating between box sections and elliptical sections causes a flow constriction at each transition, but flooding outside of the street hasn’t been reported.
12. Low point at Pilgrim Road and Homestead Road intersection experiences ponding often. This is likely the result of an undersized pipe, but could also be due to inlet capacity and/or inlet clogging. When ponding gets deep enough it overflows down the path into Pilgrim Park.
13. Along the back of homes on Cherbourg Court there is a 20 foot wide private stormwater management feature, rain garden or swale, but the City hasn’t received reports of flooding.
14. Our Redeemer Lutheran Church on McKenna Boulevard. The majority of the lot drains to the northeast corner of the property and towards the backside of several residential lots. Some runoff from Our Redeemer Lutheran Church is diverted towards the northwest corner of the lot and flows down a set of stairs to Jacobs Court, but the City hasn’t received reports of flooding.
15. The greenway and park land in Lucy Lincoln Hiestand Park is flat and the path crossings get overtopped often.
16. At the bend in Lomax Lane near Starr Court, the City installed storm sewer to intercept water that was running to the end of Starr Court. This pipe discharges to the greenway.
17. Prairie Road greenway crossing is likely undersized and has a pipe tapped into it. There are frequent observations and reports of Prairie Road overtopping during rainfall roughly equal to

the 10-percent or 20-percent chance storm events. Woody vegetation is present at both of the culvert ends so debris clogging may be an issue at the inlet of this culvert.

1.3 Flood Reduction Targets

The City established consistent targets for stormwater management flood reduction (Level of Service) throughout the City. It is the City's policy to meet the Level of Service with reconstruction and new construction of its municipal stormwater conveyance system. Specifically, the Level of Service stormwater flood reduction targets are:

1. No home or business flooding during the 1-percent chance, 24-hour design storm event (6.66 inches).
2. Eliminate flooding (surcharging of the storm sewer system onto the municipal streets) for up to the 10-percent chance, 24-hour design storm event (4.10 inches), with the exception of road low points.
3. Allow no more than 0.5 feet of stormwater ponding above storm sewer inlet rim elevations at inlet restricted low points during the 10-percent chance, 24-hour design storm event (4.10 inches).
4. Maintain drivability of municipal streets (center of the street with no more than 0.2 feet of water) during the 4-percent chance, 24-hour design storm event (5.0 inches).
5. Enclosed depressions should provide safe storage, or overflow, of stormwater during the 1-percent chance, 24-hour design storm event (6.6 inches). Flooding should be contained within public lands (streets, greenways, easements, etc.).
6. Where greenways cross streets, there should be no road overtopping during the 1-percent chance, 24-hour design storm event (6.6 inches).
7. Flooding solutions should not negatively impact downstream properties.

It should be noted that although the City strives to meet the above targets with each of its stormwater infrastructure projects, fully achieving these targets is not always feasible because of specific site constraints or other factors which cannot be controlled.

Section 2 Water Resources Inventory

2.1 Study Setting

The East Badger Mill Creek watershed is located on the southwest side of the City and covers approximately 1,297 acres. A small portion, less than 20 acres, of the watershed extends into the City of Fitchburg, as shown in **Figure 1-1**. A constructed greenway channel conveys stormwater from the northern extent of the watershed to the southern end where the watershed discharges. The watershed study area consists of four notable sections of the drainage system that direct runoff through the greenway, as described below.

1. The north portion of the watershed has upstream limits just north of Hammersley Road and drains south through the greenway channel. The greenway passes through a culvert under Prairie Road and flows through Lucy Lincoln Hiestand Park. The main channel of the greenway is joined by a short channel from the west where a storm sewer outfall daylights from beneath Frisch Road and Jacobs Way. The greenway continues flowing south to a culvert crossing at Raymond Road. Along this entire length of greenway there are several outfalls of short storm sewer runs that drain street low points.
2. The east portion of the watershed has upstream limits north of Barton Road, east of Whitney Way, and south of Williamsburg Way. The extents of this portion of the watershed are drained by flow in streets and sections of local storm sewer. The storm sewer runs connect to a long section of box culvert that flows underneath the grass median along Riva Road, which serves as the main stem of this part of the drainage network. The Riva Road box culvert discharges to a section of greenway that flows west through culverts under Westbook Lane.
3. The central portion of the watershed is primarily a section of greenway that flows from Raymond Road to Canterbury Road. Runoff from north of Raymond Road joins runoff from east of Westbrook Lane in the section of greenway in Pilgrim Park. This confluence and much of the adjacent park land is rather flat and a neighborhood of low lying homes is situated along this section of greenway. The greenway flows west through culverts under McKenna Boulevard, before turning to flow south through culverts under Pilgrim Road and on towards Canterbury Road. A large section of storm sewer that drains McKenna Boulevard, Raymond Road, and Tottenham Road has an outfall at the downstream end of the McKenna Boulevard culverts. A couple runs of local storm sewer also drain low points on streets that are adjacent to the greenway.
4. The south portion of the watershed is primarily a section of greenway that flows south from Canterbury Road to East Pass. The greenway flows through culverts under Canterbury Road, Lancaster Lane, Carnwood Road, McKee Road, and East Pass. Along this entire length of greenway there are several outfalls of short storm sewer runs that drain street low points. There are also three large sections of local storm sewer with outfalls at the Lancaster Lane, Carnwood Road, and McKee Road culvert crossings. The outfall of the East Badger Mill Creek watershed is located a short distance downstream of East Pass, before the greenway joins a branch of Badger Mill Creek that drains the area to the northwest. The watershed outfall flows directly into the Upper Badger Mill Creek watershed study area.

The watershed is almost entirely developed, with the only exceptions being parks and an undeveloped parcel at the southwest corner of the intersection of Maple Grove Drive and McKee Road. While the predominant land use in the watershed is low density residential, there are pockets of medium to high density residential and commercial development along the Raymond Road and McKee Road corridors.

Development began around 1960 in the northeast corner of the watershed and spread to south and west over the following three decades. Areas along McKee Road and to the south have developed more recently and consist primarily of higher density residential and commercial land uses. More detail on the watershed's land use is provided in Section 2.4.1

2.2 Topography

The topographic data was compiled from light detecting and ranging (LiDAR) data on the North American Vertical Datum of 1988 (NAVD88). Some data available for the project, such as past construction drawings, are in the previously used City vertical datum. The conversion factor from the historical City datum to NAVD88 is an addition of 845.6 feet. Data provided included two-foot contours, a digital elevation model (DEM) in raster format, and LiDAR point clouds.

The lowest elevations in the watershed are approximately 976 feet at the outlet of the watershed just downstream of East Pass along the main branch of the greenway. The highest elevations in the watershed are along the northwestern border of the watershed in Raymond Ridge Park and Elver Park at approximately 1,146 feet.

2.3 Constructed Drainage System

The East Badger Mill Creek watershed is fully developed and thus has a constructed drainage system that branches across much of the watershed. One of the primary drainage features is an open channel greenway that is approximately 14,000 feet long and winds through the center of the watershed. It extends from the south end of the watershed all the way to the north end of the watershed, with invert elevations of 976 feet and 1,030 feet, respectively. The channel doesn't have one continuous slope, but on average runs at approximately 0.4 percent. The greenway channel has a five to ten feet wide concrete lined bottom and mowed grass side slopes. Roughly 20 percent of the total length of greenway channel has a grass bottom rather than concrete lining. Most of the greenway channel runs through Stormwater Utility owned parcels that range from roughly 75 feet wide to 100 feet wide, with additional width in some sections. The greenway channel section between McKenna Boulevard and Raymond Road runs through Pilgrim Park and the section between Raymond Road and Prairie Road runs through Lucy Lincoln Hiestand Park. Public streets cross the greenway channel at ten locations in the watershed and various sizes of pipe culverts or box culverts convey stormwater flow at these greenway crossings.

The remainder of the drainage system in the watershed consists of storm sewers that discharge to the greenway channel. The concrete storm sewer pipe network provides street drainage throughout the watershed and is a combination of long, branching runs of larger diameter storm sewer main and short runs of smaller diameter pipe. The short runs of pipe are numerous in this watershed, which drain local street low points and discharge directly to the greenway channel. Many of the inlets in the watershed are H-inlets and in areas that experience recurring street inundation a local, case-by-case review of inlet capacity is warranted. Findings of this review are discussed later in the report. In some sections of the watershed there is no storm sewer and up to several blocks of street are drained by curb and gutter alone. Generally, these are located in upland areas in the watershed on streets with sufficient slopes to facilitate drainage. This street drainage configuration is characteristic of neighborhoods in Madison that developed in the 1960s through 1980s. However, in these areas some chronic issues exist such as street icing in winter and early spring, as well as excess runoff flowing down the street during storms.

A summary of the constructed system components in the watershed and in the model are shown in **Table 2-1**. Note there are fewer components in the model than in the watershed. The components not included are generally the smallest diameter storm sewer in the upland portions of the watershed and were excluded for the purpose of improving model construction efficiency and reducing model run time.

Table 2-1. Constructed System Components

Constructed System Component	Quantity in Watershed	Quantity in Model
Public Storm Inlets and Access Structures	805	268
Public Storm Sewer Pipes	698 segments; 10.4 miles	221 segments; 6.9 miles
Public Open Channels	11 segments; 2.7 miles	11 segments; 2.7 miles
Detention Ponds	1	1

2.4 Runoff Conditions

Stormwater runoff generated from a land surface will vary depending upon several factors including land use, impervious surfaces, soil types, and topography. The factors within the East Badger Mill Creek watershed are discussed in this section.

2.4.1 Land Use

The East Badger Mill Creek watershed includes a mix of land uses. **Table 2-2** provides a breakdown of the eight different land use types categorized within the watershed. A map of the generalized land use categories is shown in **Figure 2-1**. This gives a qualitative perspective of the type of development and associated runoff generating surfaces throughout the watershed. Additionally, it underscores the fact that there is very little remaining open area that could be repurposed for stormwater detention.

Table 2-2. Existing Land Use Areas

Land Use Type	Area (acres)	Portion
Commercial	11	0.8%
Institutional	49	3.8%
Open/Undeveloped	6	0.5%
Park	123	9.5%
Residential	793	61.2%
Stormwater	26	2.0%
Street	266	20.5%
Utilities	22	1.7%
Total	1,297	

2.4.2 Impervious Area

Impervious area ground cover for the entire watershed was determined using a GIS database impervious layer created by the University of Northern Iowa GeoTREE Center in 2020. Preparation of the impervious layer was an extensive undertaking that involved delineating all impervious areas in the city, classifying areas by land use, and classifying connectedness. **Table 2-3** shows the breakdown of pervious and impervious area in the watershed, which is also displayed in **Figure 2-2**.

The impervious layer was used to determine the amount of impervious area within each subcatchment and the portion of the impervious area that is directly connected (DCIA) to the municipal stormwater conveyance system. Impervious areas that drain to pervious areas are considered to be indirectly connected (NDCIA). See Section 4.3.2.1 for further description of the land use and impervious area categories, as well as how the data were used in the development of the PCSWMM model.

Table 2-4. Hydrologic Soil Group Areas

Surface Type	Area (acres)	Portion
Pervious	837	64.5%
DCIA	288	22.2%
NDCIA	172	13.3%
Total	1,297	

2.4.3 Soil Types and Noted Geologic Formations

Soils in the East Badger Mill Creek watershed are predominantly hydrologic soil group (HSG) B soils. The HSG classifications were used to estimate the infiltration parameters for pervious surfaces within the watershed (see Subsections 4.3.2.5 and 4.3.2.6). **Table 2-4** shows the areas for each soil group in the watershed and soil group area coverage is displayed in **Figure 2-3**. This data is based on the Natural Resources Conservation Service (NRCS) Soil Survey for Dane County.

Table 2-4. Hydrologic Soil Group Areas

HSG	Area (acres)	Portion
A	0	0.0%
B	1,105	85.2%
C	118	9.1%
D	74	5.7%
Total	1,297	

2.4.4 Mapped FEMA Floodplain

The greenway channel downstream of McKee Road (County Road PD) is a mapped FEMA Zone AE floodplain. In the Dane County Flood Insurance Study (FIS), dated June 16, 2016, this reach is referred to as East Branch Badger Mill Creek. This reach was not re-studied as part of the updated FIS report released in 2016; the analysis is dated December 31, 2006.

The Dane County FIS report lists the 1-percent chance peak flow as 779 cfs at a location approximately corresponding to the East Badger Mill Creek watershed outlet. High water elevations for the 1-percent chance peak flow at corresponding locations in the FIS report and existing conditions PCSWMM model are listed in **Table 2-5**.

Table 2-5. Greenway High Water Elevations South of McKee Road

FIS Cross Section	FIS WSE	PCSWMM WSE	Difference
D	977.7	979.64	1.9
E	979.5	980.21	0.7
F	980.5	983.20	2.7
G	982.6	983.25	0.6
H	983.4	983.60	0.2
I	984.2	984.40	0.2

The existing conditions PCSWMM peak flow rate for the 1-percent chance event at the East Badger Mill Creek watershed outlet is 1,114 cfs. This is considerably higher than the 1-percent chance FIS flow rate, but there are a few factors that help explain this. The HEC-HMS (Hydrologic Modeling System) analysis that produced the FIS flow rate was performed in 2006. At that time, the data source for design storm rainfall depths was the National Weather Service's Technical Paper 40 (TP-40), published in 1961. The rainfall depth for the 1-percent chance, 24-hour design storm from TP-40 was about 6 inches for Dane County, Wisconsin. The current NOAA Atlas 14 rainfall depth for the same storm is about 11 percent larger. The MSE4 rainfall distribution currently used for design storms in this part of Wisconsin is also different than the Type II rainfall distribution that was used with the TP-40 rainfall depths in the HEC-HMS model. Additionally, it's unlikely that the HEC-HMS model was built with a comparable resolution to the PCSWMM model for this watershed study. In particular, the City's storm sewer network and impervious areas were developed to a very high level of detail prior to inclusion in the PCSWMM model.

As a separate check on a reasonable range of peak flow rate for the watershed, the USGS flood frequency regression equations for Wisconsin urban streams (Conger 1986) were referenced. The equation for the 1-percent chance flow for urban areas outside of Milwaukee County resulted in a peak flow rate of 843 cfs. This equation has a standard error of 37 percent, which gives a range of flow rates from 531 cfs to 1,154 cfs for the East Badger Mill Creek watershed.

There is reasonable agreement between much of the 1-percent chance water surface profile from the FIS report and the PCSWMM model. The higher elevations in the PCSWMM model can mostly be explained by the larger peak flow rate. Other differences in the water surface profile, especially the larger ones, may also be explained by variations in channel geometry between the two models. For instance, the channel is defined in the HEC-RAS model using a series of cross sections and the data source can't be definitively confirmed from the notes in the Effective Model (HEC-RAS). In contrast, the channel is defined in the PCSWMM model using a 2D mesh with elevations assigned from LiDAR, as described earlier in this section. See Subsection 4.5.3 for additional discussion of PCSWMM's 2D modeling approach. It's possible that the channel shape and bottom elevation have changed over the past couple of decades, which helps explain the differences observed. PCSWMM model results are discussed further from a qualitative and quantitative perspective in Section 6.

Section 3 Guidance and Data Sources

3.1 City of Madison Model Guidance

During earlier modeling efforts in the City's watershed study program, a Modeling Guidance document was developed by the City, Brown and Caldwell (City consultant for the Stricker's/Mendota and Wingra West Watershed Studies), and AE2S (City consultant for Spring Harbor Watershed Study). This document was used to define consistent modeling parameters across the various watersheds that are being analyzed. The Modeling Guidance was developed at the onset of the project and updated throughout the study. The version of the Modeling Guidance dated July 14, 2020 was utilized when preparing the model and report for this study. A copy of the Modeling Guidance as of the date of this report is included as **Appendix A**.

3.2 List Data Sources

The East Badger Mill Creek Watershed study relies on a variety of data sources. A summary of the data sources is provided below.

1. Various datasets from the City's Geographic Information System (GIS). GIS data includes; land use, storm sewer (including associated structures), city limits, greenways and ponds, parcels, roads, and other pertinent data sets.
2. The City's GTViewer system. This system contains mapping of various City infrastructure including storm sewer, sanitary sewer, and water main. In some cases, this system contained information (such as pipe size or invert elevation) that was missing from the City's GIS data.
3. Construction and as-built drawings.
4. Photographs of various drainage features taken during field visits and survey.
5. Field surveys of selected items and locations within the watershed. Examples of survey locations include missing storm sewer pipe inverts, storm sewer structure rims and inverts, and culvert inverts at key locations.
6. Monitoring data to support this study was collected by the City and USGS. Monitoring data included rainfall, flow, and water level data at select locations. Additional information about the data collected and how the data was collected is provided in Subsection 4.2.2 for rainfall data and Section 5.1 for flow and water level data.

It should be noted that the City previously used a City vertical datum and the City is in the process of transitioning all data to NAVD88. The watershed study was conducted in NAVD88 and data that was in the old City datum was converted to NAVD88 by adding 845.6 feet.

The specific name and date of each file is listed in **Table 3-1**.

Table 3-1. Source Files

Data Type	File Name	File Date
Land Use	GISdw.DCL.LandUsePoly2020	2020
LiDAR	Citywide_Raster_small_cell	3/12/2019
Storm Sewer	Storm_Sewer_Pipes	3/21/2019
	Storm_Sewer_Structures	3/11/2019
	Storm_Pipes_Private	1/24/2019
	Storm_Structures_Private	1/24/2019
	STO_E_PVT Graphic Line	3/19/2019
	STO_E_PVT Graphic Cell	3/19/2019
Culverts	Storm_Sewer_Pipes	3/21/2019
	Storm_Sewer_Structures	3/11/2019
Greenways	Greenways_and_Ponds	1/11/2019
	PondGwayPipes	3/14/2019
	PondGwayStructures	3/14/2019
Planimetric Data	Greenways_and_Ponds	1/11/2019
	GISdw.DCL.RoadCenterline	9/1/2022
	GISdw.DCL.BuildingFootprint	9/1/2022
	Task5_WinSLAMMSourceArea_FC	2/10/2021
Aerial Imagery	WICMAD18_ReDelivery_Gen3_RDG.sid	12/3/2018

Section 4 Model Development

4.1 Modeling Software

To evaluate flooding and stormwater conveyance system capacity within the East Badger Mill Creek watershed, a model was created using PCSWMM version 7.5 to simulate the hydrology and hydraulics (H&H) within the watershed. PCSWMM is a proprietary software product of Computational Hydraulics International (CHI) (www.chiwater.com). The model created for the East Badger Mill Creek watershed is a combination one-dimensional (1D)-two-dimensional (2D) H&H model.

4.2 Rainfall Files

The analysis included an evaluation of both design storms and recorded rainfall events. A series of storm events were evaluated as part of this study to identify which events result in flooding, and the severity of that flooding. Both theoretical design storms and measured local storm events, were considered as part of the study. The rainfall events that were used in the analysis are described in the following sections.

4.2.1 Design Rain Events

The watershed flooding analysis included a series of different recurrence interval design storms (100-, 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent chance) with a 24-hour duration. The design storm events used rainfall depths from the National Oceanographic and Atmospheric Administration (NOAA) Atlas 14. The Midwest/Southeast states (MSE) 4 rainfall distribution, developed by the Natural Resources Conservation Service (NRCS), was used for the rainfall. **Table 4-1** lists the rainfall depth that were used in the H&H modeling for this study.

Table 4-1 Design Rain Events

Recurrence Interval	Rainfall Depth (inches)
100% chance	2.49
50% chance	2.84
20% chance	3.45
10% chance	4.09
4% chance	5.02
2% chance	5.80
1% chance	6.66
0.5% chance	7.53
0.2% chance	8.94

4.2.2 Measured Rain Events

Rainfall data was collected from May 2020 through November 2020, across the west-side of Madison in support of the watershed studies. The gauges were installed by the USGS with support from the City. The East Badger Mill Creek watershed study calibration process utilized a combination of four rain gauges within and near the watershed to characterize measured rainfall events. The City produced Thiessen polygons providing full coverage of the East Badger Mill Creek watershed using the locations of the four gauges. The Thiessen polygons were used to assign measured rainfall data for the calibration events and the August 2018 event to the appropriate subcatchments. The location of each rain gauge used in the study is provided in **Table 4-2** and is displayed in **Figure 4-1**.

Table 4-2 Rain Gage Locations

Gauge Location	Operated By
Greentree Park	City of Madison
Meadowood Park	City of Madison
Manchester Park	City of Madison
Waltham Park	City of Madison

All gauges were operated by the City and rainfall data was obtained from the Trimble Unity website. Trimble Unity is the City's partner for providing monitoring data on gauges of this type City-wide.

From the data collected over the entire monitoring period, May 2020 through November 2020, three measured rainfall events were selected to be used in the calibration process for this study. The events selected are displayed in **Table 4-3**. These events are the largest rain events that were successfully measured and had good corresponding water surface elevation measurements at the monitoring stations (see Sections 5.1 and 5.2). The events were selected at a meeting between City staff and the watershed study round 2 consultant teams (MSA and Stantec) where available rainfall and monitoring data was reviewed. A consensus was drawn for the events to be used based on the size of the storm events and successfully collected monitoring data. After the events were selected another storm occurred in November 2020 and it was determined to be a more useful calibration event than the May 17-18, 2020 rainfall that was included in the Greentree/McKenna and Dunn's Marsh studies.

Table 4-3 Rain Events Selected for Calibration Process

Event Date	Rain Depth (inches)*	Rain Duration (hours)	Approximate AEP (percent chance)
June 9-10, 2020	2.8 – 3.0	27.5	50%
July 9, 2020	1.9 – 2.1	4.5	100% - 50%
November 10, 2020	0.9 – 1.1	4.0	100%

*rain depth varies by station

The June 9-10 storm event had the greatest total rainfall depth that was successfully measured in 2020 at the relevant rain gauges, however, the rain fell in two peaks separated by about 16 hours. While these conditions didn't create the greatest peak runoff of the monitored events, they did provide a good event for evaluating how well the model simulates rainfall with wet antecedent conditions. The July 9 event included the most intense rainfall experienced in 2020 while monitoring gages were installed. Total rainfall depth and duration falls in the range of a 100- to 50-percent recurrence interval based on NOAA Atlas 14 Volume 8 Version 2 data. The November event produced rainfall depths slightly lower than those expected for the 100-percent recurrence interval event with equivalent duration.

4.3 Hydrologic Model Development

The process used to generate the hydrologic inputs for the PCSWMM model is described in this section.

4.3.1 SWMM Runoff Description

Hydrologic calculations were performed in the PCSWMM model using Storm Water Management Model (SWMM) runoff methodology. SWMM hydrology uses a combination of drainage area size and shape, slope, land cover (pervious, impervious indirectly connected, impervious directly connected), and soil infiltration parameters to generate runoff from a rain event. Discussions with City staff concluded that the SWMM hydrologic method was preferred over the curve number (CN) approach because of the urban land cover conditions. Although the curve number method is used in urban settings, it was originally developed for application in rural/agricultural watersheds.

The SWMM runoff methodology and associated parameters are defined in the Modeling Guidance document and can be found in **Appendix A**. The calculations were performed for each subcatchment that was delineated within the watershed. The model developed a runoff hydrograph based on the model input parameters and this is entered by the model into the hydraulic portion of the software.

4.3.2 Subcatchment Input Data

The East Badger Mill Creek watershed is divided into 111 subcatchments, which are displayed in **Figure 4-2**. Subcatchments were delineated based on topography, storm sewer maps, drainage features (such as channels and pipes), and land use maps. Each subcatchment is named based on the City's naming convention. Hydrologic input parameters were calculated for each subcatchment, which included quantifying three surface types within each subcatchment based on the impervious area layer. The subcatchment surfaces are defined as:

1. Directly connected impervious area (DCIA) – impervious areas that drain directly to the conveyance system
2. Indirectly connected impervious area (NDCIA) – impervious areas that drain over a pervious surface prior to entering the conveyance system
3. Pervious area – vegetated land surfaces or areas with no impervious surface

The input parameters and calculation methodology for hydrologic input parameters are described below. The PCSWMM model input parameters for each subcatchment are listed in **Appendix B**.

4.3.2.1 Subcatchment Areas and Surfaces

In the East Badger Mill Creek watershed, subcatchments range in size from 1.98 acres to 35.83 acres, with a median size of 10.47 acres. Subcatchments were delineated to a level of detail corresponding to that of the modeled storm sewer, discussed further in Section 4.4. An outlet junction for each subcatchment was assigned in PCSWMM, which determines where runoff from the watershed enters the model. Generally, each subcatchment contributes to a group of inlets along a street or at an intersection and the subcatchment outlet was designated as a structure junction along a storm sewer main. Alternately, some subcatchments contribute to locations with flow in streets not served by storm sewer, known overland flow, or directly to greenway channels. In these cases, the subcatchment outlet is designated as a junction connected to the 2D mesh that represents the ground surface, which is discussed further in Section 4.5.

The area for each subcatchment was calculated using the delineations developed in GIS at the beginning of the study. Due to the format of PCSWMM model input, percent impervious area is entered for each subcatchment, rather than total impervious area. In addition, the percentage of impervious area routed to pervious area (indirectly connected) is entered for each subcatchment. The hydrologic parameters for every subcatchment is listed in **Appendix B**. The impervious area inputs were calculated using the layer provided by the City (see Section 2.4.2), following this method:

1. The impervious layer was dissolved based on connection type: DCIA and NDCIA.
2. The dissolved impervious layer was used to calculate the total pervious and impervious areas for each subcatchment and was saved to a summary statistics table.
3. Impervious percentage for each subcatchment was calculated by dividing the total impervious area by the subcatchment area and multiplying by 100.
4. Impervious percentage routed (NDCIA) for each subcatchment was calculated by dividing the total DCIA by the total impervious area, subtracting from 1, and multiplying by 100.

4.3.2.2 Subcatchment Width

In SWMM hydrology, the term width refers to the general shape of a hydrologic unit (subcatchment) and the relationship of the surface flow path to the shape of the subcatchment. At the same time each subcatchment was delineated, a line was drawn to represent the longest typical flow path for each subcatchment. The length of this line was calculated and the subcatchment area was divided by the flow path length to calculate the subcatchment width.

It should be noted that the subcatchment width was used as the primary calibration parameter. See Section 5 for modifications that were made to develop the calibrated existing conditions model.

4.3.2.3 Slope

A slope for the flow path described under in Section 4.3.2.2 was calculated using the flow path length and ground elevations at both ends. The elevation at the upstream and downstream ends of the flow path was assigned from the topographic data provided by the City.

4.3.2.4 Soils and Infiltration

Soils within the watershed are classified by HSG. The soils conditions of the watershed are represented in the hydrologic calculations through the infiltration parameters selected for the study.

The Horton soil infiltration methodology was used within PCSWMM and this approach is consistent with the City's Modeling Guidance. This methodology establishes a maximum infiltration rate, a minimum infiltration rate, and the decay rate of infiltration for each HSG. Input parameters were developed for each of HSG and **Table 4-4** provides the infiltration values.

Table 4-4 Hydrologic Soil Groups and Associated Infiltration Values

HSG[1]	Maximum Infiltration Rate (in/hr)	Minimum Infiltration Rate (in/hr)	Decay Rate (1/hr)	Dry Days (day)
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

[1]Where soils are classified as A/D, B/D, or C/D a HSG D was assumed.

The amount of each HSG present in every subcatchment was calculated as an area measurement. For each subcatchment, composite infiltration parameters were developed by area-weighting each parameter based on the HSG proportion of total area of the subcatchment. For example, if a subcatchment is 50-percent HSG A and 50-percent HSB B, the maximum infiltration rate would be 3.0 inches/hour.

The values shown in **Table 4-4** are the baseline values. Infiltration rates can be used as a calibration parameter may be modified to better represent actual conditions. See Section 5 for discussion of modifications made to develop the calibrated existing conditions model.

4.3.2.5 Antecedent Runoff Conditions

The antecedent moisture condition represents the amount of moisture in the ground at the beginning of a model simulation and can range from saturated to exceptionally dry. In saturated conditions, the maximum infiltration rate of soils would be decreased and the depressional storage may be reduced. In dry conditions, the maximum infiltration rate may be higher than typical. For this analysis, typical antecedent moisture conditions were used and assigned values are listed in the Decay Rate and Dry Days columns of **Table 4-4**.

4.3.2.6 Depressional Storage

Within a subcatchment, there are surface depressions that collect runoff (puddles) and reduce the amount of runoff generated from a rainfall. Depressional storage is incorporated into the runoff calculations to account for these areas. For each subcatchment, a depression storage of 0.05 inches for impervious areas and 0.15 inches for pervious areas was included. These values meet the criteria defined in the City's Modeling Guidance.

4.3.2.7 Internally Drained Areas

Within the watershed, there are no internally drained areas of significant size. There are some highly localized depressions, such as settlement in backyards, but the scope of this study did not allow for the evaluation of each individual area through delineation of internally drained subcatchments or accounting for these areas as additional depressional storage. In this regard, the model results are already representative of runoff conditions should localized depressions be regraded to promote better drainage at any point in the future.

4.4 1D Hydraulic Model Development

The 1D hydraulic portion of the PCSWMM model represents the storm sewers and culverts that comprise the drainage system within the East Badger Mill Creek watershed. The hydraulic input parameters required by PCSWMM vary depending on the different parts of the drainage system. The source data used to compile the hydraulic model input data is summarized below. **Appendix C** provides existing and proposed conditions hydraulic input parameters from the PCSWMM model. All elements of the stormwater conveyance system, including storm sewer pipes, structures, culverts, and greenway channels, are displayed in **Figure 4-3**.

4.4.1 Closed Conduit Conveyance System – Storm Sewers

City-owned storm sewer pipes with diameter 18-inches or larger were included in the PCSWMM model, per the study's scope. Additionally, selected storm sewers that are smaller than

18-inches were included if they were deemed critical to representing the conveyance system's performance. In the East Badger Mill Creek watershed, thirteen 15-inch diameter pipes were included in the model. These pipes were deemed critical pieces of the conveyance system for one of two reasons: 1) they drain road low points and discharge directly to the greenway or 2) they provide drainage from a subcatchment that was delineated at a scale consistent with other nearby subcatchments. Each storm sewer conduit requires upstream and downstream invert elevations, pipe length, and Manning's n (roughness coefficient).

Additionally, entrance and exit losses (minor losses), as well as roughness coefficients, were added to storm sewers based on values listed the Modeling Guidance document. Losses were split evenly between the entry pipe and exit pipe at a storm access structure (SAS). For example, at a 90-degree SAS a total loss of 0.5 was assigned. An exit loss of 0.25 was assigned to the incoming pipe and an entry loss of 0.25 was assigned to the outgoing pipe. At a tee, or cross SAS structures, a loss of 0.5 was applied to each pipe.

Other smaller storm sewers, private storm sewers, and inlet leads were not included in the model because this phase of the project is focused on identifying and resolving major flooding issues on public property and flooding issues that result from stormwater leaving public property. Future phases of the process will likely incorporate smaller components of the conveyance system to aid in the design of specific management infrastructure.

The source of the closed conduit conveyance system data for the model included GIS data provided by the City, information from the City's GTViewer system, construction plans, and field surveys at select locations. Where missing data remained, assumptions were developed to fill data gaps. The assumptions made are listed below.

1. Missing invert elevations were obtained by interpolating between the nearest upstream and downstream invert elevations. Where known bounding inverts were unavailable (as in the upper most reaches of the storm sewer), the next downstream slope was continued upstream.
2. Where pipe sizes were unknown, the size of the nearest upstream pipe was used.
3. Missing pipe material was assumed to be the same as the nearest upstream pipe.

4.4.2 Closed Conduit Conveyance System – Culverts

City-owned culverts under every greenway crossing in the watershed were included in the PCSWMM model, per the study's scope. Each box culvert or pipe culvert is represented by a conduit in the model and requires upstream and downstream invert elevations, pipe length, Manning's n (roughness coefficient), and entrance and exit loss coefficients. Coefficient values were assigned to culverts based on the Modeling Guidance document. Culverts at greenway crossings are critical connections in this watershed since the greenway channel is the predominant stormwater drainage feature.

The source of the culvert data for the model included GIS data provided by the City, information from the City's GTViewer system, construction plans, and field surveys at select locations. Where missing data remained, assumptions were developed to fill data gaps. The assumptions made are listed below.

1. Missing invert elevations were obtained by interpolating between the nearest upstream and downstream invert elevations.
2. Where known bounding inverts were unavailable (as in the upper most reaches of the storm sewer), the next downstream slope was continued upstream.

After the existing conditions model was finalized it was determined during a field visit that the Westbrook Lane culverts are 47”x71” CMPA rather than 48”x76” CMPA, as listed in City records. A review showed that correcting the dimensions of these pipes in the model would only make a minor difference in model results and does not change the representation of existing flooding relative to targets. Therefore, the revision was not made.

4.4.3 Existing Inlet Capacity

Inlet capacity was not included explicitly in the modeling for this watershed. If areas are known to experience flooding, but the model results show less flooding than has been observed or reported, then those areas were subject to closer evaluation of existing inlet capacity.

4.4.4 Existing Detention Ponds

One existing detention pond was identified within the watershed and incorporated into the PCSWMM model. The stage-storage data for the ponds is defined in a 1D pond node. The outlet structure for the pond is described using 1D weirs and a 1D orifice.

A combination of available site plans, aerial photography, and 1 foot contours was used to determine the appropriate model input data for the detention pond. Input data included the stage-area relationship to represent the storage in the pond and representative elevations and dimensions of the pond outlet structure.

4.4.5 Open Water/Backwater Effects

The East Badger Mill Creek watershed does not discharge to an open waterbody, such as Lake Monona. Therefore, backwater effects are not accounted for at the downstream end of this model. Additional discussion of downstream boundary conditions is provided in Subsection 4.5.7.

4.5 2D Hydraulic Model Development

The 2D portion of the hydraulic model is utilized to represent the overland flow across the ground surface and flow in the greenway channel. The 2D model uses topographic data to define the ground surface where overland flow may find preferential flow paths throughout the watershed, including areas such as along streets, between buildings, or over open space. The 2D model is connected to the 1D model to allow flows to pass from the 1D model elements into the 2D domain of the model and vice-versa. The components of the 2D model are further described in the sections below.

4.5.1 Description of Areas Modeled in 2D

Areas within the East Badger Mill Creek watershed modeled in 2D include all greenway channels, portions of street where existing storm sewer could surcharge, and areas adjacent to these sections of channel and street. Obstructions (as described in Section 4.5.5) are excluded from the 2D domain. Elements that were not modeled in 2D include storm sewers, culverts, and the detention pond. Specific information on how the 2D area is modeled is provided below.

LiDAR data was used to populate the surface elevations for all areas where mesh was generated. City GIS data and available construction plans were used to confirm profiles along greenway channels. Aerial photography and site photos were used to select Manning’s n values (roughness coefficients) for the greenway channels.

4.5.2 Topographic Data

The City-provided elevation raster (Citywide_Raster_small) is the topographic data used as the basis for the 2D surface in the model. The raster file was clipped to the approximate watershed extents and loaded into PCSWMM. During the process of creating a 2D nodes point file, PCSWMM samples elevations from the raster at points with a resolution defined in a layer that represents the extents of the 2D domain in the model.

4.5.3 2D Mesh

PCSWMM uses a mesh comprised of conduits and junctions to complete the 2D model calculations. There are several shape options available when defining the structure of the mesh. 2D cells are generated at the same time as the mesh during model construction and are used for results reporting. While generating the mesh, style options and element characteristics can be varied for discrete areas throughout the 2D domain of the model. The mesh conduits are represented as rectangular open channels that convey flow. These are 1D elements that are used to execute flow computations in multiple directions, simulating 2D flow. CHI describes this as a quasi-2D modeling approach that provides an accurate representation of 2D flow in most typical applications. Water enters the mesh at junctions in this model and is transferred between junctions via the conduits. The mesh creation tool in PCSWMM generates mesh junctions at the locations of the 2D nodes. The same layer that was used to define 2D node resolutions also defines mesh styles/shapes and surface roughness values. Elevations are assigned to the junctions, which correspond to the center of each 2D grid cell, from the topographic data. The mesh size in the model for this study ranges from 10 by 10 foot rectangles to 1,400 square foot hexagons, with irregular shapes used around obstructions. The 2D mesh covers the entire 2D model domain, as described in Section 4.5.1.

4.5.4 2D Land Use and Roughness Values

A Manning's n value is assigned to all portions of the 2D model, based on the land use and cover present. This value represents the roughness of the ground surface, which translates to the resistance met by flow. For the East Badger Mill Creek watershed, the land cover was identified as one of four categories, each with a unique Manning's n value assigned. The land cover categories are water, impervious, pervious, wooded greenways, and (majority) grassed greenways. Roughness values were imported to PCSWMM from GIS data developed for the watershed. The Manning's n value corresponding to each land use is provided in **Table 4-5**. The land use roughness values across the 2D domain is displayed in **Figure 4-4**. It should be noted that the 2D mesh Manning's n values listed are the final, calibrated values from the computer modeling.

Manning's n values were selected from a table in a HEC-RAS 2D training manual prepared by WEST Consultants, Inc. (**Appendix D**). Under non-shallow flow conditions, Manning's n values ranging from 0.02 to 0.04 and 0.015 to 0.02 are characteristic of waterways and channels with minimal vegetation and concrete lined channels, respectively. These values were considered when assigning an n value to greenway channels in the watershed that have mowed grass side slopes, the majority of which also have a concrete lined channel bottom. Under non-shallow flow conditions, Manning's n values ranging from 0.04 to 0.10 are characteristic of vegetated waterways and channels. These values were considered when assigning an n value to the greenway channel section that has heavy tree growth. This section of greenway channel also includes a sharp change in flow direction as well as rapidly expanding and contracting flow. The roughness value was adjusted to be higher based in consideration of observed high water elevations in the upstream greenway section. Manning's n values of 0.10 to 0.15 are characteristic of paved areas (impervious) under shallow flow conditions. Manning's n values of 0.20 to

0.40 are characteristic of open areas with average grass cover (most pervious areas in this watershed) under shallow flow conditions. Data collected from monitoring equipment were also taken into consideration when adjusting Manning's n values in the model.

Table 4-5 2D Manning's Roughness

2D Land Use	Manning's n
Grass Greenways	0.028
Wooded Greenways	0.2
Impervious	0.1
Pervious	0.2

4.5.5 Obstructions

Obstruction are defined as areas where surface water cannot flow because of physical barriers, such as buildings. Obstructions were identified and added to the model using the Dane County GIS building footprint data. There are gaps in the 2D mesh at the location of every obstruction, so flow is not conveyed through these areas.

4.5.6 1D/2D Interface

The 1D and 2D portions of the model interface at model junctions. At model junctions that represent storm sewer structures where water is physically able to leave the pipe network and come onto the ground surface, the 1D junction is connected to the 2D mesh. This allows flow to be transferred from the 1D storm sewer network onto the 2D mesh at such junctions within the model. As described previously, inlet capacity was evaluated separately on a case by case basis and is not accounted for directly in the model. Additionally, pipes with open ends that discharge to a greenway or receive flow from a greenway channel are represented in the model by a conduit that connects directly to a 2D mesh junction.

4.5.7 2D Boundary Conditions

The boundary of the 2D model – the perimeter of the 2D grid defined for the study – is created in the model to be closed and acts as a vertical wall. The model results were reviewed and flow outfalls were added at locations overland flow and channel flow leaves the study area. In the PCSWMM model it is assumed that the energy grade line of flow in the greenway channel is allowed to continue as flow moves downstream. This condition is confirmed by high water elevations in the Upper Badger Mill Creek watershed study PCSWMM model results and the FIS flow profiles.

4.5.8 Model Quality Control Review

Following subcatchment delineation, Caroline Burger (City of Madison) reviewed the basin boundaries and flow paths. Comments were addressed prior to continuing with model construction and refinement. Once the existing conditions PCSWMM model was assembled and able to run, Caroline Burger performed a cursory review of the model in December 2020. The review checked the model for consistency with the City's Modeling Guidance, general modeling professional practice, pipe slopes and profiles, and minor loss coefficients. A copy of the review comments can be found in **Appendix F**. The comments were reviewed and the PCSWMM model was revised accordingly.

4.6 Existing Conditions Non-Calibrated Model Results

The PCSWMM model was constructed and executed for each of the design storms, listed in Subsection 4.2.1, and the measured storm events, listed in Subsection 4.2.2, under the existing land use and conveyance system conditions. **Appendix H** summarizes the peak water surface elevation and flows at selected locations throughout the East Badger Mill Creek watershed during the design storms. **Figure 4-5** provides the location of each of the reporting locations listed in **Appendix H**.

Section 5 Model Calibration

The calibration process focused on identifying consistent model input parameters that would provide reasonably comparable results for each of the three storm events identified in Section 4.2 as well as the major storm event that occurred in August 2018.

It is understood that the hydrologic conditions and actual runoff produced from the land surface vary from storm to storm. Additionally, it is sometimes the case that hydrologic parameters which best simulate runoff from larger rain events do not produce the most accurate simulations of smaller rain events. As a result, model simulation of the August 20th, 2018 storm relative to observations was given preference during the calibration process since the objective of this study is to assess flooding caused by large storm events. While the model produced reasonable results for the monitored calibration events, accurately modeling larger events was considered a priority.

If this model is used in the future to analyze smaller rain events, additional review of the calibration parameters should be conducted, and modifications should be considered to better represent the expected runoff from smaller storms.

As part of the model calibration process, the following steps were taken:

1. Data collected by the monitoring equipment and observations collected after the August 2018 storm event were compared to model results at the corresponding locations.
2. In this study, the goal was to simulate flow depths and flow rates within +/- 25 percent of values measured by monitoring equipment or observed values. Where the model results did not meet this performance target, model parameters were modified within the range of professional judgement.
3. Where model parameters could not be adjusted within the range of professional judgement, the area was noted.
4. Where model parameters could be adjusted within the range of professional judgement, selected parameters were adjusted until model results were within a reasonable margin of the monitoring data. The parameter adjustment process is described in greater detail in Section 5.3.

5.1 Monitored Water Levels and Flow Data

There are three monitoring locations within the East Badger Mill Creek watershed that were used as part of the calibration process. These are shown spatially in **Figure 5-1** and are described below.

1. Raymond Road Channel Level: Flow depth in the greenway channel just upstream of the culvert crossing at Raymond Road was monitored by the City, data obtained from Trimble Unity website.
2. Riva Road Sewer Level and Velocity: Flow depth and flow velocity in the storm sewer near the intersection of Riva Road and Tanager Trail was monitored by the City, data obtained from Trimble Unity website.
3. Westbrook Lane Channel Level: Flow depth in the greenway channel just upstream of the culvert crossing at Westbrook Lane was monitored by the City, data obtained from Trimble Unity website.

5.2 Selected Runoff Events

The following events were used during model calibration process.

5.2.1 2020 Monitoring Storm Events

The rain events selected for the calibration process are defined in Section 4.2.2. The events were selected based on the completeness of recorded data, rainfall intensity, and total rainfall observed. As mentioned previously, rare rainfall events resulting in severe flooding did not occur during the monitoring period. The June 9th and 10th, 2020 event had the largest cumulative rainfall (2.8 to 3.0 inches over 27.5 hours) of 2020. The total rainfall depth and duration of this event falls within the range of a 50-percent annual exceedance probability event, according to NOAA Atlas 14, Volume 8, Version 2 data. The total rainfall depth and duration of the July 2020 event falls between the 100-percent and 50-percent annual exceedance probability events, while the November 2020 event was smaller than the event with an expected 100-percent annual exceedance probability.

5.2.2 August 2018 Storm Event

A historical storm event occurred on August 20th and 21st, 2018. In the East Badger Mill Creek watershed, radar rainfall data indicates that between 6 and 9 inches of rain fell over the majority of the watershed during that event. Based on rainfall frequency statistics (NOAA Atlas 14), an event of this magnitude has between a 0.5- and 0.2-percent chance of occurring in any one year. Although the City did not have flow and level monitoring equipment in place during this event, the City collected topographic survey elevations and observations of high water marks from the storm. The City also collected photographs and flood reporting information from residents in the watershed.

5.3 Calibration Process

Using monitoring data from the three selected rainfall events, as well as the August 2018 storm, an iterative calibration process was conducted on the East Badger Mill Creek watershed model. The parameters that were adjusted during the calibration process are discussed in greater detail below.

1. Culvert inlet treatments:
    a. Flow depths were not simulated accurately at several culvert crossings in the non-calibrated existing conditions model.
    b. The inlet end of each culvert was carefully reviewed in the field and entrance loss coefficients were adjusted accordingly.
    c. Culvert invert elevations were confirmed and channel invert elevations were adjusted as needed to create representative transitions between channel and culvert.
2. 2D surface roughness:
    a. Manning's n values assigned to the portions of the 2D mesh representing grass greenway channels, with and without concrete liners, were decreased from their initial values since modeled water surface elevations in the channels were higher than expected. These values also have better agreement with suitable reference materials (**Appendix D**).
    b. Manning's n values assigned to the portion of the 2D mesh representing wooded greenway channel was adjusted to the higher end of the justifiable range to produce results representative of observations from the areas upstream of McKenna Boulevard.
3. Subcatchment width:
    a. Documentation from CHI indicates that this parameter has a higher degree of uncertainty than other model parameters, as well as a wide range of variability, making it a good candidate for calibration. This was the primary hydrologic parameter adjusted in the model.

b. The model was run for a range of subcatchment width values. Relative to the initially calculated subcatchment widths, the adjusted values included: 40 percent decrease, 20 percent decrease, 20 percent increase, 40 percent increase. The corresponding results were compared and decreasing subcatchment width by 40 percent was deemed to produce model results best aligned with observations.

5.4 Calibration Results

A summary of observed data and simulated data at the monitoring locations documented during the calibration process are provided in **Table 5-1**. Graphs of the recorded and modeled runoff from the 2020 calibration events are displayed in **Appendix G**. Approximate peak water surface elevations for the August 2018 storm, listed in **Table 5-2**, are based on resident accounts collected during focus group meetings. These ranges are approximate since they were observed, rather than measured, and observations did not necessary correspond to the timing of peak flow during the event. Despite this, the observations reported from this event were a very important point of reference for checking the model's performance against reality. After calibration was completed it was determined during a field visit that the Westbrook Lane culverts are 47”x71” CMPA rather than 48”x76” CMPA, as listed in City records. The difference in conduit size at this location was determined not to have a significant impact on model calibration.

Table 5-1 Calibration Event Water Surface Elevations (WSEs)

Location	Recorded Peak WSE (ft)	Uncalibrated Model Peak WSE (ft)	Calibrated Model Peak WSE (ft)
June 9-10, 2020			
Raymond Road	1015.61	1016.90	1016.35
Westbrook Lane	1012.51	1012.74	1012.41
Riva Road	1017.94	1017.39	1016.85
July 9, 2020			
Raymond Road	1015.76	1016.91	1016.44
Westbrook Lane	1012.94	1013.17	1012.91
Riva Road	1018.28	1018.21	1017.67
November 10, 2020			
Raymond Road	1015.42	1015.57	1015.12
Westbrook Lane	1011.96	1012.16	1011.67
Riva Road	1017.12	1016.54	1016.07

The monitoring equipment installed in the storm sewer structure at Riva Road included a velocity sensor and was intended to provide measured flow rate data. The flow data reported on the Trimble Unity website was incorrect, extremely low flow rates were displayed, and could not be troubleshot for use in the calibration process. Next, a rating curve was developed to convert flow depths at this location to flow area, which was multiplied by the recorded velocity reading to create a calculated-measured flow rate time series. However, further data quality issues arose in the velocity readings. The maximum velocity recorded for all three events is 8.6 ft/s even though the events had different rainfall and runoff characteristics, which should have resulted in varied peak flow velocity measurements. This velocity is roughly 40 percent higher than velocities listed in the PCSWMM model results for the same events, so it's possible that the inaccurate readings resulted from turbulence in the structure. Higher than expected flow velocities result in higher than expected flow rates. Since the issue of flow velocity accuracy could not be resolved, a comparison of measured and modeled flow rates at the Riva Road monitoring location are not included in the summary of the calibration process.

An important consideration is that not all residents who witnessed the August 2018 storm actually observed the peak of that event. Some of the most intense rainfall and resulting peak flows occurred during the overnight hours when not everyone was awake and making clear observations was made more difficult due to darkness. Despite this, several instances of focus group resident feedback were particularly helpful in helping to validate the model results.

Table 5-2 August 20, 2018 Modeled Water Surface Elevations (WSEs)

Location	Recorded Peak WSE (ft)	Uncalibrated Model Peak WSE (ft)	Calibrated Model Peak WSE (ft)
Frisch Road	1015-1016	1015.94	1016.36
Lancaster Lane Crossing	1002-1002.5	1002.35	1002.39
Carnwood Road Crossing	992-992.5	993.59	992.98

5.5 Calibration Conclusions

The peak water surface elevations predicted by the model for the August 2018 storm match the observations of residents and City staff within +/ 1.0 feet. Given the magnitude of the event, the model is considered a good representation of this event.

For the monitored events in 2020, the shape and timing of the model results compares relatively well to the monitored data. Most of the focus of the calibration effort was placed on the August 2018 storm observed high water due to the fact that the objective of this study is to assess flooding from large storm events. The calibration process is considered to have been successful since it brought many modeled high water elevations in the watershed closer to recorded or observed values and the process developed a single set of parameters that can be used for larger storm events.

Section 6 Model Results

6.1 Existing Conditions Calibrated Model Results

The calibrated PCSWMM model executed for each of the design storms. **Appendix H** summarizes the peak water surface elevation and the duration of flooding at selected locations throughout the East Badger Mill Creek watershed. **Figure 4-5** provides the location of each of the reporting locations listed in **Appendix H**.

The existing inundation mapping for each modeled event are found in **Figures 6-1** through **6-10** and display the maximum modeled water depths across the watershed during 100-percent chance event through the 0.2-percent chance event, in addition to the August 2018 storm.

6.2 Model Results Evaluation

By reviewing the 10-percent chance event, the most flood-prone areas become readily apparent, as indicated by flooding depths greater than half a foot. The areas that appear to be most flood-prone, based on a review of the 10-percent chance event include:

1. Raymond Road east of McKenna Boulevard
2. McKenna Boulevard south of Tottenham Road
3. Frisch Road south of Brompton Circle and Tottenham Road east of McKenna Boulevard
4. Riva Road east of Prairie Road
5. Thrush Lane east of Riva Road
6. Whitney Way at Barton Road
7. Frisch Road south of Jacobs Way

Several conditions can influence the flooding including inlet capacity, storm sewer capacity, overland flow from other sources, or a combination of all of these conditions. The causes of flooding at the above locations, and other locations in the watershed with chronic flooding issues, are discussed in greater detail later in this section.

6.2.1 Comparison to City Flood Reduction Targets

The existing conditions flooding results were compared to the City's flood reduction targets to quantify the performance of the stormwater conveyance system in the East Badger Mill Creek watershed. The performance of the system's pipe capacity, inlet capacity, street flooding, road overtopping at greenway crossings, and structure flooding was evaluated and is described in further detail in the following sections.

6.2.1.1 Pipe Capacity

For pipe capacity, the City's target is to eliminate surcharging from the storm sewer system onto City streets for up to the 10-percent chance event. The pipe capacity was determined to be exceeded if the peak water surface elevation at the upstream end of the pipe was above the ground surface elevation. There are a total of 6.9 miles of storm sewer pipe included in the PCSWMM model and approximately 58 percent of the pipes in the watershed have their capacity exceeded during the 10-percent chance event. This results in inundation on 6.57 miles of street in the watershed, which is displayed in **Figure 6-11**.

6.2.1.2 Inlet Capacity

For inlet capacity, the City's target is to allow less than 0.5-feet of ponding above storm sewer inlets rim elevations at inlet restricted low-points for the 10-percent chance event. As part of this study, inlet capacity was evaluated at the subcatchment level (see Section 4.4.3 for additional detail) and was not explicitly included in the model. Areas with known flooding were reviewed on a case by case basis. Within the study area, there are 45 locations deemed to have insufficient inlet capacity, and of these 36 (80 percent) have ponding depth of greater than 0.5-feet above the inlet rim elevation during the 10-percent chance event. Inlet capacity limitations are discussed further in Sections 9 and 10, with preliminary recommendations for inlet capacity upgrades are summarized in **Appendix J**. It is assumed that sufficient inlet capacity to fill storm sewer pipes will be evaluated and included in design of all recommended storm sewer improvements implemented in the future.

6.2.1.3 Street Flooding

Along streets, the City's target is to maintain drivability of municipal streets for the 4-percent chance event. Drivability is defined as having less than 0.5 feet of flooding along the centerline of the street. Within the watershed there are a total of 35.9 miles of streets, of which 2.47 miles have a water depth of more than 0.5 feet at the street centerline during the 4-percent chance event. This equates to 7 percent of the streets not meeting the target and these sections of street are displayed in **Figure 6-12**. To evaluate street flooding, the Dane County road centerline GIS layer (GISdw.DCL.BuildingFootprint; _County_DirectConnection.sde) was intersected with the 1-percent chance inundation extents for depth greater than 0.5 feet.

6.2.1.4 Structure Flooding

At structures, the City's target is to eliminate structure flooding during the 1-percent chance event. Structure flooding is defined as having an inundation depth of 0.5 feet or more within five feet of a building. Within the watershed there are a total of 3,089 structures, of which 70 structures have 0.5 feet of inundation or more during the 1-percent chance event. This equates to 2 percent of structures not meeting the target and these structures are displayed in **Figure 6-13**. To evaluate structure flooding, the Dane County building footprint GIS layer (GISdw.DCL.RoadCenterline; _County_DirectConnection.sde) was intersected with the 4-percent chance inundation extents for depth greater than 0.5 feet. Building footprints with an area less than 150 square feet were removed from the data set, since structures of this size in the watershed are sheds or similar small outbuildings.

6.2.1.5 Greenway Crossings

At locations where a greenway crosses under a street, the City's target is to safely pass the 1-percent chance event without overtopping the street. The crossing is considered to be overtopped if the high water elevation at the upstream end of the culvert is above the low terrace/sidewalk elevation along the upstream side of the road. There are ten existing greenway crossings within the East Badger Mill Creek watershed. Performance at these locations is summarized in **Table 6-1**.

Table 6-1 Existing Conditions Greenway Crossing Performance

Location	Performance In 1% Chance Event	Notes
East Pass	No Overtopping	
McKee Road	No Overtopping	Minor ponding from street runoff
Carnwood Road	No Overtopping	Some ponding from street runoff
Lancaster Lane	Overtopping	Also observed on August 20, 2018
Canterbury Road	No Overtopping	Some ponding from street runoff
Pilgrim Road	No Overtopping	
McKenna Boulevard	No Overtopping	
Westbrook Lane	Overtopping	
Raymond Road	No Overtopping	Minor ponding from street runoff
Prairie Road	Overtopping	Frequent OT observed, but not modeled; debris likely a factor

6.2.2 Comparison to Known Flooding in Watershed

In Section 1.3, known flooding areas in the watershed, based on City staff accounts, were identified. The areas identified are shown in **Figure 1-4**. Review of model results included a close evaluation of these known flooding areas. Flooding is observed in the model for almost all of these areas. A summary of the known flooding locations identified by City staff, and the relative accuracy with which the model depicts flooding in these areas, is provided below.

1. Stonecreek Drive north of East Pass

    a. Flooding Description: Flooding occurs at the low point near this intersection. This is caused by a combination of inlet capacity, pipe capacity, and overland flow from the north on Stonecreek Drive. When apartments were built east of Stonecreek Drive, the elevation of the driveway to underground parking was allowed to be constructed too low. This allows ponded water to leave the road low point and flows east into the underground parking garage at 6926 East Pass.

    b. Model Results: 0.4 feet of ponding occurs in the 10-percent chance event. During larger events the ponding becomes more substantial, exceeding a depth of 1 foot during the 2-percent chance event, when water begins to leave the public right-of-way and flow into the underground parking garage. Ponding appears to be caused by a combination of inlet capacity and pipe capacity limitations. See Location 12 in **Figure 4-5**.

2. East side of Silverton Trail north of McKee Road

    a. Flooding Description: The greenway section just north of McKee Road has been a source of flooding for several properties along the west side of the greenway over the past few decades. Contributing to flood vulnerability at these properties is the fact that the low building opening elevation is only about six feet above the flow line of the greenway channel. A large amount of flow is conveyed by the channel even during common rainfall events. Until 1999, the culverts at the McKee Road greenway crossing had a pipe arch shape, which led to higher water elevations in the channel during storms due to the flow depth-conveyance characteristics of this pipe shape. These pipe were replaced with box culverts that have the capacity to convey large flow rates at a depth of six feet or less. Flooding at the properties along the greenway has become a rare occurrence since the installation of the box culverts. There is also a longstanding issue with ponding at the intersection of Tempe Drive and Silverton Trail, which is a low point.

b. Model Results: The existing conditions modeling only includes the two 10' span by 6' rise box culverts at this crossing; the old arch pipes were not evaluated. However, flow from the greenway only begins to reach the low building opening elevations at the properties in question between the 2-percent and 1-percent chance events. This is consistent with the fact that there have been fewer instances of reported flooding at this location since the box culvert installation. At the intersection of Tempe Drive and Silverton Trail 0.7 feet of ponding occurs in the 10-percent chance event. Ponding depths exceed 1.5 feet in the 1-percent chance event and water leaves the public right-of-way. See Locations 17 and 18 in **Figure 4-5**.

3. Lancaster Lane at Whitlock Road

    a. Flooding Description: The property at the northeast corner of this intersection of has a low building opening elevation is only about five or six feet above the flow line of the greenway channel. A large amount of flow is conveyed by the channel even during common rainfall events and as a result this property has experienced recurrent flooding. Residents have observed that permanent sandbags are installed to provide flood protection to a higher elevation than the low building opening.

    b. Model Results: Flow from the greenway reaches a depth of almost 0.7 feet at the structure on this property in the 10-percent chance event and this depth increases to more than 2.3 feet in the 1-percent chance event. Flow depths at this location are subject to the size of the culverts under Lancaster Lane as well as the characteristics of the downstream channel. See Location 23 in **Figure 4-5**.

4. Greenway between McKenna Boulevard and Pilgrim Road

    a. Flooding Description: The section of greenway between McKenna Boulevard and Pilgrim Road is heavily wooded and water has to make a sharp turn from flowing to the west to flowing to the south-southwest. Additionally, flow expands as it leaves the McKenna Boulevard culverts and is forced to contract rapidly before going through the Pilgrim Road culverts. While no structure flooding occurs at this location, the inefficient hydraulic configuration contributes to high water elevations upstream of McKenna Boulevard that take hours to recede.

    b. Model Results: Flow depths just upstream of McKenna Boulevard are 6.9 feet and 10.7 feet for the 50-percent chance event and 1-percent chance event, respectively. Based on anecdotal accounts of flooding in the area, the model appears to accurately represent this portion of the system. See Location 7 in **Figure 4-5**.

5. McKenna Boulevard south of Tottenham Road

a. Flooding Description: The City was not aware of flooding at this location until 2017. It was brought the attention of City staff as a resurfacing project was being completed, so no changes in pipe size were able to be incorporated into that project. Flooding was described as frequent ponding of water at the street low point.

b. Model Results: 0.7 feet of ponding occurs in the 50-percent chance event. During larger events the ponding becomes more substantial, exceeding a depth of 2.5 feet during the 1-percent chance event, and water leaves the public right-of-way. Ponding appears to be caused by a combination of inlet capacity and pipe capacity limitations. See Locations 28 in **Figure 4-5**.

6. Raymond Road east of McKenna Boulevard

   a. Flooding Description: Flooding has been observed and reported at the low point at this location frequently in the past, during rainfall roughly equivalent to the 20-percent chance event. Ponded water spreads across one lane on each side of Raymond Road and spreads all the way across the street in larger events. In June and August of 2018, ponding became deep enough that it spilled down the driveway of the McKenna Rowhouses and entered underground parking garages.

   b. Model Results: 0.4 feet of ponding occurs in the 50-percent chance event. During larger events the ponding becomes more substantial, reaching a depth of 1.7 feet during the 1-percent chance event. Water begins to leave the public right-of-way and flow overland to the south along driveways in the 10-percent chance event. Ponding appears to be caused by a combination of inlet capacity and pipe capacity limitations. See Location 31 in **Figure 4-5**.

7. Tottenham Road east of McKenna Boulevard and Frisch Road south of Brompton Circle

   a. Flooding Description: Flooding has been observed and reported frequently along the Frisch Road cul-de-sac, during rainfall roughly equivalent to the 20-percent chance event. The street in the cul-de-sac is only about four feet higher than the flow line of the greenway channel and many of the buildings are not situated much higher than the road. Flow leaves the greenway and fills the street often. Additionally, runoff flows down Tottenham Road and reaches the low point, where the pipe is unable to discharge due to tailwater in the channel. These factors combine to produce some of the most severe flooding in the watershed. In August 2018, flood depths reached several feet and took many hours to recede. This flooding is further documented in the focus group summary for this area.

   b. Model Results: Up to 2 feet of ponding occurs in the 50-percent chance event. During larger events the flooding becomes more severe, exceeding a depth of 5.5 feet during the 1-percent chance event. This amount of inundation causes structure flooding at many homes on Frisch Road and Tottenham Road. Flooding is caused by the fact that the homes sit only a few feet above the greenway channel, the large amount of flow conveyed by the greenway, and downstream flow restrictions described earlier. See Location 33 in **Figure 4-5**.

8. Pilgrim Road at Homestead Road

    a. Flooding Description: Street flooding has been observed and reported at the low point at this location frequently in the past. Residents report that it is common for ponded water to fill the entire intersection of Pilgrim Road and Homestead Road each year. The street low point is located at the entrance to Pilgrim Park and the path leading into the park was reconstructed in the past to act as a flume that conveys flow from the low point into the park towards the greenway channel.

    b. Model Results: 0.8 feet of ponding occurs in the 50-percent chance event and runoff flows overland along the path into the park. During larger events the ponding becomes more significant, reaching a depth of 1.2 feet during the 1-percent chance event. However, the modeling does not show the same spread across the intersection that has been described by residents. The pipes are undersized for the 10-percent chance event, but inlet capacity limitations likely result in deeper ponding than is observed in the model at this location. Issues with debris clogging at inlets also contribute to ponding. See Location 34 in **Figure 4-5**.

9. Riva Road east of Prairie Road

    a. Flooding Description: Street flooding has been observed and reported at the low point at the intersection of Prairie Road and Riva Road and extends east. Residents report that street ponding used to be more common until 2015 when a street resurfacing project was completed. Water ponded in the street used to extend beyond the right-of-way in some events, but even in August 2018 water only came several feet up driveways on the north side of the street. There were also accounts that the grass median could just barely be seen in the early evening during the August 2018 storm, though this observation didn’t correspond to the peak of the storm.

    b. Model Results: Up to 1.4 feet of ponding at the low point occurs in the 50-percent chance event and it extends from curb to curb on both sides of Riva Road. During larger events the ponding becomes more significant, reaching a depth of 2.4 feet during the 1-percent chance event. While the grass median is fully covered by ponded water during the 1-percent chance event, this location appears to be accurately represented in the model. Capacity in the storm sewer box culvert under the Riva Road median is limited by constrictions at HERCP connections as well as by a corrugated arch pipe at the outfall to the greenway channel. The outfall pipe has less than 60 percent of the capacity of the upstream system. See Locations 36 and 37 in **Figure 4-5**.

10. Thrush Lane at Riva Road

    a. Flooding Description: Street flooding has been observed and reported at the low point at this location in the past. Residents report that it is common for water to flow quickly down Thrush Lane from curb to curb with the crown barely visible.

    b. Model Results: Up to 0.9 feet of ponding occurs in the 50-percent chance event and runoff flows down Thrush Lane from curb to curb. During larger events the ponding at the intersection becomes more significant, reaching a depth of 1.7 feet during the 1-percent chance event. Street flooding at this location appears to be caused by a combination of inlet capacity and pipe capacity limitations. See Location 38 in **Figure 4-5**.

11. Drainage to Jacobs Court

    a. Flooding Description: The City is aware of runoff that originates from the northwest portion of 1701 McKenna Boulevard and flows overland until it reaches a steep sidewalk that connects McKenna Boulevard to Jacobs Court. A considerable amount of runoff may follow this flow path depending upon the size of the event, however, there are not many detailed accounts of structure or street flooding on Jacobs Court.

    b. Model Results: The model does not show runoff coming down the steep sidewalk towards Jacobs Court. Based on the scale at which subcatchments were delineated in the watershed, there isn't a modeled subcatchment that releases runoff to a junction upslope of Jacobs Court. However, runoff from another upslope source does flow overland through properties along Jacobs Court during the 1-percent chance event. If the modeled and un-modeled sources of runoff cause structure flooding in the future, private storm sewer solutions that connect to public storm sewer can be explored.

12. Frisch Road between Lucy Lane and greenway outfall

    a. Flooding Description: Street flooding has been observed and reported at the low point on Frisch Road at the location of the storm sewer outfall to the greenway channel. Runoff reaches the low point from the north and from the east on Jacobs Way. Occasionally, runoff from the north on Frisch Road and from the east on Lucy Lane flows onto private property near the intersection of Frisch Road and Lucy Lane. This flow has not caused structure flooding, according to residents.

    b. Model Results: Up to 0.8 feet of ponding occurs at the low point on Frisch Road in the 10-percent chance event and runoff flows down Frisch Road and Jacobs Way from curb to curb. During larger events the ponding becomes more significant, reaching a depth of 2.1 feet at the low point during the 1-percent chance event. Ponding and street flooding appear to be caused by a combination of inlet capacity and pipe capacity limitations. See Locations 43 and 44 in **Figure 4-5**.

13. Lomax Lane at Starr Court

    a. Flooding Description: Street flooding was observed frequently along Lomax Lane and at the low point at the end of Starr Court until 2012, when storm inlets and pipes were added to collect water before it reaches Starr Court. This pipe discharges directly to the greenway channel.

    b. Model Results: The model shows no ponding at the low point on Starr Court in the 10-percent chance event. However, the pipe flows full in the model and case by case evaluation of inlet capacity shows that there isn't sufficient inlet capacity at the low point to allow the full pipe capacity to be utilized. While the model output doesn't show this location as failing to meet flood targets, inlet capacity needs to be added to allow this section of storm sewer to function as modeled. Ponding at the low point considering inlet capacity could reach a depth of more than 1.5 feet during the 4-percent chance event. Due to the inlet capacity limitation existing ponding depths are greater than shown in the inundation mapping.

14. Theresa Terrace at Jacobs Way

    a. Flooding Description: Street flooding has been observed and reported at this location and to the north along Theresa Terrace where there is currently no storm sewer. Runoff leaves the right-of-way and flows through private property on the west side of Theresa Terrace and on the south side of Jacobs Way. Issues with private drainage along back lot lines also exist and have led to structure flooding. The frequency of flooding in this area is not fully understood since it hasn't been reported to the City, but was shared by residents at focus groups for this study and by the Theresa Terrace Neighborhood Resource Team (NRT).

    b. Model Results: Flow reaches a depth of 0.8 feet at this intersection in the 10-percent chance event and leaves the right-of-way on Theresa Terrace and Jacobs Way. During larger events the flow becomes more significant, reaching a depth of 1.2 feet during the 1-percent chance event. Flooding at this location is a result of the lack of storm sewer along Theresa Terrace. See Location 45 in **Figure 4-5**.

15. Prairie Road greenway crossing

    a. Flooding Description: Flooding has been observed often at the low point on Prairie Road where it crosses the greenway channel. This is believed to be a combination of runoff ponding at the low point and flow leaving the greenway and overtopping Prairie Road. City staff estimate that this greenway crossing overtops during approximately a 20-percent to 10-percent chance event.

    b. Model Results: The modeled high water elevation in the greenway channel falls 1.8 feet short of overtopping Prairie Road during the 10-percent chance event. Even during the 1-percent chance event high water in the greenway falls 0.1 feet short of overtopping the road. The model results at this location do not replicate the frequency of road overtopping that has been repeatedly observed at this location. A field review of this culvert inlet suggest that thin stemmed woody vegetation around the inlet gets bent down and obstructs the culvert during flow events, as shown in pictures in **Appendix E**. This is a challenging condition to incorporate into a model and as a result the conditions at this location are explained here and in the recommended solutions section of this report. See Locations 11 and 47 in **Figure 4-5**.

6.2.3 Comparison to Focus Group Flooding Reports

As part of the public engagement effort for this study, focus group meetings were conducted. The overall intent of the focus group meetings was to provide residents an opportunity to share their observations of flooding in their neighborhood and to allow City staff to gain an understanding of the flooding issues that residents have experienced. The focus group meetings were hosted after existing conditions model results had been produced. This enabled focus group discussion to help validate model results or find out where issues exist that the model was not simulating. In many cases, flooding depicted by the model reflected the residents observations from past storm events. This also led to conversations about what the City can do to solve the stated flooding problems. The flooding described by residents during focus group meetings is similar to what is depicted on the flood inundation mapping. The focus group meetings are described in greater detail in Section 7 and in **Appendix I**.

An important consideration is that not all residents who witnessed the August 2018 storm actually observed the peak of that event. The most intense rainfall and resulting peak flows occurred overnight when not everyone would have been awake and making clear observations was made more difficult due to darkness. Several instances of focus group resident feedback were particularly helpful in helping to validate the model results or bring attention to flooding issues of which the City had not previously been aware:

1. Carnwood Road – Residents stated by email and in person that the Carnwood Road greenway crossing did not overtop during the August 2018 storm. They also reported that flow in the greenway spread laterally to just past a paved path that runs between the back property line along Muir Field Road and the edge of the greenway parcel. These relative high water elevations were considered during calibration and are within 0.5 feet of model results.

2. Lancaster Lane – Residents stated that the Lancaster Lane greenway crossing did overtop during the August 2018 storm and they provided pictures and video of this occurrence. The approximate observed flow depth over the road was considered during calibration and are within 0.5 feet of model results.

3. Raymond Road east of McKenna Boulevard – Residents stated that the low point on Raymond Road, near the entrance to the McKenna Rowhouses, becomes impassible a couple times each year due to ponding. Water got up to the curb at this location twice during the summer of 2020 and in August 2018 it crested the driveway. This is supported by the model results.

4. Tottenham Road and Frisch Road – Residents stated that the cul-de-sac end of Frisch Road up to the intersection with Tottenham Road floods frequently, including twice during the summer of 2020. During the August 2018 storm water along Frisch Road reached a depth of several feet and extended all the way north to Brompton Circle. Specific indications of relative high water observations from August 2018 are documented in greater detail in Section 7. These high water elevation estimates were considered during calibration efforts and are within 1 foot of model results.

5. Riva Road – Residents stated that street ponding used to be much more frequent before the street resurfacing project that was completed in 2015. In the early evening during the August 2018 storm, water came up to the curbs on Riva Road and the median was an island. The model results show slightly more water during the August 2018 than described here, but this observation was from before the peak of the storm. This offers relatively good agreement with the model results.

6. Thrush Lane – Residents stated that a lot of water runs down Balsam Road in heavy rains and that runoff flows down Thrush from the curb almost to the crown on both sides of the road during most heavy rains. This is supported by the model results.

7. Barton Road-Lynndale Road – Residents stated that a large amount of runoff flows down Barton Road during heavy rains. Ponding at the low point on Lynndale Road at the outfall to the greenway came up driveways past the sidewalk during the August 2018 storm. This is relatively well represented by the model, but inlet capacity limitations are also a factor at this location.

8. Golden Oak Lane-Redwood Lane-Barton Road – Residents stated that water frequently fills the entire intersection where these three roads meet, including during spring snow melt. During the August 2018 storm water overflowed from this intersection out the greenway and entered at least one home on the north side of the street. This is relatively well represented by the model, but inlet clogging is likely an additional factor.

9. Theresa Terrace – Residents stated that water has entered homes along the east side of Theresa Terrace coming from the back and north sides. Another resident reported that the intersection of Theresa Terrace and Jacobs Way floods during heavy rains since there is no storm sewer. Runoff sometimes leaves the street and flows through properties on the west side of Theresa Terrace, including during the August 2018 storm. These observations are supported by model results.

10. Frisch Road from Lucy Lane to greenway outfall – A resident stated that runoff from the north on Frisch Road and from Lucy Lane sometimes flows onto private property during heavy rains. During the August 2018 storm, street flooding at the low point on Frisch Road at the outfall to the greenway become so deep that buses on this street needed to be re-routed. This is supported by the model results, but inlet capacity limitations likely contribute to ponding here as well.

A few instances of focus group resident feedback do not agree with the model results and are summarized here:

1. Canterbury Road – A resident stated that there have been multiple (approximately six) instances of road overtopping at Canterbury Road since the 1980s and estimated that this happens around the 2-percent chance event. Road overtopping is not indicated by the model at this location even in the 1-percent chance event. It's possible that the culvert inlet clogged with debris during past events and that the road overtopped as a result. However, if this happened, at least five homes along the greenway would have flooded as a result, but the City is not aware of this happening. It's more likely that severe street ponding was mistaken for road overtopping. If this is the case, inlet capacity limitations are a concern to be addressed at this location.

2. McKenna Boulevard low point – A resident stated that a low point along McKenna Boulevard between Yorktown Circle and Pilgrim Road frequently experiences ponding when it rains hard. Water spreads from curb to curb and the road is just barely passable at the crown. There is less ponding observed in the model results than was described by the resident at this location. Inlet capacity limitations likely contribute to additional street flooding at this location.

3. Pilgrim Road at Homestead Road – Residents stated that this intersection experiences street flooding frequently. While the model does show a pipe capacity limitation at this location, the simulated inundation extents are not as wide as residents described, especially during more frequent rainfall events. Inlet capacity limitations likely contribute to additional street flooding at this location.

6.4 Model Uncertainty

In general, all models are approximations, and as such, there is a given amount of uncertainty in the results. Model uncertainty is due to approximations in the input data, simplification of the methods used to calculate flow and water level, uncertainty in the measured flow and level data, etc. This model is built following the City's Modeling Guidance document and is calibrated to monitored storm events as described in previous sections. The model was constructed at the watershed-level and is intended to identify flooding problems at that scale. It can be used to determine if the City's flooding targets are met within the watershed. Caution should be exercised when evaluating flooding problems at finer scales and additional refinement of model input parameters may be required.

The model calibration was focused on developing a single set of input parameters that would reasonably simulate large storm events. Additionally, only a limited amount of calibration data was available for this study. The number of field monitoring locations and the length of the monitoring period were limited. If this model is used in the future to analyze smaller rain events, additional review of the calibration parameters should be conducted, and modifications should be considered to better represent the expected runoff from smaller storms.

Additionally, the June 2020 storm event, which was the largest calibration event, was at most a 50-percent chance event. There is uncertainty with how model input parameters and the results associated with them project to larger design storm events, such as the 1-percent chance, 24-hour design storm event. It is believed that the calibrated model accurately depicts the impacts of flooding from large storm events because the input parameters are within accepted ranges and the model results correlate to anecdotal accounts of flooding from both City staff and residents. As part of the design and implementation of flood reduction solutions, the City may wish to further evaluate model uncertainty and consider how the solutions could be impacted.

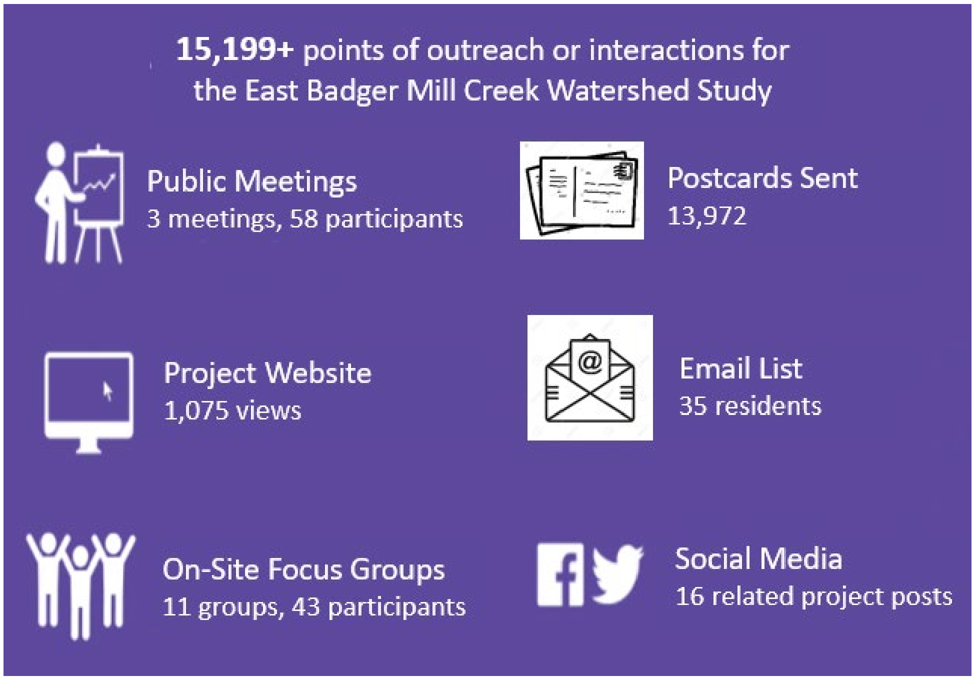
1. Design flexibility – To address model uncertainty as well as uncertainty associated with changing future conditions, design flexibility could be considered. An example of design flexibility is to consider increases (or decreases) in pipe sizes as part of a storm sewer improvement flood reduction measure. For instance, a 48-inch diameter storm sewer may be identified as the required size to provide the desired level of service (e.g. elimination of surcharging from the 10-percent chance event). Further increased pipe sizes could be considered to determine the degree to which level of service is improved (e.g. reduction of inundation depth at the street centerline for the 4-percent chance event). Incremental increases in pipe size can then be evaluated to determine the cost effectiveness of an added factor of safety or improved Level of Service.

2. Sensitivity analysis – A sensitivity analysis could be conducted to determine how changes to model input parameters impact the model results and performance of reduction measures. If changes to input parameters result in only limited impacts, it would suggest that the level of uncertainty in the model is lower.

Section 7 Public Engagement

As part of the East Badger Mill Creek watershed study, the City carried out an extensive public information and outreach effort. In addition to various social media and web-based communication methods, public meetings were held as summarized below. **Figure 7-1** shows a summary of the outreach for the study.

Figure 7-1 Public Outreach Summary



7.1 Public Information Meetings

An initial Public Information Meeting (PIM) was held on October 29, 2019, at Meadowridge Library. According to the sign-in sheet, 24 residents attended the meeting. The purpose of this meeting was to inform residents of the initiation of the study, provide an overview of what will be accomplished during the study, and to collect feedback from residents who have experienced flooding. The PIM began with an open house where residents could view display boards and ask questions and then transitioned to a presentation followed by a question and answer session. Residents also had the opportunity to request a neighborhood focus group meeting with City staff. Additional information on PIM #1 and the watershed is provided on the City's project website: https://www.cityofmadison.com/engineering/projects/east-badger-mill-creek-watershed-study

A second PIM was held virtually on January 14, 2021 and 14 residents were in attendance based on a count at the end of the presentation. The purpose of this meeting was to update residents on the status of the study, provide an overview of the work conducted to date, and to display existing conditions flood inundation mapping for the watershed. The PIM consisted of a presentation followed by a question and answer session, as well as focus group breakout sessions. No questions were asked by residents during the question and answer session. A recording of PIM #2 and a copy of the presentation slides are available at the project website listed above.

A third PIM was held virtually on December 13, 2022 and 20 residents were in attendance based on a count at the end of the presentation. The purpose of this meeting was to update residents on the status of the study, provide an overview of the work conducted to date, and to share concepts for each of the recommended flood reduction solutions. PIM #3 consisted of a presentation followed by a question and answer session. Due to the number of attendees at the meeting, focus group breakout sessions were not utilized and the question and answer period was extended to allow discussion of location specific issues with all attendees of the meeting. A recording of this PIM and a copy of the presentation slides are available at the project website listed above.

7.2 Focus Group Meetings

Focus group meetings were held with smaller groups of residents in specific geographic areas that have experienced flooding. The focus group locations were selected based on resident requests at PIM #1, knowledge of areas that have previously experienced flooding, and evaluation of areas with the potential for flooding where residents have not historically reported it. Gaps in the City's flood reporting records exist in some parts of the City, including areas of lower income and areas with a larger proportion of rental housing. This study was viewed as an opportunity to connect with all residents in the watershed to determine where flooding issues exist, especially those previously unknown to the City. The intent of the focus group meetings was to provide residents an opportunity to share their observations of flooding in their neighborhood and to allow City staff to gain an understanding of the flooding issues that residents have experienced and discuss the issues in further detail.

Addressing flooding issues throughout the watershed in an equitable manner is a priority of this study and rather than assuming that an absence of flood reports indicated no existing problems, City staff made additional efforts to collect observations of flooding in these areas. Some traditionally underserved areas in the City of Madison have Neighborhood Resource Teams (NRTs) established, which hold the stated mission of promoting racial equity and improving the quality of life for residents by understanding and elevating the needs, issues, and priorities of people living in areas with NRTs. There are two NRTs located in this watershed: Balsam/Russett and Hammersley/Theresa.

Eleven focus group meetings were hosted in eight specific locations during the summer of 2020, after PIM #1 and before PIM #2, which allowed information collected from residents to be used in the model building and refinement processes. A summary of each focus group meeting is included in **Appendix I**. The location of each meeting is provided below and shown in **Figure 7-2**.

1. Lancaster Lane-Carnwood Road (6:30 PM – 7:30 PM, July 28, 2020, 8 attendees)
2. Frisch Road-Theresa Terrace (11 AM – 12 PM, August 5, 2020, 6 attendees; 6:30 PM – 7:30 PM, August 13, 2020, 1 attendee)
3. McKee Road-Silverton Trail (4 PM – 5 PM, August 5, 2020, 2 attendees)
4. Tottenham Road-McKenna Boulevard (6:30 PM – 7:30 PM, August 5, 2020, 8 attendees)
5. Cameron Drive-Russett Road (11 AM – 12 PM, August 6, 2020, 0 attendees; 6:30 PM – 7:30 PM, August 12, 2020, 0 attendees)
6. Barton Road-Lynndale Road (4 PM – 5 PM, August 6, 2020, 12 attendees)
7. Riva Road-Balsam Road (6:30 PM – 7:30 PM, August 6, 2020, 1 attendee; 11 AM – 12 PM, August 12, 2020, 2 attendees)
8. Pilgrim Road-Monticello Way (4 PM – 5 PM, August 13, 2020, 3 attendees)

As part of PIM #2, focus group discussions were held in breakout sessions following the presentation and question and answer session in the virtual meeting. These meetings were held for each of the eight areas listed above, along with a focus group for the remaining areas of the watershed. This provided the opportunities for residents not located in one of the areas shown in **Figure 7-1** to have their questions answered and participate in more detailed discussion. The focus group discussions were held simultaneously. During this portion of the meeting inundation mapping for the 10-percent chance event, 1-percent chance event, and August 2018 storm event was shared with residents in the focus groups. In general, the inundation mapping shown to participants reflected what they've observed during large flood events.

Location specific comments and questions collected during PIM #2, PIM #3, and the breakout sessions that followed, are documented in **Appendix I** with the summaries of the other focus group meetings.

7.3 Public Comment Period

A thirty-day public comment period was held for the public to review and comment on the final draft of the East Badger Mill Creek Watershed Study Report. The public comment period ends in April 2023. The public comments and response to comments will be documented in **Appendix N**.

Section 8 Recommended Solutions Development

8.1 Overall Evaluation Process Methodology

Upon completion of the existing conditions analysis portion of the study, outlined in Sections 1 through 6 of this report, the process of developing and evaluating potential flood reduction solutions began. The recommended solutions development process described in the following sections focuses on identifying Peak Flow Control Infrastruction (PFCI) solutions to reduce flooding. PFCI 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 City of Madison included an assessment of Green Infrastructure (GI) in the flood reduction alternatives analysis conducted for the Pheasant Branch watershed study, which had the same overall purpose and approach as the East Badger Mill Creek watershed study. The report for the Pheasant Branch watershed study documents the difference between these two studies as well as the detailed approach used to evaluate performance of GI in providing flood reduction benefits. The findings of the GI analysis indicated that exceptionally intensive application of GI across an entire watershed is necessary to achieve meaningful benefits in terms of flood reduction. While the City considers GI an important tool and is committed to implementing GI as opportunities arise, the need to provide clear solutions to address known problems with immediately recognizable results precludes relying on GI as a stand-alone solution to mitigate flooding in this watershed. As a result, a specific analysis of GI was not included in this study.

This section outlines the methodology and process used to identify recommended flood reduction solutions. PFCI, sometimes referred to as grey infrastructure, was evaluated to understand how capacity of the stormwater system needs to be improved in order to achieve the level of service associated with each of the City's flood reduction targets in the East Badger Mill Creek watershed. Peak flow control includes a variety of approaches to convey or store runoff that is not currently being managed to the targeted level of service. The process included incorporating input gathered from residents throughout the course of the study as well as eliciting feedback from different agencies within the City. Section 8.1 includes the process used to develop and evaluate flood reduction solution concepts, while Section 8.2 provides a brief description of considerations associated with all solution concepts, including those not ultimately recommended. Section 9 provides more detailed descriptions of each specific recommended solution as well as the associated benefits.

8.1.1 Data Review

To commence the solutions development process, the existing conditions results were further reviewed to identify constriction points within the watershed. These locations were selected by considering existing flooding conditions and identifying the associated causes of flooding. Possible causes of flooding include: larger storm sewer discharges into smaller sewer, storm sewer is undersized, inadequate inlet capacity, lack of an overland flow path, and undersized culverts at greenway crossings.

Additionally, pertinent data within the watershed was reviewed to further determine restrictions to implementation of potential solutions. No major restrictions, such as Madison Gas and Electric (MG&E) high-pressure gas mains or significant sanitary sewer conflicts.

8.1.2 Solution Brainstorming

Nearly all improvements in the watershed involve a combination of upsized pipe infrastructure, added inlet capacity, and upsized culvert infrastructure. Solutions were targeted within the public street right-of-way and property already owned by the City's Stormwater Utility. Several informal meetings were held among City Engineering staff to consider constriction points at various locations within the watershed, to discuss solution concepts and logistics, and to identify potential opportunities for flood reduction measures. Solutions on private property were not considered as part of this study.

8.1.3 Evaluation of Potential Solutions

Following solutions brainstorming, preliminary increased pipe and culvert sizes were determined based on hydrologic and hydraulic data from the model. The process of evaluating and refining flood reduction solutions and conduit sizes involved numerous iterations. The calibrated existing conditions PCSWMM model was utilized to evaluate the flood reduction performance of the various potential solutions by modifying the hydraulic input parameters for components of the stormwater conveyance system corresponding to each improvement. The evaluation process is described below.

Local Storm Sewers – Throughout the East Badger Mill Creek watershed flooding exists that is caused by insufficient storm sewer capacity. An initial step of evaluating potential solutions was identifying local storm sewer improvements. Improvements to these storm sewers can impact the sizing of other reduction measures in the system, and as such this is an important set of improvements to incorporate into the model early in the process of developing potential solutions. Enlarged upstream storm sewers can result in increased peak flow rates into a greenway channel and impact the peak water surface elevation and required culvert capacity. For the purposes of the East Badger Mill Creek watershed, the vast majority of the system was considered local storm sewer pipe. As part of this study, local storm sewers were defined as those that are not impacted by upstream flood solutions. To determine potential improvements to these areas, the following steps were taken:

1. Based on the layout of the storm sewer system within the watershed, individual sections of storm sewer were isolated and evaluated for improvement. Many sections of the system are a relatively short run of storm sewer pipe that drain one subcatchment from a street low point and discharge directly to the main greenway channel.

2. Individual sections of storm sewer were identified as needing to be upsized to meet the City's 10-percent chance or 4-percent chance event level of service target based on the existing flooding conditions present in model results for each specific area. Using the flow quantity from the model for the corresponding location and event, pipe flow capacity was computed outside of the model and an increased pipe size was selected for the section of storm sewer under evaluation. Pipe size and dimension selection accounted for cover and other local conditions.

3. The process described above was repeated for each subsequent section of the storm sewer system until all portions of the local storm sewer not meeting level of service targets had been analyzed.

4. The local storm sewer improvements were incorporated into the PCSWMM watershed model where the impacts of the local improvements, in conjunction with regional improvements, were analyzed. This version of the PCSWMM model was executed for the 10-percent chance, 4-percent chance, and 1-percent chance events and the results were reviewed to compare system performance to the desired flood reduction targets. Local storm sewers were modified iteratively with regional improvements until targets were met to the greatest degree practicable.

Relief/Main Line Sewer Improvements – Relief and main line storm sewer improvements were evaluated alongside the local storm sewer improvements and were analyzed using the same process described above. A concerted focus was placed on longer runs of storm sewer that needed to be sized to meet the 4-percent chance event flood reduction target, as well as areas where storm sewer needed to be sized to meet the 1-percent chance event flood reduction target.

Greenway Crossing Improvements – As described in the introduction to this report, a constructed greenway channel runs from the northern extents of the East Badger Mill Creek watershed all the way to the discharge point at the southern end of the watershed. This is the most noteworthy component of the stormwater drainage system in the watershed, due to its flow conveyance capacity, as well as the fact that it is a contributing source of flooding for some properties. Much of the greenway channel has a concrete lined channel bottom with a width of up to ten feet and mowed grass side slopes that extend out to the edge of Stormwater Utility owned property. Stormwater Utility property varies from 75 to 100 feet wide along most of the length of greenway. In some sections of the greenway available flow width exceeds 100 feet by a considerable amount, but in these areas property is owned by the Parks Division. The greenway channel crosses public streets at ten locations in the watershed. Flow from the channel is conveyed under the street by a series of culverts at each greenway crossing. It is known that the culvert open area at each greenway crossing does not increase in a sequential manner from upstream to downstream. As a result, structure flooding and road overtopping are common issues upstream of some greenway crossings, while others rarely experience any problems.

1. Starting at the upstream end of the watershed, increased culvert sizes were selected to eliminate road overtopping in the 1-percent chance event.

2. Further downstream in the watershed, increased culvert sizes were selected to eliminate or prevent road overtopping in the 1-percent chance event, while also accounting for increased flows caused by local and main line storm sewer improvements.

3. Near the downstream end of the watershed, increased culvert sizes or relief culverts were selected to prevent road overtopping in the 1-percent chance event and to resolve existing structure flooding, where possible.

4. Greenway crossings were modified iteratively in an effort to avoid causing new structure flooding on private property, to prevent road overtopping, and to moderate the increase in flows to downstream, while allowing the greatest practicable benefit from local and main line storm sewer improvements.

Regional Stormwater Detention Improvements – At a couple locations in the watershed (described in Subsection 8.2.1) additional stormwater detention volume was considered. Due to the developed nature of the watershed, opportunities to add detention volume were extremely limited, and as a result, underground storage was the only type of detention evaluated. The detention improvements were considered after local storm sewer improvements.

8.1.4 Discussion of Potential Solutions with City Engineering Staff

Throughout the proposed solutions development, numerous informal meetings were held between City Engineering staff to discuss the benefits and drawbacks of each solution evaluated based on modeling results. Review of model results included discussions of achievable level of service improvements and the manner in which solution concepts change flow patterns within the watershed.

8.1.5 Convergence on Solutions

As the evaluation progressed, a set of solutions (described in Subsection 8.2.2) was determined to provide the most viable path towards meeting the flood reduction targets for the watershed. Convergence on a set of recommended solutions was based upon performance of the solutions, technical feasibility, and the input from City Engineering staff.

8.1.6 City Agency Meetings

Following the convergence on a set of recommended solutions for the East Badger Mill Creek watershed, City Engineering staff met with City agencies to discuss those solutions and challenges to implementing them. The purpose of this coordination was to avoid future logistical challenges during implementation, which helps ensure that the recommended solutions are practical and are supported outside of the Engineering Division. Agency coordination involved general discussions with the Streets Design Section and four more formal meetings listed below. Input on recommended solutions was gained via email correspondence and virtual meetings. Summaries of the meetings with DPCED and Parks are included in **Appendix L**.

1. City Engineer – Friday, November 11th, 2022; presentation and follow-up discussion
2. Public Works Improvements (PWI) – Thursday, December 8th, 2022; presentation and follow-up questions
3. Department of Planning and Community and Economic Development – Thursday, December 22nd, 2022
4. Parks Division – Friday, February 3rd, 2023

8.1.7 Finalization of Solutions

Meetings with the agencies did not result in modifications to the solutions. Therefore, the solutions discussed with the agencies were considered the final versions of the recommended solutions.

8.2 Description of All Solutions Considered

Flood reduction improvements were considered at locations all across the East Badger Mill Creek watershed. Ultimately, a set of solutions were selected that are recommended for implementation. Through the process of developing these solutions, a number of potential solutions were evaluated, but not recommended. The following subsections provide descriptions and consideration for all solutions that were considered.

8.2.1 Solutions Reviewed – Not Recommended

The following flood reduction methods were considered during the evaluation process, however, they were not recommended for implementation. Alternatives described in the following subsections were only evaluated so far as was necessary to find them infeasible or less effective than other solutions at addressing the same flooding concern. In the future, if recommended alternatives are abandoned in favor of any solutions described below, additional detail evaluation and modeling will be required to determine the feasibility and effectiveness of any individual alternative. The locations of these solutions are displayed in **Figure 8-1**.

8.2.1.1 Lowering Greenway Channel from Lancaster Lane to Raymond Road

Conceptual Project Description – As discussed in Subsection 6.2.2, the cul-de-sac end of Frisch Road is subject to frequent flooding since it is situated only a few feet higher than the flow line of the greenway channel. Even if greenway channel flow capacity could not be increased, flood reduction could be provided to the low lying properties along Frisch Road if it were possible to convey greenway flows at a lower elevation. Lowering the channel bottom elevation would allow the channel to convey the same amount of flow at a lower elevation, allowing properties on Frisch Road to sit higher than high water elevations for certain flow events. A review of the greenway channel profile shows that much of the channel runs at an approximate 0.3 percent grade, but a section of channel starting just downstream of Lancaster Lane and extending past Canterbury Road runs at a 1.0 percent grade. If the greenway channel could be run at a flatter grade from this location to a match point near Raymond Road, it would result in lowering the channel bottom elevation by two to four feet along this section of greenway. Providing a large relief box culvert from McKenna Boulevard to Lancaster Lane was also evaluated as a variation on the channel lowering concept. A few compelling reasons for excluding both solutions from consideration exist and as a result this concept was never incorporated into the model.

Reasons for Exclusion – Lowering the existing greenway channel would require removing the existing concrete channel lining and excavating a large amount of earth in order to create a similar channel cross section at a lower elevation. Based on the City's previous experience permitting projects with the WDNR, installing a new concrete lining in the lowered channel would not be an acceptable option. Without a concrete lining, it would be very challenging to establish and maintain vegetation over the long term future along the bottom of channel with a 0.5 percent grade or flatter. This would likely result in muddy channel bottom that lacks stability and conditions that support seasonal mosquito populations. Additionally, lowering the channel elevation is not viable in the 500 feet downstream of Pilgrim Road and the 150 feet upstream of Pilgrim Road where Stormwater Utility property is narrow and channel side slopes are already relatively steep. Newly graded side slopes would need to be steeper than is allowable for safety and maintenance purposes in order to tie in to existing ground on Stormwater Utility property. An approximate, preliminary cost estimate was developed for extensive re-grading of 4,600 feet of greenway channel or installing up to 3,400 feet of large relief box culvert. Either project would be anticipated to cost five to six million dollars at a bare minimum. The estimated flood reduction benefit of either alternative if roughly four to five million dollars.

8.2.1.2 Alternative A Solution Set

Conceptual Project Description – Alternative A was a set of local storm sewer and regional solutions in which emphasis was placed on upsizing box culverts, particularly from Carnwood Road to Canterbury Road. The objective was to accommodate added flows from ambitious upstream local and main line storm sewer solutions to meet as many flooding targets as possible. Additionally, new box culverts were configured in an attempt to alleviate flooding on properties directly adjacent to the greenway that have existing low openings exposed to high water elevations.

Reason for Exclusion – Alternative A allowed many flood reduction targets to be met across the watershed, but targets were also exceeded in many locations. While the degree of improvement is a positive, this was also a demonstration that parts of the system can be designed to alleviate flooding during rarer events. However, these solutions were effectively oversized for meeting the established flood reduction targets and as a result would be more expensive. When compared to recommended solutions in other watersheds across the City, more expensive solutions would be less competitive when selecting solutions to be implemented. Additionally, this set of solutions was not able to alleviate existing flooding at properties along the greenway and it increased flows leaving the watershed by more than 50 percent. This was anticipated to move the existing flooding issues downstream, which explicitly goes against the stated objectives of the study and established flood reduction targets.

8.2.1.3 Alternative B Solution Set

Conceptual Project Description – Alternative B was a set of local and main line sewer improvements that were slightly downsized from Alternative A. Culvert sizes in this set of solutions were scaled back considerably and approximately match the sizes of existing culvert openings. The objective of this sizing was to reduce drastic flow increases to downstream that were observed in Alternative A.

Reason for Exclusion – Although local and main line storm sewer pipes were modestly downsized from Alternative A, they were still large enough to cause increased peak flows and high water elevations in the greenway, specifically between East Pass and Canterbury Road. This resulted in new structures being flooded along the greenway in the 1-percent chance event and caused additional local sewer flooding since outfalls along this section of the greenway become further limited by tailwater. In order to avoid these increases in high water elevation, the local and main line storm sewer improvements would need to be scaled back further to the point where few flood reduction targets would be met across the entire watershed. Additionally, providing no flood reduction for the properties along Frisch Road was determined to be a nonviable option.

8.2.1.3 Stormwater Detention Opportunities

Conceptual Project Description – Providing stormwater detention is a preferred approach to reducing flooding since it holds more water in place rather than pushing it downstream faster. However, traditional stormwater detention requires open space, which is very limited in this developed watershed. There are a couple areas that have a large enough open space footprint to warrant investigating detention: Pilgrim Park and Huegel Park. Due to the size and current use of the open space in these parks underground detention was viewed as the only viable option. In Pilgrim Park, detention would effectively be overbank storage where flow is diverted out of the channel and into underground vaults north and south of the channel. In Huegel Park, storm sewer would discharge into an underground vault with a smaller diameter outlet pipe.

Reason for Exclusion – The locations of these areas in the watershed, limited available space, and cost of underground storage posed significant challenges to this solution. Preliminary costs were estimated from approximate square foot costs gathered from recent StormTrap installations. Model results showed that stormwater detention in these areas only provided very modest reduction in high water elevations upstream of McKenna Boulevard and peak flows downstream of McKenna Boulevard. Stormwater detention does not provide enough flood reduction benefit in this watershed to be evaluated further in this study.

8.2.2 Solutions Reviewed – Recommended

The section provides a brief description of flood reduction solutions that are recommended for implementation in the East Badger Mill Creek watershed. The locations of all the solutions are displayed in **Figure 8-2** and further details about each design is provided in Section 9. The solutions include local storm sewer improvements (storm sewer and inlet capacity), main line storm sewer system improvements, and greenway crossing replacements.

8.2.2.1 Local Storm Sewer Improvements

Conceptual Project Description – Improve storm sewers along streets throughout the watershed, including at street low points that discharge directly to the greenway channel. Improvements include increasing pipe size and/or modifying pipe elevations and slopes.

Iterations Considered – Different pipe sizes were evaluated until flood reduction targets were met to the greatest degree practicable at each location.

8.2.2.2 Terrace Inlets

Conceptual Project Description – Improve inlet capacity and low point locations throughout the watershed. Improvements include increasing the number of inlets and/or modifying the inlet types.

Iterations Considered – None.

8.2.2.3 McKenna Boulevard-Raymond Road Reconstruction

Conceptual Project Description – Increase pipe capacity to reduce street flooding along McKenna Boulevard and Raymond Road and to meet the 1-percent chance event structure flooding target.

Iterations Considered – Different pipe sizes, shapes, and slopes were evaluated until flood reduction targets were met to the greatest degree practicable.

8.2.2.4 Riva Road Reconstruction

Conceptual Project Description – Replace the HERCP located at intersections along Riva Road that connect existing box culvert sections under the grass medians. Replace the pipe arch located at the outfall from the Riva Road box culvert system to the greenway channel; its capacity is less than 60 percent of the upstream system. This reduces street flooding along Riva Road and facilitates other storm sewer improvements upstream.

Iterations Considered – Different box culvert sizes were evaluated to meet flood reduction targets. 6' span by 5' rise box culverts were first modeled at the replacement locations to match existing box culvert dimensions, but a constructability issue involving box culvert cover was identified. 8' span by 4' rise box culverts were modeled at the replacement locations and provide similar flood reduction performance while working better with the limited cover depth available. Different box culvert dimensions at the greenway outfall were tested to ensure that reducing flooding upstream didn't cause new flooding issues in the greenway downstream.

8.2.2.5 Raymond Road-Cameron Drive-Barton Road-Whitney Way Reconstruction

Conceptual Project Description – Increase pipe capacity to reduce street flooding in this area and to meet the 1-percent chance event structure flooding target.

Iterations Considered – Different pipe sizes, shapes, and slopes were evaluated until flood reduction targets were met to the greatest degree practicable.

8.2.2.6 McKenna Boulevard-Pilgrim Road Greenway Crossing

Conceptual Project Description – Increase the size of the greenway crossing at McKenna Boulevard and Pilgrim Road to reduce upstream street and structure flooding. While evaluating this solution, improving the hydraulic efficiency of the area between McKenna Boulevard and Pilgrim Road was also analyzed.

Iterations Considered – Different box culvert sizes and configurations were evaluated to manage upstream flood reduction along with downstream flow increases. There were two primary configurations: maintaining the existing greenway channel between the box culverts and installing continuous box culverts, using two bends, to eliminate hydraulic losses associated with rapid contraction and expansion, as well as the heavily wooded bend in the channel. Model results showed that connecting the box culverts is critical to effectively reducing upstream flooding.

8.2.2.7 Other Greenway Crossings

Conceptual Project Description – Increase the size of greenway crossings to eliminate road overtopping.

Iterations Considered – Different box culvert sizes, configurations, and invert elevations were evaluated to meet greenway conveyance needs and flood reduction targets.

Section 9 Recommended Solutions

The recommended solutions were introduced in Section 8 of this report. **Figure 8-2** shows an overall recommended improvements map for the East Badger Mill Creek watershed, identifying the locations of the recommended solutions.

In Sections 9.1 through 9.14, the recommended solutions for the East Badger Mill Creek watershed are described in detail. Pertinent information regarding the nature of the proposed solutions, the flood reduction benefits, critical implementation details, and other considerations are discussed. Due to the nature of the watershed, and the greenway channel that drains it, box culvert replacements at greenway crossings comprise a critical portion of the recommended solutions discussed in this section. When it's stated that a solution meets a target to the greatest degree practicable, it means that the effectiveness of the solution is limited by tailwater, avoiding moving a flooding issue downstream, constructability, or other site specific constraints.

The improvements documented in this report are not meant to be full design level efforts; they are conceptual solutions to help the City's Engineering Division understand the magnitude of improvement needed meet flood reduction targets in specific locations throughout the watershed. As projects are evaluated further, and if they reach the point of being programmed, then projects will need to undergo a more detailed design phase at that time. A future project design phase will include collection of survey data and other data needed to refine the design, secure required permits, and evaluate environmental issues associated with the particular project. Additionally, none of the recommended solutions have associated water quality benefits.

9.1 Local Storm Sewer Improvements

9.1.1 Detailed Project Description

Throughout the course of this study, it became apparent that many of the flooding issues throughout the East Badger Mill Creek watershed are the result of undersized local storm sewers. These storm sewers are incapable of conveying peak flows during intense peak rainfall events. During such events, the undersized pipes surcharge, which pushes stormwater onto the street and ground surface, resulting in overland flow and associated flood impacts.

Pipes that were identified as having exceeded capacities for the 10-percent chance event and were upsized iteratively until the City's target of no surface flooding for this event was met. In locations where pipes did not meet the 4-percent chance and 1-percent chance event targets, pipe sizes were modified further until the targets were met to the greatest degree practicable. There are some locations where targets are not met and these are described further detail in Section 11. Locations of local storm sewer improvements are shown in **Figure 9-1**.

9.1.2 Associated Flood Reduction Benefits

The level of flood reduction associated with the local storm sewer improvements varies, but are generally very effective. These solutions are spread across the watershed in many locations and benefits resulting from these improvements are best described by the comparison to the City's flood reduction targets as documented in Section 10 and **Figures 10-10** through **10-12**.

9.1.3 Project Constraints/Considerations

Due to the fact that local storm sewer improvements involve replacement of storm sewer on its existing alignment, there are relatively few project constraints. The majority of this work will be contained with the public right-of-way and will not impact privately owned property. However, at several locations where terrace inlets are proposed, the associated pipe improvements run through storm sewer easements on private property. These locations are discussed in greater detail in the next subsection. Additionally, pipe cover will need to be evaluated further on a case by case basis for upsized outfall pipes that discharge to the greenway. Locations with suboptimal cover could be addressed by using horizontal elliptical rather than round pipe, stopping the pipe short and extending a lined or armored flume to the outfall, or re-grading over the pipe to add cover.

Potential conflicts with existing utilities may occur in some locations where upsized pipes must be lowered to maintain cover requirements. To this point, there are likely to be conflicts with existing water mains and water laterals, which would need to be lowered. Widespread sanitary sewer conflicts are not anticipated since an effort was made to maintain clearance between storm sewer improvements and existing sanitary sewer. However, it is possible that sanitary sewer conflicts will become apparent during the design phase of projects. Individual conflicts should be resolved during street project utility design by adjusting sewer locations or elevations.

Local storm sewer improvements will increase peak flows to downstream discharge locations. The impact of these improvements on downstream flows have been considered and are incorporated into the recommended solutions discussed later in this section.

9.2 Terrace Inlets

9.2.1 Detailed Project Description

Comparison of the existing conditions model to areas with known flooding indicates that in some locations insufficient inlet capacity contributes to flooding. Additionally, terrace inlets will be needed in some key locations to take advantage of the capacity of recommended increased pipe sizes.

The locations of recommended terrace inlets are shown in **Figure 9-2**. Several of the terrace inlets were recommended for installation with the 2022 Waterways improvement project program. These locations include: cul-de-sac end of Chester Drive, low point on Lynndale Road, low point at Jacobs Way-Loreen Drive. However, as of February 2023 these improvements are planned for construction in 2023.

Several other of the terrace inlet locations require installation during future a future resurfacing or reconstruction project when larger pipes are being installed. These locations include: Whitlock Road-Lancaster Lane, Pilgrim Road-Homestead Road, McKenna Boulevard south of Tottenham Road, Raymond Road east of McKenna Boulevard, Riva Road-Prairie Road, and Frisch Road south of Jacobs Way.

9.2.2 Associated Flood Reduction Benefits

Eliminating inlet capacity limitations reduces flooding within the watershed. However, additional storm sewer improvements are typically needed to meet the City's targets. The amount of flood reduction associated with the inlet capacity improvements varies based on the ponding at each location.

9.2.3 Project Constraints/Considerations

Inlet capacity improvements are primarily contained within public street right-of-way. However, in order to reach a discharge point along the greenway channel, some of the outfall pipe improvements associated with terrace inlets could impact private property. The following terrace inlet outfall pipes run through Stormwater Utility property and do not impact private property: Chester Drive, Lynndale Road, and Loreen Drive. The following terrace inlet outfall pipes run through Parks Division property and do not impact private property: Waltham Road and Pilgrim Road. The following terrace inlet outfall pipes run through storm sewer easements and installation would need to be coordinated with private property owners: Silverton Trail and McKenna Boulevard.

As with local storm sewer improvements, inlet capacity improvements will increase peak flows downstream as water is moved through the system more efficiently. The impact of these improvements is factored into the recommended solutions described later in this section.

9.3 McKenna Boulevard-Raymond Road Reconstruction

9.3.1 Detailed Project Description

This main line storm sewer improvement would require reconstruction of McKenna Boulevard and Raymond Road, extending 1,300 feet west, 300 feet east, and 1,400 feet south from the intersection of these streets. The focus of the project would be installing larger storm sewer and higher capacity inlets, while the street profiles would remain essentially the same. Storm sewer from Raymond Road to the greenway outfall near the intersection of McKenna Boulevard and Pilgrim Road would need to be replaced with a box culvert to provide sufficient capacity. The elements of the project are displayed in **Figure 9-3**.

9.3.2 Associated Flood Reduction Benefits

Storm sewer replacement on Raymond Road west of the intersection with McKenna Boulevard would increase pipe capacity to convey the 10-percent chance event without surcharging. While the pipes were sized to convey the 10-percent chance event, the improvement would also allow the 4-percent and 1-percent chance targets to be met, by reducing street centerline inundation and inundation at structures, respectively.

Storm sewer replacement on Raymond Road east of the intersection with McKenna Boulevard would increase inlet and pipe capacity to convey the 4-percent chance event. While this exceeds the target for the 4-percent chance event, there is also existing structure flooding at this location that needs to be addressed. This improvement would allow the 1-percent chance structure flooding target to be met at 6513 Raymond Road and 2001 McKenna Boulevard (McKenna Rowhouses) and removes a total of seven structures, including four multi-family residences, from flooding.

Storm sewer on McKenna Boulevard would be replaced with a box culvert to provide sufficient capacity for the upstream improvement described above. The storm sewer and inlet capacity improvements on McKenna Boulevard would reduce street flooding for the 10-percent and 4-percent chances events to the greatest extent practicable, however, it does not fully meet either target.

9.3.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project may be designed and constructed as a street resurfacing project, though the impacts would be extensive due to the recommended storm sewer sizes.
2. McKenna Boulevard was resurfaced in 2017, but this project is the only way to fully and effectively reduce structure flooding that exists near the intersection with Raymond Road, while also reducing street flooding in the area.

3. If there is an opportunity to implement the Raymond Road east portion of the improvement, it could reduce flooding by 0.3 feet in the 10-percent chance event and eliminate flooding of the McKenna Rowhouse underground parking garages in that event. Partial implementation could potentially show a greater benefit during smaller, more frequent events. Implementing only the east portion of this improvement would provide minimal improvement over existing conditions in storms larger than the 10-percent chance event.
4. Traffic control, including maintaining emergency vehicle access, would be a major component of this project during construction and needs to be accounted for accordingly.
5. Due to the recommended improvements at this greenway crossing, discussed in Section 9.11, the connection between a new box culvert along McKenna Boulevard and the large box culvert crossing will require careful planning and design.
6. Catch basins with sumps could be added to provide water quality benefits.

9.4 Riva Road Reconstruction

9.4.1 Detailed Project Description

This main line storm sewer improvement would require spot replacements of large storm sewer along Riva Road. At the median openings along Riva Road at Jonquil Road, Rae Lane, Tanager Trail, and Thrush Lane, existing 48”x76” HERCP need to be replaced with box culvert sections to remove flow constrictions. Additionally, the existing pipe that runs to the greenway outfall is approximately a 35”x57” corrugated metal pipe arch that has less than 60 percent of the capacity of the upstream system. This pipe also needs to be replaced with a box culvert section to remove the flow constriction. The focus of the project would be installing larger storm sewer and higher capacity inlets, particularly near the intersection of Riva Road and Prairie Road, while the street profile would remain essentially the same at each median opening. The elements of the project are displayed in **Figure 9-4**.

9.4.2 Associated Flood Reduction Benefits

Storm sewer replacement along Riva Road would increase inlet and pipe capacity to convey almost the 4-percent chance event. This improvement would allow the 4-percent chance event target to be met along most of Riva Road, in addition to removing one structure from flooding. While the 4-percent chance event target isn’t met at the intersection of Riva Road and Prairie Road, street flooding would be reduced to the greatest extent practicable, which is a significant improvement. This improvement would also provide sufficient capacity for the upstream improvement described in Section 9.5.

9.4.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project may be designed and constructed as a street resurfacing project, but if spot replacements can be performed, it would result in less street work.
2. Much of the existing box culvert under the Riva Road grass median is 6’ span x 5’ rise, but there is one portion that has a 4.5’ rise and one that has a 5.5’ rise. The replacement box culvert sections were sized as 8’ span x 4’ to maintain the existing open area. Cover over the box culvert is tight at each median opening and is the reason a lower rise section was selected. Box culvert invert elevations should be matched at every connection and a taper will be required at each connection in order to transition between the differing spans and rises.

9.5 Raymond Road-Cameron Drive-Barton Road-Whitney Way Reconstruction

9.5.1 Detailed Project Description

This main line storm sewer improvement would require reconstruction of Raymond Road (1,300 feet of pipe), Cameron Drive (1,500 feet of pipe), Barton Road (1,400 feet of pipe), and Whitney Way (500 feet of pipe). The focus of the project would be installing larger storm sewer and adding inlet capacity, while the street profiles would remain essentially the same. The elements of the project are displayed in **Figure 9-5**.

9.5.2 Associated Flood Reduction Benefits

Storm sewer replacement along these streets would increase inlet and pipe capacity to convey the 4-percent chance event while meeting both the 4-percent chance event target and 1-percent chance event structure flooding target. Five structures, including three multi-family residences, would be removed from flooding with implementation of this solution.

9.5.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project may be designed and constructed as a street resurfacing project, unless street reconstruction is indicated for any other reason.
2. This is a relatively large amount of storm sewer work, so the project could be broken into phases, if necessary.
3. Traffic control, including maintaining emergency vehicle access, would be a major component of this project during construction and needs to be accounted for accordingly.
4. Catch basins with sumps could be added to provide water quality benefits.

9.6 East Pass Relief Box Culvert

9.6.1 Detailed Project Description

An 8’ span x 4’ rise relief box culvert would need to be added at the East Pass greenway crossing, which involves reconstructing the inlet and outlet wingwalls and aprons. This greenway crossing and elements of the project are displayed in **Figure 9-7**.

9.6.2 Associated Flood Reduction Benefits

The box culvert was sized to convey peak flows in the greenway channel that are increased by upstream solutions without road overtopping.

9.6.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project is intended to be designed and constructed as a spot installation of one box culvert.
2. The existing box culvert wingwalls on the west side of the existing crossing would need to be removed and replaced with new wingwalls in conjunction with the box culvert installation.
3. The modeling and **Figure 9-7** used the assumption that box culvert wingwalls and apron are constructed in accordance with City of Madison S.D.D. 5.5.1 A & B.

4. This greenway crossing is located in a mapped FEMA floodplain and is listed in the 2016 Dane County Flood Insurance Study. When this culvert is replaced a CLOMR and LOMR will need to be prepared and submitted to FEMA. The effective hydraulic model (HEC-RAS file) is available online on the WDNR's Surface Water Data Viewer website.
5. Utility relocation is not anticipated since the relief box culvert would be installed at the same invert elevation as the adjacent existing culvert, as indicated in **Figure 9-7**. However, it would need to be determined if existing water main uses a window to go below the existing box culverts.

9.7 McKee Road Relief Box Culvert

9.7.1 Detailed Project Description

A 10' span x 4' rise relief box culvert would need to be added at the McKee Road greenway crossing, which involves reconstructing the inlet and outlet wingwalls and aprons. This greenway crossing and elements of the project are displayed in **Figure 9-8**.

9.7.2 Associated Flood Reduction Benefits

The box culvert was sized to convey peak flows in the greenway channel that are increased by upstream solutions without road overtopping. Additionally, the relief box culvert lowers the high water elevation in the 1-percent chance event slightly, as compared to existing conditions, which results in one structure being removed from flooding.

9.7.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project is intended to be designed and constructed as a spot installation of one box culvert.
2. The existing box culvert wingwalls on the west side of the existing crossing would need to be removed and replaced with new wingwalls in conjunction with the box culvert installation. At the upstream end of the box culverts, this may require a full reconstruction of the wingwalls and apron in order to effectively convey incoming flow.
3. When reconstructing the inlet end of the culverts a beveled inlet treatment would need to be installed to replace the existing square edge across the entire box culvert inlet. This assumption was included in the modeling and is noted in **Figure 9-8**.
4. The modeling and **Figure 9-8** used the assumption that box culvert wingwalls and apron are constructed using a special detail that is closely based on City of Madison S.D.D. 5.5.1 A & B.
5. Significant utility relocation is not anticipated since the relief box culvert would be installed at the same invert elevation as the adjacent existing culvert, as indicated in **Figure 9-8**. However, coordination with electric, gas, communications, and other utilities would still be required.
6. Traffic control would be a major component of this project during construction and needs to be accounted for accordingly.

9.8 Carnwood Road Box Culverts

9.8.1 Detailed Project Description

Two 11’ span x 5’ rise box culverts would need to be installed at the Carnwood Road greenway crossing to replace the two existing 63”x98” HERCP culverts. This greenway crossing and elements of the project are displayed in **Figure 9-9**.

9.8.2 Associated Flood Reduction Benefits

The box culverts were sized to convey peak flows in the greenway channel that are increased by upstream solutions without road overtopping.

9.8.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project is intended to be designed and constructed as a spot replacement of culverts.
2. The new box culverts need to be installed at the invert elevations indicated in **Figure 9-9**. These were set to balance upstream high water elevations and flow conveyed downstream, as well as providing just enough cover for a typical culvert crossing installation.
3. The modeling and **Figure 9-9** used the assumption that box culvert wingwalls and apron are constructed in accordance with City of Madison S.D.D. 5.5.1 A & B.
4. If implemented, residents will be concerned about whether the road needs to be closed during construction and duration of a closure.
5. During design consideration needs to be given to locating low point inlets near the box culvert. These can be offset and drain by pipe through the box culvert wall or can be saddled and drain directly through an opening in the roof of the box culvert.
6. Significant utility relocation is not anticipated since the box culverts would be installed at a similar invert elevation as the existing culverts. However, coordination with Water Utility, electric, gas, communications, and other utilities would still be required.

9.9 Lancaster Lane Box Culverts

9.9.1 Detailed Project Description

Two 7’ span x 6’ rise box culverts would need to be installed at the Lancaster Lane greenway crossing to replace the two existing 72” diameter RCP culverts. This greenway crossing and elements of the project are displayed in **Figure 9-10**.

9.9.2 Associated Flood Reduction Benefits

The box culverts were sized to convey peak flows in the greenway channel that are increased by upstream solutions without road overtopping. This resolves known, existing road overtopping.

9.9.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project is intended to be designed and constructed as a spot replacement of culverts.

2. The new box culverts need to be installed at the invert elevations indicated in **Figure 9-10**. These were set to balance upstream high water elevations and flow conveyed downstream, as well as providing just enough cover for a typical culvert crossing installation.
3. The modeling and **Figure 9-10** used the assumption that box culvert wingwalls and apron are constructed in accordance with City of Madison S.D.D. 5.5.1 A & B.
4. If implemented, residents will be concerned about whether the road needs to be closed during construction and duration of a closure.
5. During design consideration needs to be given to locating low point inlets near the box culvert. These can be offset and drain by pipe through the box culvert wall or can be saddled and drain directly through an opening in the roof of the box culvert.
6. These box culverts would be installed slightly lower than the existing culverts and as a result sanitary sewer may need to be lowered. It appears that the receiving sanitary SAS has a low enough invert to allow the main entering from the southeast to be lowered. To minimize impacts, a SAS could be added in the terrace and only 70 feet of 8” main would need to be replaced. Coordination with Water Utility, electric, gas, communications, and other utilities would also still be required.

9.10 Canterbury Road Box Culverts

9.10.1 Detailed Project Description

Two 7’ span x 6’ rise box culverts would need to be installed at the Canterbury Road greenway crossing to replace the two existing 72” diameter RCP culverts. This greenway crossing and elements of the project are displayed in **Figure 9-11**.

9.10.2 Associated Flood Reduction Benefits

The box culverts were sized to convey peak flows in the greenway channel that are increased by upstream solutions without road overtopping.

The greenway channel between Canterbury Road and Pilgrim Road shows a high water elevation increase of up to 0.2 feet in the 1-percent chance event. Existing inundation extends slightly beyond the Stormwater Utility property line in this section of greenway and the stated increase does not measurably increase the inundation extents and does not create new flooding at any structures. Proposed inundation mapping shows new inundation coming very close to a home along the west side of the greenway, however, a review of ground contours shows that this structure is not expected to flood in the 1-percent chance event. The location in question corresponds to 2D cell SJ74612 in the model, which has a ground elevation of 1006.79 and a high water elevation of 1007.32. Due to mesh resolution at this location in the model, the cell shows inundation extending all the way to the elevation 1008 contour line. In reality, inundation depth on half of cell SJ74612 is less than half a foot and water would not reach low openings on this property, which appear to be situated at elevation 1008 or above. Changing the recommended culvert sizes at Canterbury Road to resolve the 0.2 foot increase described above would require downstream solutions to be further upsized in order to continue meeting targets.

9.10.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project is intended to be designed and constructed as a spot replacement of culverts.

2. The new box culverts need to be installed at the invert elevations indicated in **Figure 9-11**. These were set to balance upstream high water elevations and flow conveyed downstream.
3. The modeling and **Figure 9-11** used the assumption that box culvert wingwalls and apron are constructed in accordance with City of Madison S.D.D. 5.5.1 A & B.
4. If implemented, residents will be concerned about whether the road needs to be closed during construction and duration of a closure.
5. During design consideration needs to be given to locating low point inlets near the box culvert. These can be offset and drain by pipe through the box culvert wall or can be saddled and drain directly through an opening in the roof of the box culvert.
6. Significant utility relocation is not anticipated since the box culverts would be installed at a similar invert elevation as the existing culverts. However, coordination with Water Utility, electric, gas, communications, and other utilities would still be required.

9.11 McKenna Boulevard-Pilgrim Road Box Culverts

9.11.1 Detailed Project Description

Two 8' span x 5' rise box culverts would need to be installed at the McKenna Boulevard-Pilgrim Road greenway crossing to replace the two existing 72" diameter RCP culverts. The two existing greenway crossings are recommended to be combined into one to reduce the impact of hydraulic losses present in the existing configuration. This greenway crossing and elements of the project are displayed in **Figure 9-12**.

9.11.2 Associated Flood Reduction Benefits

The box culverts were sized to convey peak flows in the greenway channel that are increased by upstream solutions without road overtopping.

Existing flooding upstream of this greenway crossing, along Frisch Road, is recurring and has been severe at times. Initially, the intention was to meet the 1-percent chance structure flooding target with an improvement at this greenway crossing. However, lengthy model iteration showed this would not be feasible given the constraints of the greenway system. If implemented, this improvement would reduce the number of structures flooded in the 1-percent chance event from 29 to 19. While this falls short of the overall City flood reduction target, far more significant reductions in structure flooding are provided for smaller events. This improvement would reduce the number of structures flooded in the 4-percent chance event from 17 to 3 and in the 10-percent chance event from 12 to 0. Overall, this is considered to be a vast improvement over the existing flooding conditions.

9.11.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project is intended to be designed and constructed as a spot replacement of culverts.
2. The new box culverts need to be installed at the invert elevations indicated in **Figure 9-12**. These were set to balance upstream high water elevations and flow conveyed downstream.
3. The modeling and **Figure 9-12** used the assumption that box culvert wingwalls and apron are constructed in accordance with City of Madison S.D.D. 5.5.1 A & B.
4. The connection between a new box culvert along McKenna Boulevard, described in Section 9.3, and the box culverts at this crossing will require detailed planning and design.

5. Bends will need to be used on both culverts to achieve the layout displayed in **Figure 9-12**. These will need special design and will require additional attention during installation.
6. Based on current policy of the Engineering Division and recent practice, grates will be required at the ends of the box culverts since either end of the box culverts will not be visible from the other end. These grates will require detailed design to ensure that they allow debris to be cleared by crews relatively easily and that flow capacity is maintained to the greatest degree possible when debris accumulates.
7. If implemented, residents will be concerned about whether the road needs to be closed during construction and duration of a closure.
8. Traffic control would be a major component of this project during construction and needs to be accounted for accordingly.
9. During design consideration needs to be given to locating low point inlets near the box culvert. These can be offset and drain by pipe through the box culvert wall or can be saddled and drain directly through an opening in the roof of the box culvert.
10. These box culverts would extend through existing greenway channel that an existing 18" RCP sanitary sewer main runs underneath. To avoid having sanitary sewer buried below large box culverts, relocation would be required. A new sanitary SAS could be installed to the northwest of the existing main and sanitary sewer would be routed along the west side of the new box culverts. Coordination with Water Utility, electric, gas, communications, and other utilities would also still be required.

9.12 Westbrook Lane Box Culverts

9.12.1 Detailed Project Description

Two 14' span x 4' rise box culverts would need to be installed at the Westbrook Lane greenway crossing to replace the two existing 47"x71" corrugated metal pipe arch culverts. This greenway crossing and elements of the project are displayed in **Figure 9-13**.

9.12.2 Associated Flood Reduction Benefits

The box culverts were sized to convey peak flows in the greenway channel that are increased by upstream solutions without road overtopping. This resolves known, existing road overtopping.

Additionally, this improvement, in combination with the downstream improvement, helps to remove one additional structure from flooding.

9.12.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project is intended to be designed and constructed as a spot replacement of culverts.
2. The new box culverts need to be installed at the invert elevations indicated in **Figure 9-13**. These were set to balance upstream high water elevations and flow conveyed downstream.
3. The modeling and **Figure 9-13** used the assumption that box culvert wingwalls and apron are constructed in accordance with City of Madison S.D.D. 5.5.1 A & B.
4. Field observation shows that existing wingwalls on this culvert are beginning to fail. Rather than structurally repair the existing wingwalls, the proposed box culverts can be installed when the

condition of the existing culverts necessitates replacement. Reference Section 13 for additional information that is critical to implementation sequence of the recommended solutions.

5. If implemented, residents will be concerned about whether the road needs to be closed during construction and duration of a closure.
6. During design consideration needs to be given to locating low point inlets near the box culvert. These can be offset and drain by pipe through the box culvert wall or can be saddled and drain directly through an opening in the roof of the box culvert.
7. Significant utility relocation is not anticipated since the box culverts would be installed at a similar invert elevation as the existing culverts. However, coordination with Water Utility, electric, gas, communications, and other utilities would still be required.

9.13 Lucy Lincoln Hiestand Park Box Culvert & Frisch Road-Jacobs Way Storm Sewer

9.13.1 Detailed Project Description

One 10’ span x 4’ rise box culvert would need to be installed at the path greenway crossing in Lucy Lincoln Hiestand Park, just west of the Frisch Road greenway outfall, to replace the existing 34”x53” HERCP culvert. Additional improvements include installing upsized storm sewer along Frisch Road to about 600 feet of north of the greenway outfall, installing upsized storm sewer along Jacobs Way to about 300 feet west of the intersection with Frisch Road, and increased inlet capacity. This greenway crossing and elements of the project are displayed in **Figure 9-14**.

9.13.2 Associated Flood Reduction Benefits

Model iterations demonstrated that increasing the size of the culvert at the path crossing lowers the high water elevation upstream, which plays a critical role in the performance of the storm sewer outfall at Frisch Road. This outfall is currently both undersized and tailwater controlled. Lowering the high water elevation in the receiving channel allows the storm sewer improvements to meet multiple flood reduction targets.

Storm sewer replacement along Frisch Road and Jacobs Way would increase inlet and pipe capacity to convey the 4-percent chance event. This would allow the 10-percent chance and 4-percent chance event targets to be fully met along these streets, in addition to removing two structures from flooding.

9.13.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project is intended to be designed and constructed as a spot replacement of culverts.
2. The modeling and **Figure 9-14** used the assumption that box culvert wingwalls and apron are constructed in accordance with City of Madison S.D.D. 5.5.1 A & B.
3. Significant utility relocation is not anticipated since the box culvert and storm sewer would be installed at a similar invert elevation as the existing culverts. However, coordination with Water Utility, electric, gas, communications, and other utilities would still be required.
4. The modeling and recommended solutions GIS layer show the greenway outfall as an 8’ span x 3’ rise box culvert, however, this could be changed to improve constructability or cost effectiveness. Alternatives include two 4’ span x 3’ rise box culverts or two 34”x53” HERCP. The slightly smaller cross sectional area of the HERCP should be acceptable since the modeled configuration exceeds the 4-percent chance event target. Further variation could include two outfalls to the greenway: one 6’ span x 3’ rise box culvert, or equivalent, outfall just north of the

street low point along with one 36” RCP, or equivalent, outfall from the two recommended terrace inlets located at the street low point.

5. This recommended solution was shared with Parks and on November 28th, 2022, Engineering received a response that Parks has no concerns with it.

9.14 Prairie Road Box Culvert & Jacobs Way-Theresa Terrace Storm Sewer Extension

9.14.1 Detailed Project Description

One 6’ span x 3’ rise box culvert would need to be installed at the Prairie Road greenway crossing to replace the existing 42” diameter RCP culvert. Additional improvements include installing upsized storm sewer along Prairie Road to about 300 feet of north of the greenway crossing, extending new storm sewer along Jacobs Way to the intersection with Theresa Terrace (about 300 feet), extending new storm sewer along Theresa Terrace to the intersection with Hammersley Road (about 850 feet), and increased inlet capacity. This greenway crossing and elements of the project are displayed in **Figure 9-15**.

9.14.2 Associated Flood Reduction Benefits

The box culverts were sized to convey peak flows in the greenway channel that are increased by upstream solutions without road overtopping. This resolves known, existing road overtopping.

Extending storm sewer along Jacobs Way and Theresa Terrace would provide inlets and pipes to better convey the 4-percent chance event. This improvement would allow the 10-percent chance and 4-percent chance event targets to be fully met along these streets, in addition to removing three structures from flooding. This neighborhood has long dealt with flooding that was not known to the City and this improvement is an opportunity to show that recently shared information is resulting in action.

9.14.3 Project Constraints/Considerations

The following potential project constraints were identified and need to be considered as part of future project implementation:

1. The project is intended to be designed and constructed as a spot replacement of culverts.
2. The modeling and **Figure 9-15** used the assumption that box culvert wingwalls and apron are constructed in accordance with City of Madison S.D.D. 5.5.1 A & B.
3. During design consideration needs to be given to locating low point inlets near the box culvert. These can be offset and drain by pipe through the box culvert wall or can be saddled and drain directly through an opening in the roof of the box culvert.
4. Significant utility relocation is not anticipated since the box culvert and storm sewer would be installed at a similar invert elevation as the existing culverts. However, coordination with Water Utility, electric, gas, communications, and other utilities would still be required.
5. This solution extends new storm sewer to a street where Engineering has received more accounts of flooding during the outreach efforts associated with this study. Accounts have been provided by residents and the Theresa Terrace NRT.
6. This recommended solution and overall drainage concerns on Theresa Terrace were discussed with Department of Planning and Community and Economic Development staff, including a member of the Theresa Terrace NRT, on December 22, 2022. Of particular concern from an equity standpoint is that if this is implemented as an assessable project, it will be very important to pursue grant or other funding options to assist property owners with these costs. Theresa Terrace has a significant portion of renter occupied residences with lower incomes.

Section 10 Evaluation of Model Results with Recommended Solutions Implemented

The PCSWMM model that includes all of the recommended solutions, referred to as proposed conditions, was executed for each of the design storms. **Appendix K** summarizes the peak water surface elevation and the peak flows at selected locations throughout the East Badger Mill Creek watershed for existing and proposed conditions. **Figure 5-1** provides the location of each reporting location listed in **Appendix K**. The maximum water depths and inundation extents for the modeled design storms under proposed conditions are displayed in **Figures 10-1** through **10-9**.

10.1 Comparison to City Flood Reduction Targets with Recommended Solutions

The proposed conditions flooding results were compared to the City's flood reduction targets to quantify the performance of the recommended solutions in the East Badger Mill Creek watershed. The performance of the system's greenway crossings, pipe capacity, inlet capacity, and street flooding were each closely analyzed. Performance of the system relative to these targets is displayed in **Figures 10-10** through **10-12**.

10.1.1 Pipe Capacity

The City's target is to eliminate surcharging from the storm sewer system onto streets for up to the 10-percent chance event. Pipe capacity was determined to be exceeded if water is present on the street in the model during the 10-percent chance, 24-hour design storm event.

Under existing conditions, 6.6 out of 35.9 miles of street have water ponded or surcharged during the 10-percent chance event, which equates to 18 percent of street miles not meeting the target. Under proposed conditions, 0.7 out of 35.9 miles of street have water ponded or surcharged during the 10-percent chance event, which equates to 2 percent of street miles not meeting the target.

10.1.2 Inlet Capacity

The City's target is to allow no more than 0.5 feet of ponded water above storm sewer inlets or rim elevations at inlet restricted low-points for the 10-percent chance event. Existing inlet capacity was not included in the PCSWMM mode as part of this study.

In the proposed conditions it is assumed that inlet capacity improvements are incorporated such that inlet capacity is no longer the limiting factor. Therefore, this target would be met in all locations where pipe capacity targets are met, as described in Subsection 10.1.1. Further detailed analysis is required to determine the exact number, type, and location of inlets required to be implemented and needs to be conducted during the design process for the recommended solutions. Additional detail on locations where inlet capacity needs to be improved is provided in **Appendix J**.

10.1.3 Street Flooding

The City's target is to maintain drivability of public streets for the 4-percent chance event. Maintaining drivability is defined as having no more than 0.5 feet of inundation at the street centerline.

Under existing conditions, 2.5 out of 35.9 miles of street have water ponded at the centerline during the 4-percent chance event, which equates to 7 percent of street centerline miles not meeting the target. Under proposed conditions, 0.6 out of 35.9 miles of street have water ponded at the centerline during the 4-percent chance event, which equates to less than 2 percent of street centerline miles not meeting the target.

10.1.4 Structure Flooding

The City's target is to eliminate structure flooding during the 1-percent chance event. Structure flooding is defined as having an inundation depth of 0.5 feet or more within five feet of a building.

Under existing conditions, 70 out of 3,089 structures are inundated 0.5 feet or more during the 1-percent chance event, which equates to 2 percent of structures not meeting the target. Under proposed conditions, 29 out of 3,089 structures are inundated 0.5 feet or more during the 1-percent chance event, which equates to 1 percent of structures not meeting the target.

10.1.5 Greenway Crossings

The City's target is to eliminate road overtopping at greenway crossings during the 1-percent chance event. A crossing is considered to be overtopped if the high water elevation at the upstream end of the culvert is above the low terrace/sidewalk elevation along the upstream side of the road. There are several cases where street ponding at greenway crossings is the result of local runoff and the road does not overtop as a result of flow leaving the greenway channel.

Under existing conditions, 3 out of 10 greenway crossings overtop during the 1-percent chance event, which equates to 30 percent of greenway crossings not meeting the target. Under proposed conditions, 0 out of 9 greenway crossings overtop during the 1-percent chance event, which equates to 0 percent of greenway crossings not meeting the target. The recommended solutions combine the existing McKenna Boulevard and Pilgrim Road greenway crossings into one, which results in one fewer crossings in the proposed conditions.

10.2 Improvements to Known Flooding in Watershed from Recommended Solutions

Areas in the watershed with known previous flooding are identified in Section 1.2 and discussed in further detail in Section 6.2. The areas that were identified are shown in **Figure 1-4**. Additionally, focus group meetings were held in areas throughout the watershed that have been impacted by flooding. The focus group locations are shown in **Figure 7-2** and the issues identified by each are discussed in Subsection 6.2.3 and **Appendix F**.

The recommended solutions generally targeted meeting the City's flood reduction targets throughout the East Badger Mill Creek watershed. Known flooding locations were taken into consideration while developing solutions. A summary of flood reductions that result from the recommended solutions, specifically at locations known to previously experience flooding, are listed below:

1. Stonecreek Drive north of East Pass – street and structure flooding

    a. Solutions Benefitting Area: Local sewer improvements at the Stonecreek Drive-Mader Drive and Stonecreek Drive-East Pass intersections increase conveyance to the greenway.

    b. Flood Reductions Observed: Street flooding is eliminated along Stonecreek Drive in the 4-percent chance event and structure flooding is eliminated in the 1-percent chance event.

2. East side of Silverton Trail north of McKee Road – street flooding about 1 foot deep

    a. Solutions Benefitting Area: Local sewer improvements at the Silverton Trail-Tempe Drive intersection increases conveyance to the greenway.

    b. Flood Reductions Observed: Street flooding is eliminated at this intersection in the 4-percent chance event.

3. Lancaster Lane at Whitlock Road – road overtopping and structure flooding

    a. Solutions Benefitting Area: Local sewer improvements on Lancaster Lane and Whitlock Road, along with greenway crossing culvert replacement, both increase conveyance.

    b. Flood Reductions Observed: Street flooding is reduced in the 4-percent chance event, structure flooding is reduced in the 1-percent chance event, and road overtopping is eliminated in the 1-percent chance event.

4. Greenway between McKenna Boulevard and Pilgrim Road – hydraulically inefficient section of the system causes upstream flooding issues

    a. Solutions Benefitting Area: Greenway crossing culvert replacement increases hydraulic efficiency and conveyance.

    b. Flood Reductions Observed: Upstream high water elevation is reduced and implementation of upstream improvements is facilitated.

5. McKenna Boulevard south of Tottenham Road – street flooding almost 2 feet deep

    a. Solutions Benefitting Area: Main line sewer improvements on McKenna Boulevard increase conveyance to the greenway.

    b. Flood Reductions Observed: Street flooding is reduced by almost 1 foot in the 4-percent chance event and implementation of upstream improvements is facilitated.

6. Raymond Road east of McKenna Boulevard – street flooding about 1.5 feet deep and structure flooding beginning in the 10-percent chance event

    a. Solutions Benefitting Area: Main line sewer improvements on Raymond Road increase conveyance.

    b. Flood Reductions Observed: Street flooding is reduced by more than 1 foot in the 4-percent chance event and structure flooding is eliminated in the 1-percent chance event.

7. Tottenham Road east of McKenna Boulevard and Frisch Road south of Brompton Circle – significant street and structure flooding from greenway channel and storm sewer surcharging beginning in the 10-percent chance event

a. Solutions Benefitting Area: Local sewer improvements on Frisch Road increase conveyance during small events and downstream greenway crossing culvert replacement increases conveyance.

b. Flood Reductions Observed: Street flooding is reduced by about 1.5 feet in the 10-percent chance event and structure flooding is reduced in the 1-percent chance event. Structure flooding is significantly reduced in the 4-percent chance event, from 17 structures to 3.

8. Pilgrim Road at Homestead Road – street flooding about 1 foot deep

   a. Solutions Benefitting Area: Local sewer improvements, including increased inlet capacity, at this intersection increases conveyance to the greenway.

   b. Flood Reductions Observed: Street flooding is reduced by almost 0.5 feet at this intersection in the 4-percent chance event and is not present at the street centerline.

9. Riva Road east of Prairie Road – street flooding about 1 to 2 feet deep along length of the road

   a. Solutions Benefitting Area: Main line sewer improvements along Riva Road increases conveyance to the greenway.

   b. Flood Reductions Observed: Street flooding is eliminated in the 10-percent chance event, length of street centerline flooding in the 4-percent chance event is significantly reduced, and structure flooding is eliminated 4-percent chance event. Implementation of upstream improvements is facilitated.

10. Thrush Lane at Riva Road – street flooding up to about 1.5 feet deep

    a. Solutions Benefitting Area: Local sewer improvements along Thrush Lane increases conveyance.

    b. Flood Reductions Observed: Street flooding depths are reduced by about 0.5 feet and significantly reduced length of street centerline flooding in the 4-percent chance event.

11. Drainage to Jacobs Court – runoff from uphill goes through backyards along Jacobs Court

    a. Solutions Benefitting Area: No sewer improvements are recommended in this area since runoff comes from private property. Local sewer improvements along Jacobs Way increase conveyance.

    b. Flood Reductions Observed: Backyard drainage issues could be addressed through private improvements, which are not evaluated in this study. Street flooding downstream on Jacobs Way is eliminated in the 4-percent chance event.

12. Frisch Road between Lucy Lane and greenway outfall – street flooding up to about 1.5 feet deep

    a. Solutions Benefitting Area: Local sewer improvements and a culvert replacement both increase capacity.

    b. Flood Reductions Observed: Street flooding is eliminated in the 4-percent chance event. The culvert replacement lowers channel tailwater at the storm sewer outfall to facilitate reductions in street flooding.

13. Lomax Lane at Starr Court – street flooding in Starr Court cul-de-sac end

    a. Solutions Benefitting Area: Local sewer improvements installed in 2012 effectively intercept flow on Lomax Lane from the south and any remaining flooding on the cul-de-sac is the result of inlet capacity limitations. Inlet capacity needs to be increased with a future improvement to fully utilize pipe capacity, which is the assumption used in the proposed conditions modeling.

    b. Flood Reductions Observed: Inlet capacity limitations could cause up to 1.5 feet of flooding in the cul-de-sac in the 4-percent chance event, but this is not reflected in the inundation mapping since inlet capacity was not modeled. Increasing inlet capacity would reduce street flooding by more than 1 foot. Proposed conditions inundation mapping shows flooding in the 1-percent chance event resulting from the Prairie Road culvert replacement, but the depth is lower than ponding from inlet capacity limitations.

14. Theresa Terrace at Jacobs Way – street and structure flooding caused by lack of storm sewer

    a. Solutions Benefitting Area: New local storm sewer along Jacobs Way and Theresa Terrace conveys flow subsurface.

    b. Flood Reductions Observed: Street flooding is eliminated in the 4-percent chance event and structure flooding is eliminated in the 1-percent chance event.

15. Prairie Road greenway crossing – road overtops (observed) relatively frequently

    a. Solutions Benefitting Area: Greenway crossing culvert replacement increases conveyance.

    b. Flood Reductions Observed: Road overtopping is eliminated in the 4-percent chance event.

A summary of flood reductions that result from the recommended solutions, specifically at locations identified during focus group outreach not included in the list above, are discussed below:

1. Carnwood Road – residents observed that road did not overtop in August 2018

    a. Solutions Benefitting Area: Greenway crossing culvert replacement increases greenway channel conveyance.

   b. Flood Reductions Observed: Upstream improvements are facilitated without structure flooding or road overtopping in the 1-percent chance event.

2. Lancaster Lane – residents observed road overtopping in August 2018

   a. Solutions Benefitting Area: Greenway crossing culvert replacement increases greenway channel conveyance.

   b. Flood Reductions Observed: Upstream improvements are facilitated without structure flooding and road overtopping is eliminated in the 1-percent chance event.

3. Canterbury Road – residents have observed street flooding at the greenway crossing

   a. Solutions Benefitting Area: Greenway crossing culvert replacement increases greenway channel conveyance and inlet capacity improvements.

   b. Flood Reductions Observed: Upstream improvements are facilitated without creating new structure flooding. Street flooding can be reduced with increased inlet capacity.

4. McKenna Boulevard low point – residents have observed street flooding at the low point north of Yorktown Circle

   a. Solutions Benefitting Area: Local storm sewer improvements, including increased inlet capacity, at this low point increase conveyance to the greenway.

   b. Flood Reductions Observed: Street flooding is eliminated in the 4-percent chance event.

5. Barton Road-Lynndale Road – street flooding about 0.5 feet deep

   a. Solutions Benefitting Area: Local storm sewer improvements on Lynndale Road, Cameron Drive, and Barton Road increase conveyance.

   b. Flood Reductions Observed: Street flooding is eliminated in the 4-percent chance event.

6. Golden Oak Lane-Redwood Lane-Barton Road – street flooding about 1 foot deep and structure flooding in August 2018

   a. Solutions Benefitting Area: Local storm sewer improvements at this intersection increase conveyance to greenway.

   b. Flood Reductions Observed: Street flooding is eliminated in the 4-percent chance event.

Section 11 Areas Flood Reduction Targets Are Not Met

In most of the East Badger Mill Creek watershed, the City's flood control targets are met. However, there are several instances of the targets not being met. Further discussion of areas not meeting the 4-percent chance event street centerline flooding target and 1-percent chance event structure flooding target are provided in this section.

As noted in Section 10.1, there are 0.6 miles of street centerline that flood during the 4-percent chance event and 29 structures that have risk of flooding during the 1-percent chance event under proposed conditions. The locations where targets are not met in the proposed conditions were evaluated in greater detail to determine the nature of the flooding. Although targets are not met in these locations, flooding is reduced, which moves these locations closer to meeting the targets than under the existing conditions.

Locations where streets are not meeting the drivability target in the 4-percent chance event:

1. Although storm sewer size along Whitlock Road from Gladstone Drive to Lancaster Lane would be increased significantly, flooding at the street centerline still reaches 0.8 feet. Street flooding is reduced by 0.2 feet and one structure is removed from flooding as a result of implementing the recommended solutions. Pipe cover along Whitlock Road and grade at the greenway outfall on Lancaster Lane limit storm sewer from being upsized further.

2. At the Waltham Road low point, flooding at the street centerline still reaches 0.6 feet. Street flooding is reduced by almost 1 foot and two structures are removed from flooding as a result of implementing the recommended solutions. The greenway outfall from this low point is somewhat tailwater limited and pipe cover prevents storm sewer from being upsized further.

3. Although storm sewer size along McKenna Boulevard between Raymond Road and the low point would be increased significantly, flooding at the street centerline still reaches 0.6 feet in short sections. Street flooding is reduced by more than 0.5 feet and as a result of implementing the recommended solutions. Pipe cover along McKenna Boulevard and capacity of the receiving box culvert limit storm sewer from being upsized further.

4. Flooding along Frisch Road south of Brompton Circle is a function of the high water elevation in the adjacent greenway. Water from the greenway directly causes inundation, but also limits the effectiveness of storm sewer to drain the street once the greenway outfall is submerged. Flooding depth is reduced from about 2 to 4 feet along Frisch Road to about 1 to 2.5 feet. Tottenham Road between McKenna Boulevard and Frisch Road does not have storm sewer, but the downstream tailwater limitations would prevent a storm sewer extension from providing a meaningful reduction in street flooding. Flooding depth is reduced from about 1 to 2 feet along Tottenham Road to about 0.5 to 1 foot. Changing the high water elevation in the adjacent greenway is limited by constraints described in Subsection 8.2.1.1 and Section 9.11.

5. Although the greenway outfall at Riva Road and Prairie Road would be increased significantly, flooding at the Riva Road street centerline still reaches about 0.5 to 1 foot in a short section near the intersection. Street flooding is reduced by about 0.5 feet and the length of street centerline flooding is significantly reduced. Box culvert cover and avoiding increased flooding downstream limit storm sewer from being upsized further.

Locations where structures are not meeting the flooding target in the 1-percent chance event:

1. One structure at the northeast corner of Whitlock Road and Lancaster Lane is still shown to have flood risk resulting from the greenway flows. The grading on this property is very low and the high water elevation in the greenway can't be lowered enough with new box culverts in a manner that can be implemented effectively and avoid increasing flooding downstream.

2. Two structures along McKenna Boulevard, just northeast of Canterbury Road, are still shown to have flood risk resulting from greenway flows. It's possible that these structures may have lower flood risk than indicated by the inundation mapping, based on a condition discussed further below. The Canterbury Road greenway crossing can't be further upsized without needing to be offset by considerably increasing the size of downstream recommended solutions.

3. One structure south of Raymond Road and west of McKenna Boulevard is still shown to have flood risk. Storm sewer improvements along Raymond Road and McKenna Boulevard were maximized to the greatest degree practicable, based on other constraints in the area. More importantly, the existing and proposed conditions structure flooding shown in the model may not occur during the corresponding events in reality. Some of the runoff that leaves Raymond Road and flows south onto private property is less than six inches deep at the edge of the road. Based on field review of this section of Raymond Road, this runoff would not be deep enough to flow over the curb and sidewalk, even at driveway aprons. Additional discussion of this condition is included below.

4. Nineteen structures adjacent to the greenway in Pilgrim Park, including those on Frisch Road, are still shown to have flood risk resulting from greenway flows. Many homes along this section of greenway are situated only a few feet above the channel and as a result are subject to frequent and recurrent flooding. Additionally, the greenway channel has very little topographic relief. These two factors combine to make reducing flood risk very challenging. The high water elevation in the greenway is lowered about 1.5 feet as a result of implementing the recommended solutions, but further reduction is limited by constraints described in Section 9.11. To fully reduce flood risk, even more significant solutions would need to be evaluated such as filling the area and raising the structures, installing large pumping systems, or lowering the greenway channel (Subsection 8.2.1.1). Further evaluation of any large scale solution would also need to take potential increases in downstream flooding into account.

5. One structure along the greenway just east of Westbrook Lane is still shown to have flood risk resulting from greenway flows. The high water elevation in the greenway is decreased as a result of implementing recommended greenway crossing improvements at McKenna Boulevard and Westbrook Lane by more than 1 foot. It's possible that this structure may have lower flood risk than indicated by the inundation mapping, based on a condition discussed further below.

6. Three structures on Monticello Way with backyards along the ditch north of Huegel Elementary School and Huegel Park are still shown to have flood risk. Flooding is only reduced slightly as a result of implementing recommended solutions. However, the City has not received reports of flooding along Monticello Way. It is possible that the location where runoff enters the 2D mesh in the model does not accurately represent drainage conditions in this area.

There are several structures in the locations described above and in other isolated locations that are shown to have flood risk in the 1-percent chance event model results that are likely caused by model limitations. The mesh dimensions are representative of a watershed study of this scope and nature, however, it does not reflect all of the nuances within an urban area, which is a limitation of modeling. For instance, the detailed grading surrounding a building may not be represented by the mesh or the 6-inch curb height along the edge of a road might not be fully captured.

During the design phase of each solution, the following can be carried out to more accurately determine flood risk in these areas:

1. Refinement of the model during subsequent planning, design, and implementation phases for solutions can verify pipe sizing and confirm whether structures are expected to flood or not. Refining the model could include revising topographic data (e.g. supplementing LiDAR data with survey data), decreasing the grid size in specific locations of interest, splitting subcatchments, or adding additional storm sewer. Inlets, inlet leads, storm sewer smaller than 18”, and private storm sewer were not modeled with this study, but could provide further insight in a refined model. Additionally, further structure elevation data (such as first floor or low opening elevations) could be obtained to verify whether the structure would be flooded.

2. The storm sewer improvements can be reviewed and sizes may potentially be increased to provide a greater level of flood protection. However, caution must be used when evaluating changes to recommended pipe sizes to ensure unintended increases in downstream flooding do not result.

The solutions recommended as a result of this study do increase peak flow rates at the outlet of the East Badger Mill Creek watershed. Existing conditions in the Upper Badger Mill Creek watershed were studied separately by Brown and Caldwell and the City used this model to evaluate potential downstream impacts. Proposed conditions flow hydrographs from the outlet of the East Badger Mill Creek watershed were entered into the Upper Badger Mill Creek PCSWMM model as inflow to evaluate the associated impacts. This was closely checked at three particular locations along the downstream greenway:

1. Pond on Stormwater Utility property adjacent to Country Grove Park – High water elevation is increased by 0.3 to 0.4 feet in the 1-percent chance event. This increase results in a negligible increase in inundation extents that is confined almost exclusively to Stormwater Utility property.

2. Greenway crossing on Rockstream Drive – High water elevation is increased by 0.7 feet in the 1-percent chance event. This increase does not result in road overtopping at this crossing and inundation extents are confined to Stormwater Utility property.

3. Greenway crossing at Nesbitt Road and Maple Grove Drive - High water elevation is increased by 0.7 feet in the 1-percent chance event. This increase does result in road overtopping at this crossing. This could be addressed in the future by increasing culvert capacity at this crossing or by building up the back of sidewalk elevation. Inundation extents are confined to Stormwater Utility property in the upstream greenway and this would remain the case even if sidewalk elevations are increased in the future.

Section 12 Cost Estimating

As part of this study, planning level cost estimates were prepared for each of the stand-alone recommended solutions described in Section 9. This section describes the methodology used for estimating costs.

Cost estimates were not prepared for local storm sewer or inlet capacity improvements. In general, these improvements will be implemented in conjunction with street resurfacing projects. The costs associated with these storm sewer improvements will be developed by the City as they are scheduled for implementation in the City's five year CIP.

To prepare cost estimates, anticipated quantities for each material to be used on the project were first developed. The City provided average unit costs for typical bid items included as part of stormwater improvement projects. The standard unit costs were adjusted based on specific project conditions that may result in higher or lower than average unit costs.

The total estimated cost for each of the stand-alone projects is provided in **Table 12-1**. A detailed breakdown of the cost estimate for each project is included in **Appendix M**.

Table 12-1. Stand-Alone Project Cost Estimates

Project Name	Design & Construction Cost
McKenna Boulevard-Raymond Road Reconstruction	$4,273,439
McKenna Boulevard and Raymond Road West Improvements	*$3,704,439*
Raymond Road East Improvements	*$569,000*
Riva Road Reconstruction	$1,164,407
Raymond Road-Cameron Drive-Barton Road-Whitney Way Reconstruction	$2,526,520
East Pass Relief Box Culvert Replacement	$420,103
McKee Road Relief Box Culvert Replacement	$681,113
Carnwood Road Box Culvert Replacement	$860,305
Lancaster Lane Box Culvert Replacement	$981,021
Canterbury Road Box Culvert Replacement	$766,385
McKenna Boulevard-Pilgrim Road Box Culvert Replacement	$2,666,682
Westbrook Lane Box Culvert Replacement	$742,922
Lucy Lincoln Hiestand Park Culvert and Frisch Road Storm Sewer	$1,255,896
Lucy Lincoln Hiestand Park Culvert	*$243,000*
Frisch Road Storm Sewer	*$1,012,896*
Prairie Road Box Culvert and Theresa Terrace Storm Sewer	$1,039,724
Total	$17,378,517

Section 13 Implementation Sequence

13.1 Technical Implementation Needs

Implementation of individual recommended solutions in the watershed can impact other parts of the watershed. For instance, implementing a conveyance improvement project could have a negative impact by increasing peak flows to the downstream area. Within the East Badger Mill Creek watershed there is a small amount of flexibility in implementing the recommended solutions. The following guidelines for implementation are provided.

1. Storm sewer improvements should generally be implemented from downstream to upstream to prevent increased downstream flooding. However, these improvements will typically be implemented with road reconstruction projects and many other factors contribute to the scheduling road reconstruction projects. These factors may dictate that projects be implemented outside of the preferred sequence. As part of this approach, the specific improvements can be reviewed as part of the design process to determine if any temporary measures, such as bulkheads or restrictor plates, are needed to offset downstream concerns.

2. The greenway crossing replacements downstream of Pilgrim Road must be implemented prior to the Pilgrim Road-McKenna Boulevard greenway crossing replacement. All other downstream greenway crossing replacements must be implemented from downstream to upstream. Otherwise, instances of significant road overtopping and structure flooding along the downstream greenway will result.

3. The McKenna Boulevard and Raymond Road main line storm sewer improvements must occur after, or at the same time as, the Pilgrim Road-McKenna Boulevard greenway crossing replacement. However, the portion of the Raymond Road improvement east of McKenna Boulevard could be implemented at any time.

4. The Westbrook Lane greenway crossing replacement could be implemented at any time. This is an important consideration since the existing culvert wingwalls are showing significant signs of deterioration. If these culverts need to be replaced due to structural issues, the recommended box culverts can be implemented as described in Section 9.12.

5. The Riva Road main line storm sewer improvements must occur after the Pilgrim Road-McKenna Boulevard greenway crossing replacement. Otherwise, significant additional structure flooding will occur between McKenna Boulevard and Prairie Road.

6. The Raymond Road-Cameron Drive-Barton Road-Whitney Way main line storm sewer improvements must occur after the Riva Road improvements. Otherwise, significant street flooding and structure flooding will occur along Riva Road.

7. The Prairie Road greenway crossing replacement could be implemented at any time.

8. The Lucy Lincoln Hiestand Park culvert replacement could be implemented at any time, but should be done before, or at the same time as, the upstream improvements on Frisch Road and Jacobs Way to allow them to function as modeled.

13.2 Citywide Implementation Prioritization

The City is conducting similar watershed studies for all the watersheds in the City. Each watershed study is expected to generate numerous recommended solutions. The City is developing a process to rank and prioritize the order in which 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.

Section 14 References

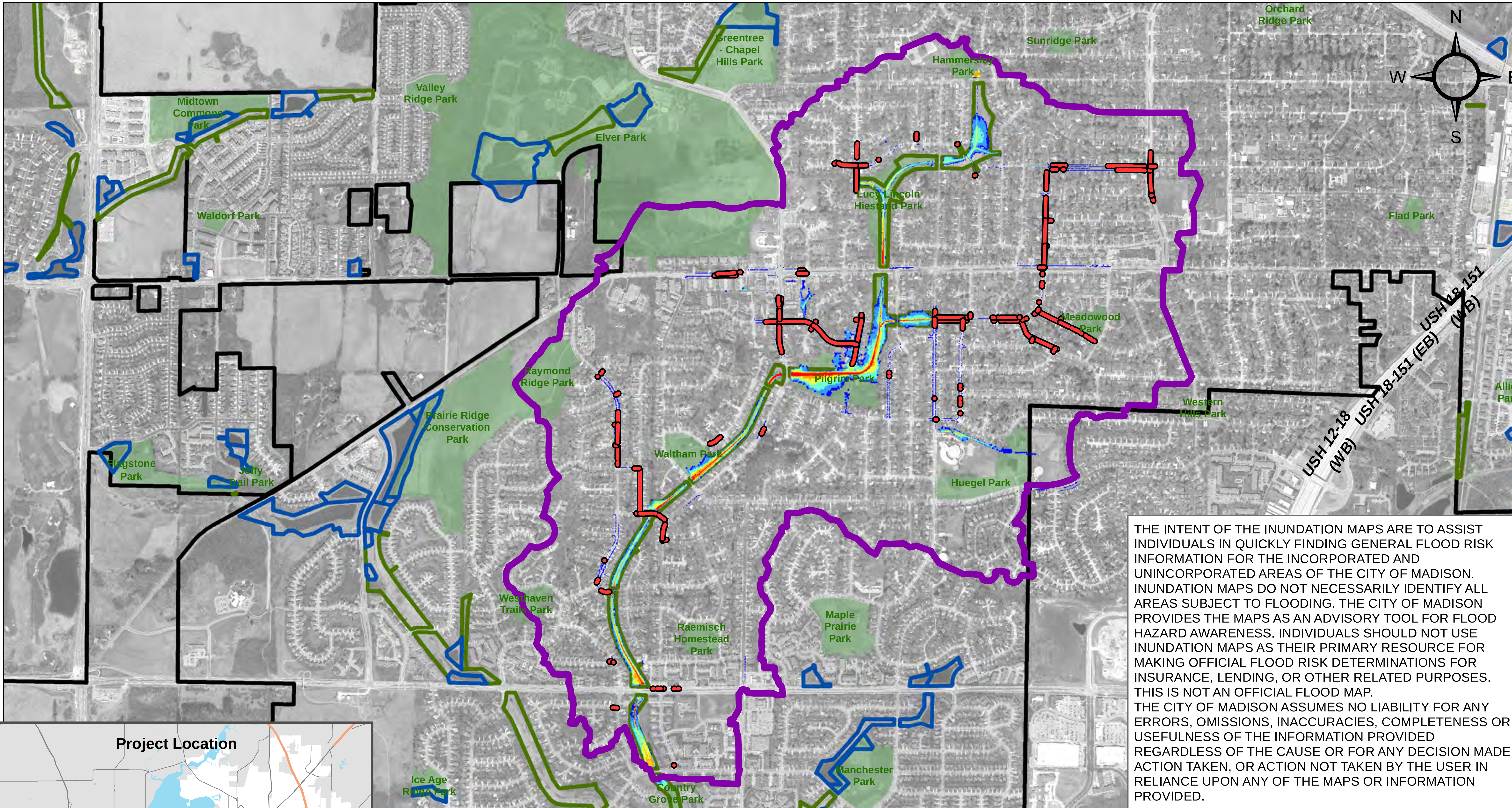
Section 3 describes the specific files and data sources used in the development of the PCSWMM model. The Model Guidance Document includes a list of references used in creation of that document. Below are a couple of additional information sources referenced during this study.

Federal Emergency Management Agency. Flood Insurance Study for Dane County, Wisconsin and Incorporated Areas. Flood Insurance Study Number 55025CV001D. June 16, 2016.

United States Geological Survey. Estimating magnitude and frequency of floods for Wisconsin urban streams. Water-Resources Investigations Report 86-4005. D.H. Conger. December 1986. https://pubs.er.usgs.gov/publication/wri864005

University of Wisconsin-Madison. Wisconsin Geological Geologic and Natural History Survey. Soil Survey of Dane County, Wisconsin, 1917. https://wgnhs.wisc.edu/pubs/000057/

Wisconsin Department of Natural Resources. Surface Water Data Viewer. https://dnr.wi.gov/topic/surfacewater/swdv/



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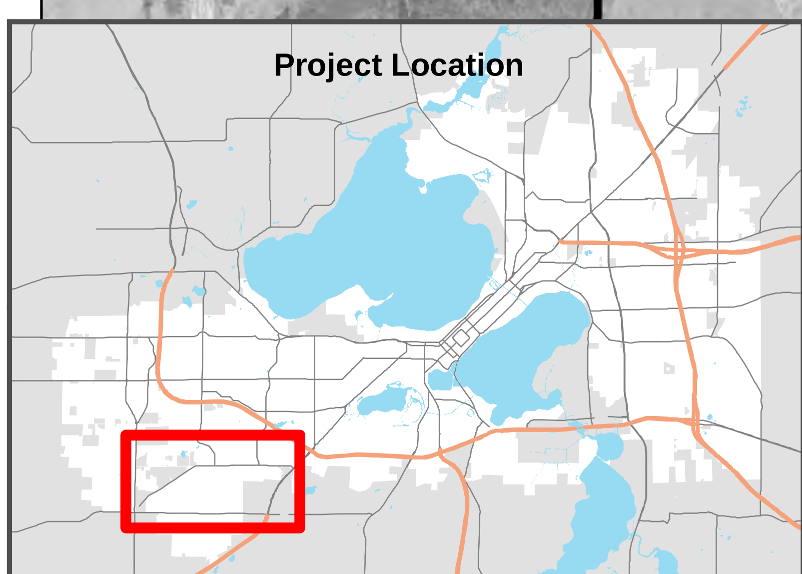


Legend

Watershed Boundary
Greenway
Pond
Municipal Limits
Park

Maximum Depth Feet
.5-1
1-2
2-3
3-4
4-5
5+
Street Segments not Meeting Target

Figure ES-1
Streets Not Meeting Target
Existing Conditions; 4 % Chance Event
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

CITY OF MADISON ENGINEERING

Date: 2/3/2023

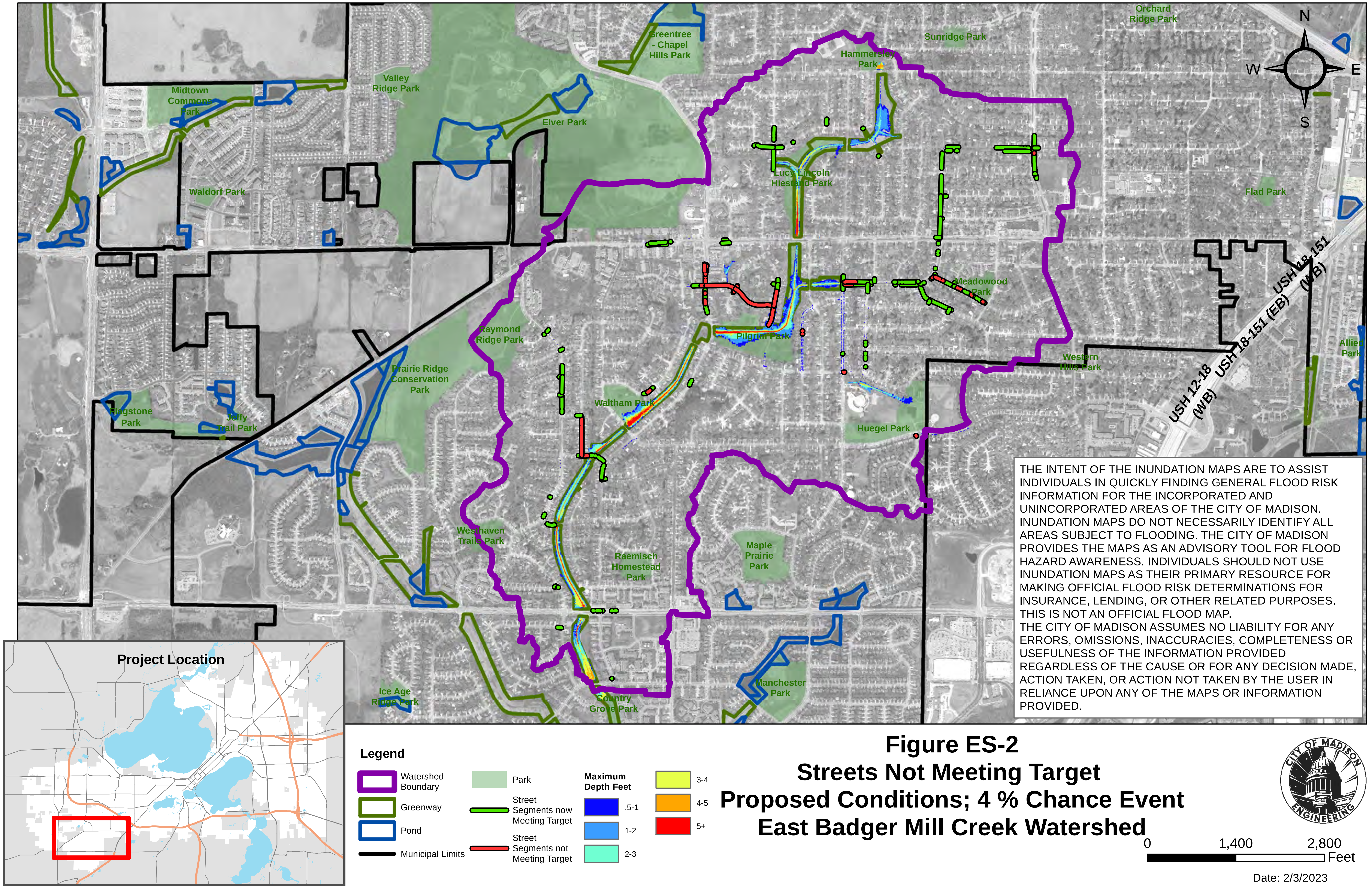
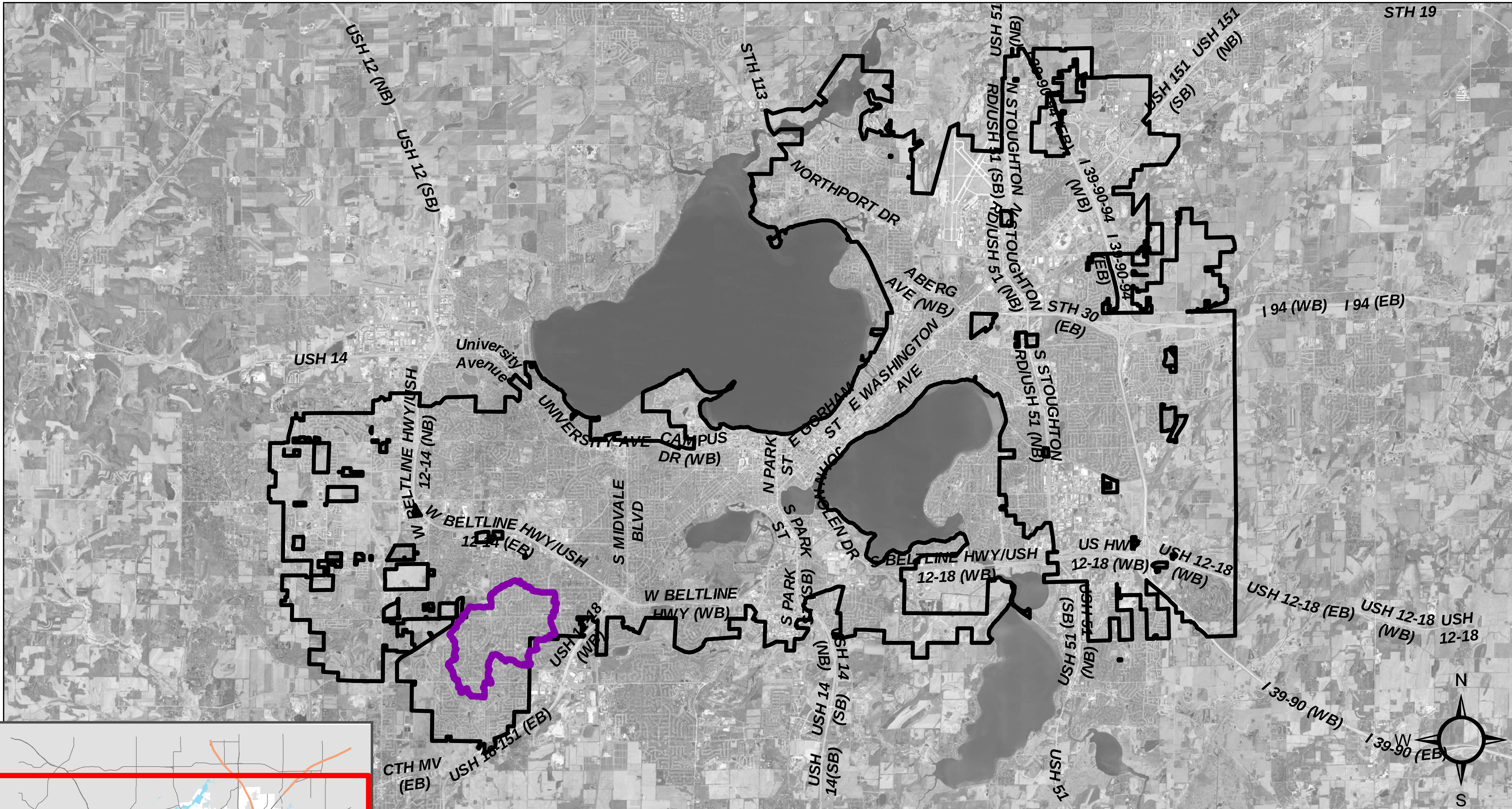
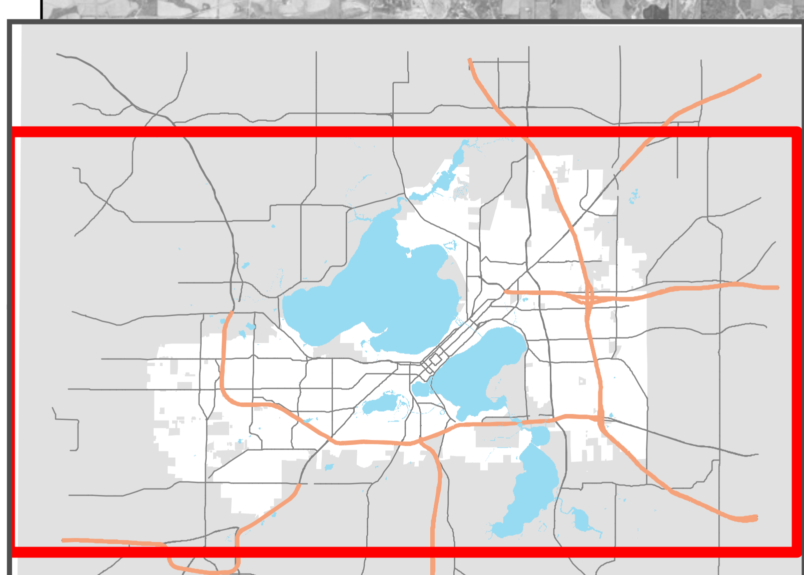


Figure ES-2
Streets Not Meeting Target
Proposed Conditions; 4 % Chance Event
East Badger Mill Creek Watershed





Legend

Watershed Boundary

Municipal Limits

Figure 1-1
Study Location
East Badger Mill Creek Watershed

0 9,000 18,000 Feet

Date: 2/3/2023

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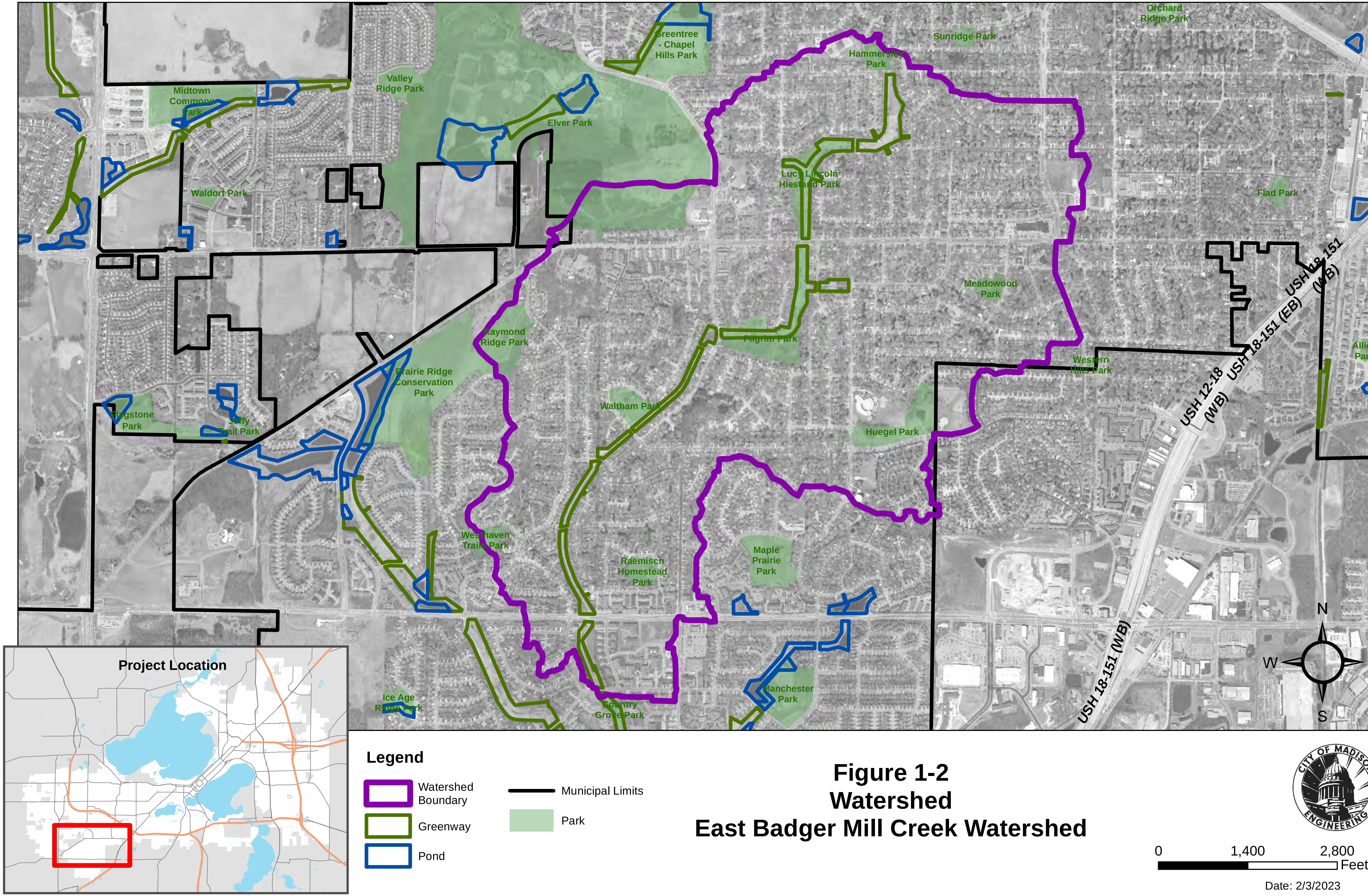

Figure 1-2
Watershed
East Badger Mill Creek Watershed

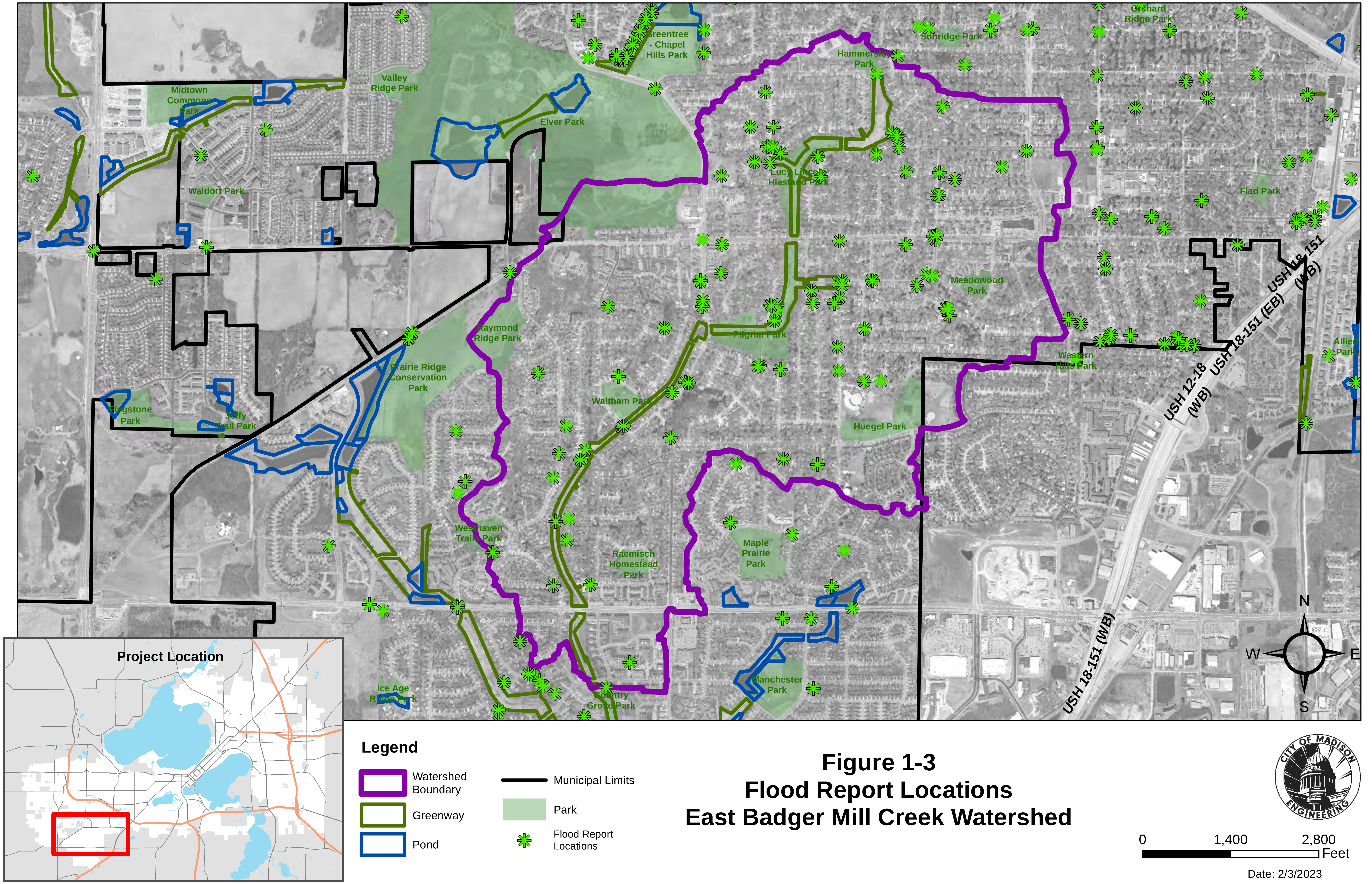

Figure 1-3
Flood Report Locations
East Badger Mill Creek Watershed

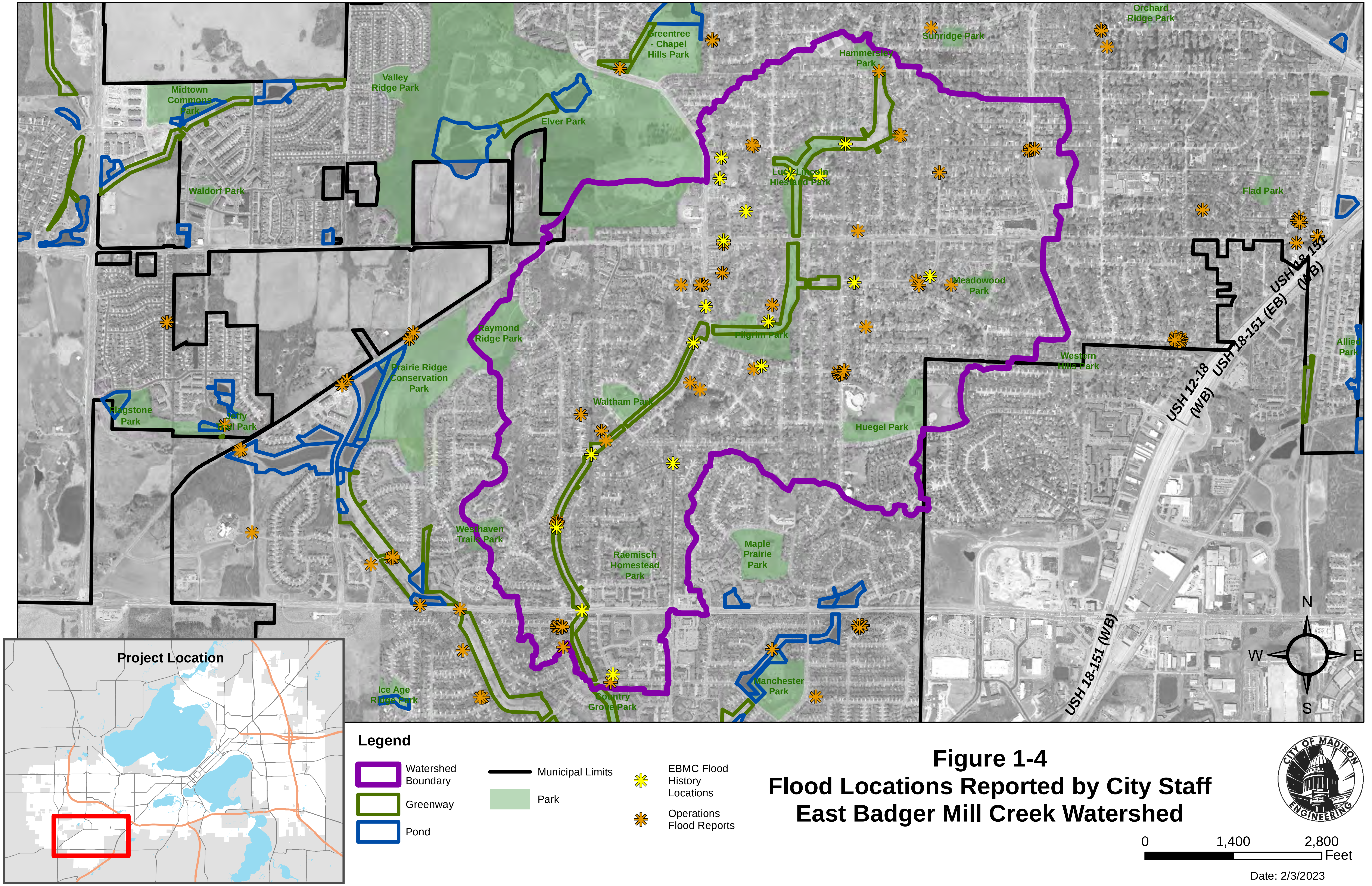

Figure 1-4
Flood Locations Reported by City Staff
East Badger Mill Creek Watershed

Date: 2/3/2023

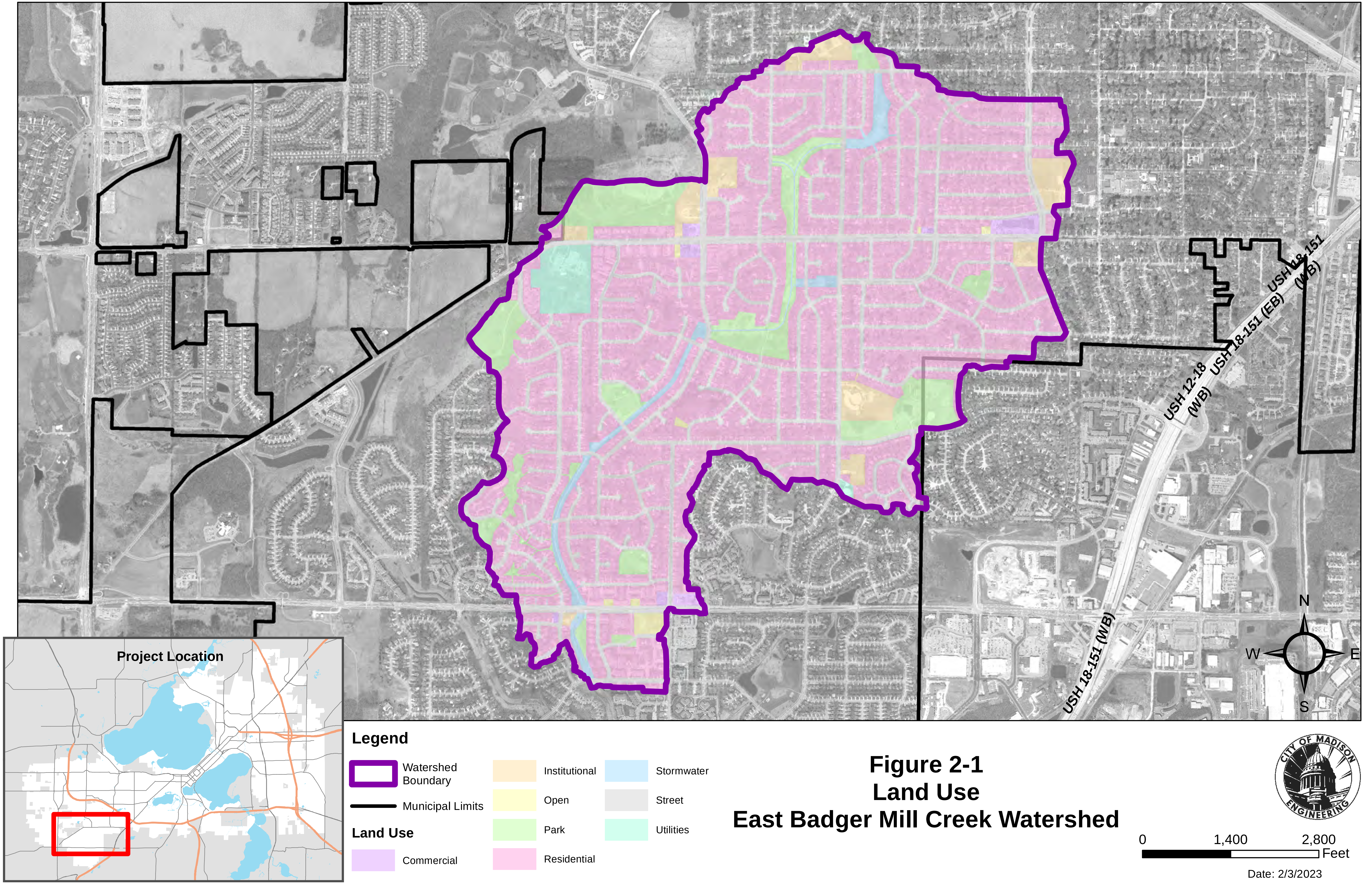

Figure 2-1
Land Use
East Badger Mill Creek Watershed

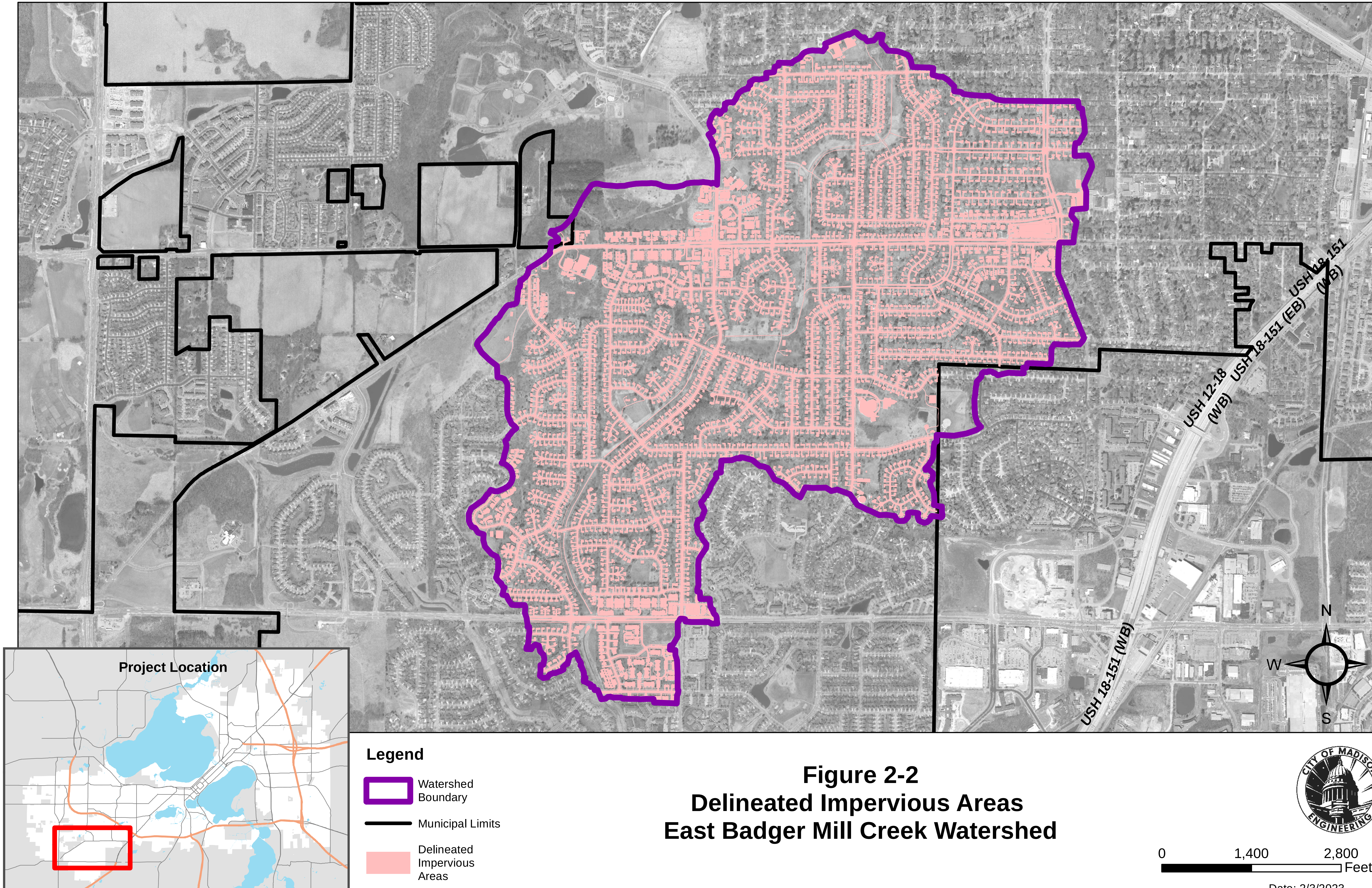

Figure 2-2
Delineated Impervious Areas
East Badger Mill Creek Watershed

Date: 2/3/2023

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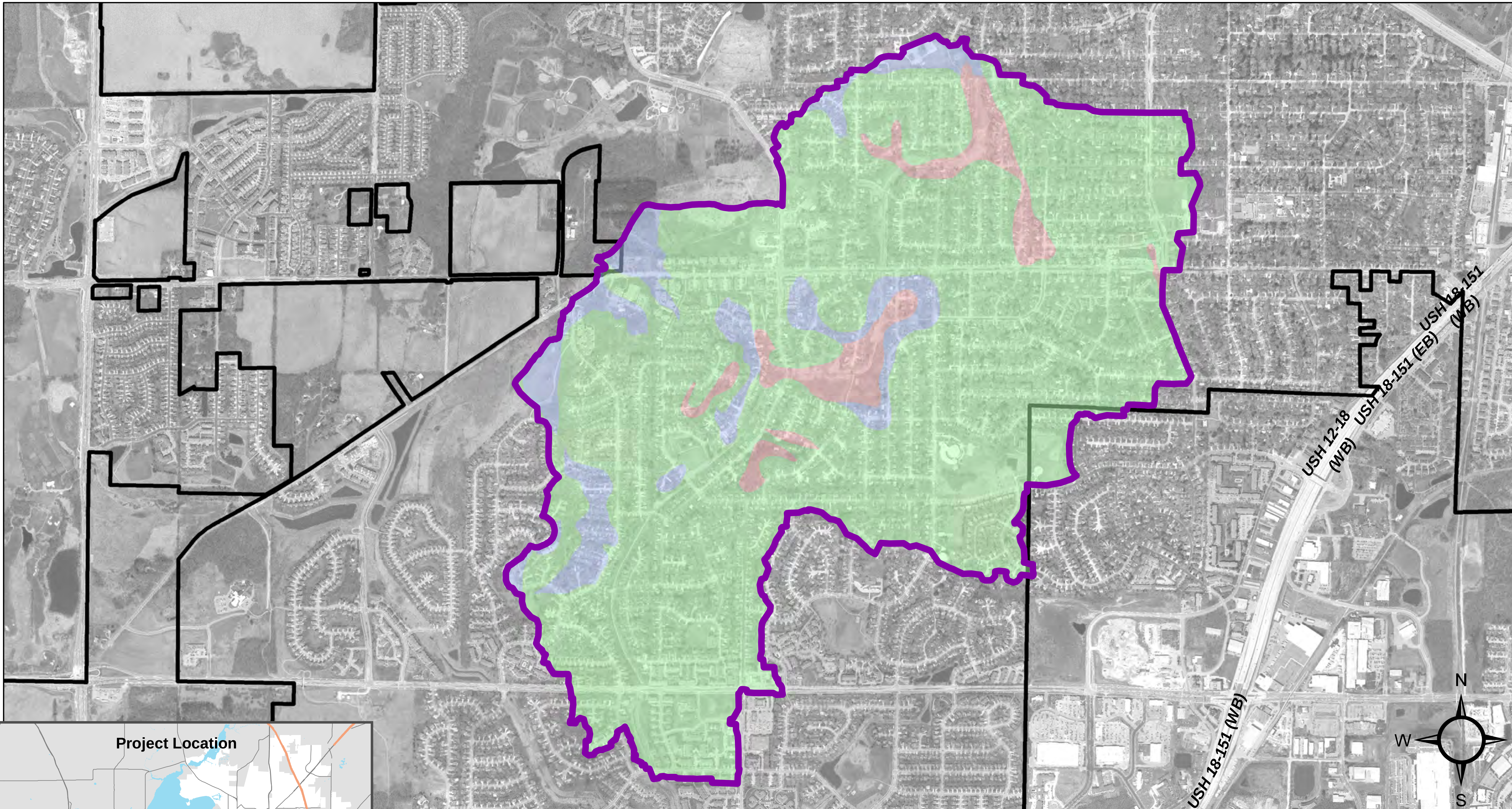

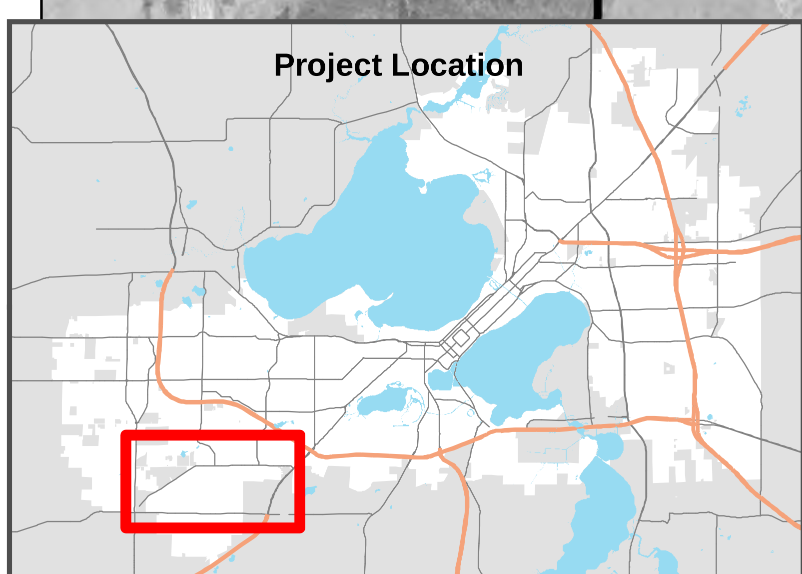

Legend

Hydrologic Soil Group

- B
- C
- D

Watershed Boundary

Municipal Limits

Figure 2-3
Hydrologic Soil Groups
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023

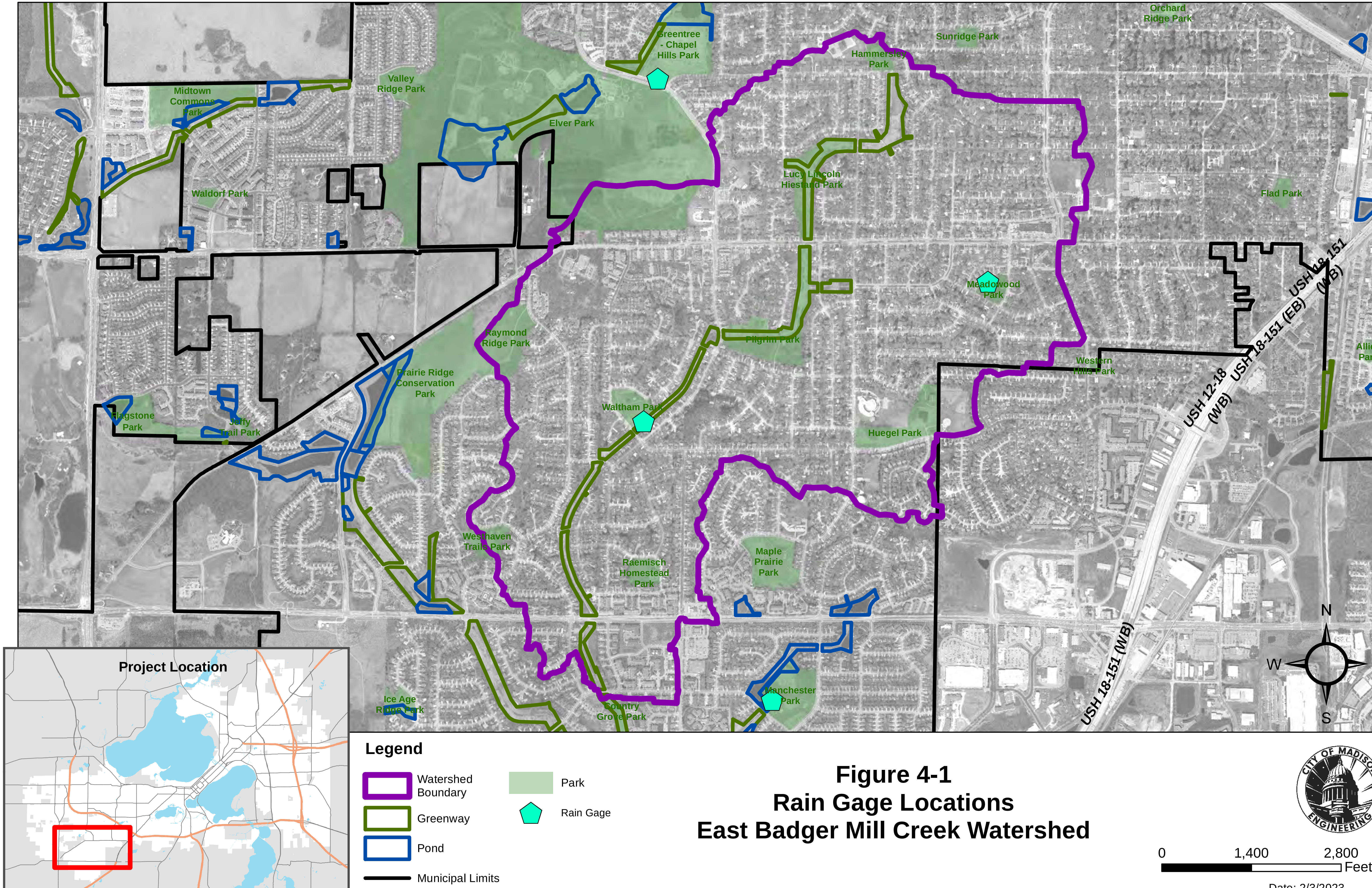

Figure 4-1
Rain Gage Locations
East Badger Mill Creek Watershed

Date: 2/3/2023

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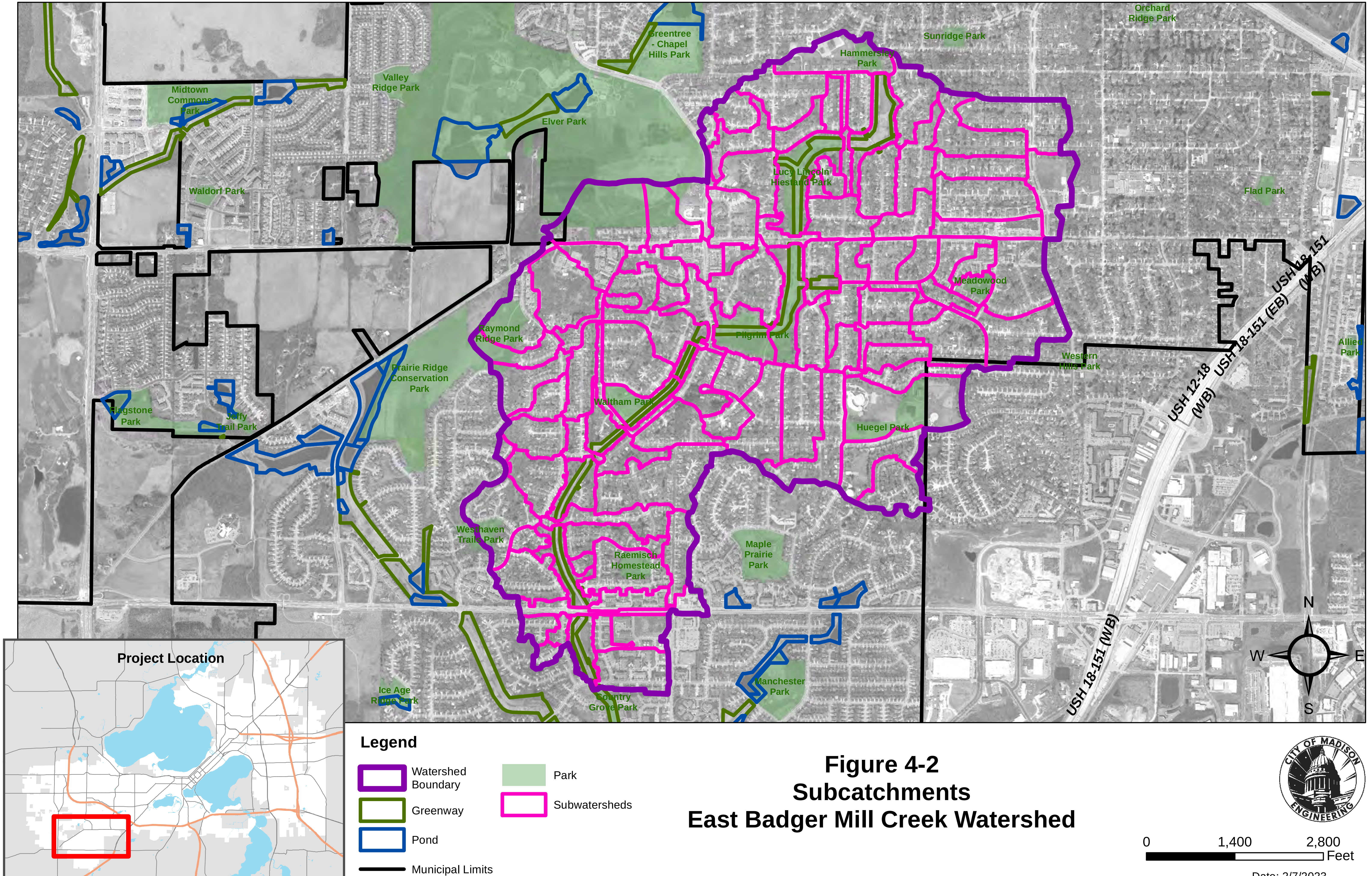
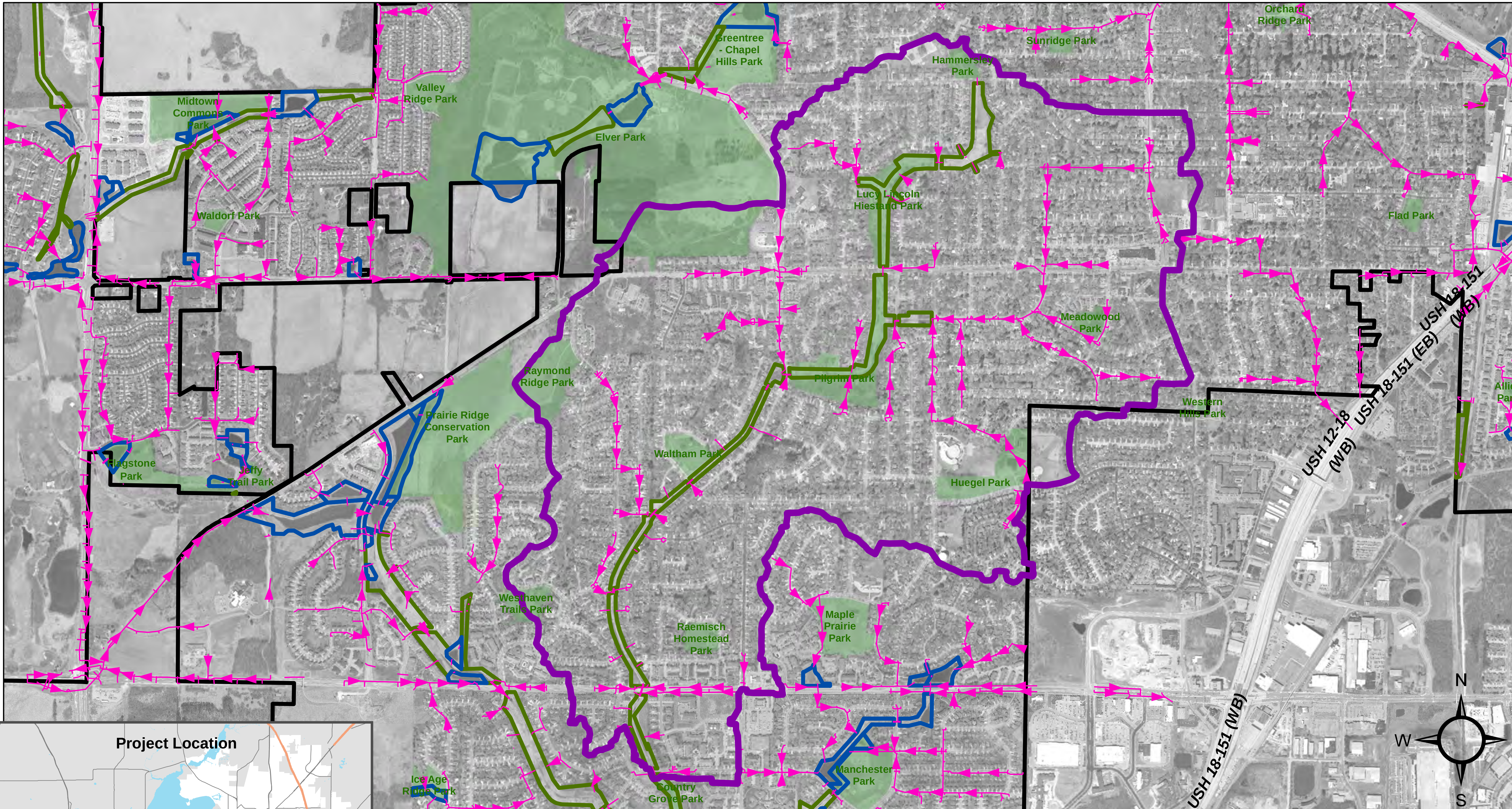
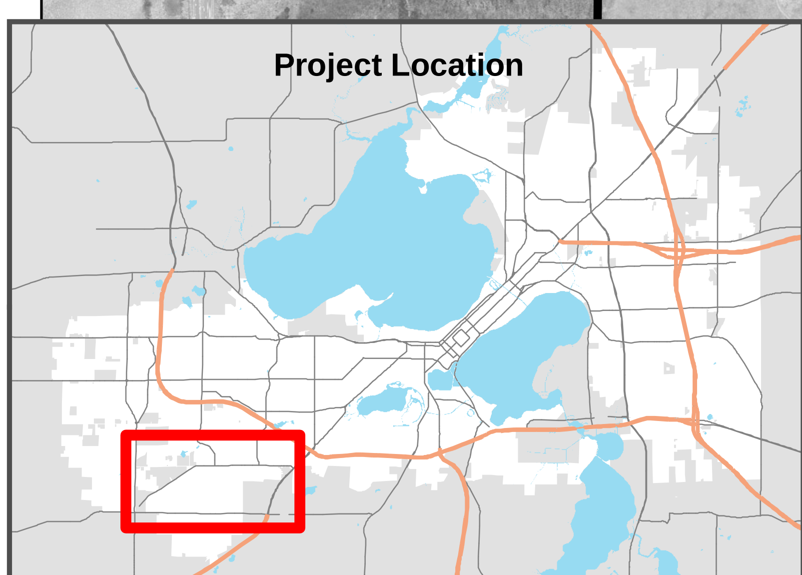


Figure 4-2
Subcatchments
East Badger Mill Creek Watershed

Date: 2/7/2023





Legend

- Watershed Boundary
- Storm Pipe
- Greenway
- Pond
- Municipal Limits
- Park

Figure 4-3
Stormwater Conveyance System
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023

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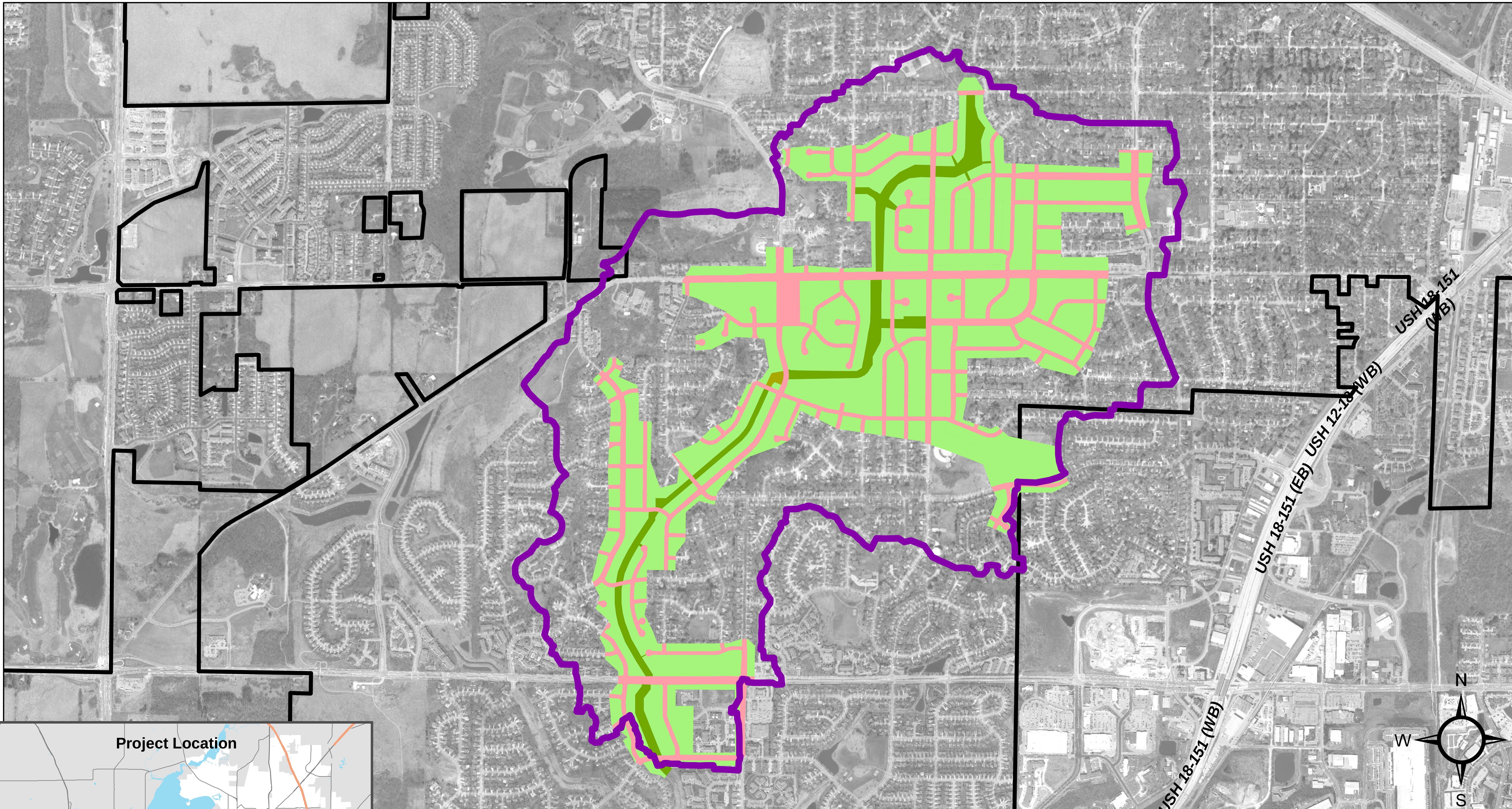

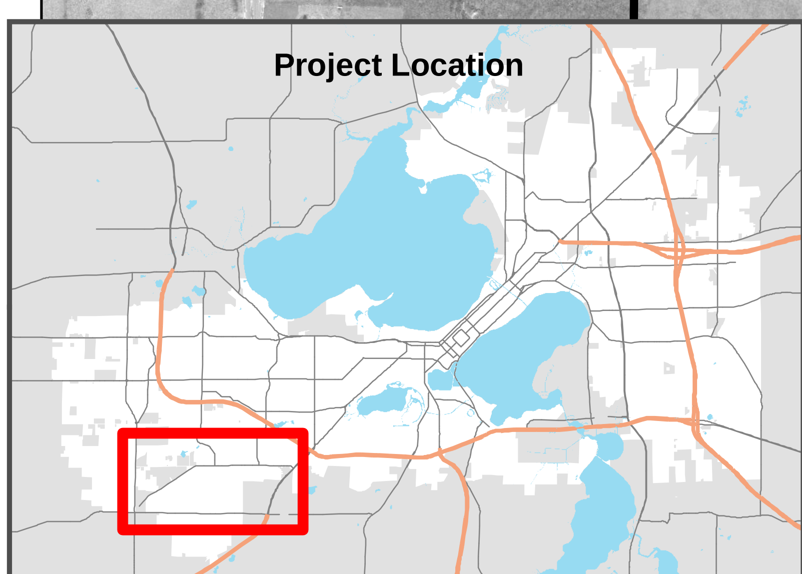

Legend

- Watershed Boundary
- Municipal Limits
- Grass Greenway
- Impervious
- Pervious
- Wooded Greenway

Figure 4-4
2D Model Roughness
East Badger Mill Creek Watershed

0 1,450 2,900 Feet

Date: 2/3/2023

Document Path: \\Gisserver\data\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure4_4_2DModelRoughness.mxd

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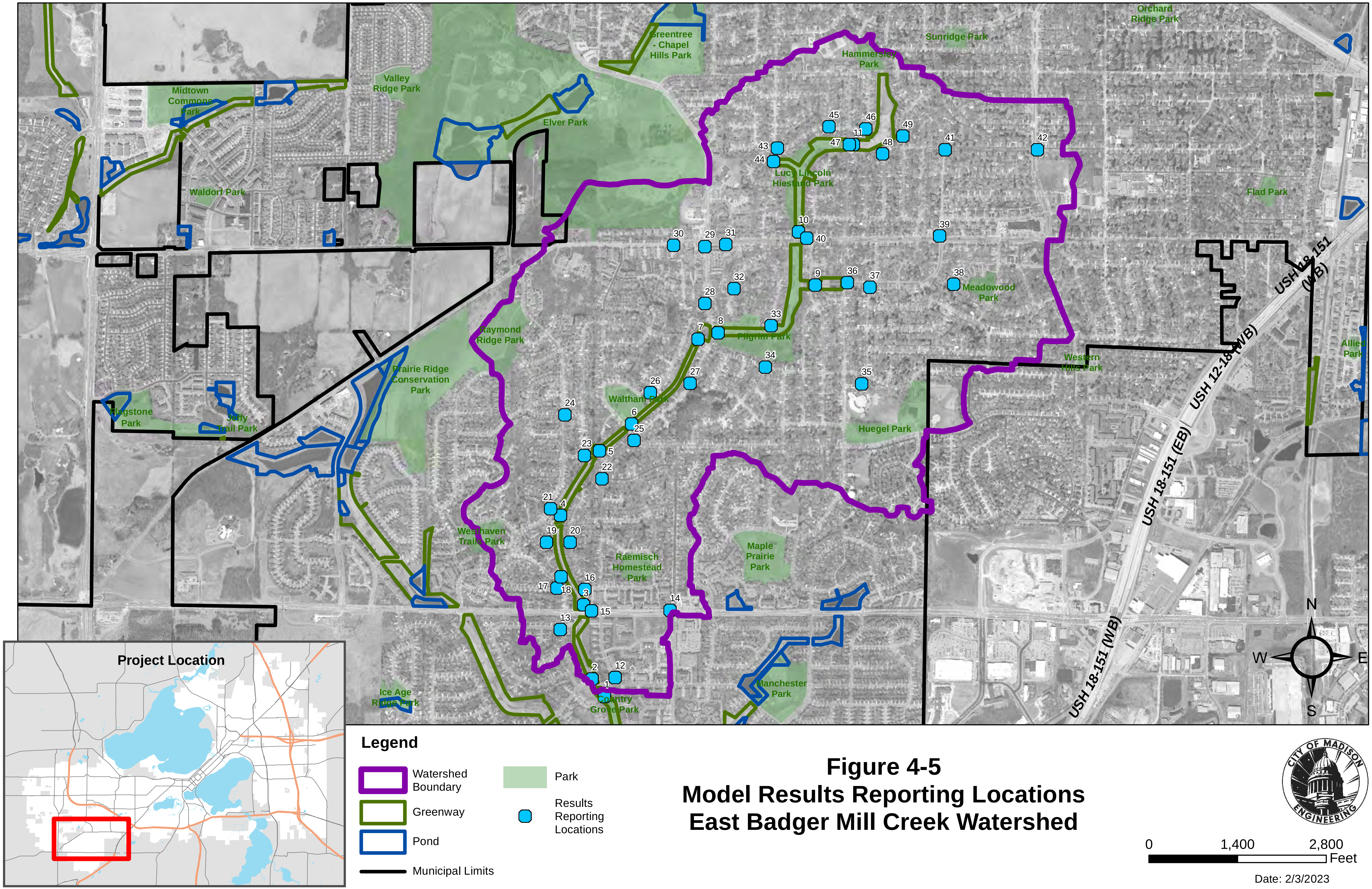

Figure 4-5
Model Results Reporting Locations
East Badger Mill Creek Watershed

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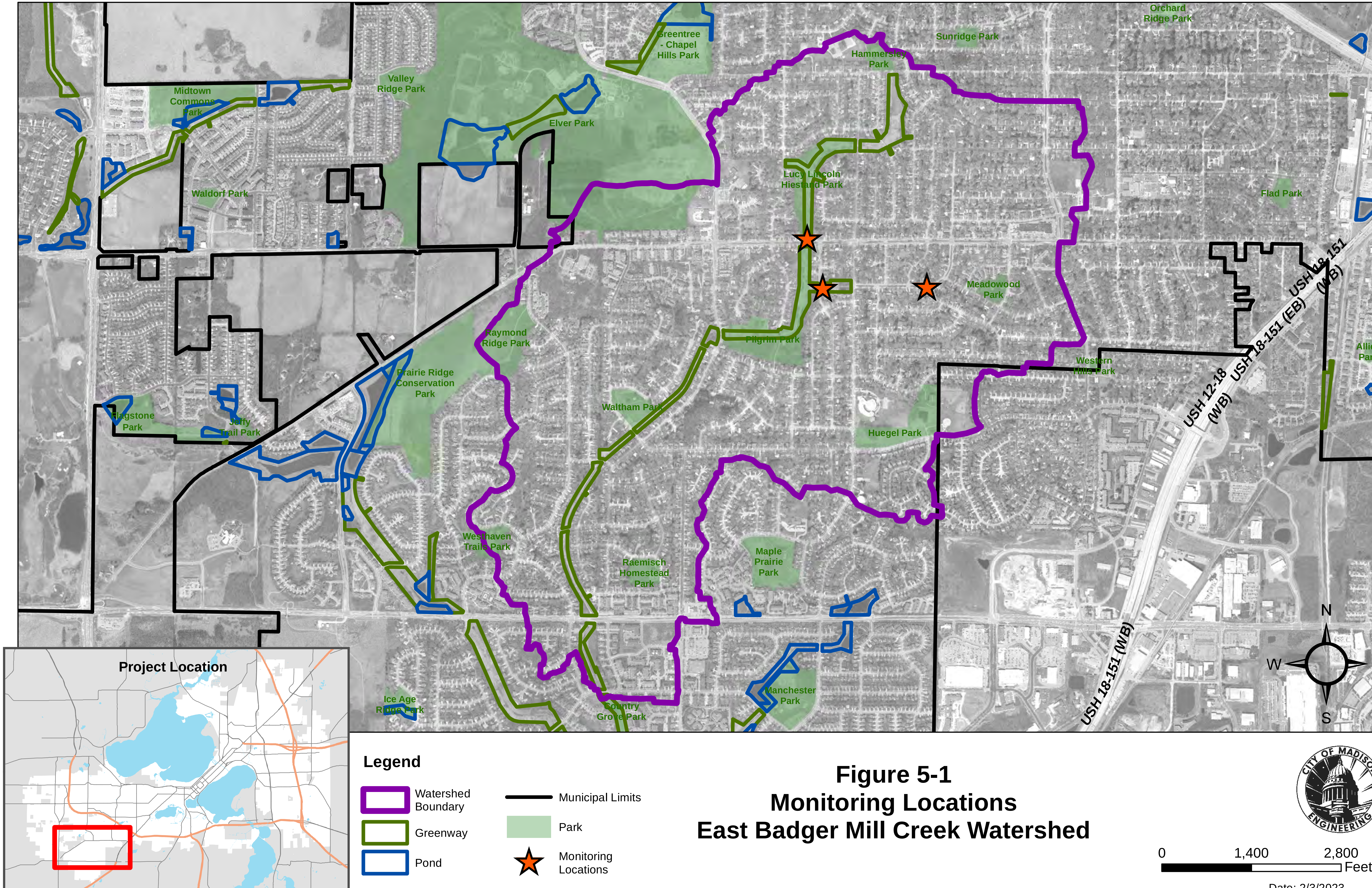


Figure 5-1
Monitoring Locations
East Badger Mill Creek Watershed

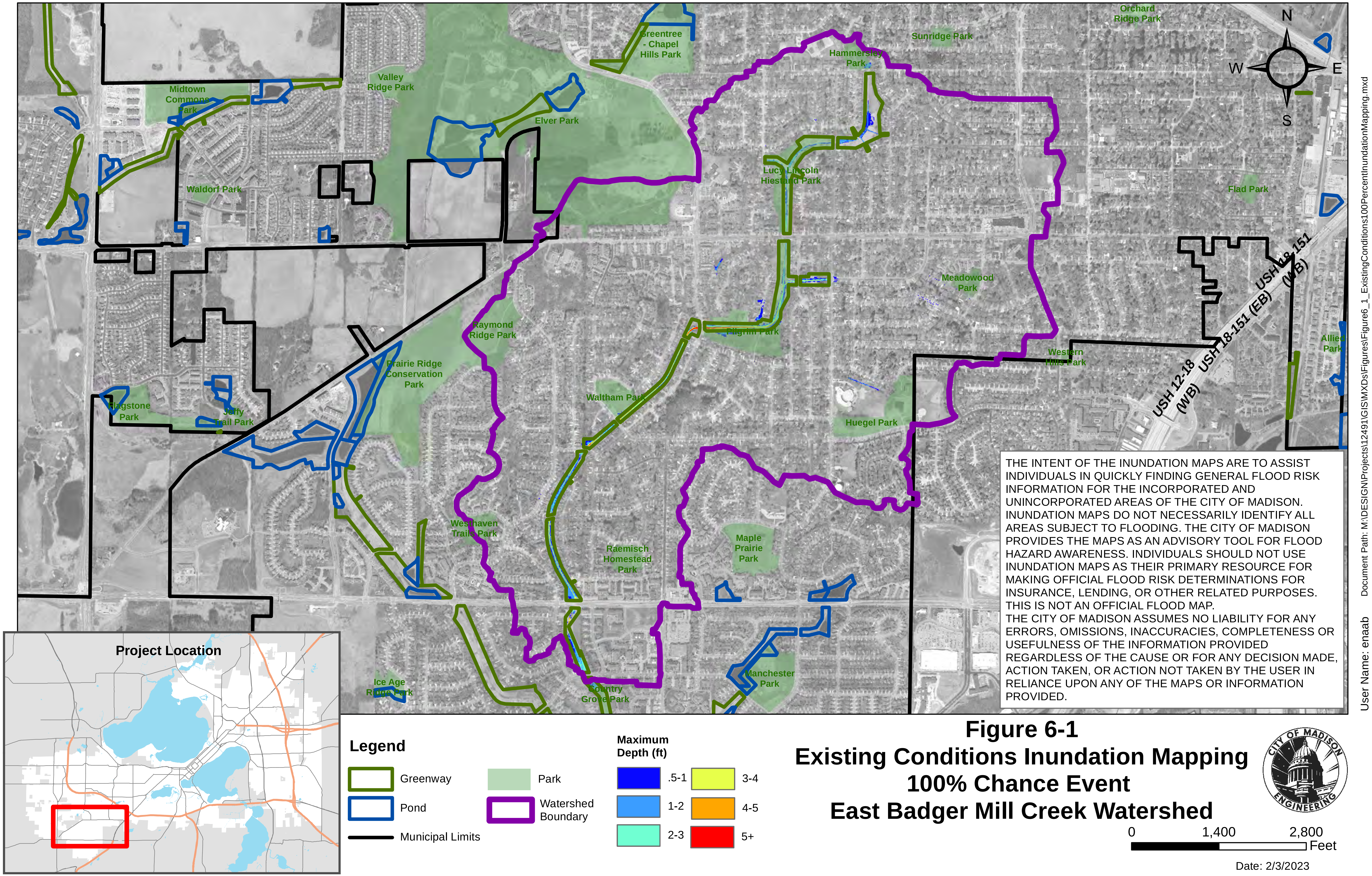
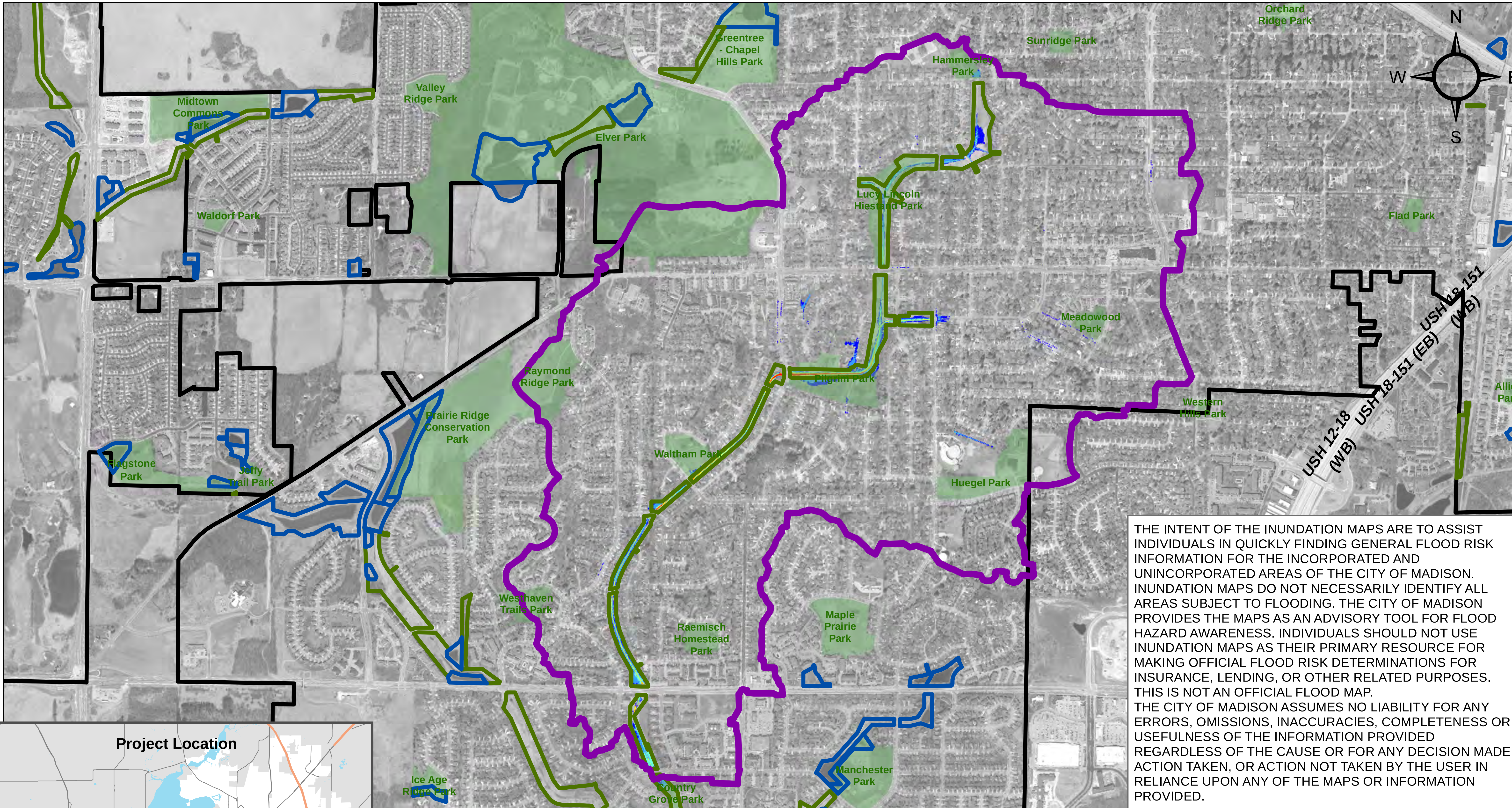


Figure 6-1
Existing Conditions Inundation Mapping
100% Chance Event
East Badger Mill Creek Watershed



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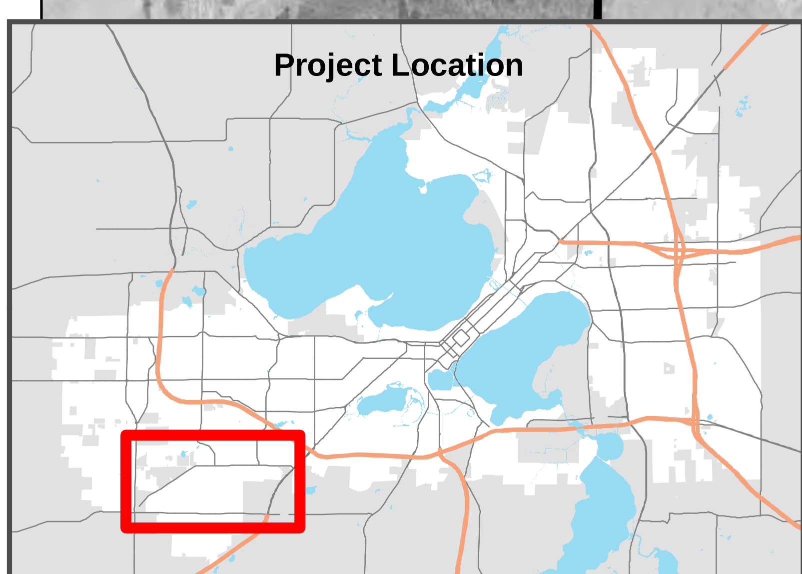


Legend

Greenway
Pond
Municipal Limits
Park
Watershed Boundary

Maximum Depth (ft)

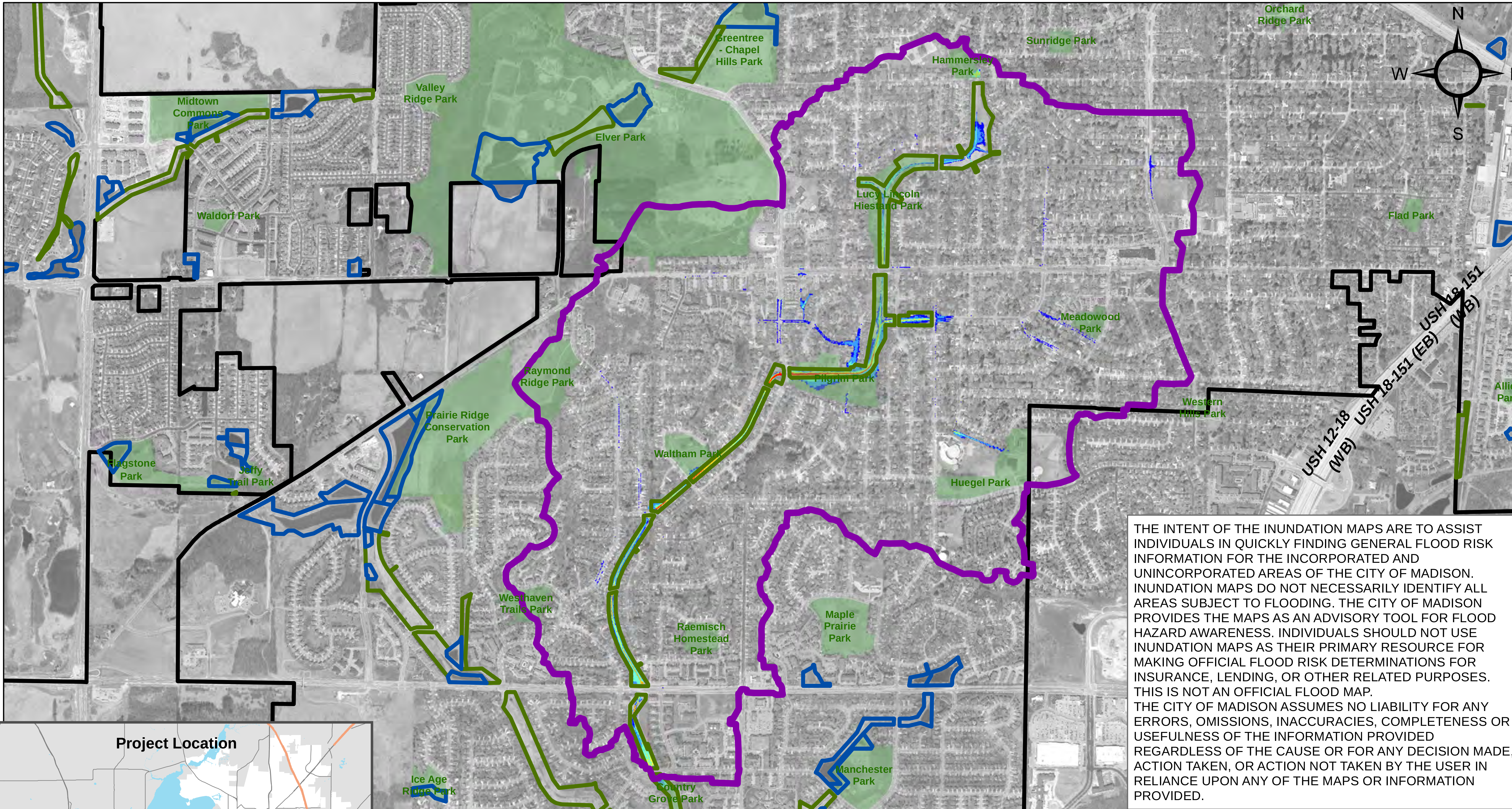
.5-1
1-2
2-3
3-4
4-5
5+

Figure 6-2
Existing Conditions Inundation Mapping
50% Chance Event
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023

Document Path: M:\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure6_2_ExistingConditions50PercentInundationMapping.mxd
User Name: enaab



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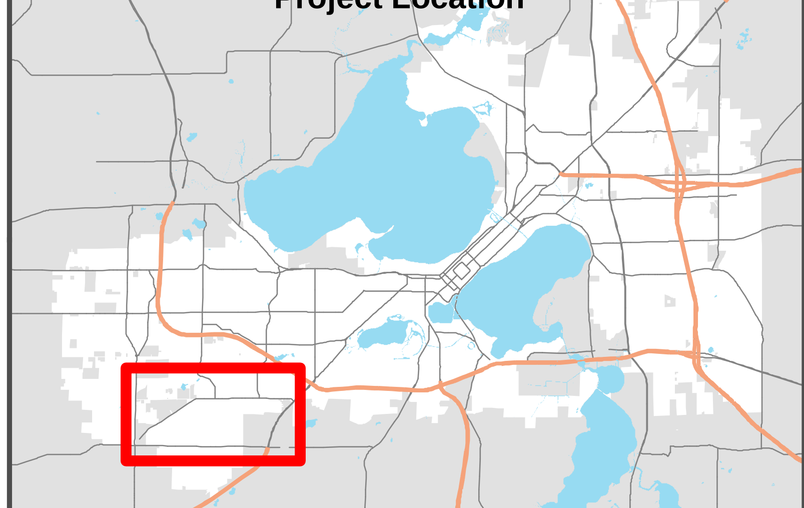


Legend

Greenway
Pond
Municipal Limits
Park
Watershed Boundary

Maximum Depth (ft)

.5-1
1-2
2-3
3-4
4-5
5+

Figure 6-3
Existing Conditions Inundation Mapping
20% Chance Event
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023

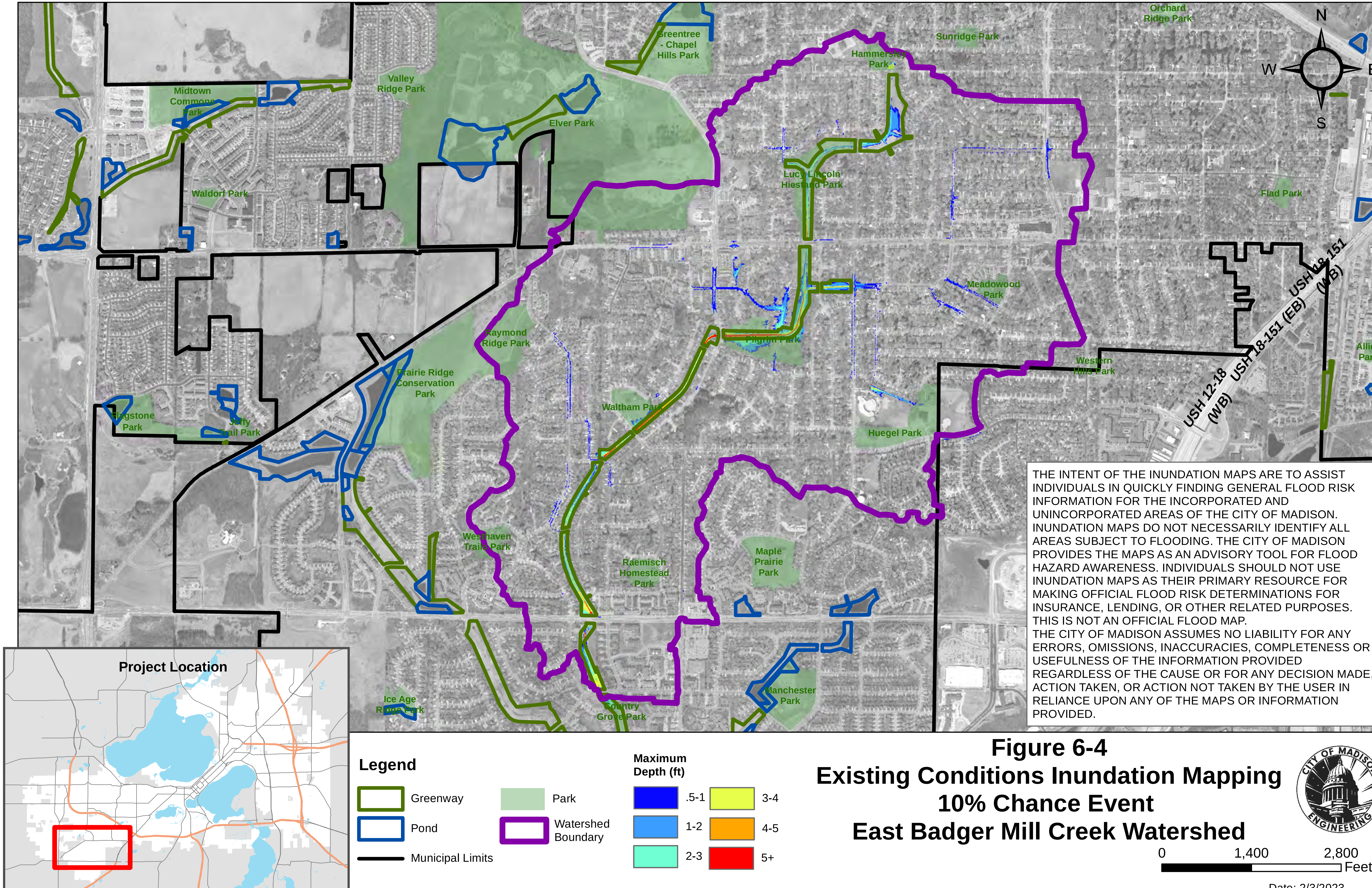
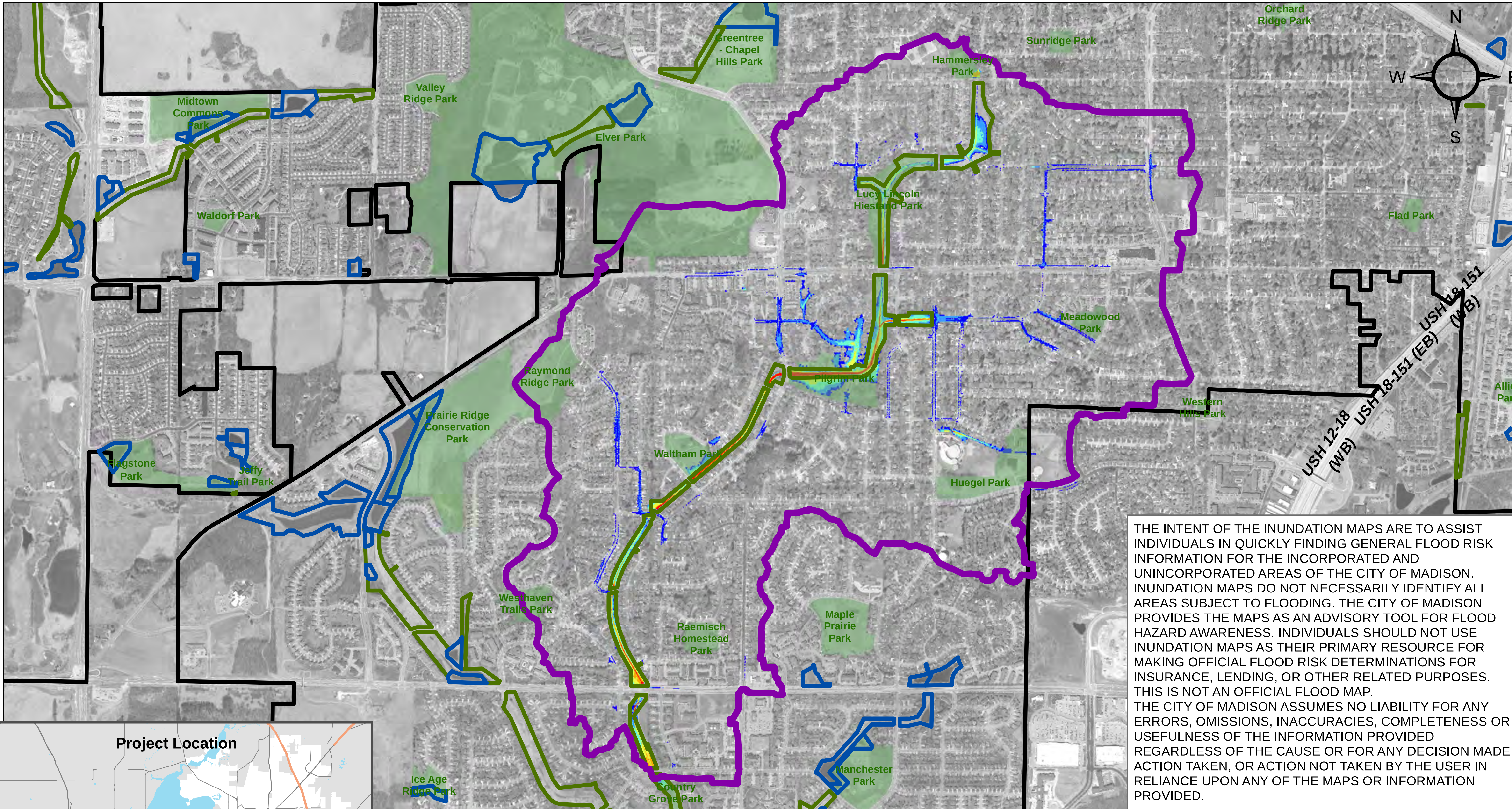


Figure 6-4
Existing Conditions Inundation Mapping
10% Chance Event
East Badger Mill Creek Watershed



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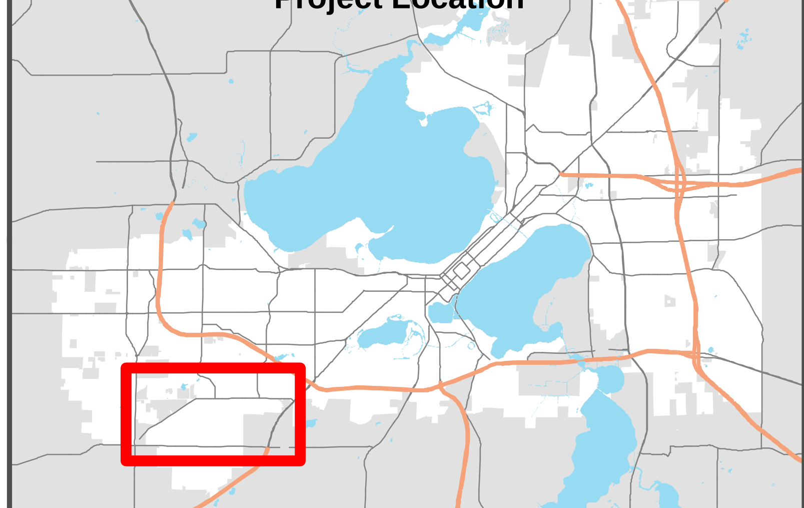


Legend

- Greenway
- Pond
- Municipal Limits
- Park
- Watershed Boundary

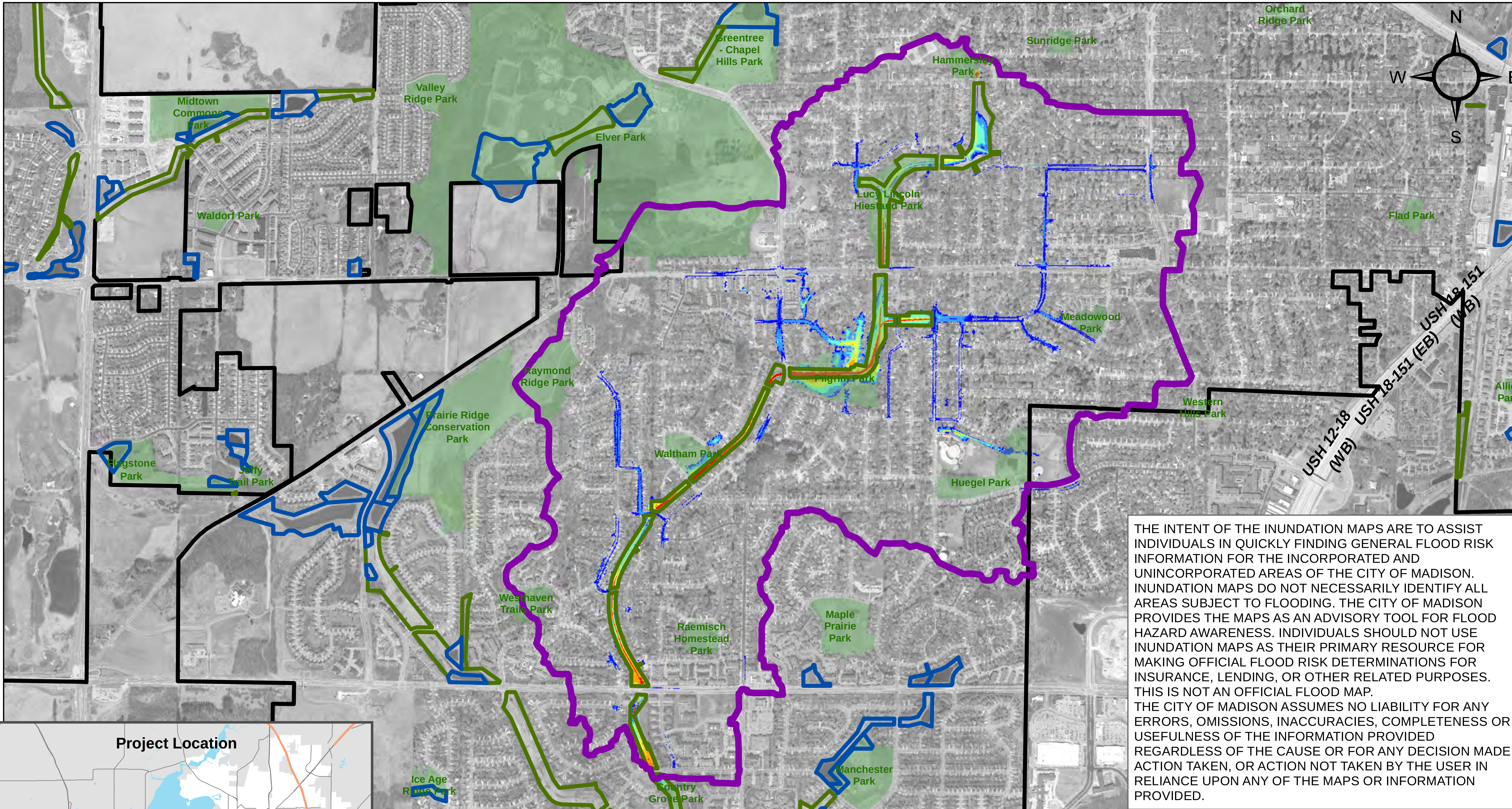
Maximum Depth (ft)

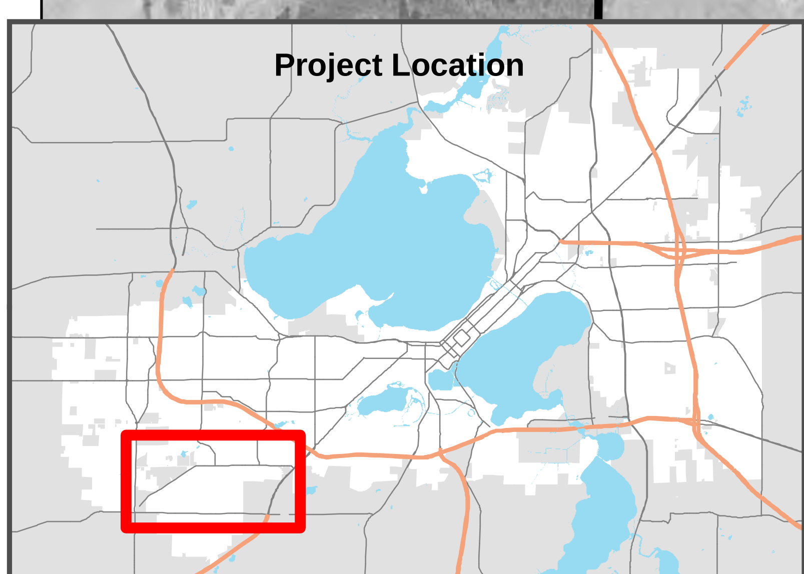
- .5-1
- 1-2
- 2-3
- 3-4
- 4-5
- 5+

Figure 6-5
Existing Conditions Inundation Mapping
4% Chance Event
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023





Legend

- Greenway
- Pond
- Municipal Limits
- Park
- Watershed Boundary

Maximum Depth (ft)

- .5-1
- 1-2
- 2-3
- 3-4
- 4-5
- 5+

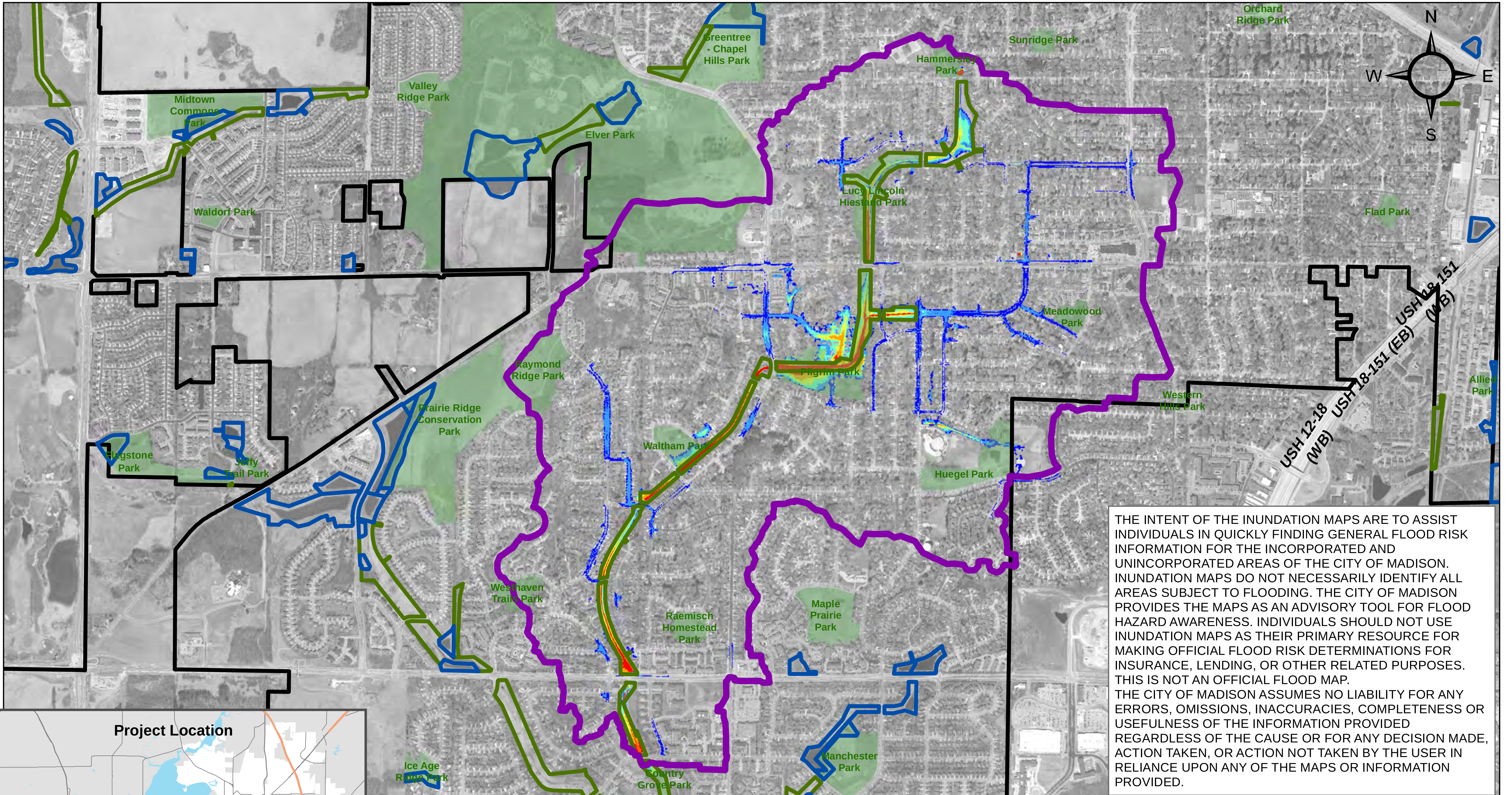
Figure 6-6
Existing Conditions Inundation Mapping
2% Chance Event
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023

Document Path: M:\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure6_6_ExistingConditions2PercentInundationMapping.mxd

User Name: enaab



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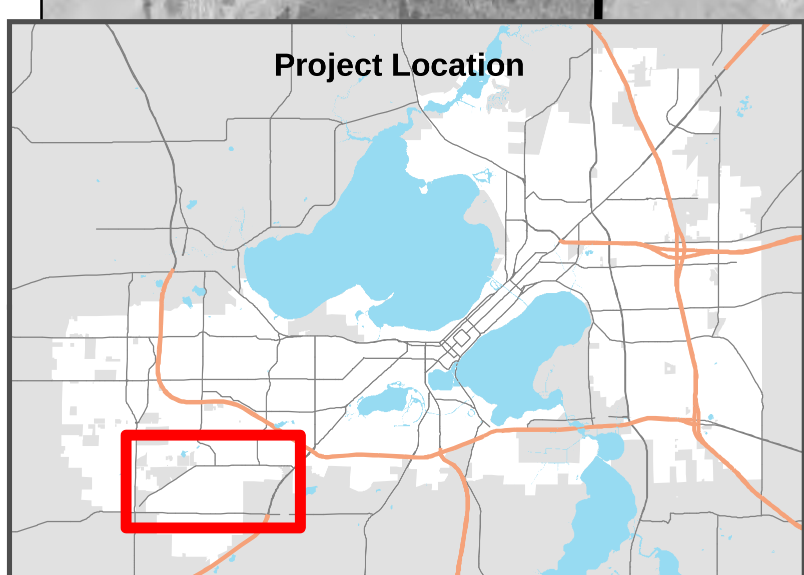


Legend

- Greenway
- Pond
- Municipal Limits
- Park
- Watershed Boundary

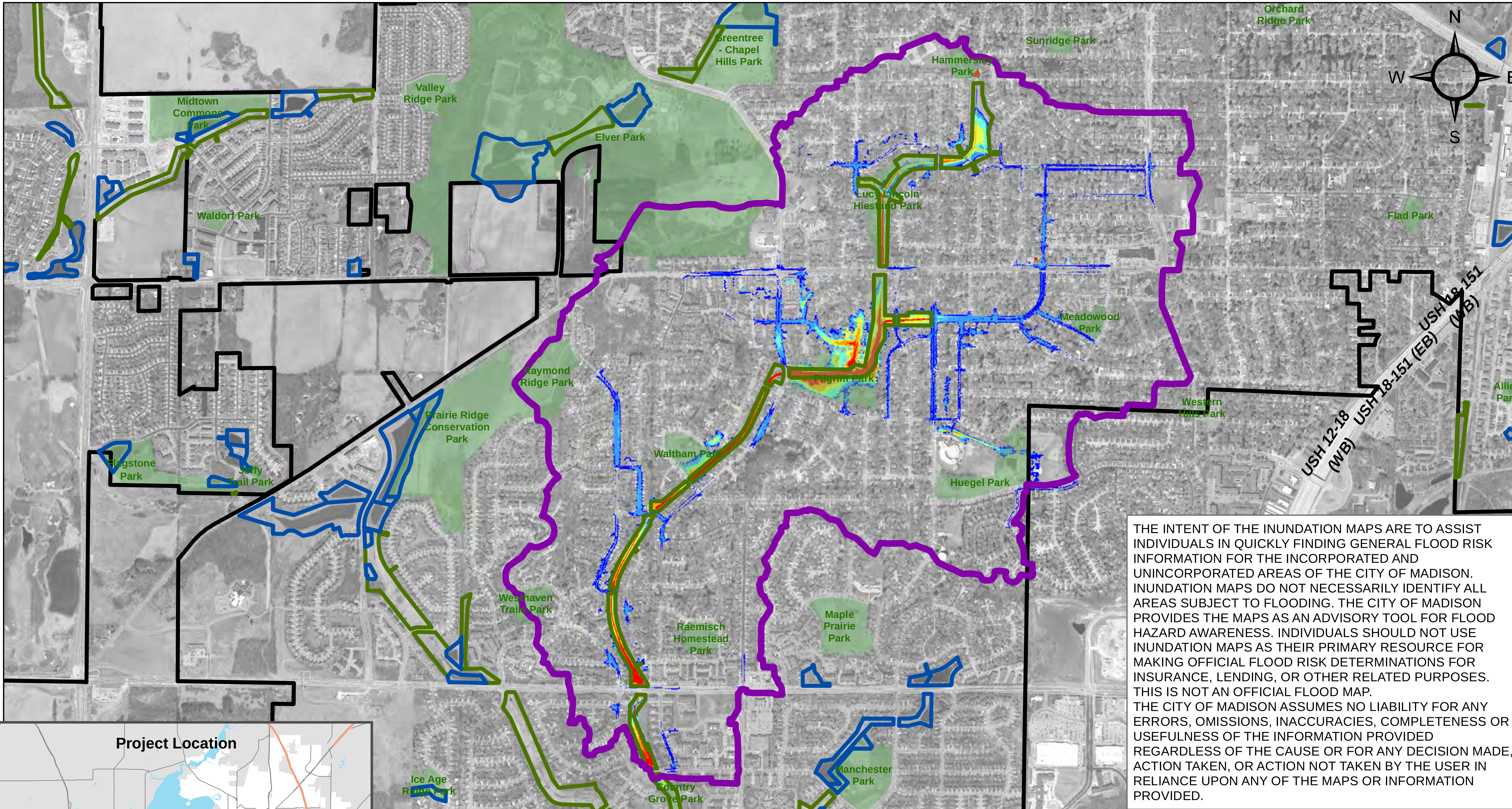
Maximum Depth (ft)

- .5-1
- 1-2
- 2-3
- 3-4
- 4-5
- 5+

Figure 6-7
Existing Conditions Inundation Mapping
1% Chance Event
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023



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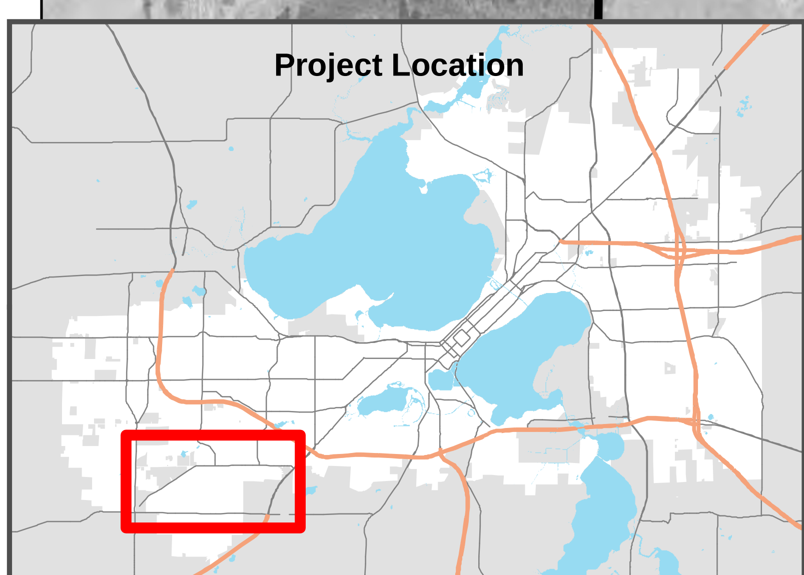


Legend

Greenway
Pond
Municipal Limits
Park
Watershed Boundary

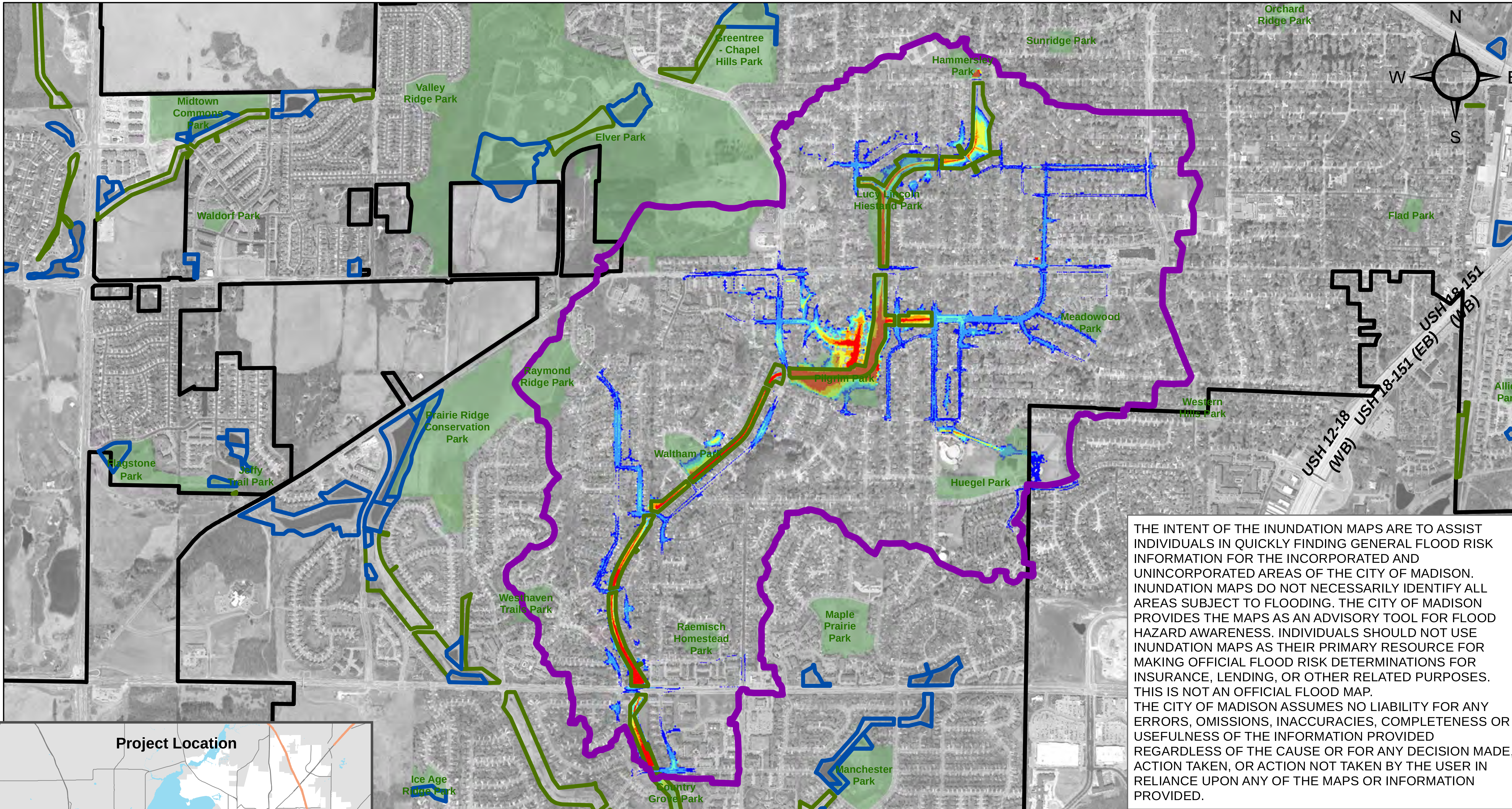
Maximum Depth (ft)

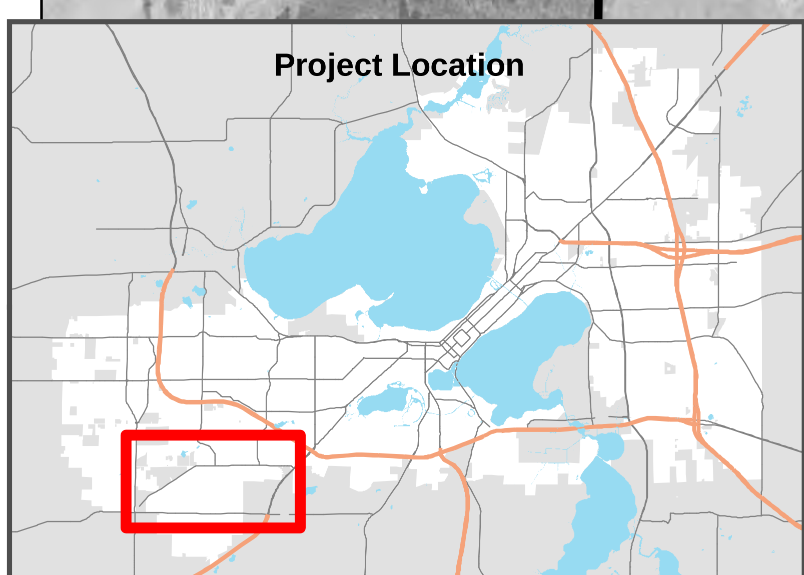
.5-1	3-4
1-2	4-5
2-3	5+

Figure 6-8
Existing Conditions Inundation Mapping
0.5% Chance Event
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023





Legend

Greenway
Pond
Municipal Limits
Park
Watershed Boundary

Maximum Depth (ft)

.5-1
1-2
2-3
3-4
4-5
5+

Figure 6-9
Existing Conditions Inundation Mapping
0.2% Chance Event
East Badger Mill Creek Watershed

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0 1,400 2,800 Feet

Date: 2/3/2023

Document Path: M:\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure6_9_ExistingConditions.2PercentInundationMapping.mxd

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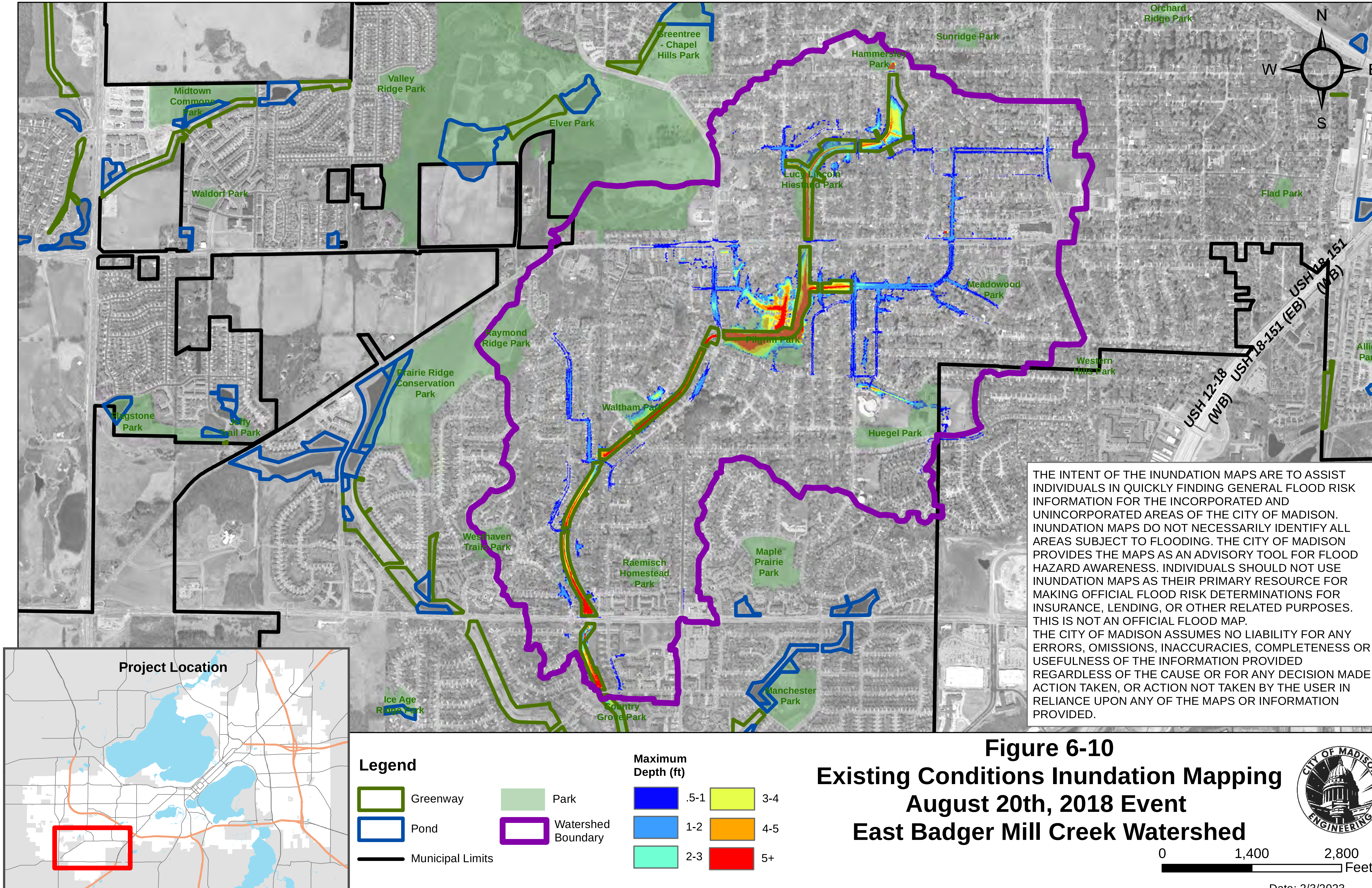

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Legend

- Greenway
- Pond
- Municipal Limits
- Park
- Watershed Boundary

Maximum Depth (ft)

- .5-1
- 1-2
- 2-3
- 3-4
- 4-5
- 5+

Figure 6-10
Existing Conditions Inundation Mapping
August 20th, 2018 Event
East Badger Mill Creek Watershed

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0 1,400 2,800 Feet

Date: 2/3/2023

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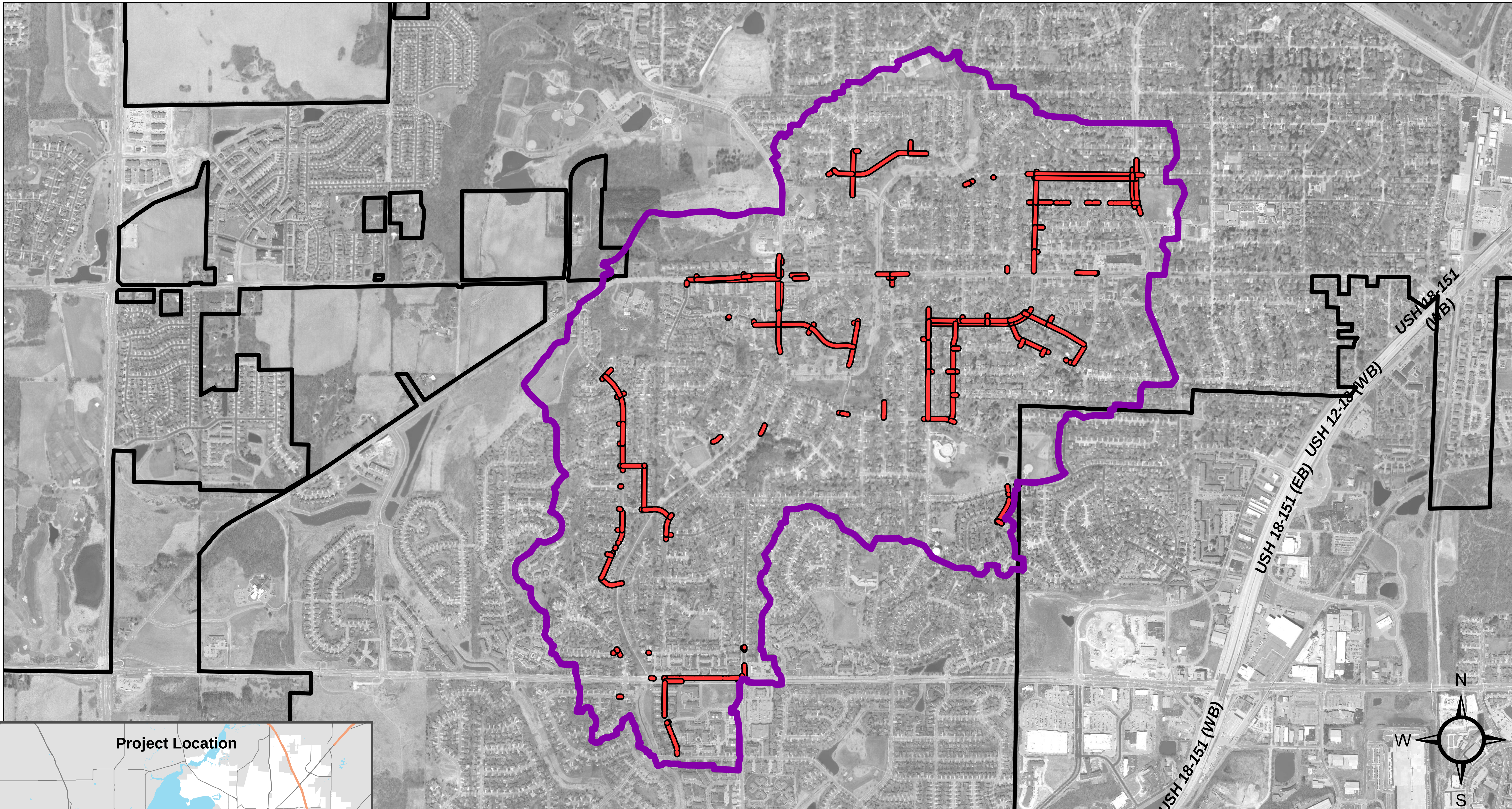

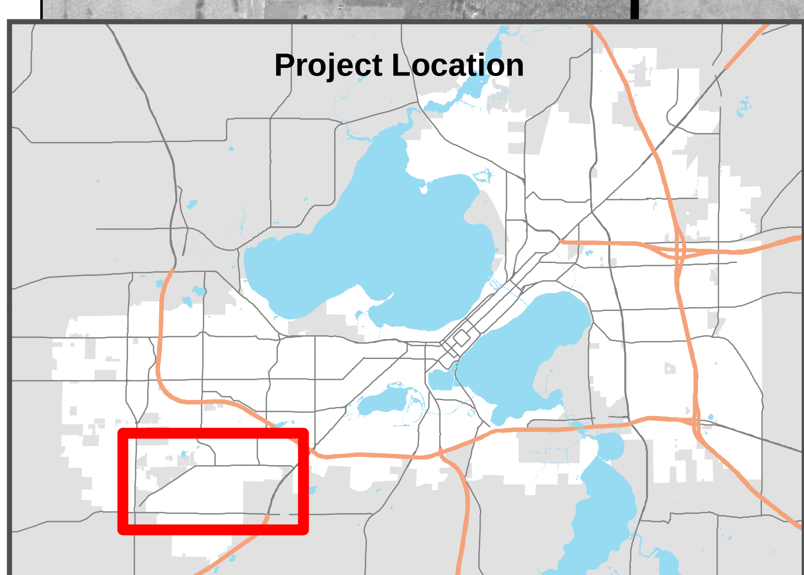

Legend

- Watershed Boundary
- Municipal Limits
- Streets Not Meeting Target

Figure 6-11
Existing Conditions
Streets Not Meeting 10% Chance Event Target
East Badger Mill Creek Watershed

0 1,450 2,900 Feet

Date: 2/3/2023

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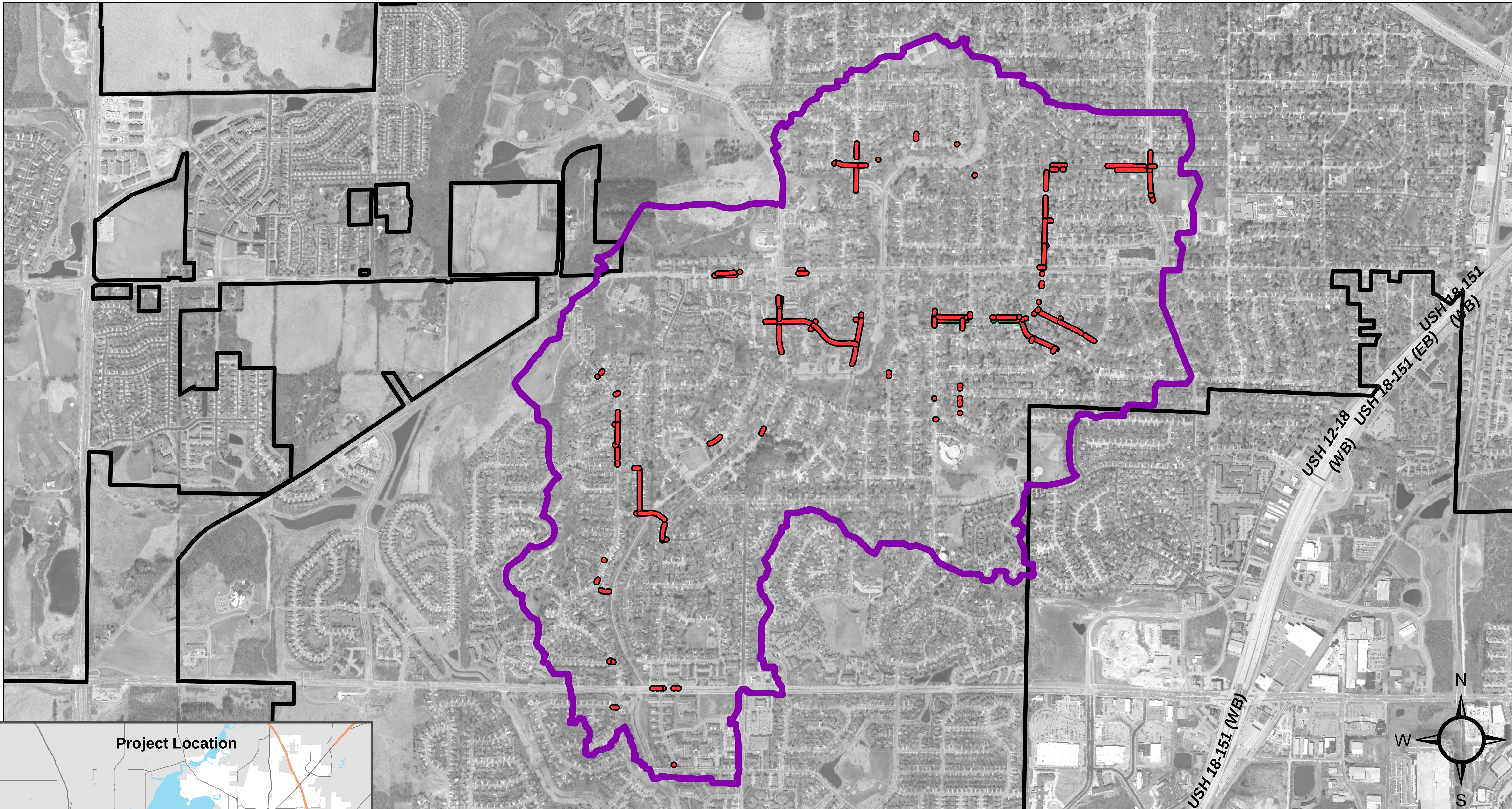

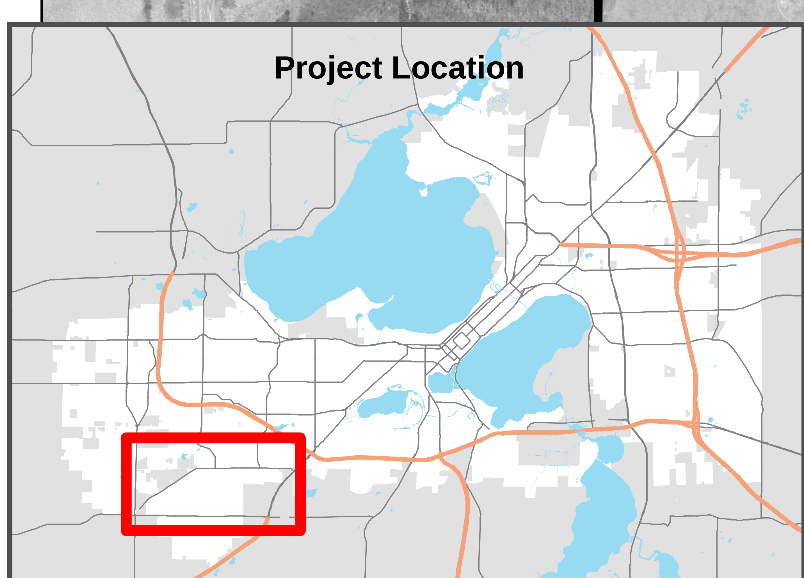

Legend

Watershed Boundary

Municipal Limits

Streets Not Meeting Target

Figure 6-12
Existing Conditions
Streets Not Meeting 4% Chance Event Target
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

CITY OF MADISON ENGINEERING

Date: 2/3/2023

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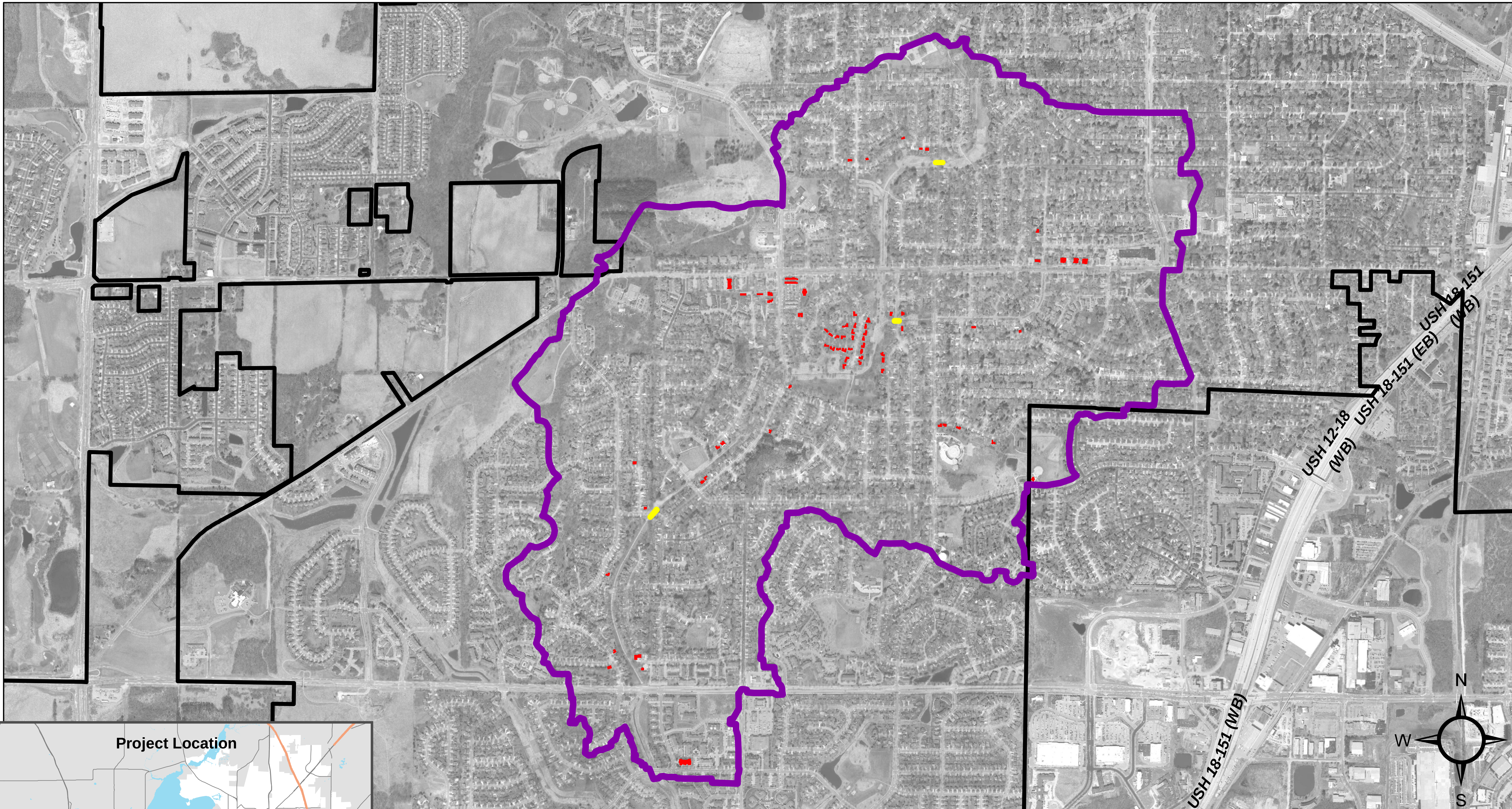

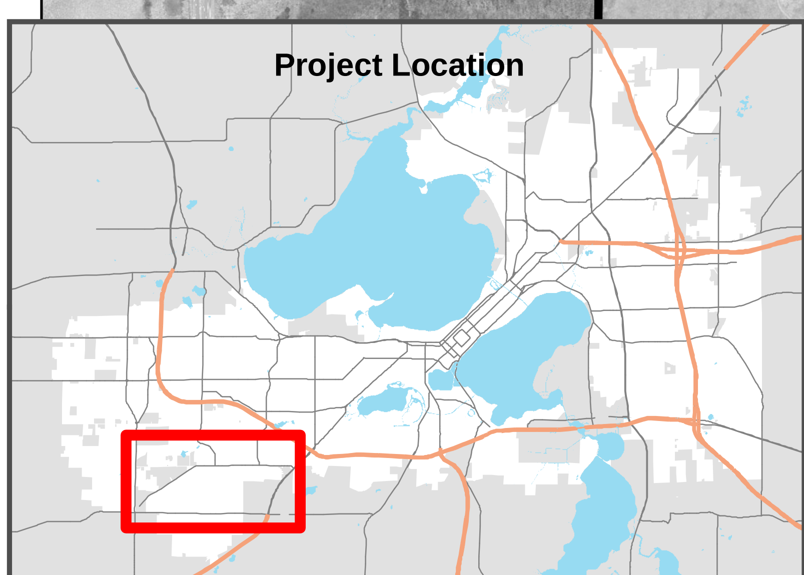

Legend

- Watershed Boundary
- Municipal Limits
- Structures Not Meeting Target
- Greenway Crossing Not Meeting Target

Figure 6-13
Existing Conditions
Structures & Greenway Crossings Not Meeting 1% Chance Event Target
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023

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User Name: enaab

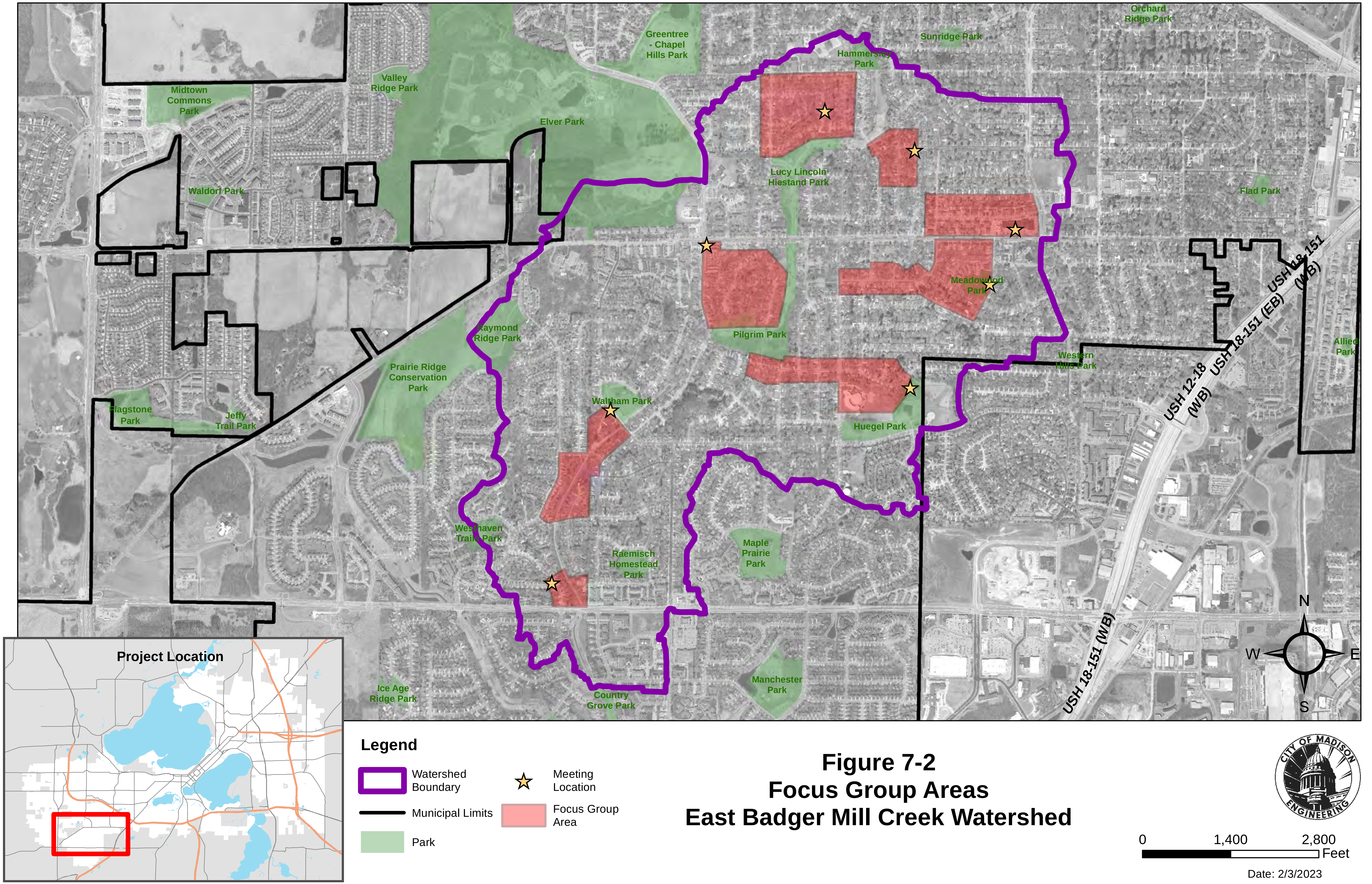
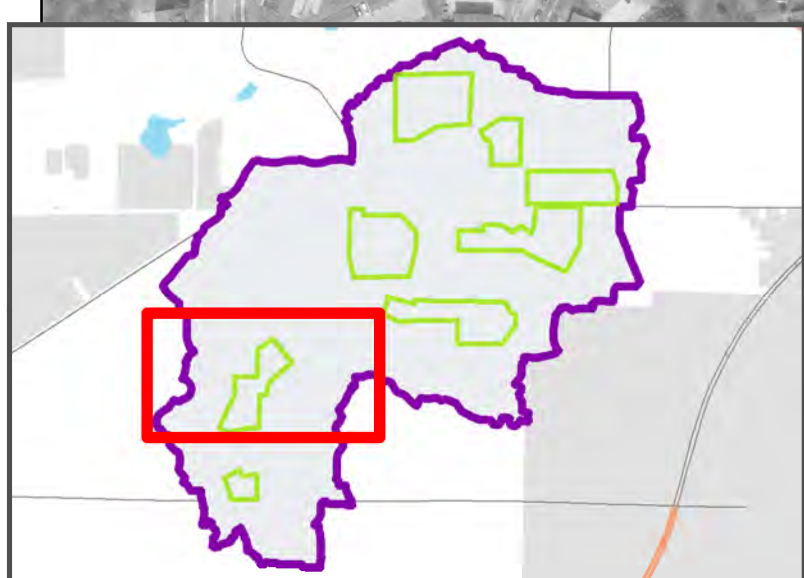


Figure 7-2
Focus Group Areas
East Badger Mill Creek Watershed

Figure 7-3
McKee Road-Silverton Trail
Focus Group Map
East Badger Mill Creek Watershed



Legend

- Watershed Boundary
- Municipal Limits
- Park
- Meeting Location
- Focus Group Area
- Focus Group Observations

Figure 7-4
Lancaster Lane-Carnwood Road Focus Group Map
East Badger Mill Creek Watershed

0 310 620 Feet

Date: 2/3/2023

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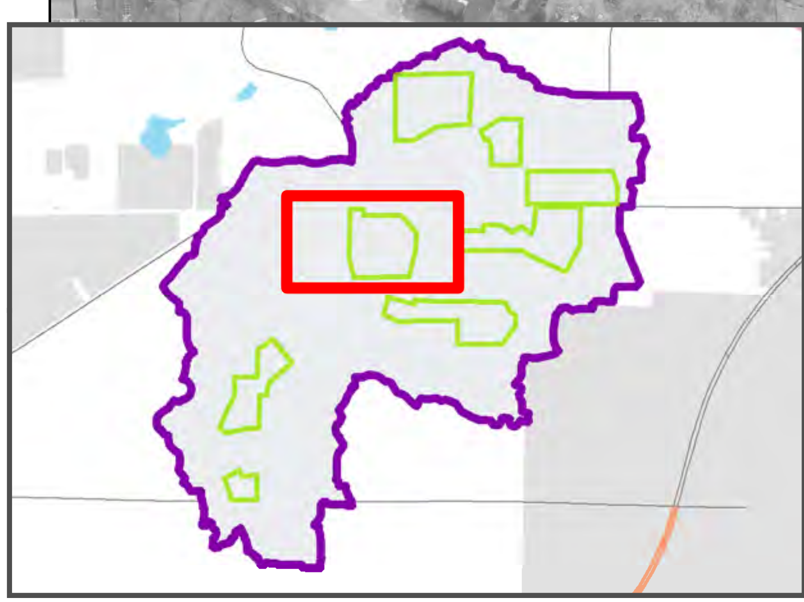


Legend

- Watershed Boundary
- Municipal Limits
- Park
- Meeting Location
- Focus Group Area
- Focus Group Observations

Figure 7-5
Tottenham Road-McKenna Boulevard Focus Group Map
East Badger Mill Creek Watershed

0 230 460 Feet

Date: 2/3/2023

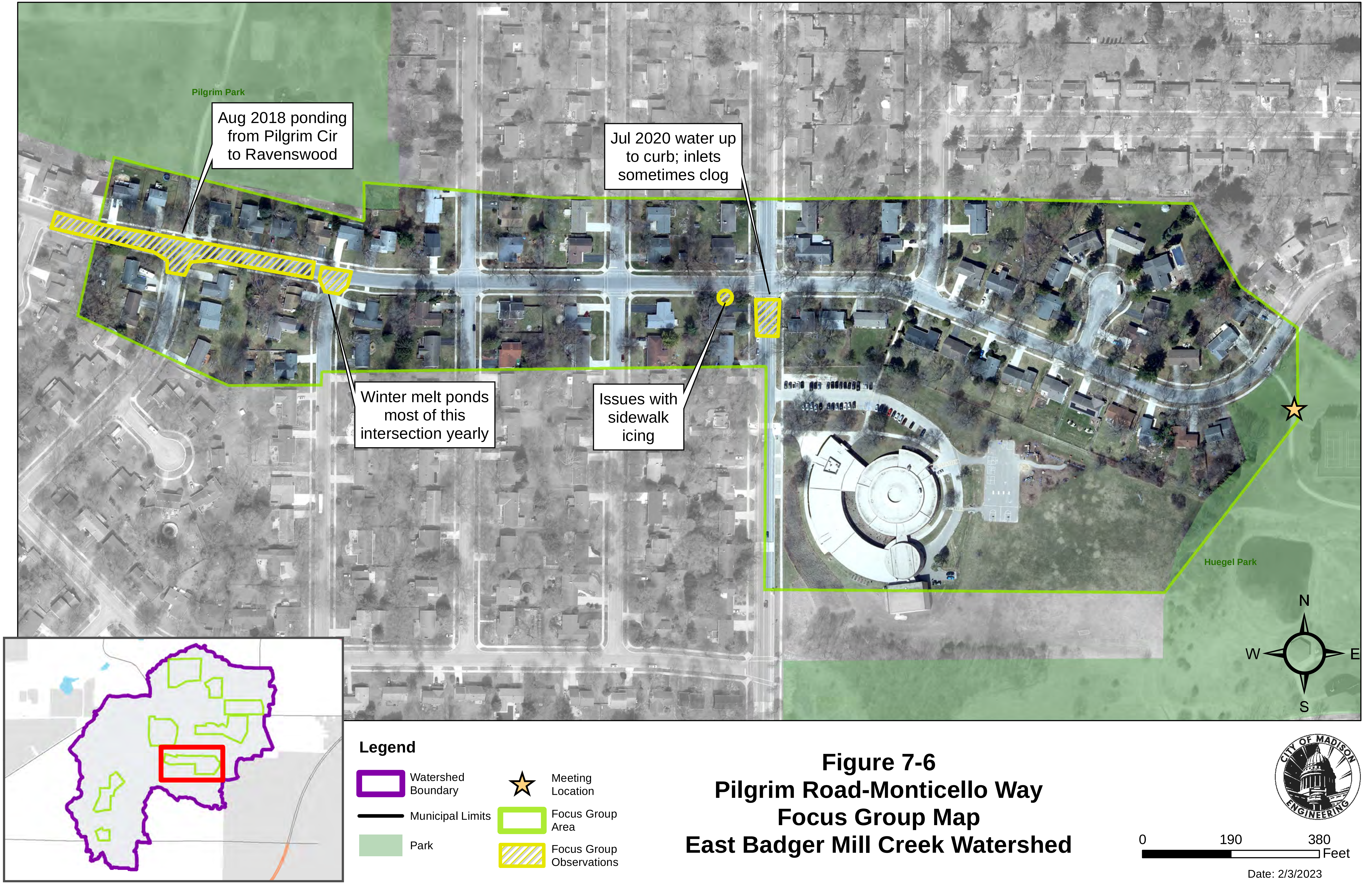
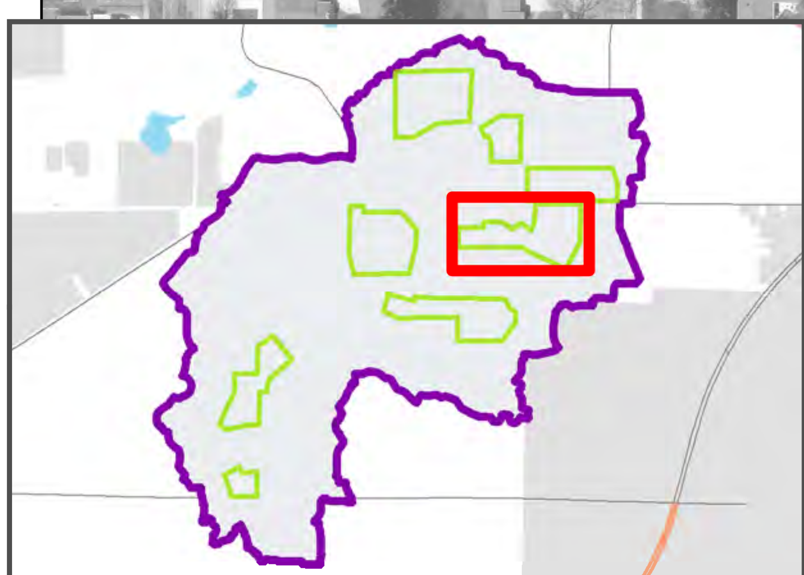


Figure 7-6
Pilgrim Road-Monticello Way
Focus Group Map
East Badger Mill Creek Watershed

Date: 2/3/2023



Legend

- Watershed Boundary
- Municipal Limits
- Park
- Meeting Location
- Focus Group Area
- Focus Group Observations

Figure 7-7
Riva Road-Balsam Road Focus Group Map
East Badger Mill Creek Watershed

0 180 360 Feet

Date: 2/3/2023

Document Path: \\Gisserver\data\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure7-7RivaRoadBalsamRoadFocusGroupMap.mxd

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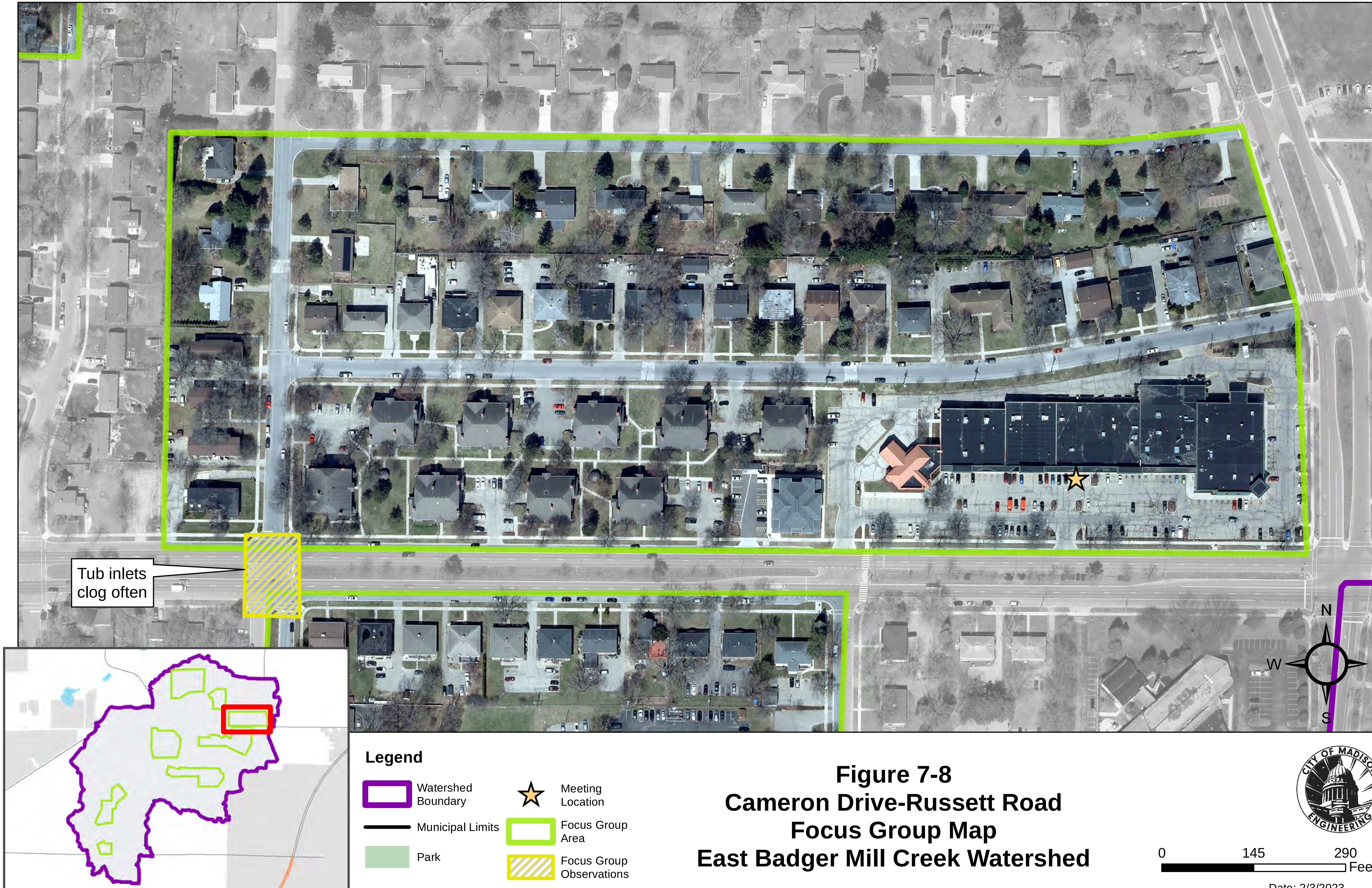

Figure 7-8
Cameron Drive-Russett Road
Focus Group Map
East Badger Mill Creek Watershed

Date: 2/3/2023

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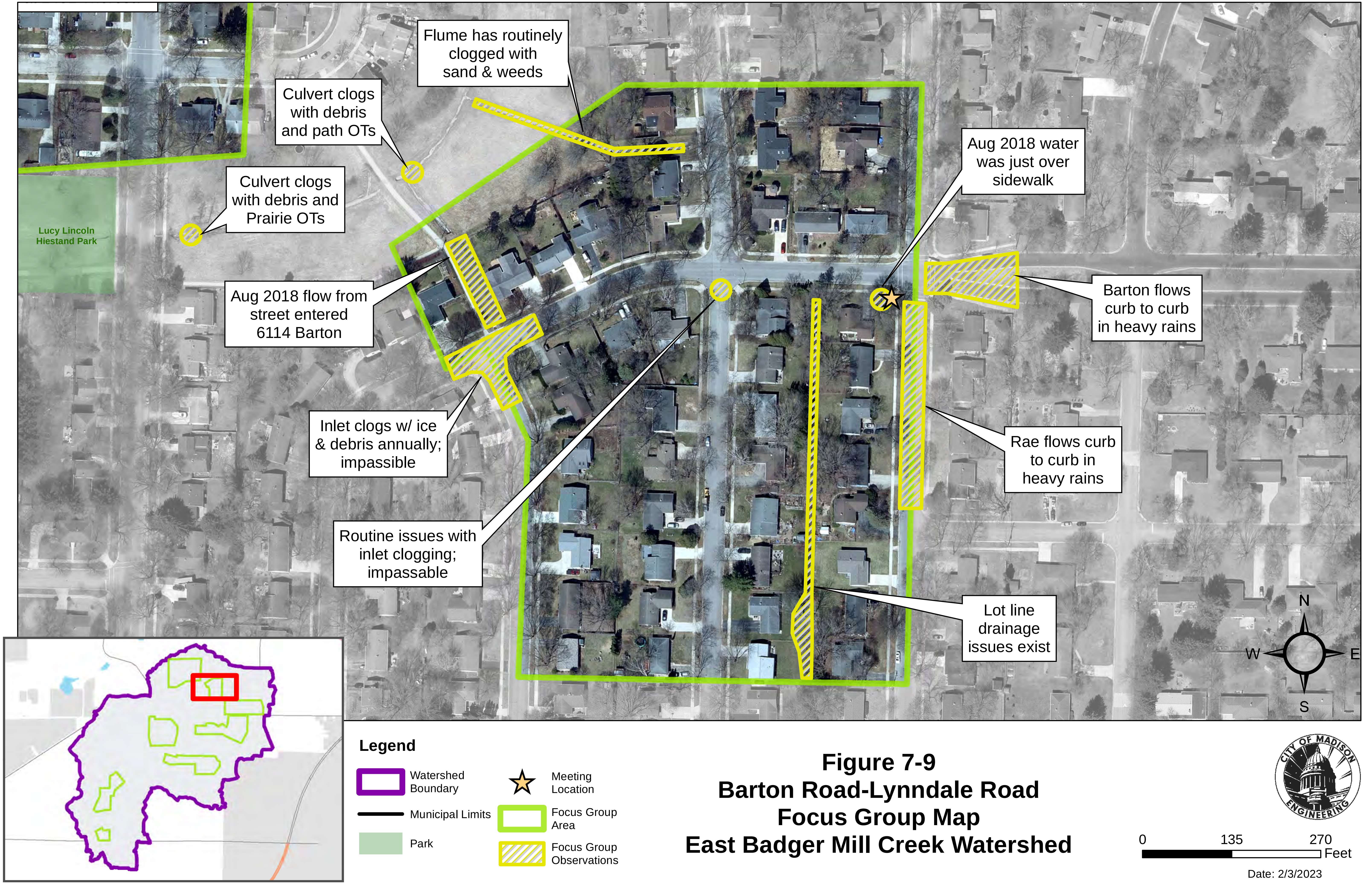
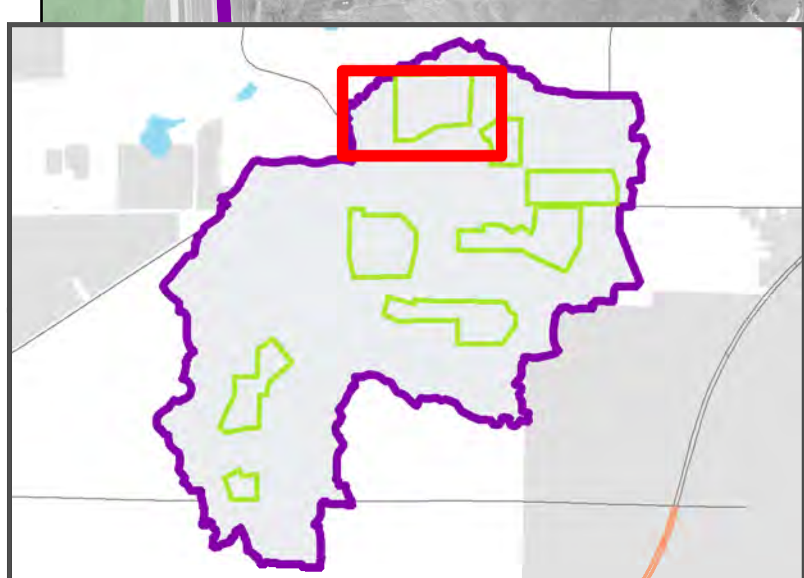


Figure 7-9
Barton Road-Lynndale Road Focus Group Map
East Badger Mill Creek Watershed



Legend

- Watershed Boundary
- Municipal Limits
- Park
- Meeting Location
- Focus Group Area
- Focus Group Observations

Figure 7-10
Frisch Road-Theresa Terrace
Focus Group Map
East Badger Mill Creek Watershed

CITY OF MADISON ENGINEERING

0 212.5 425 Feet

Date: 2/3/2023

Document Path: \\Gisserver\data\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure7-10FrischRoadTheresaTerrace.mxd

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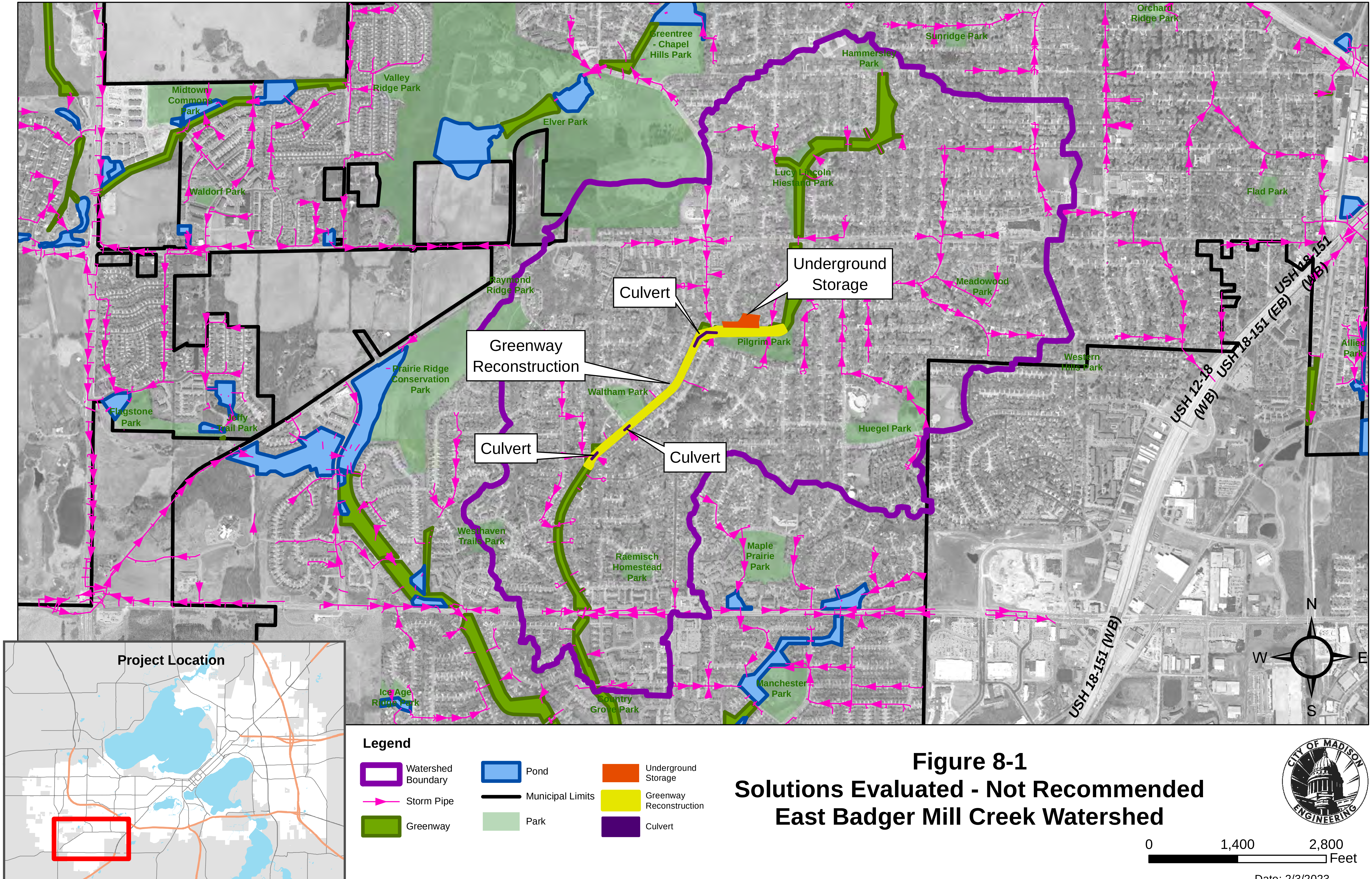


Figure 8-1
Solutions Evaluated - Not Recommended
East Badger Mill Creek Watershed

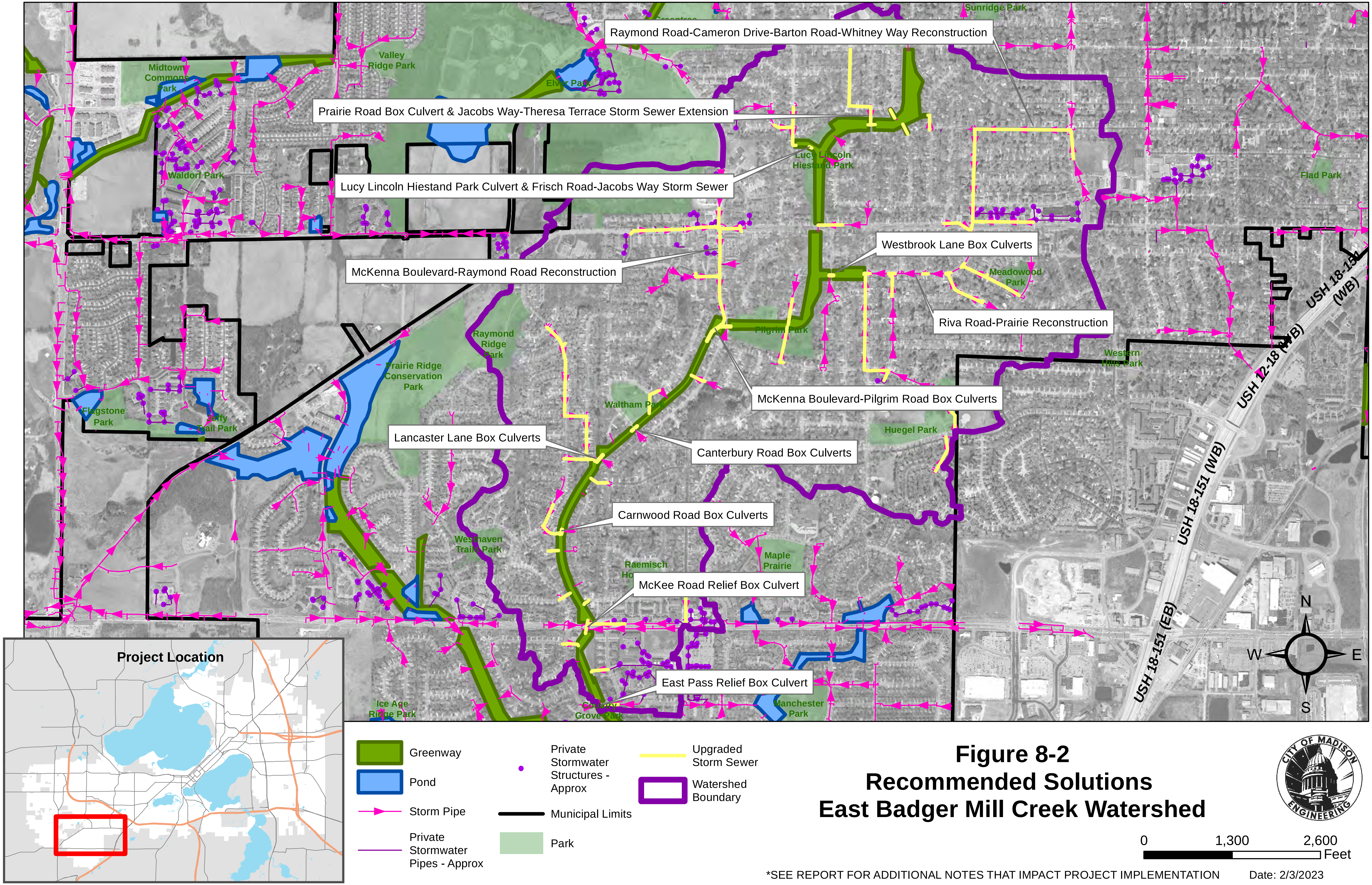
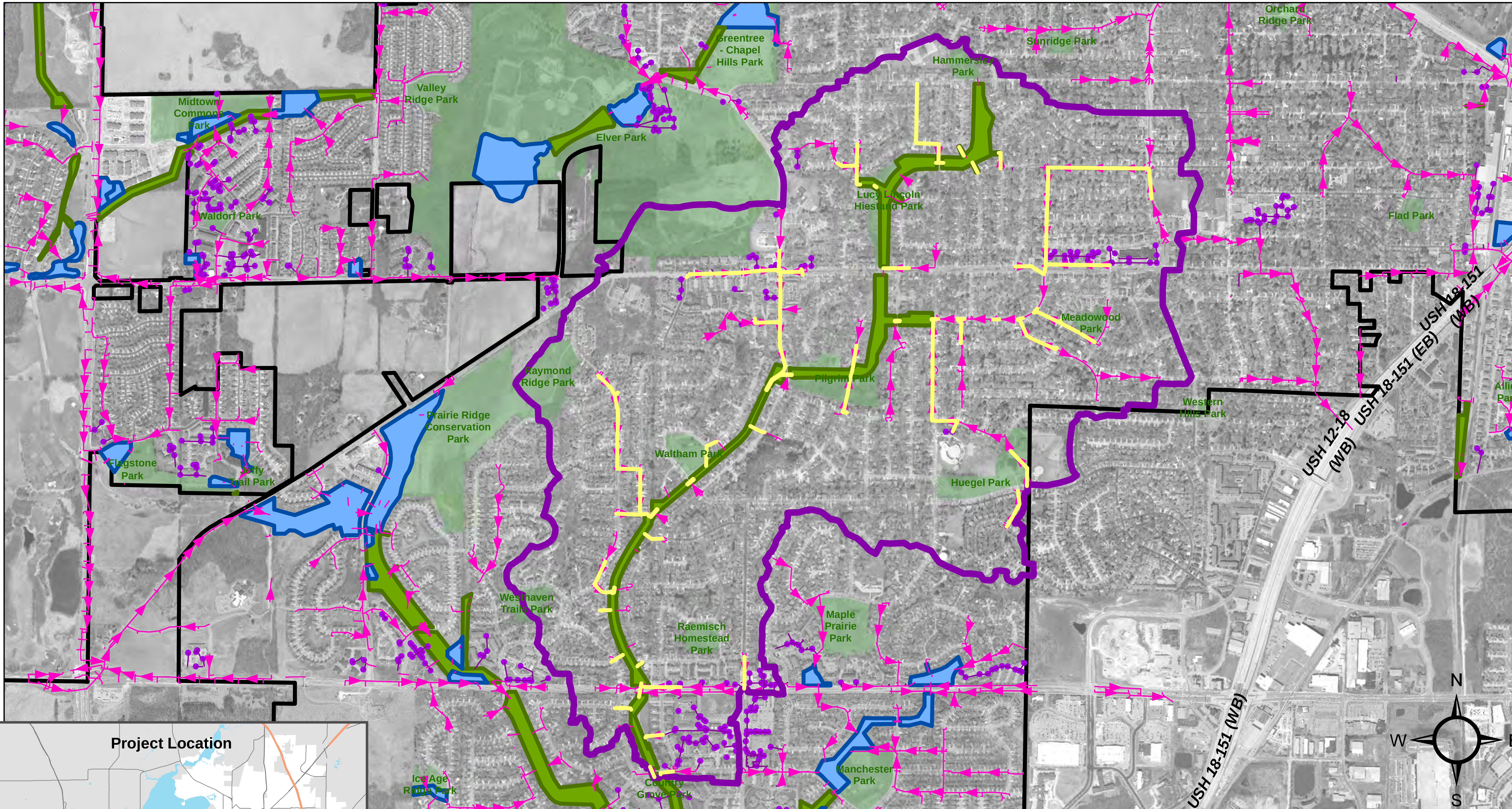
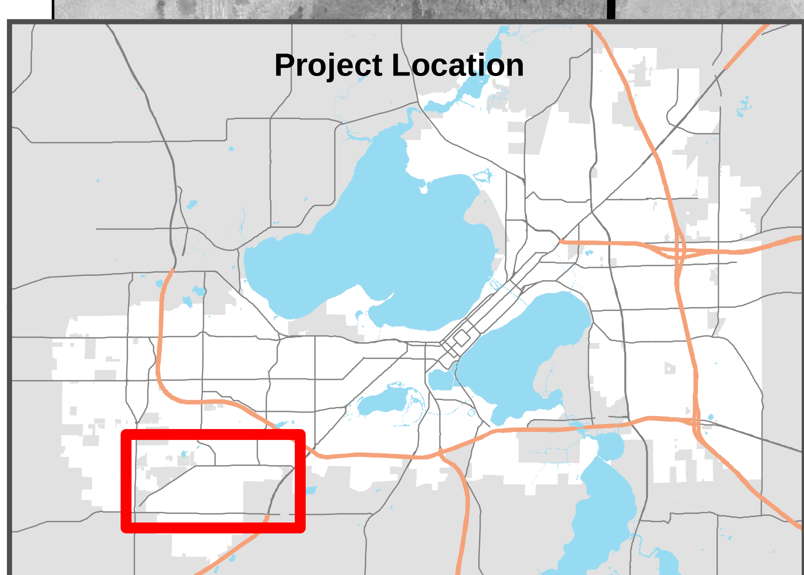


Figure 8-2
Recommended Solutions
East Badger Mill Creek Watershed

*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023





Greenway

Pond

Storm Pipe

Private Stormwater Pipes - Approx

Private Stormwater Structures - Approx

Municipal Limits

Park

Upgraded Storm Sewer

Watershed Boundary

Figure 9-1
Proposed Local Sewer Upgrades
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023

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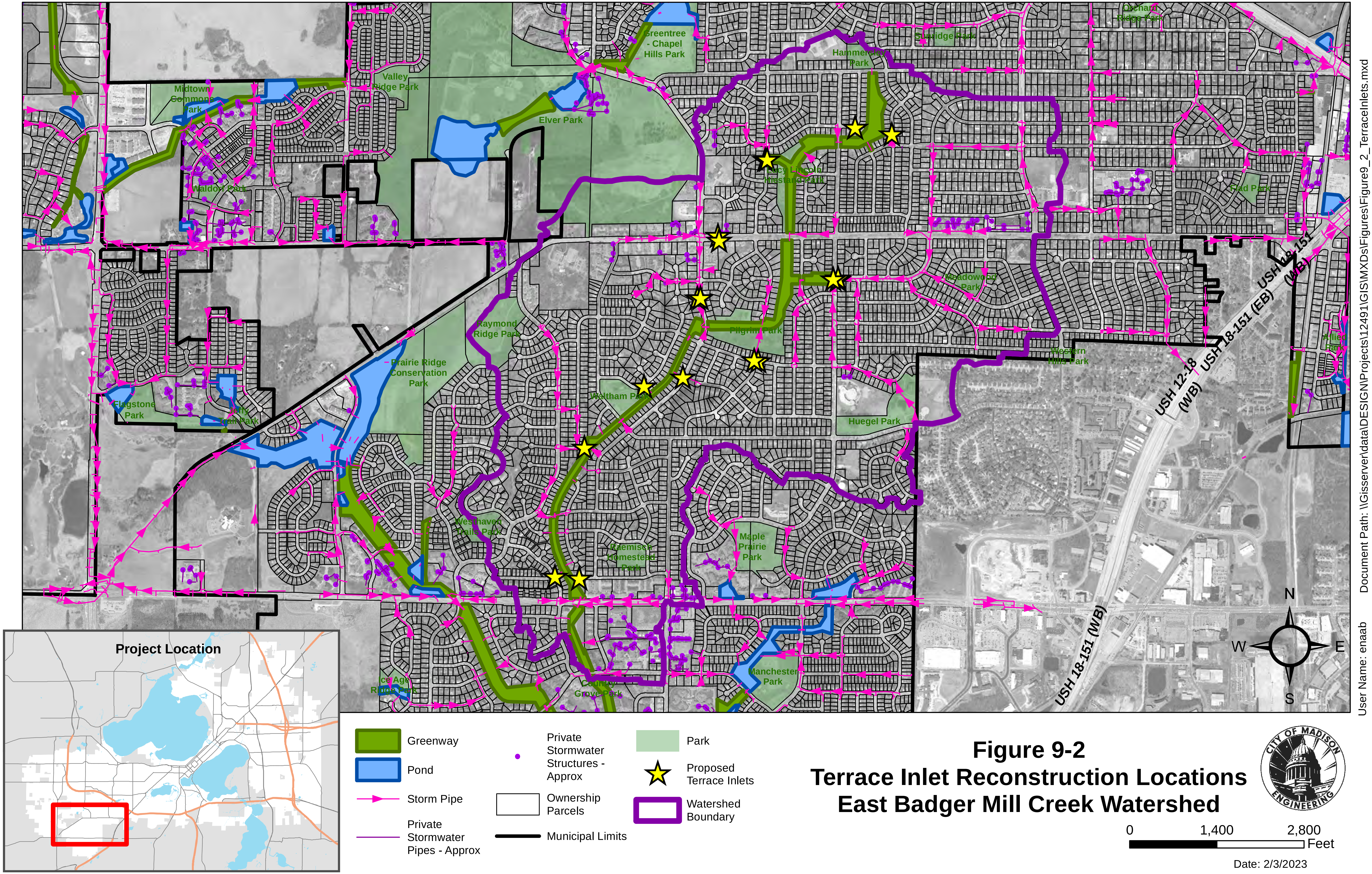
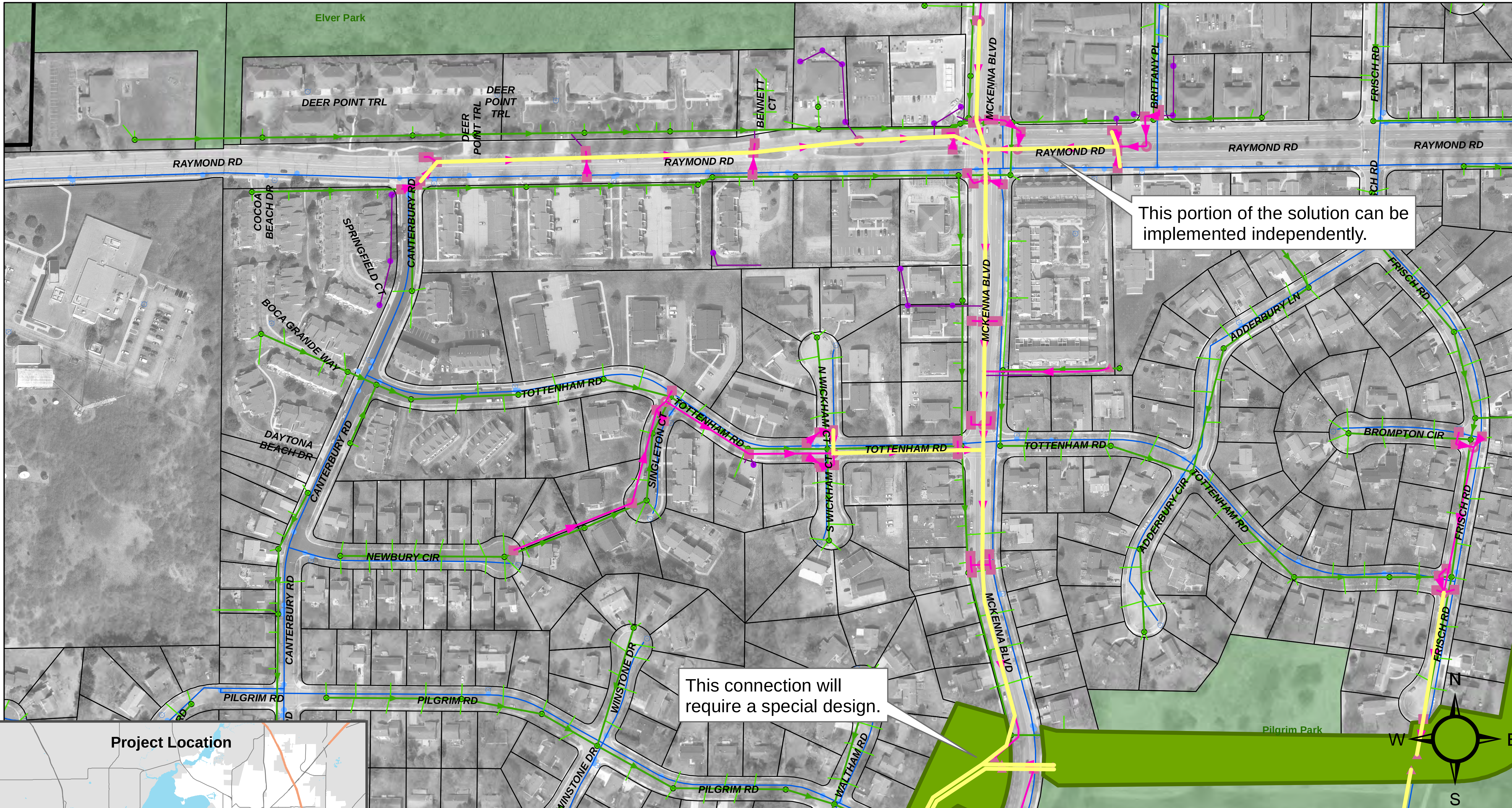
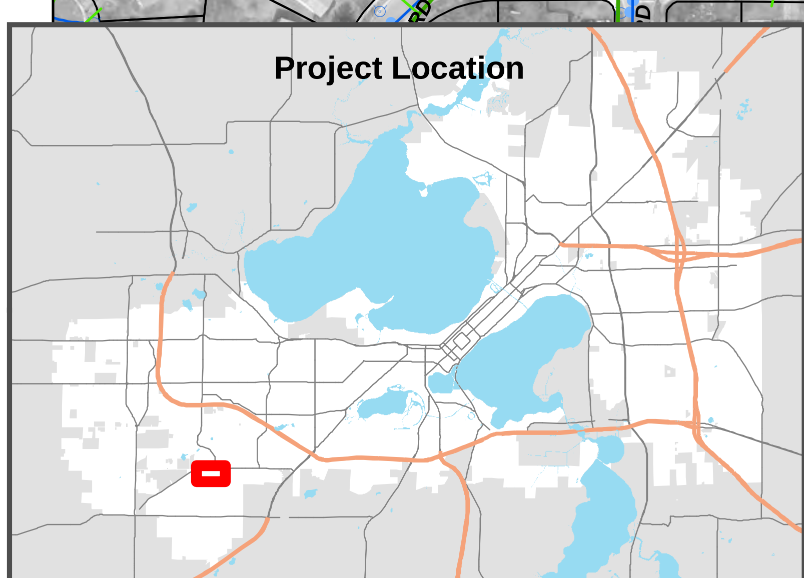


Figure 9-2
Terrace Inlet Reconstruction Locations
East Badger Mill Creek Watershed





- Greenway
- Storm Pipe
- Other Storm Structure
- Access Structures
- Apron
- Inlet
- Private Stormwater Pipes - Approx
- Private Stormwater Structures - Approx
- Sanitary Mains
- SAS
- Sanitary Laterals
- Water Main
- Water Valve
- Water Hydrant
- Ownership Parcels
- Municipal Limits
- Park
- Upgraded Storm Sewer

Figure 9-3
McKenna Boulevard-Raymond Road Reconstruction
East Badger Mill Creek Watershed

0 237.5 475 Feet

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*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023

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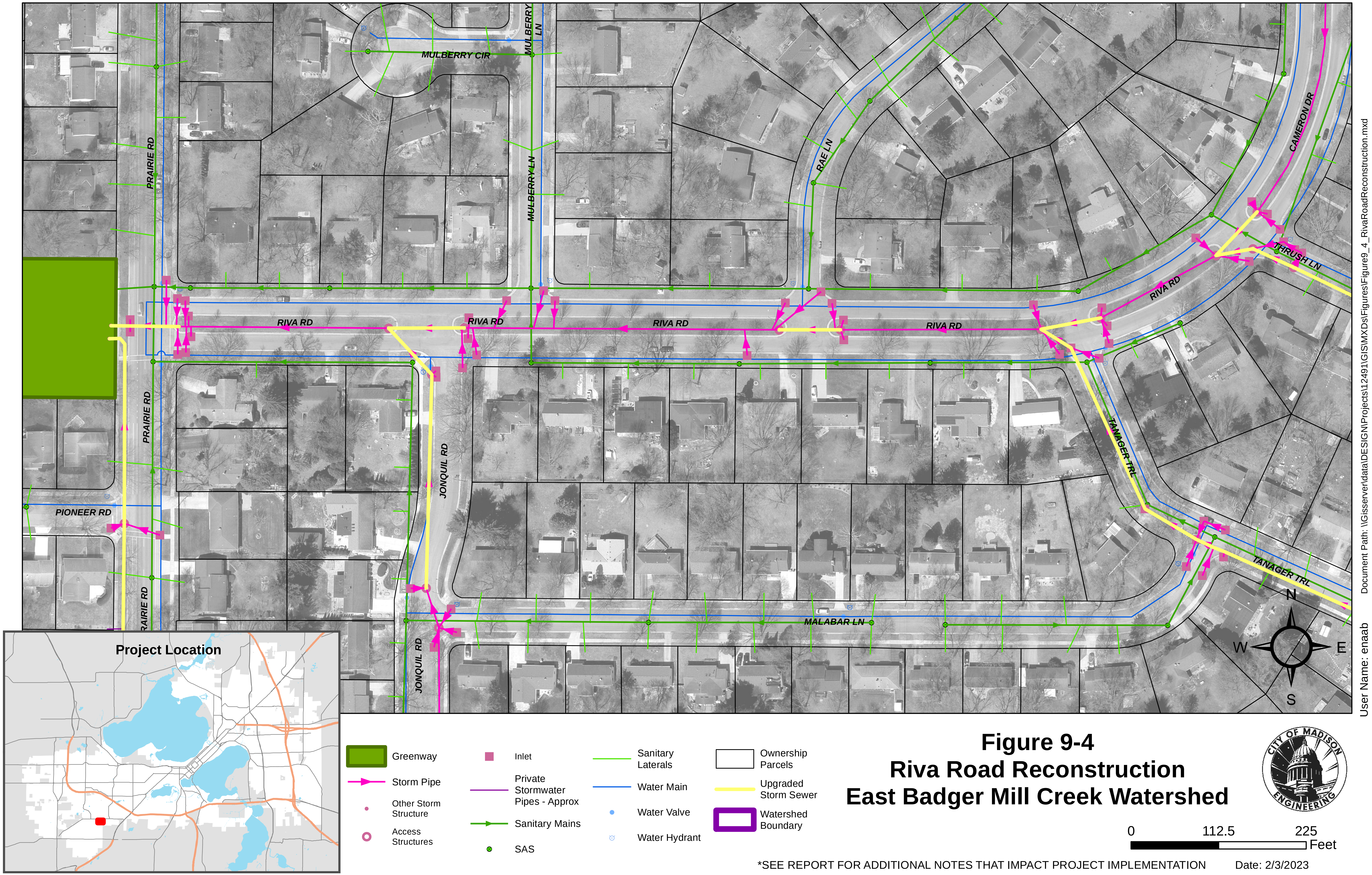


Figure 9-4
Riva Road Reconstruction
East Badger Mill Creek Watershed

*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023

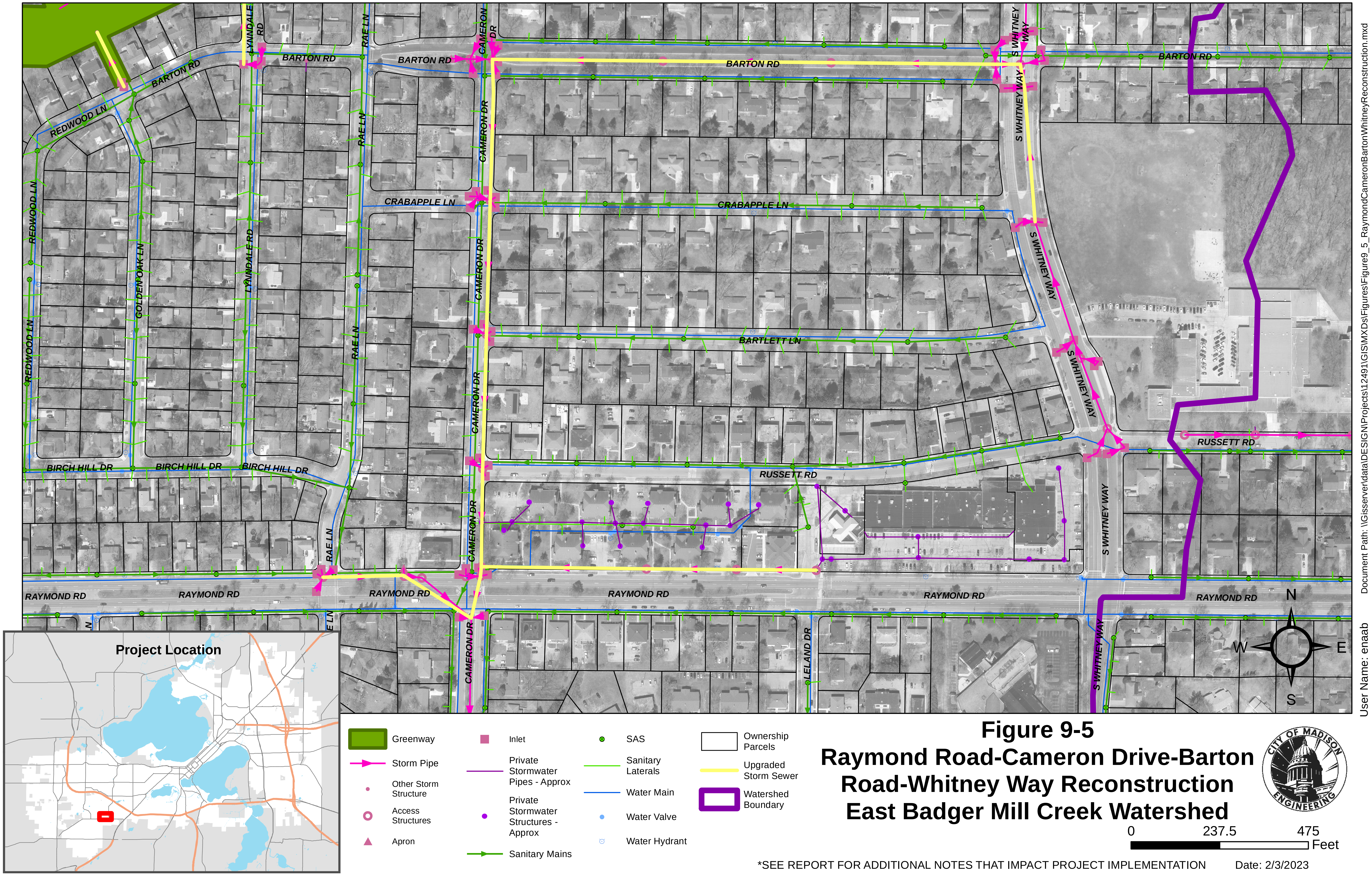
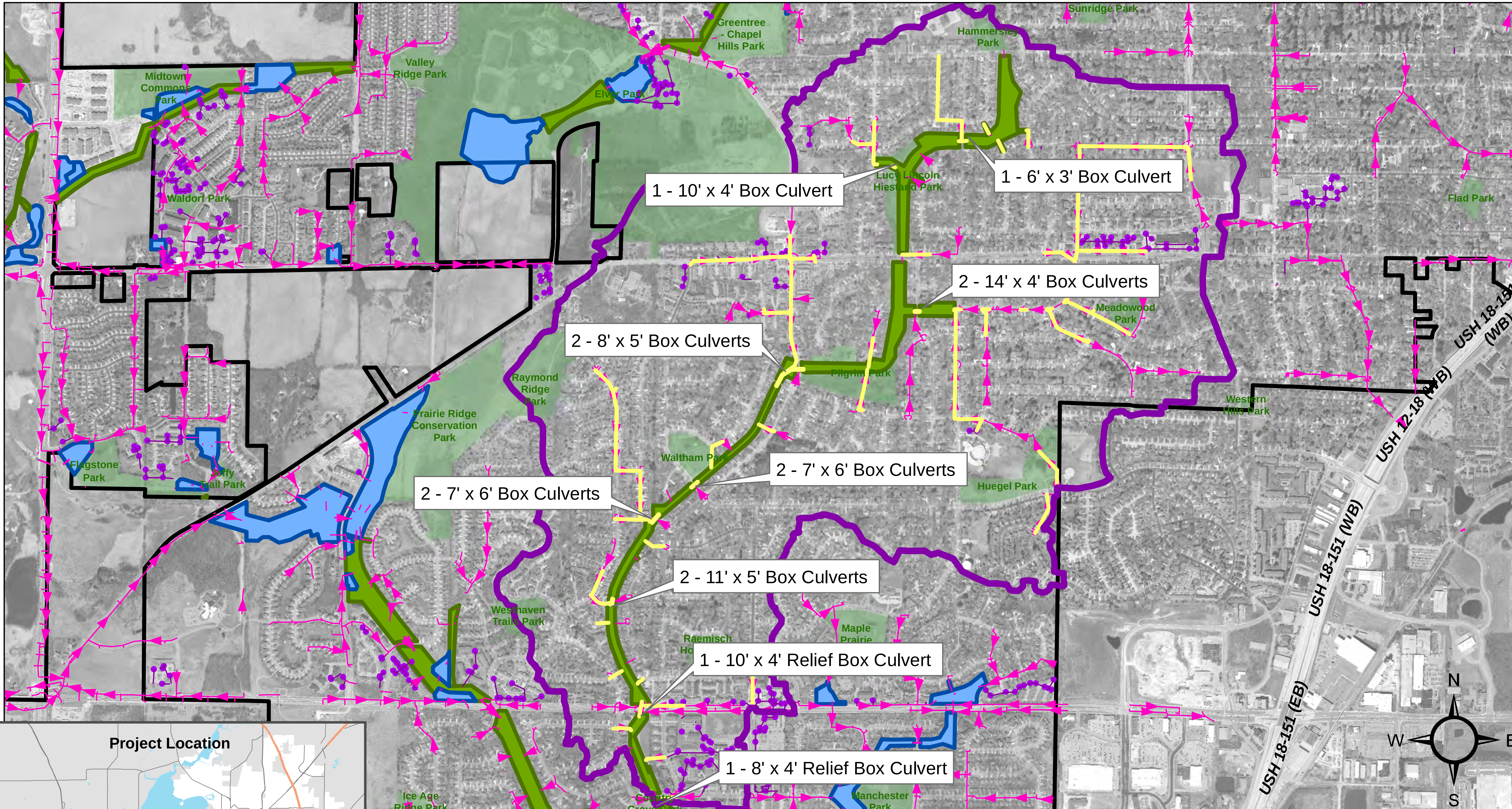
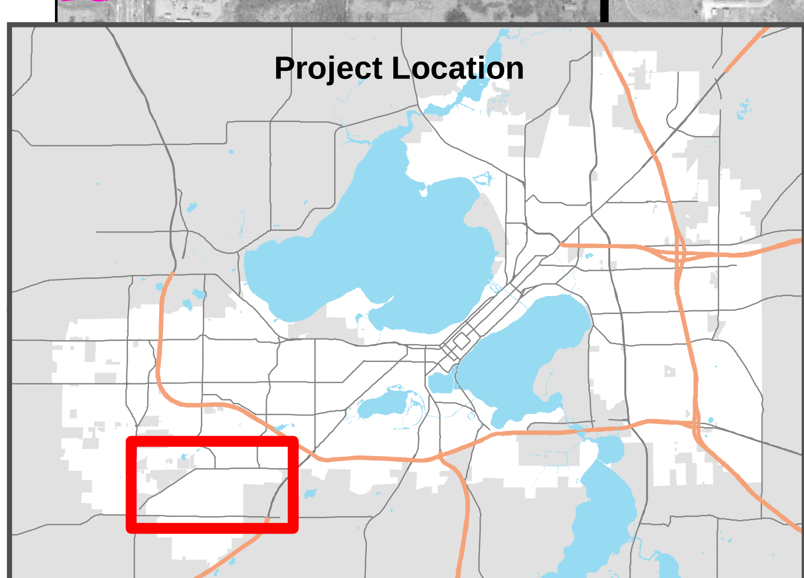


Figure 9-5
Raymond Road-Cameron Drive-Barton Road-Whitney Way Reconstruction East Badger Mill Creek Watershed

*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023





Greenway

Pond

Storm Pipe

Private Stormwater Pipes - Approx

Private Stormwater Structures - Approx

Municipal Limits

Park

Upgraded Storm Sewer

Watershed Boundary

Figure 9-6
Greenway Crossing Improvement Overview
East Badger Mill Creek Watershed

0 1,300 2,600 Feet

*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023

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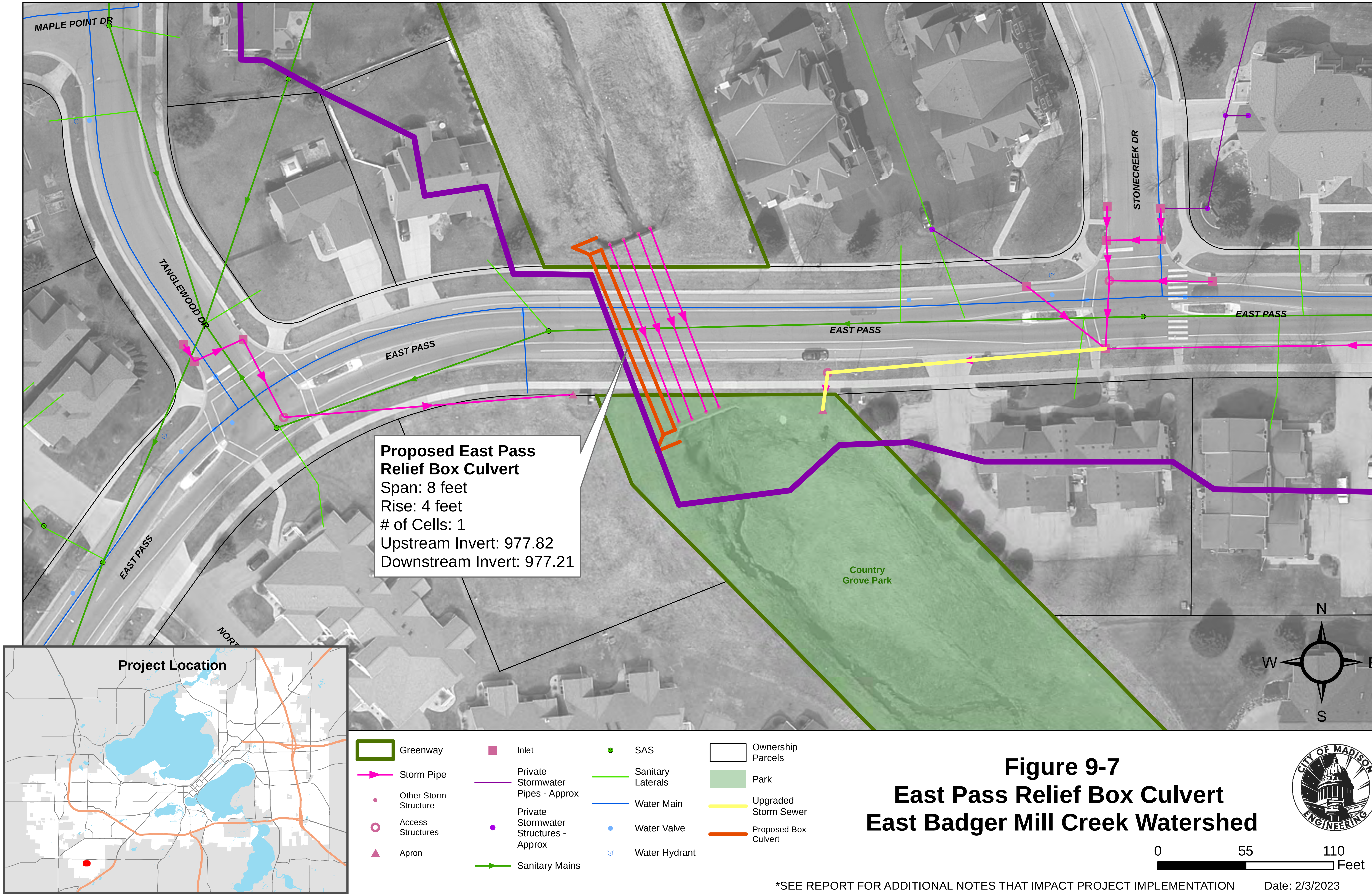


Figure 9-7
East Pass Relief Box Culvert
East Badger Mill Creek Watershed

*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023

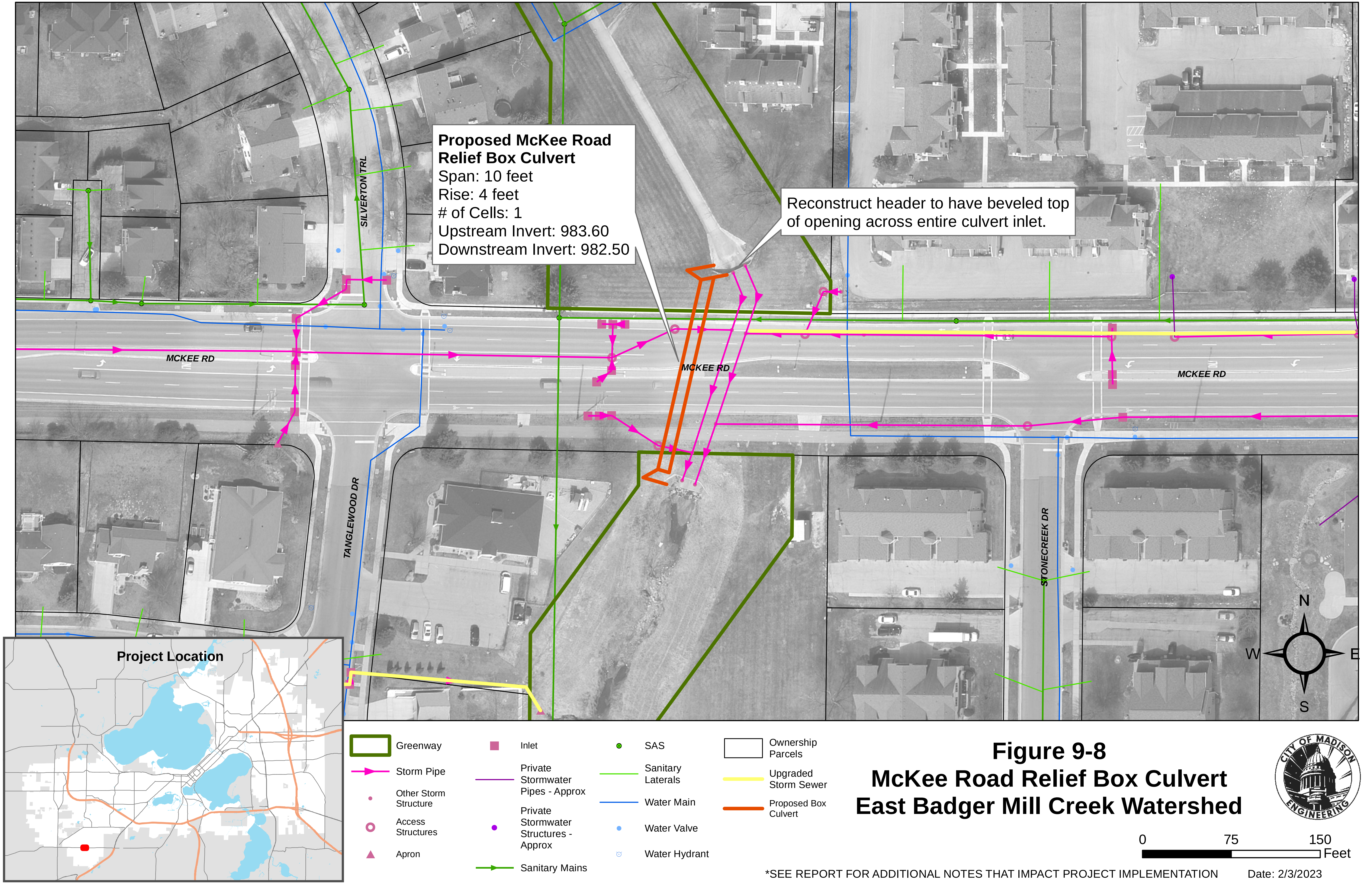
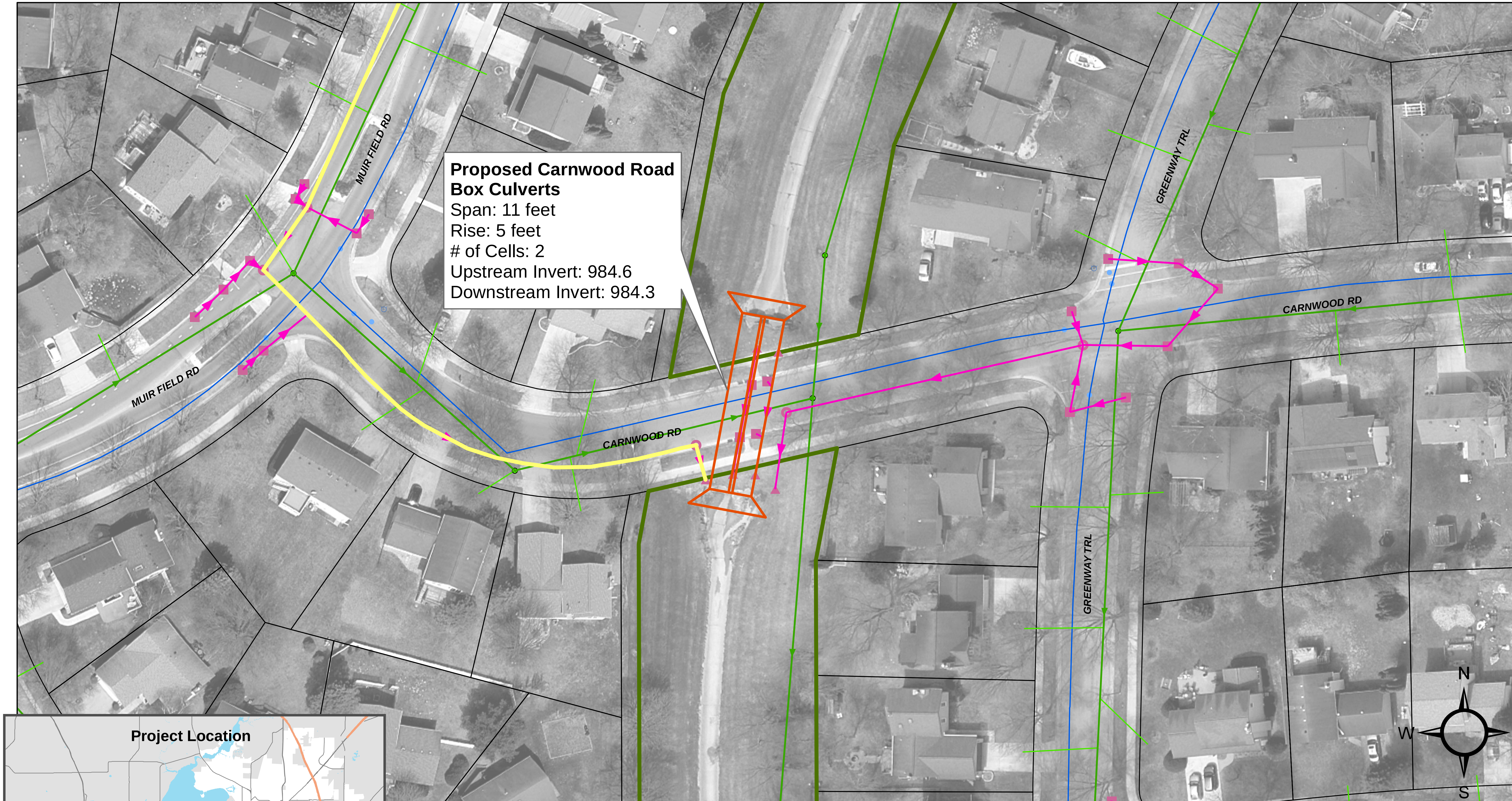
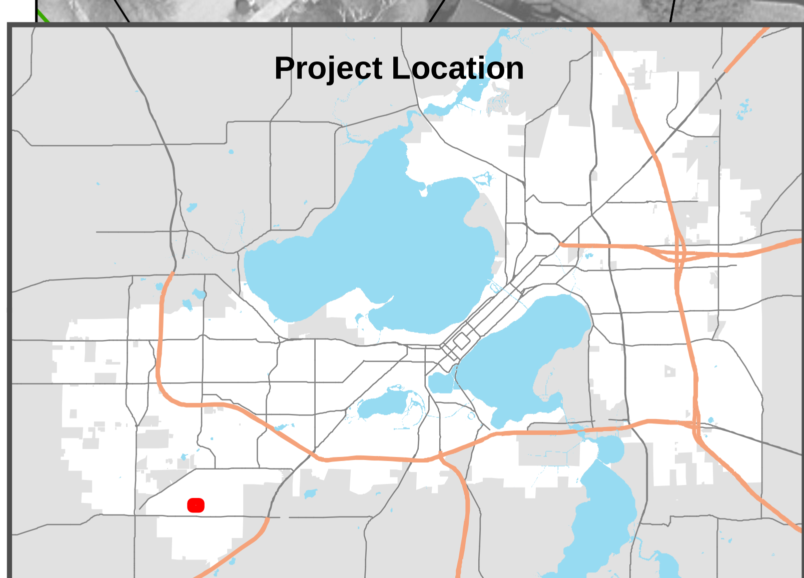


Figure 9-8
McKee Road Relief Box Culvert
East Badger Mill Creek Watershed

*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023





Greenway
Storm Pipe
Access Structures
Apron
Inlet
Sanitary Mains
SAS
Sanitary Laterals
Water Main
Water Valve
Water Hydrant
Ownership Parcels
Upgraded Storm Sewer
Proposed Box Culvert

Figure 9-9
Carnwood Road Box Culverts
East Badger Mill Creek Watershed

0 55 110 Feet

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*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023

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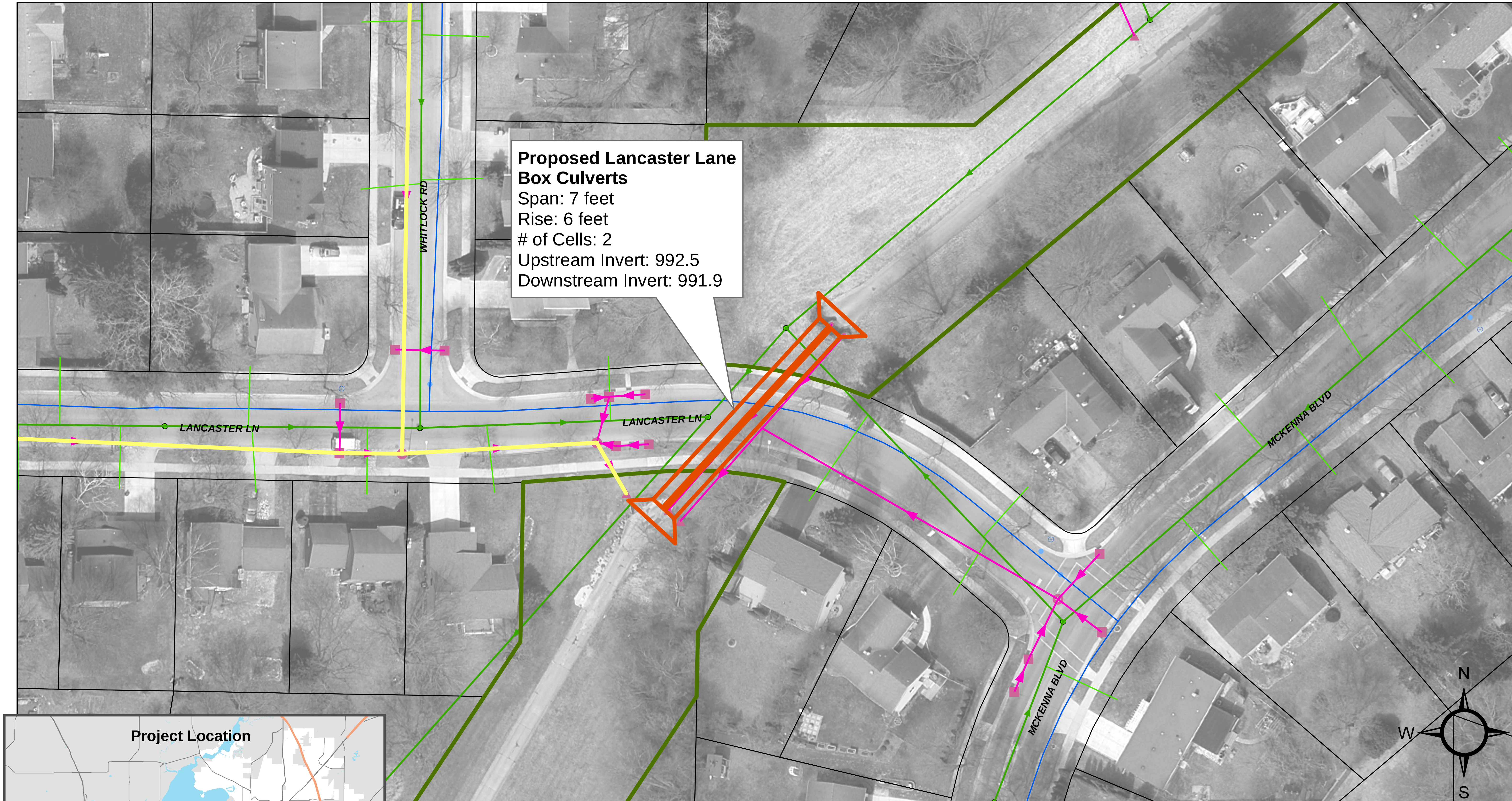


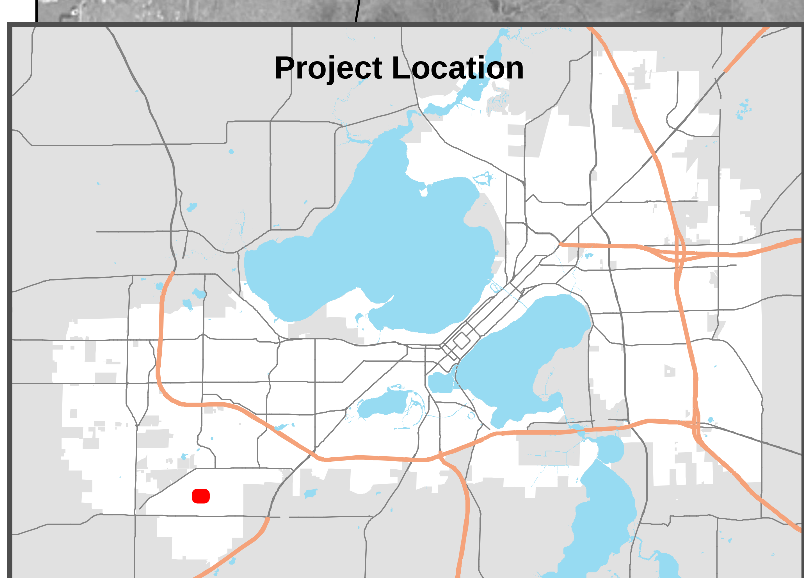
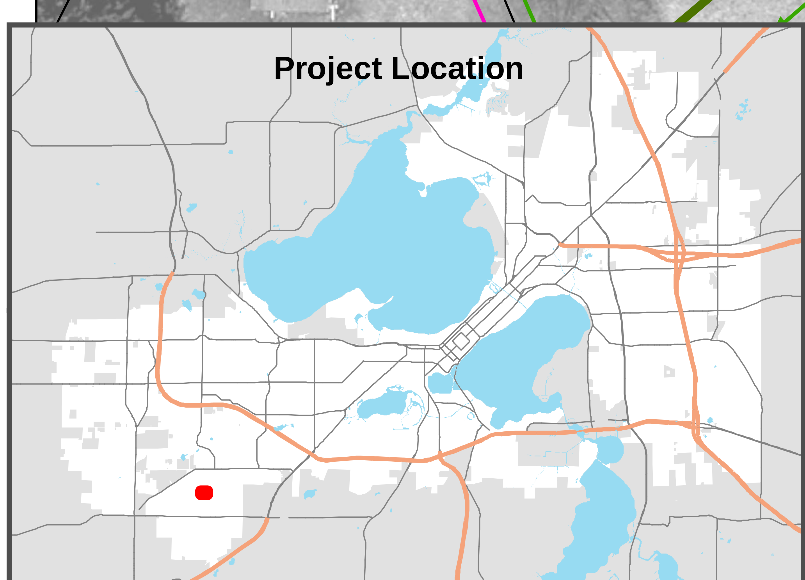


Figure 9-10
Lancaster Lane Box Culverts
East Badger Mill Creek Watershed

*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023



Greenway	Sanitary Mains	Ownership Parcels
Storm Pipe	SAS	Park
Other Storm Structure	Sanitary Laterals	Upgraded Storm Sewer
Access Structures	Water Main	Proposed Box Culvert
Apron	Water Valve	
Inlet	Water Hydrant	

Figure 9-11
Canterbury Road Box Culverts
East Badger Mill Creek Watershed

0 55 110 Feet

*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023

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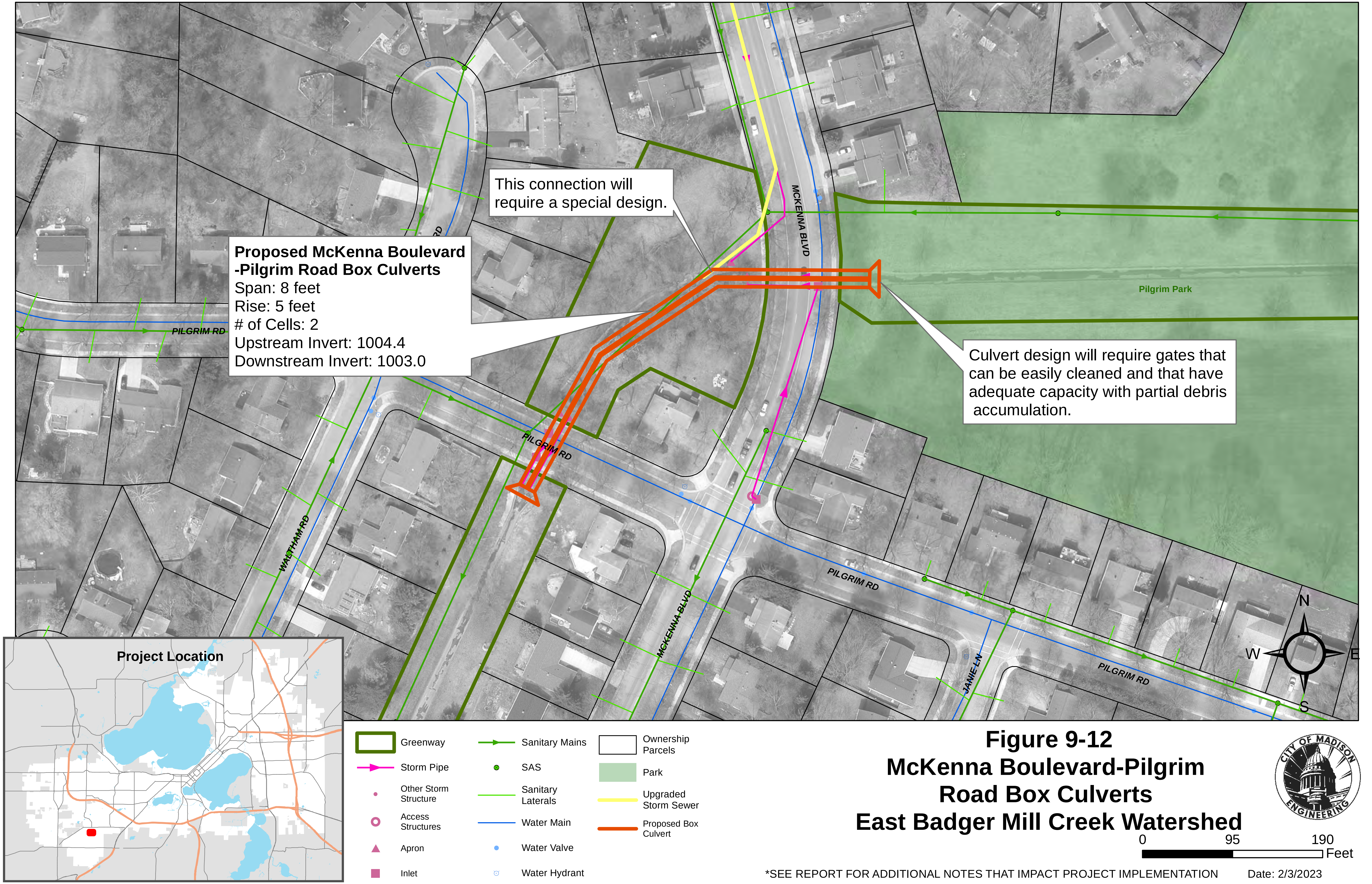
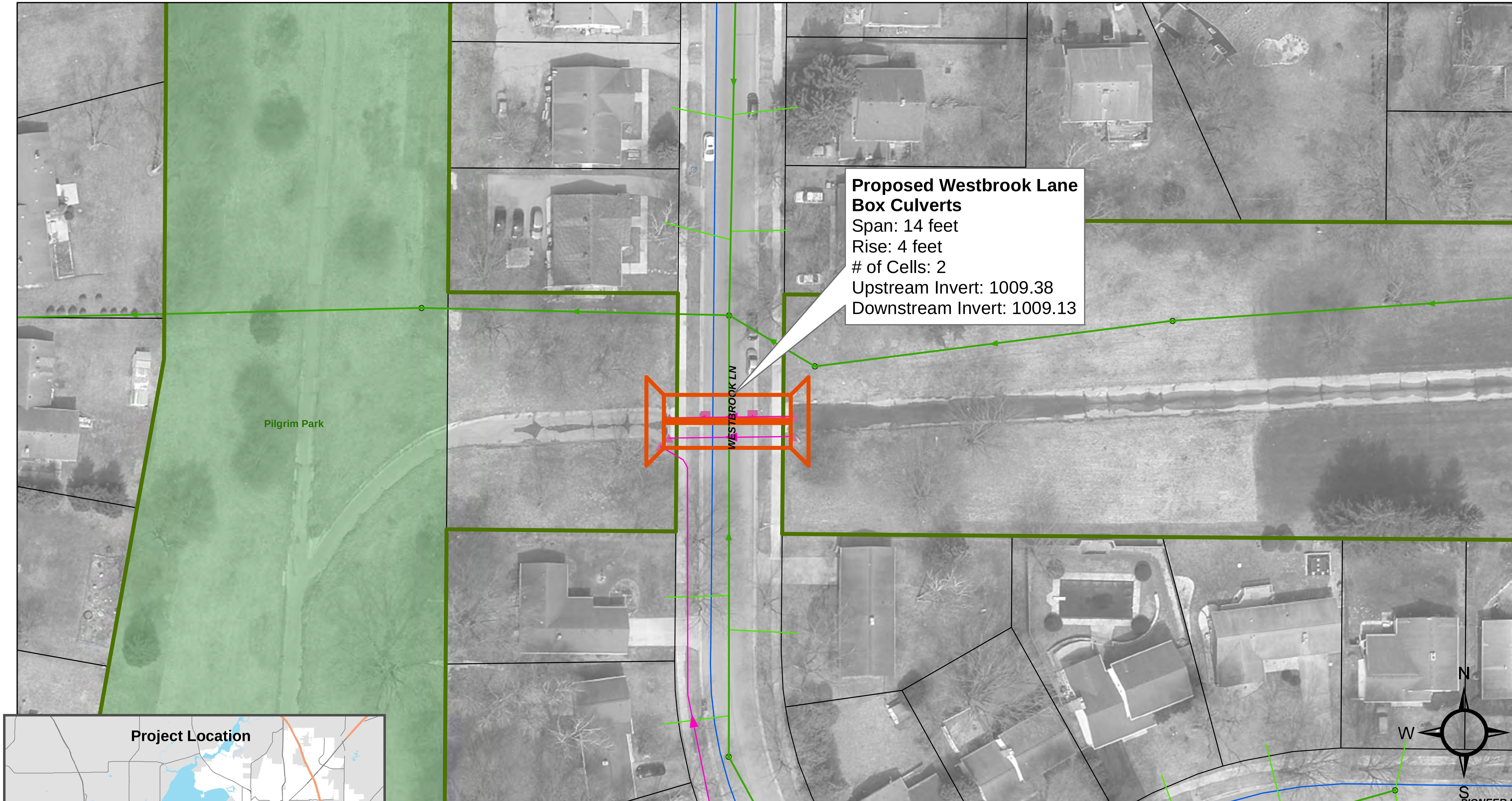
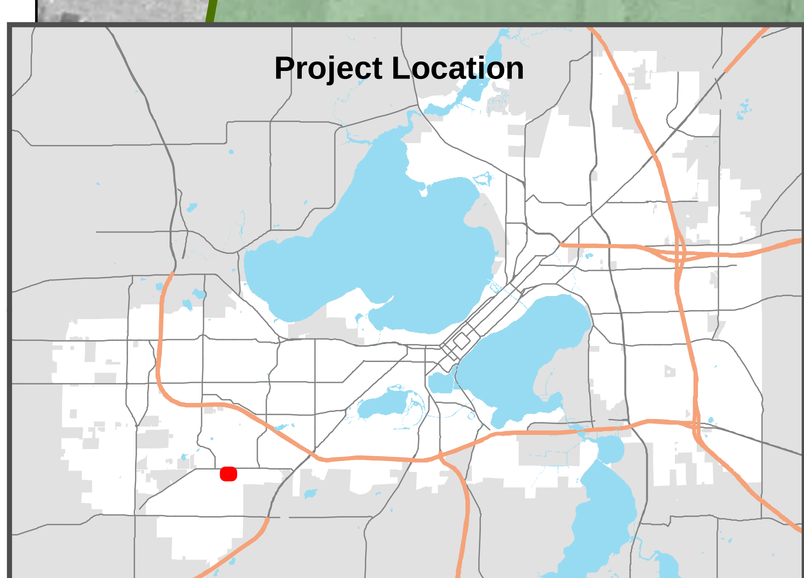


Figure 9-12
McKenna Boulevard-Pilgrim Road Box Culverts
East Badger Mill Creek Watershed





Greenway
Storm Pipe
Apron
Inlet
Sanitary Mains
SAS
Sanitary Laterals
Water Main
Water Hydrant
Ownership Parcels
Park
Proposed Box Culvert

Figure 9-13
Westbrook Lane Box Culverts
East Badger Mill Creek Watershed

0 55 110 Feet

*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023

Document Path: \\Gisserver\data\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure9_13_WestbrookLaneBoxCulverts.mxd

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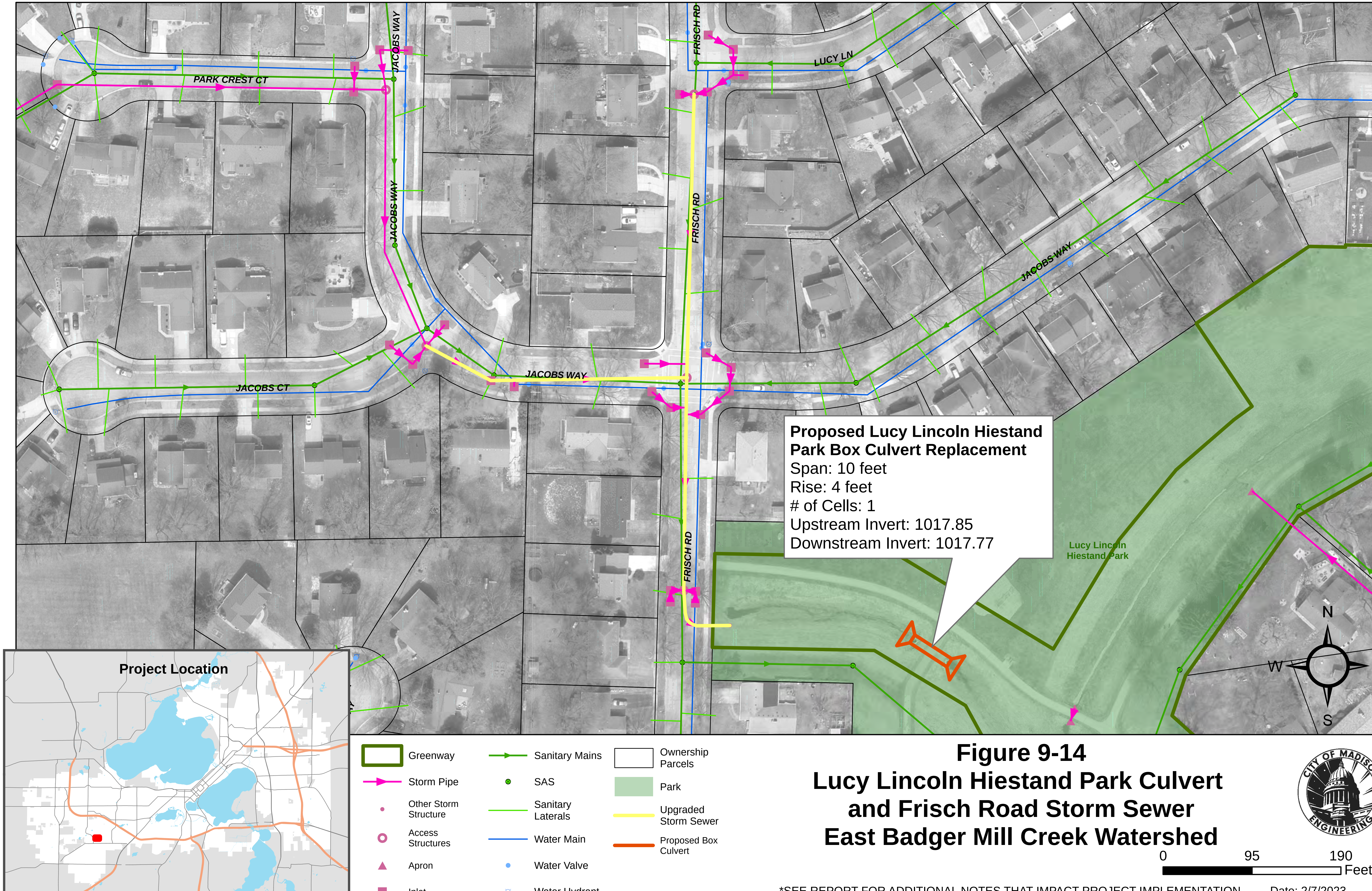

Greenway
Storm Pipe
Other Storm Structure
Access Structures
Apron
Inlet
Sanitary Mains
SAS
Sanitary Laterals
Water Main
Water Valve
Water Hydrant
Ownership Parcels
Park
Upgraded Storm Sewer
Proposed Box Culvert

Figure 9-14
Lucy Lincoln Hiestand Park Culvert and Frisch Road Storm Sewer
East Badger Mill Creek Watershed

0 95 190 Feet

*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/7/2023

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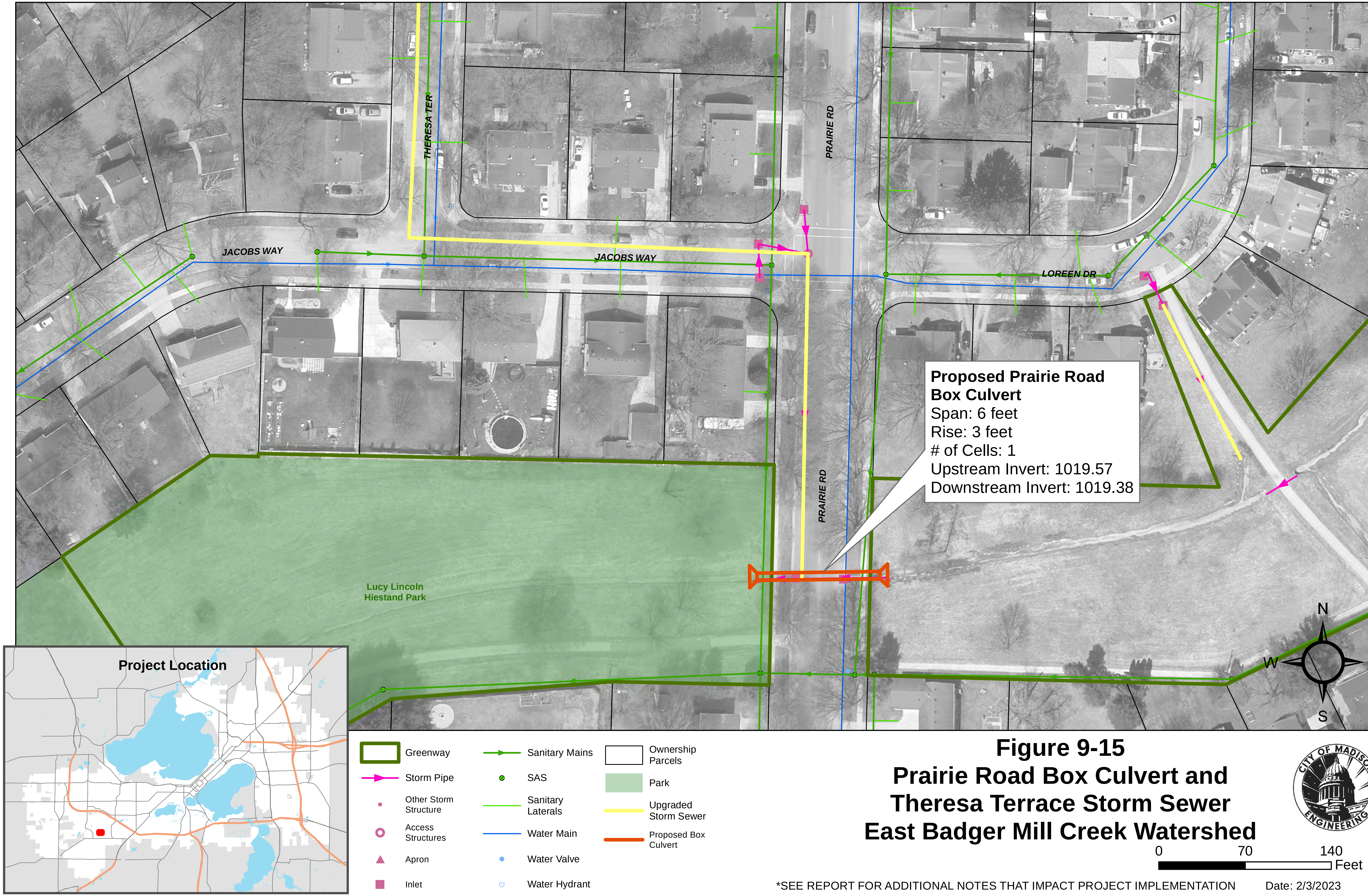
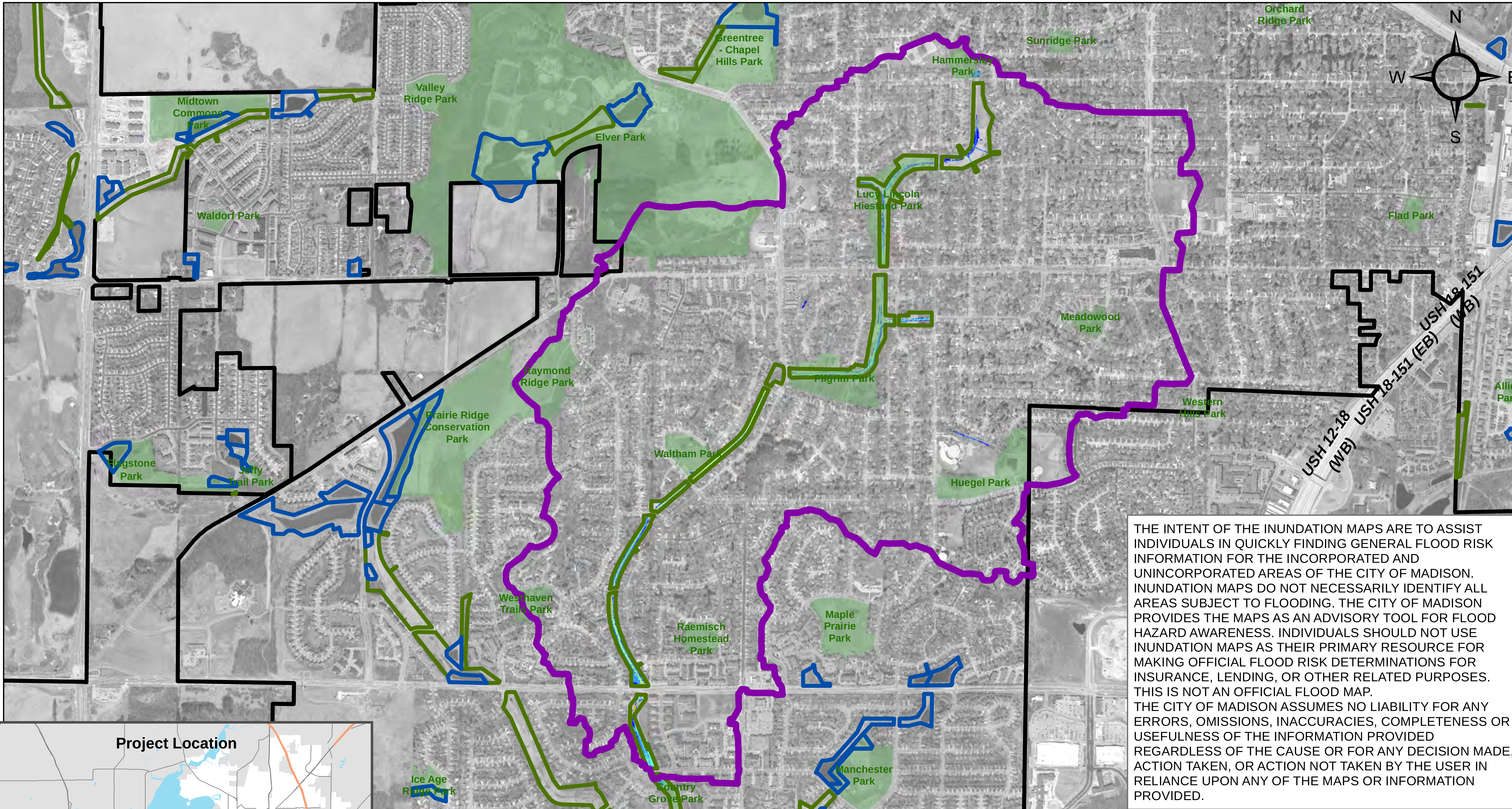


Figure 9-15
Prairie Road Box Culvert and Theresa Terrace Storm Sewer East Badger Mill Creek Watershed

*SEE REPORT FOR ADDITIONAL NOTES THAT IMPACT PROJECT IMPLEMENTATION

Date: 2/3/2023



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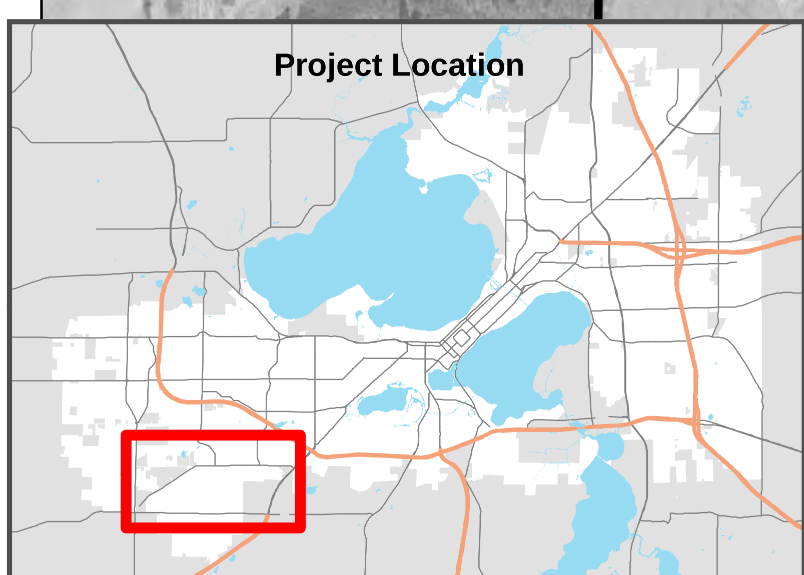
Project Location



Legend

Greenway
Pond
Municipal Limits
Park
Watershed Boundary

Maximum Depth (ft)

.5-1
1-2
2-3
3-4
4-5
5+

Figure 10-1
Proposed Conditions Inundation Mapping
100% Chance Event
East Badger Mill Creek Watershed

CITY OF MADISON ENGINEERING

0 1,400 2,800 Feet

Date: 2/3/2023

Document Path: M:\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure10_1_ProposedConditions100PercentInundationMapping.mxd

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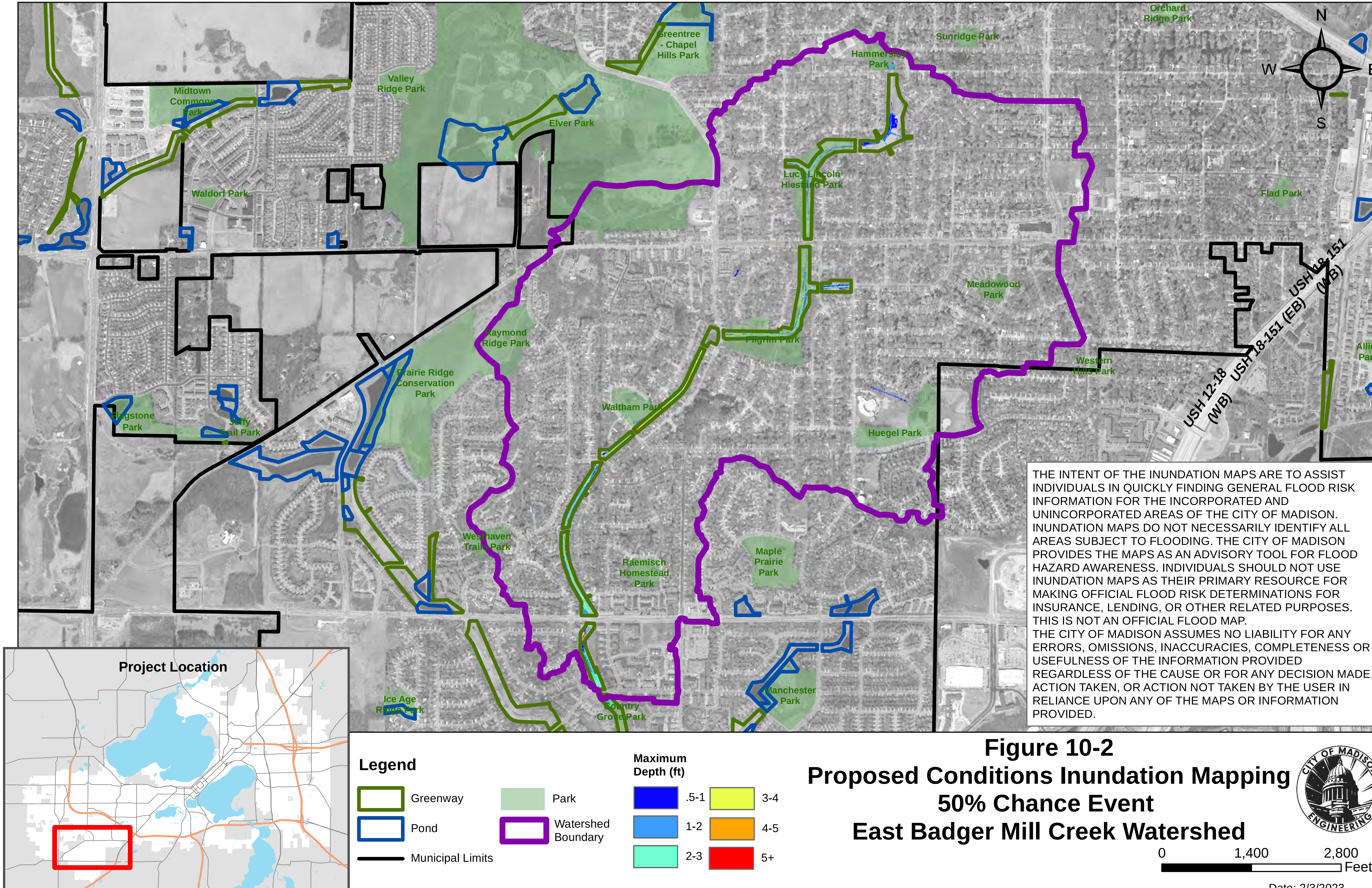

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Figure 10-2
Proposed Conditions Inundation Mapping
50% Chance Event
East Badger Mill Creek Watershed

CITY OF MADISON ENGINEERING

Date: 2/3/2023

Document Path: M:\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure10_2_ProposedConditions50PercentInundationMapping.mxd

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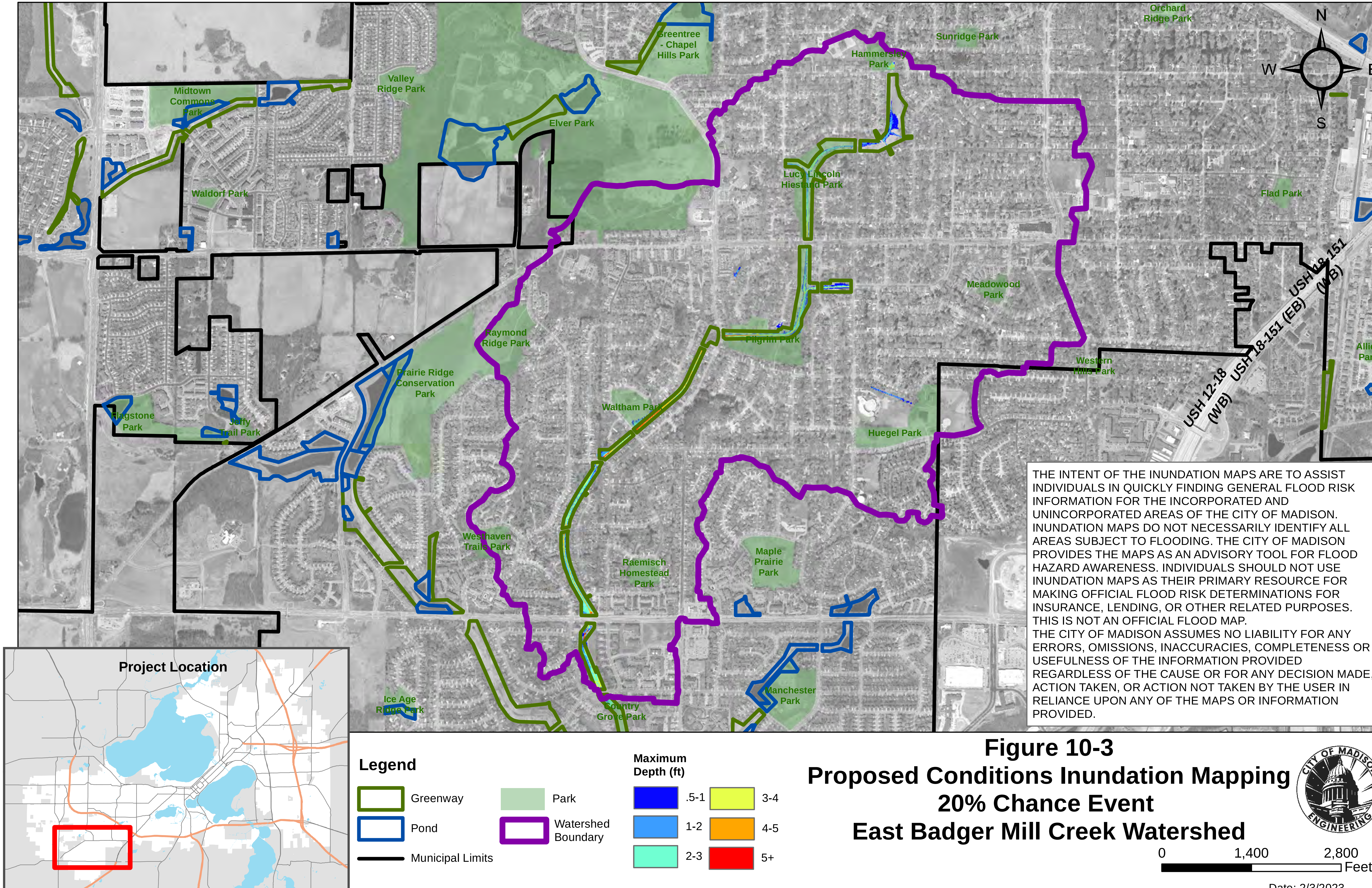

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Legend

Greenway
Pond
Municipal Limits
Park
Watershed Boundary

Maximum Depth (ft)

.5-1
1-2
2-3
3-4
4-5
5+

Figure 10-3
Proposed Conditions Inundation Mapping
20% Chance Event
East Badger Mill Creek Watershed

CITY OF MADISON ENGINEERING

0 1,400 2,800 Feet

Date: 2/3/2023

Document Path: M:\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure10_3_ProposedConditions20PercentInundationMapping.mxd

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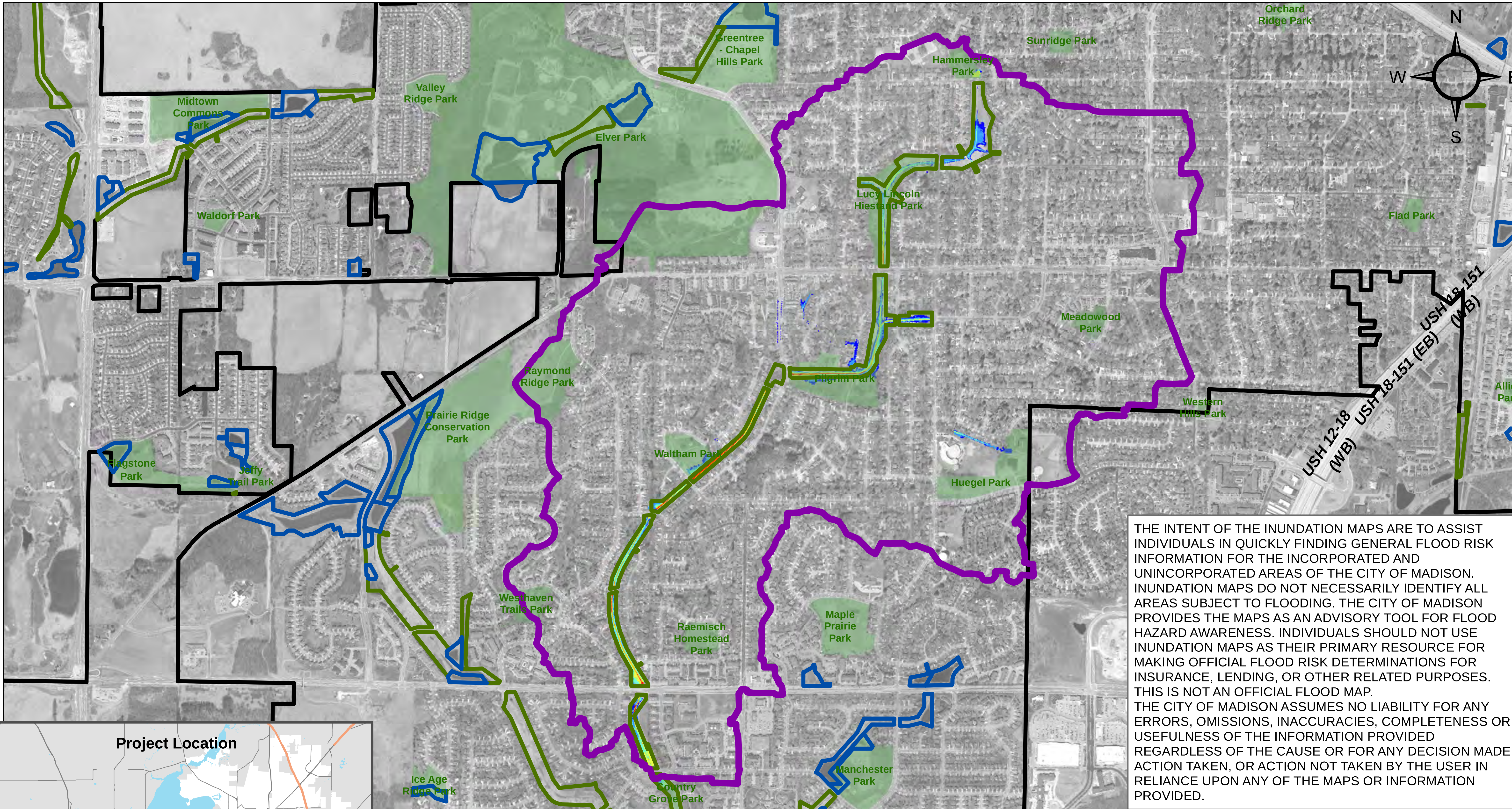

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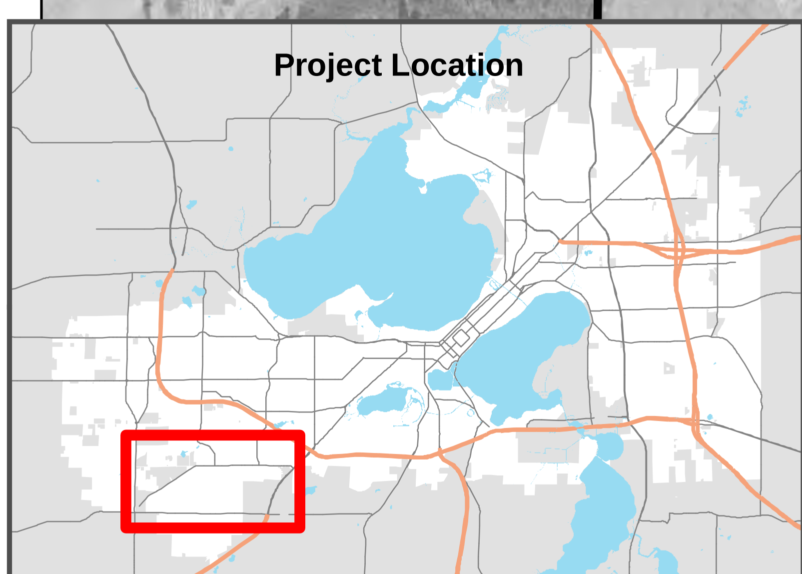

Legend

Greenway
Pond
Municipal Limits
Park
Watershed Boundary

Maximum Depth (ft)

.5-1
1-2
2-3
3-4
4-5
5+

Figure 10-4
Proposed Conditions Inundation Mapping
10% Chance Event
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023

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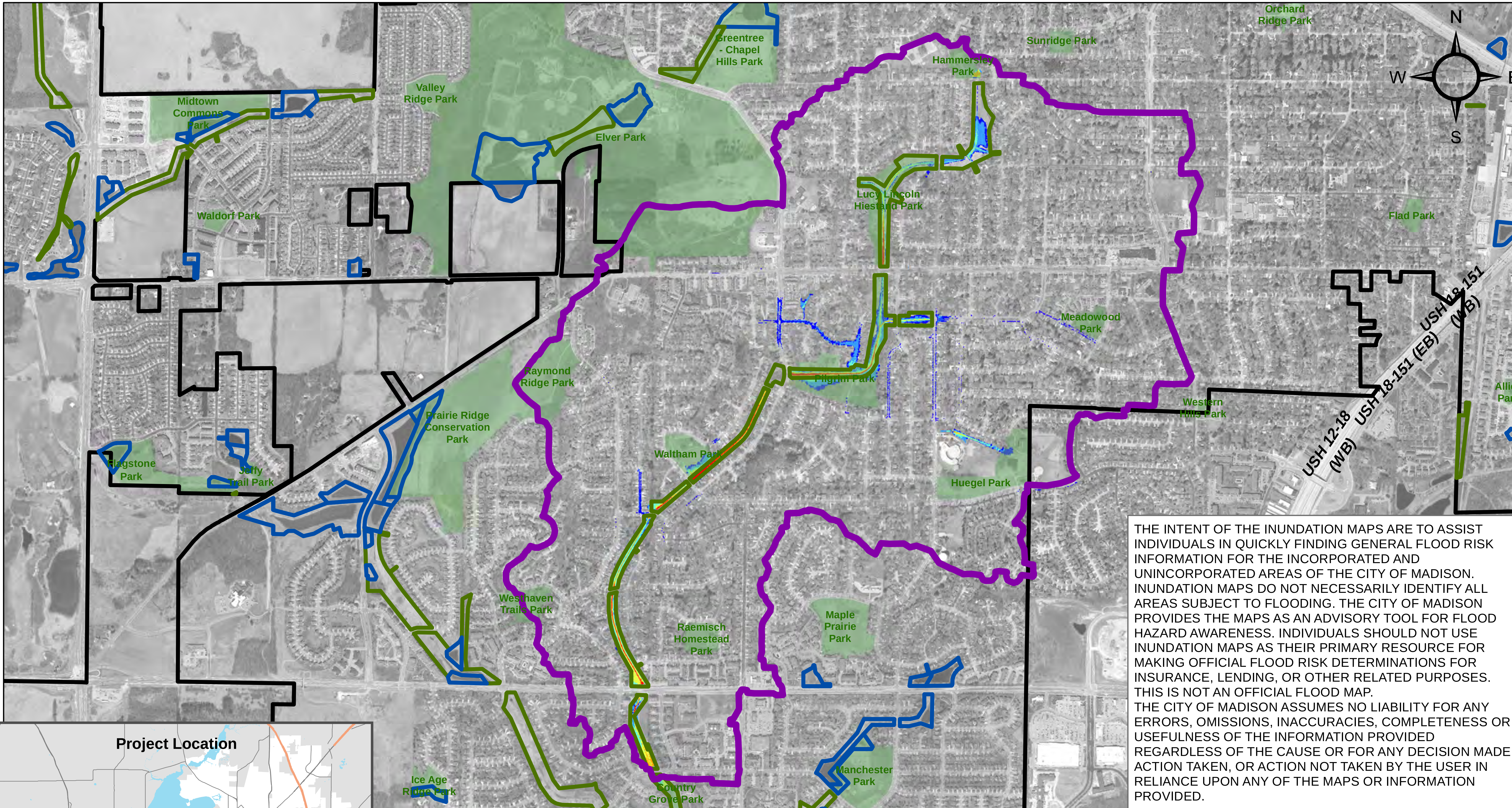

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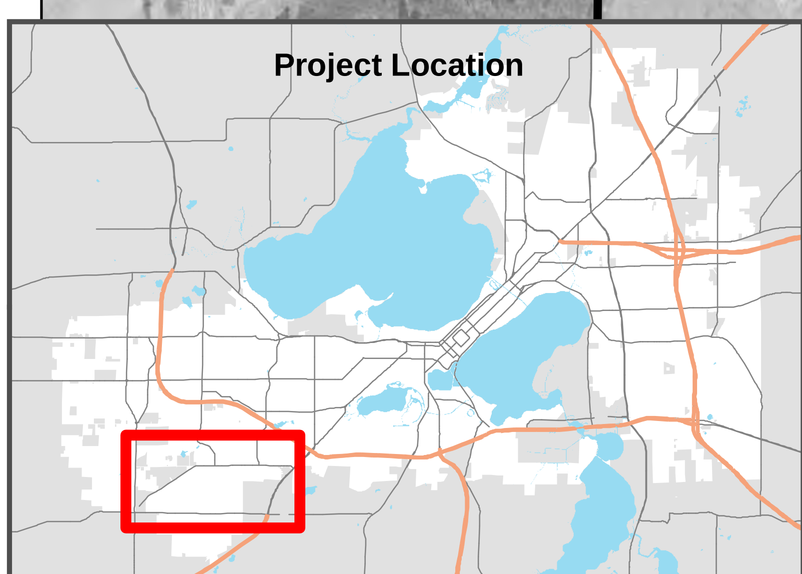

Legend

- Greenway
- Pond
- Municipal Limits
- Park
- Watershed Boundary

Maximum Depth (ft)

- .5-1
- 1-2
- 2-3
- 3-4
- 4-5
- 5+

Figure 10-5
Proposed Conditions Inundation Mapping
4% Chance Event
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023

Document Path: M:\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure10_5_ProposedConditions4PercentInundationMapping.mxd

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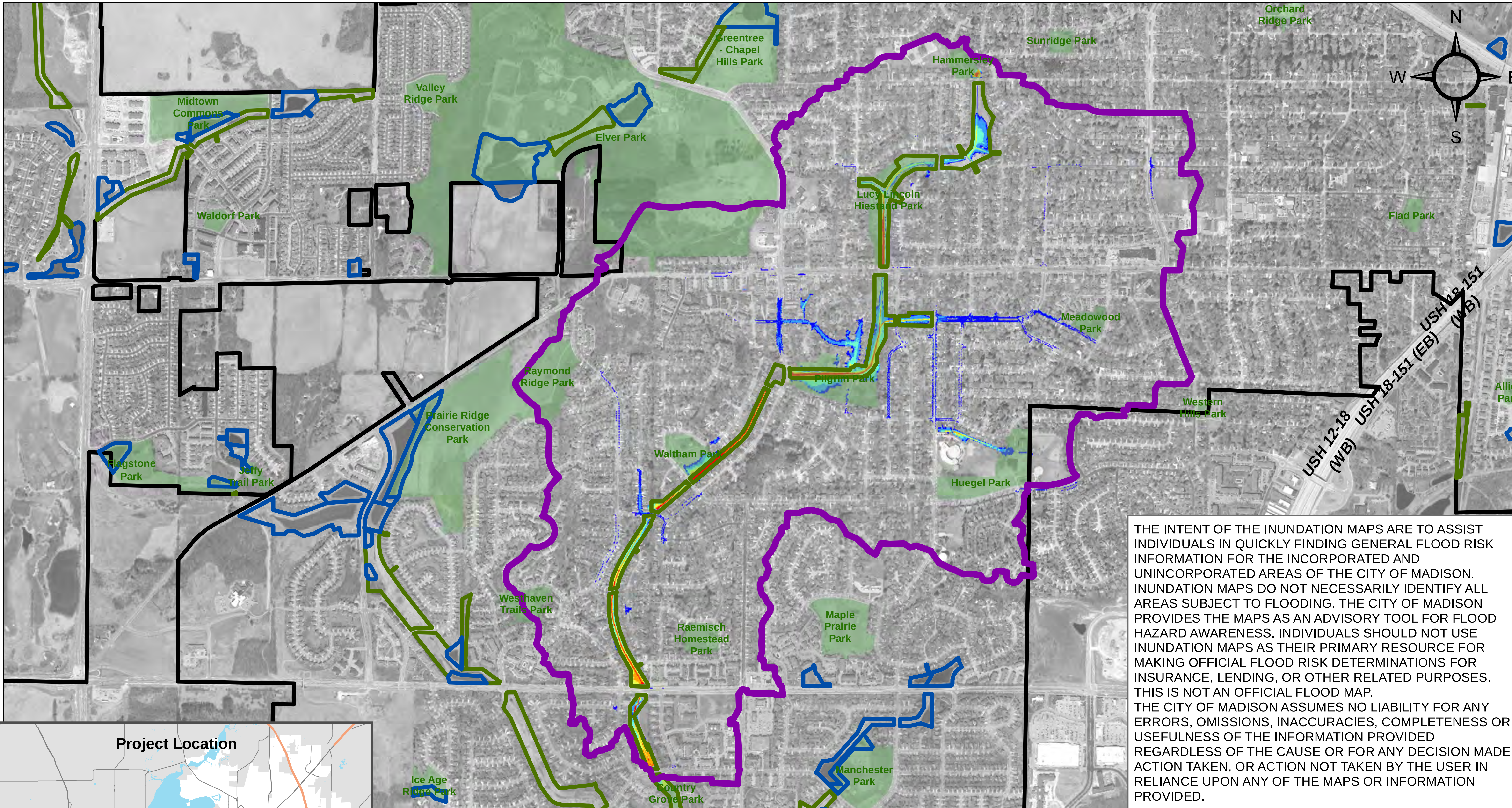

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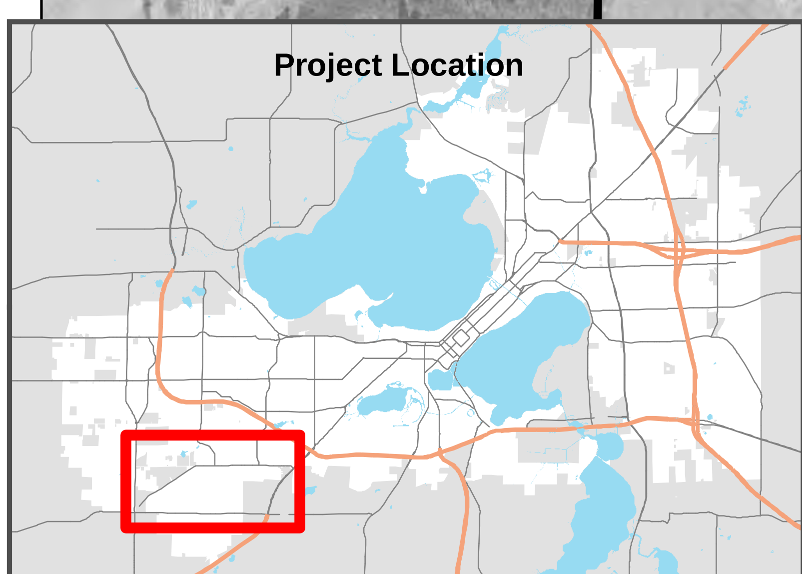


Legend

Greenway
Pond
Municipal Limits
Park
Watershed Boundary

Maximum Depth (ft)

.5-1
1-2
2-3
3-4
4-5
5+

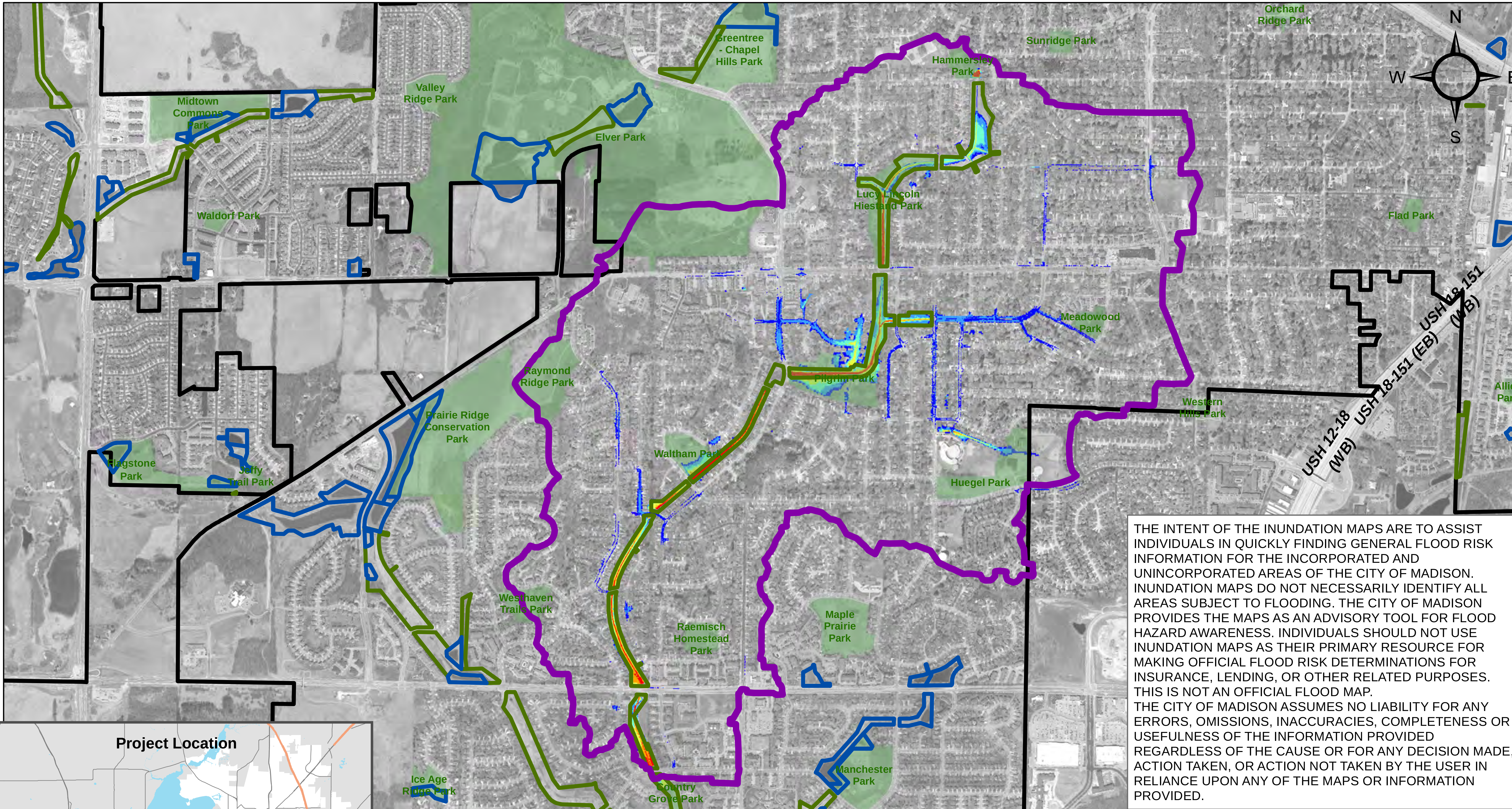
Figure 10-6
Proposed Conditions Inundation Mapping
2% Chance Event
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023

Document Path: M:\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure10_6_ProposedConditions2PercentInundationMapping.mxd

User Name: enaab



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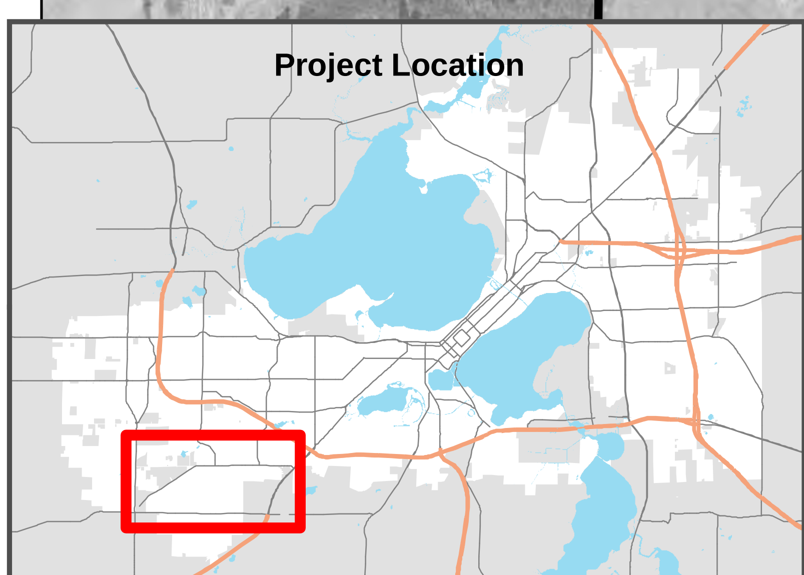

Legend

- Greenway
- Pond
- Municipal Limits
- Park
- Watershed Boundary

Maximum Depth (ft)

- .5-1
- 1-2
- 2-3
- 3-4
- 4-5
- 5+

Figure 10-7
Proposed Conditions Inundation Mapping
1% Chance Event
East Badger Mill Creek Watershed

CITY OF MADISON ENGINEERING

0 1,400 2,800 Feet

Date: 2/3/2023

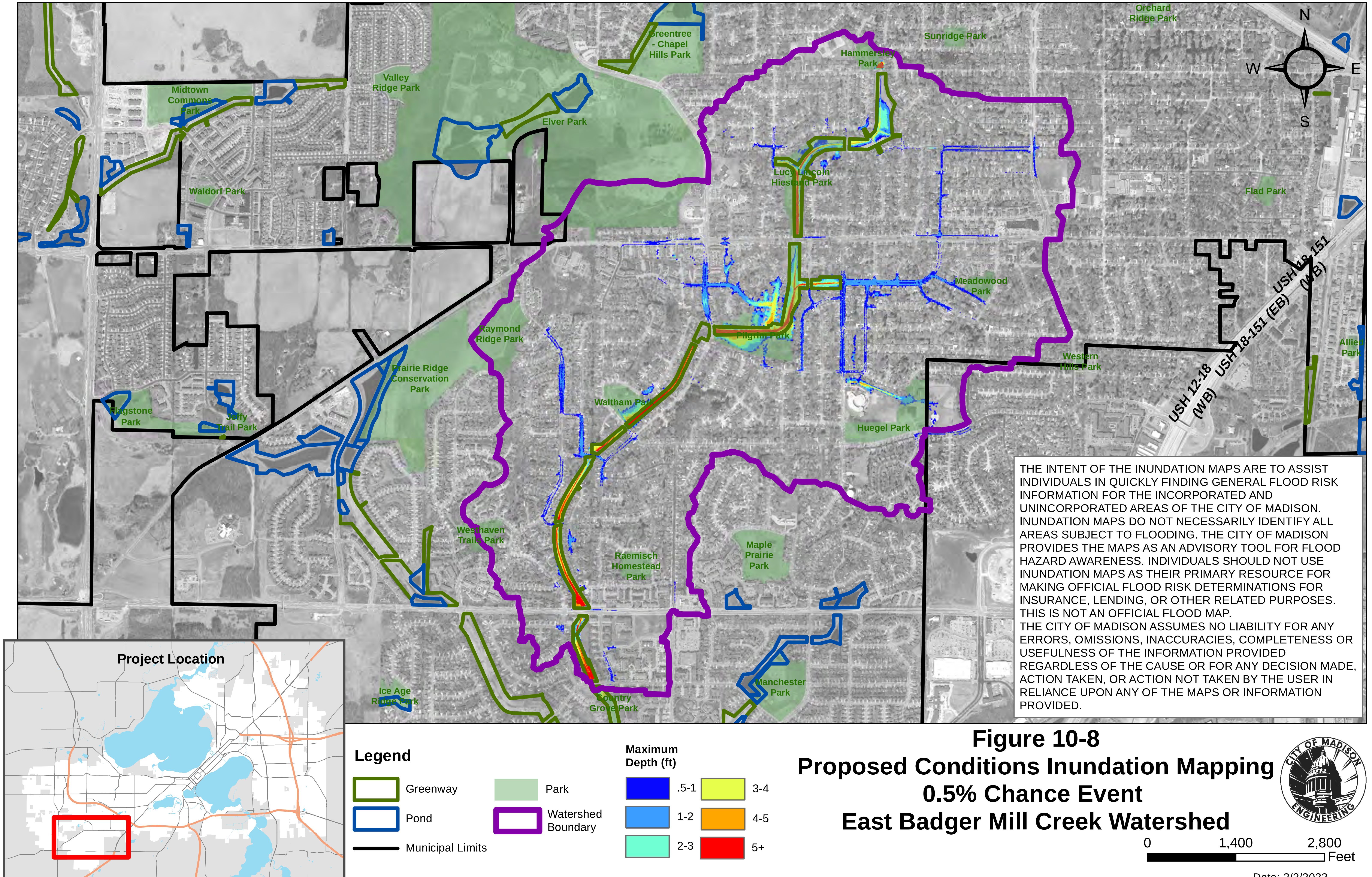

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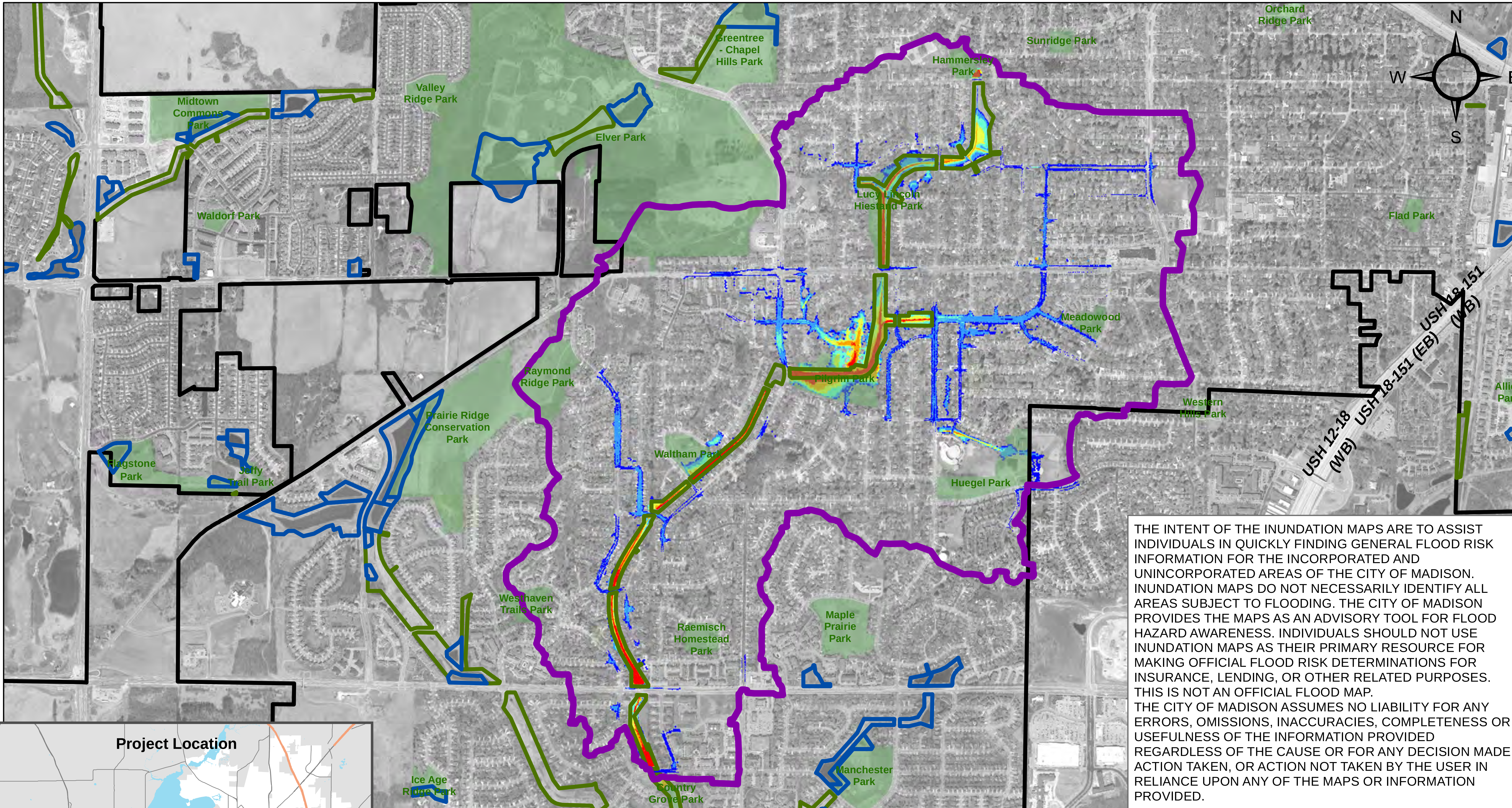
Figure 10-8
Proposed Conditions Inundation Mapping
0.5% Chance Event
East Badger Mill Creek Watershed



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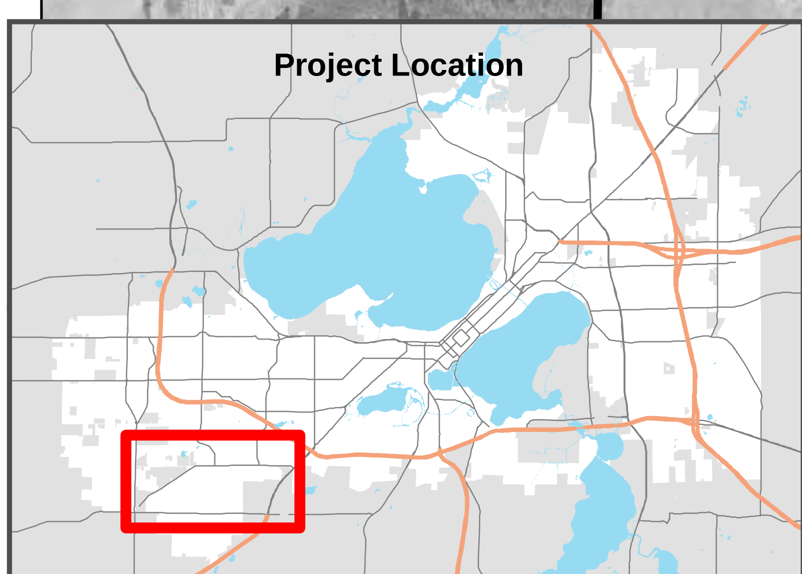


Legend

- Greenway
- Pond
- Municipal Limits
- Park
- Watershed Boundary

Maximum Depth (ft)

- .5-1
- 1-2
- 2-3
- 3-4
- 4-5
- 5+

Figure 10-9
Proposed Conditions Inundation Mapping
0.2% Chance Event
East Badger Mill Creek Watershed

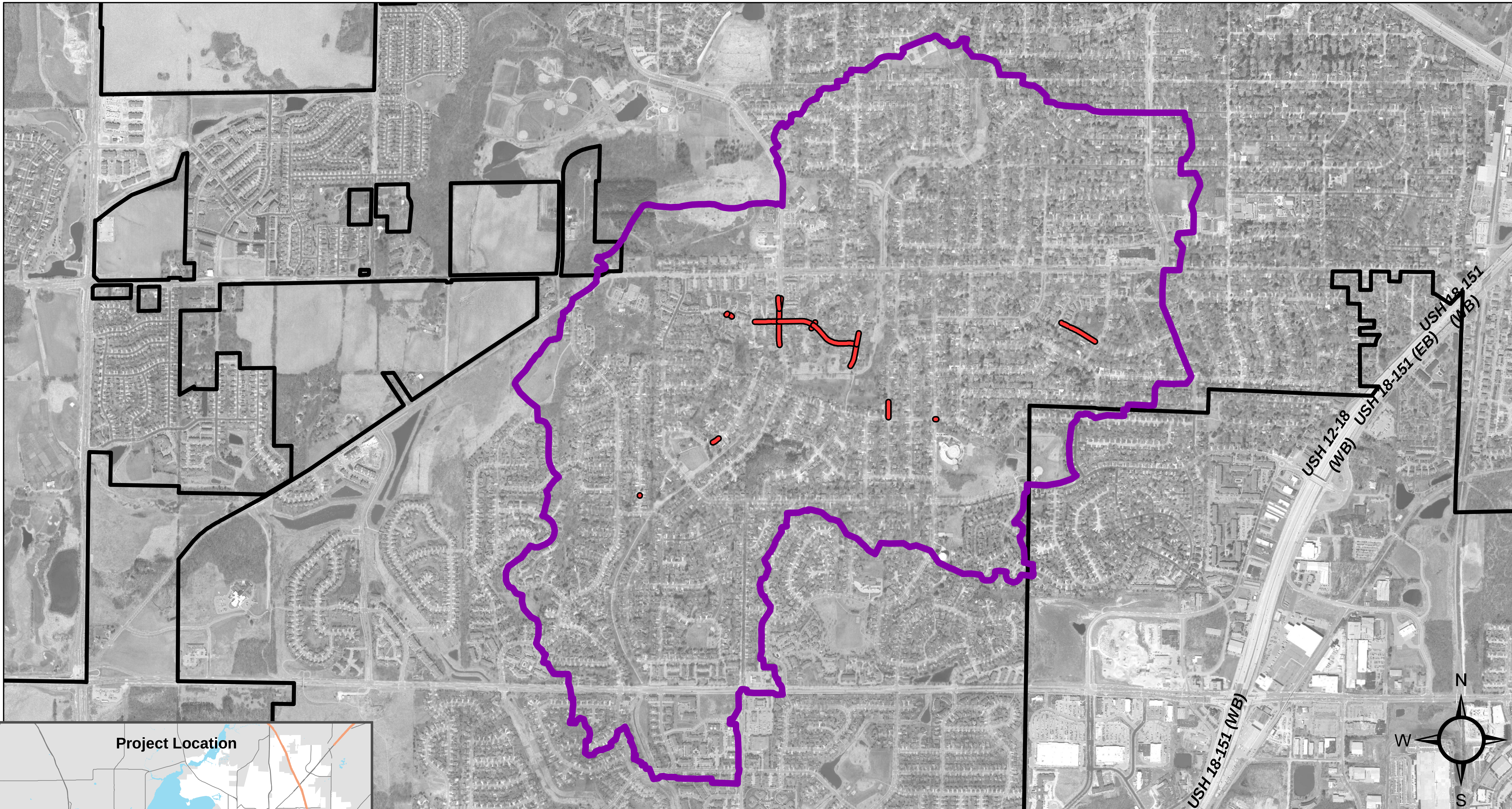
CITY OF MADISON ENGINEERING

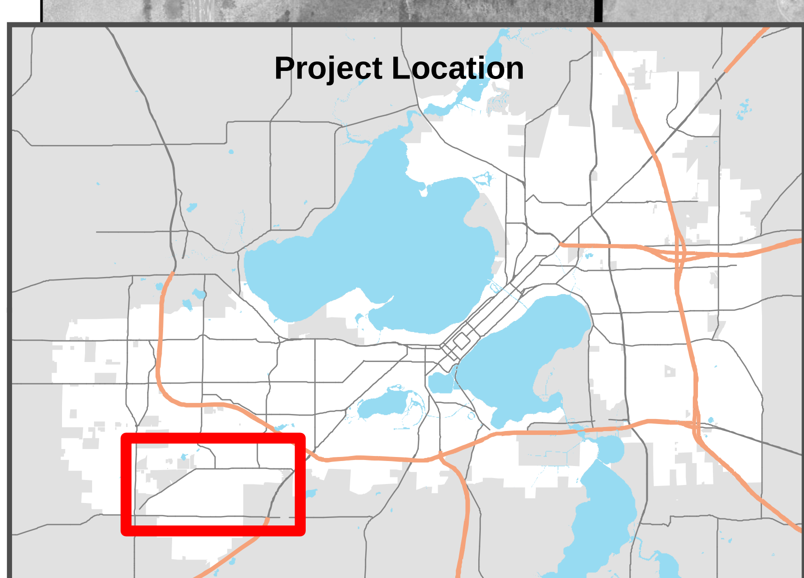
0 1,400 2,800 Feet

Date: 2/3/2023

Document Path: M:\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure10_9_ProposedConditions.2PercentInundationMapping.mxd

User Name: enaab





Legend

- Watershed Boundary
- Municipal Limits
- Streets Not Meeting Target

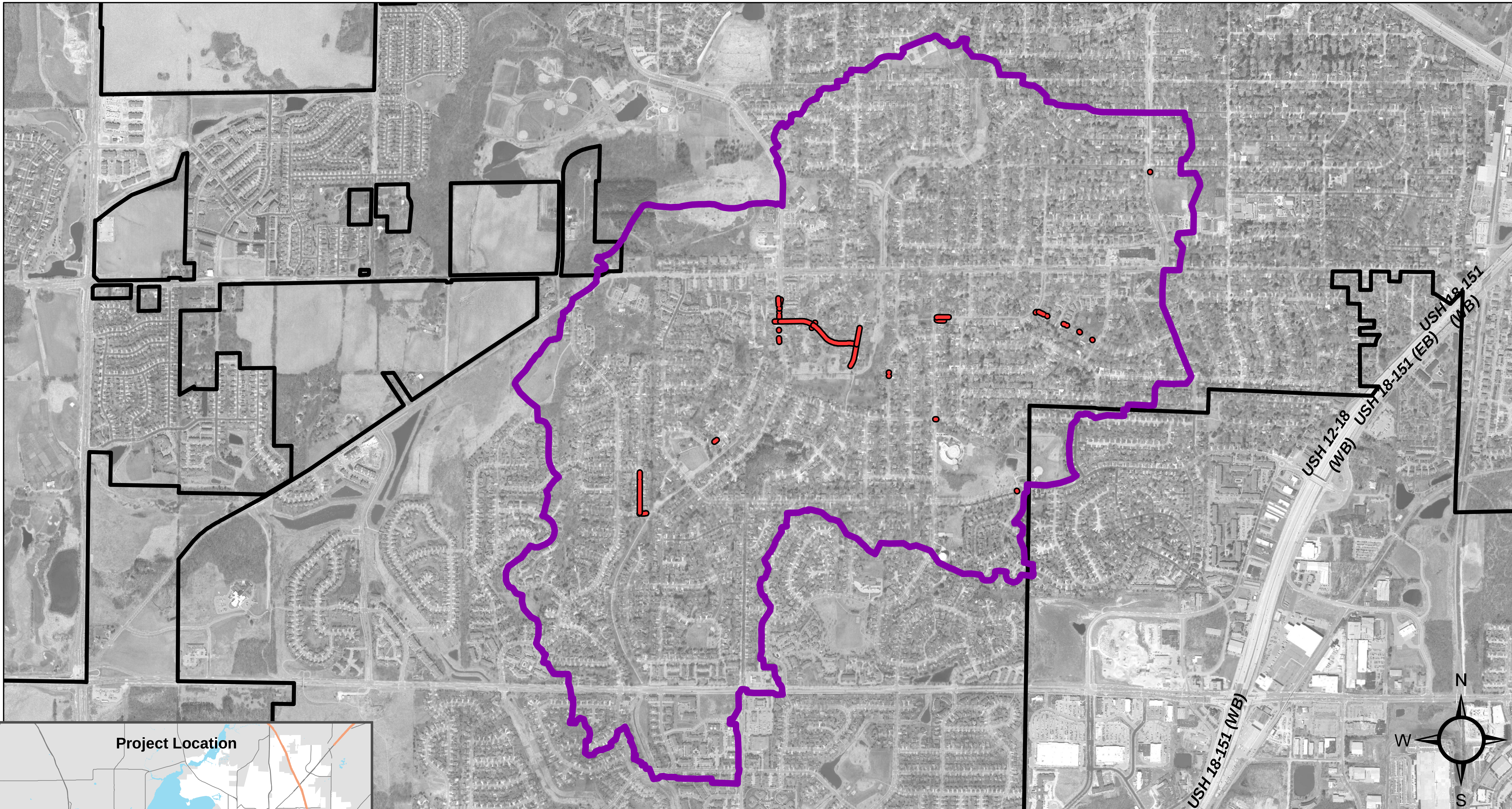
Figure 10-10
Proposed Conditions
Streets Not Meeting 10% Chance Event Target
East Badger Mill Creek Watershed

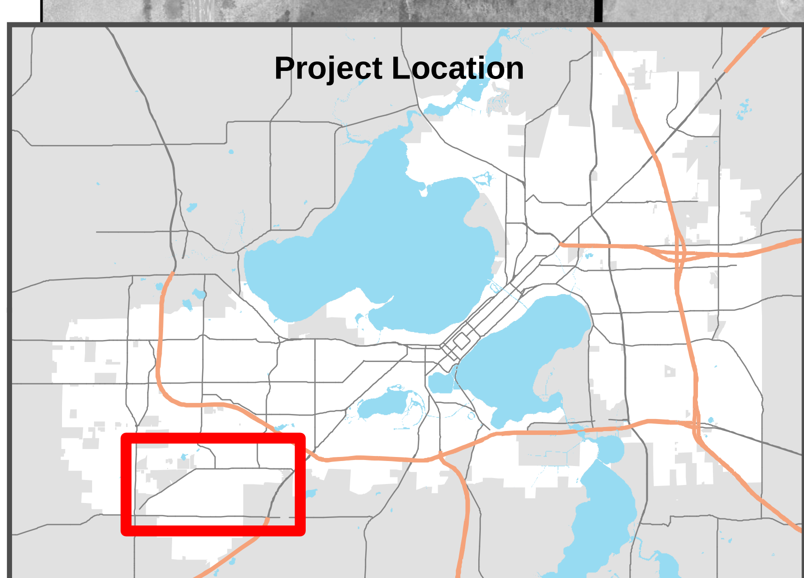
0 1,400 2,800 Feet

Date: 2/3/2023

Document Path: \\Gisserver\data\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure10_10_StreetsNotMeeting10PercentChanceEventTargetProposed.m

User Name: enaab





Legend

- Watershed Boundary
- Municipal Limits
- Streets Not Meeting Target

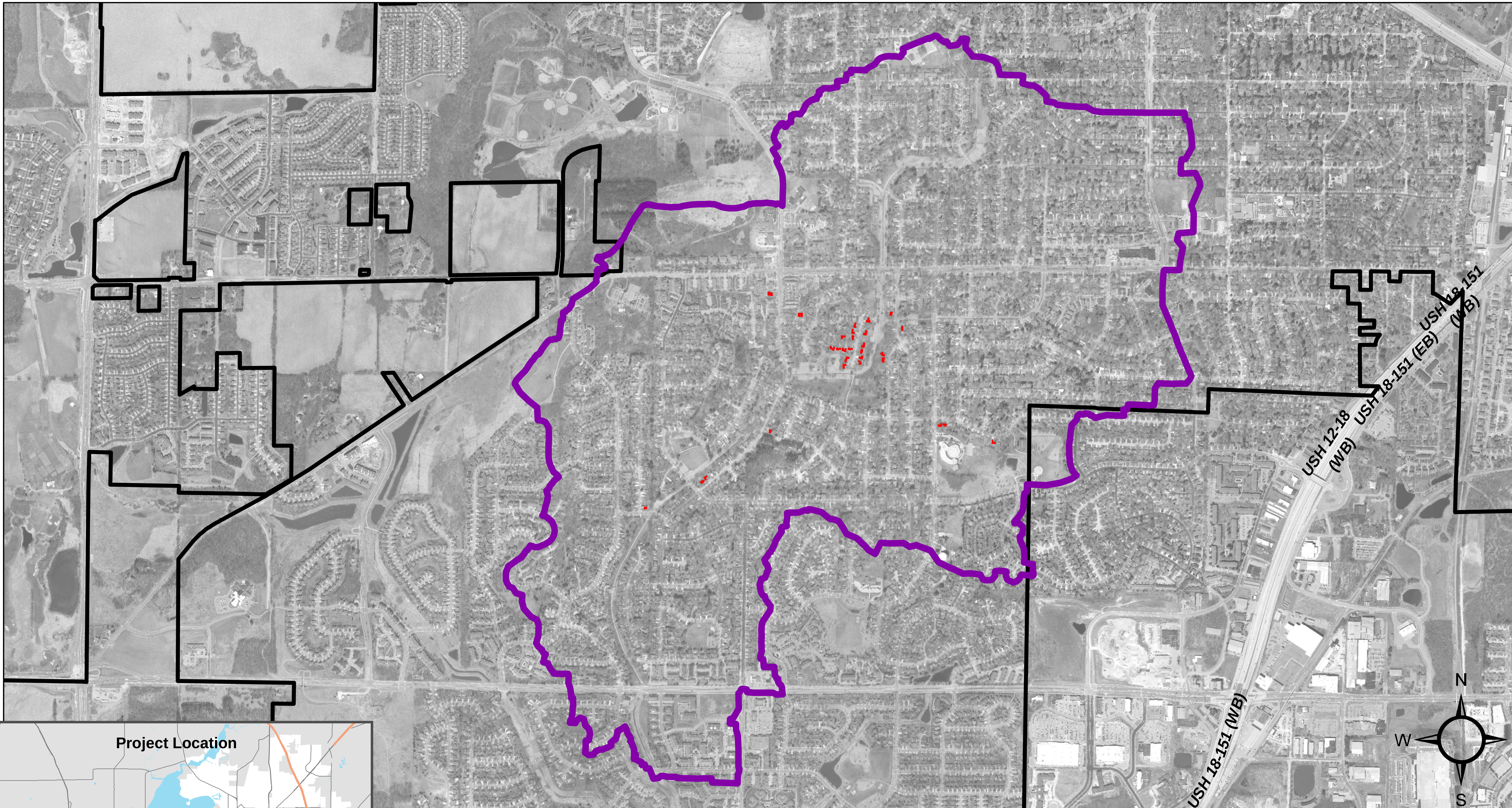
Figure 10-11
Proposed Conditions
Streets Not Meeting 4% Chance Event Target
East Badger Mill Creek Watershed

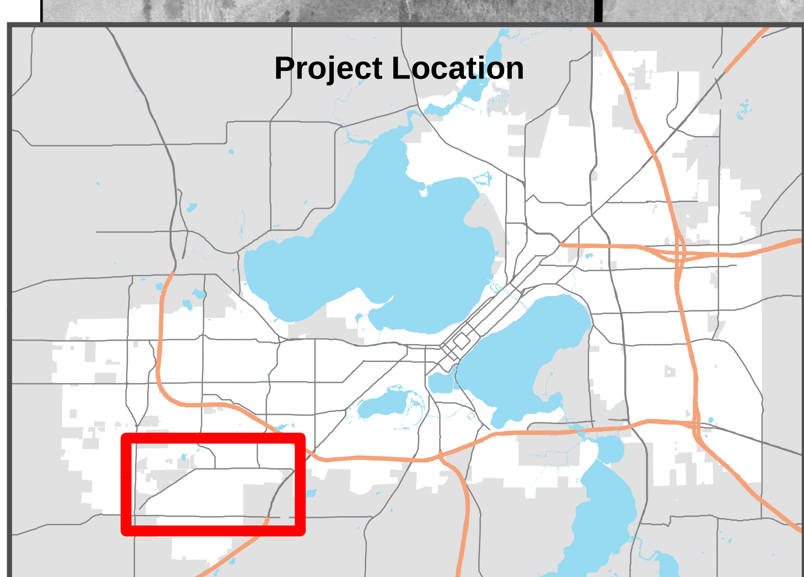
0 1,400 2,800 Feet

Date: 2/3/2023

Document Path: \\Gisserver\data\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure10_11_StreetsNotMeeting4PercentChanceEventTargetProposed.mx

User Name: enaab





Legend

- Watershed Boundary
- Municipal Limits
- Streets Not Meeting Target
- Structures & Greenway Crossings Not Meeting Target

Figure 10-12
Proposed Conditions
Structures & Greenway Crossings Not Meeting 1% Chance Event Target
East Badger Mill Creek Watershed

0 1,400 2,800 Feet

Date: 2/3/2023

Document Path: \\Gisserver\data\DESIGN\Projects\12491\GIS\MXDs\Figures\Figure10_12_Structures&GreenwayCrossingsNotMeeting1PercentChance

User Name: enaab

Appendix A. – Modeling Guidance

MODELING GUIDANCE

Version 2020-07-14 (DRAFT)

Round 1 and Round 2 Study Consultants

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 aim for relative uniformity amongst all City models. Therefore, the Consultant may be expected to justify, document, and in some instances, modify various model inputs and assumptions.

City of Madison Flood Mitigation Goals

1. No home or business will be flooded during the 100-year design storm.
2. Eliminate flooding from the storm sewer system for up to the 10-year design storm; all water shall be contained within the pipes and structures (exception: low points).
3. Allow no more than 0.5 feet of water above storm sewer inlet rim at inlet-restricted low points for up to the 10-year design storm.
4. Centerline of street to remain passable during 25-year design storm with no more than 0.2 feet of water at the centerline.
    a. 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.
5. 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).
6. Greenway crossings at streets to be served to the 100-year design storm.
7. Provide flooding solutions that do not negatively impact downstream properties.
8. 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 1-7 above.

Guidance for Solutions

1. Watershed deficiencies will be reviewed, and solutions will be provided up to the 100-yr design storm.
2. 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.
3. Proposed solutions will be identified for only the publicly owned drainage system. 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 identified 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. Arterials
    a. SUVs – up to 6-inches
    b. Large Trucks – up to 3-feet
    c. Ambulances, vans, and pick-up trucks – between 6-inches and 3-feet

MODELING PARAMETERS:

Initial model parameters are the following items:

1. Model all storm sewer and culvert segments 18 inches in diameter (or equivalent) and larger, noting that the model will be required to identify all watershed deficiencies, including inlet capacity. Inclusion of smaller diameter pipes may be required to meet the goals of the model.

2. Street inlets are to be aggregated within the model to the 18-inch diameter (or equivalent) storm sewer level.
3. Incorporate 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: Wisconsin County Coordinate System – Dane Zone NAD83 (HARN).
    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.
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
    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.
    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) will be removed
            2. Leads with an asset ID that takes up all 20 characters can be shortened to the corresponding assigned ID. For example, 3350-032_3350-007_3350-001 can be changed to 3350-032_3350-001_01
        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. Rainfall
   a. MSE4 24-hour Distribution and NOAA Atlas 14 Depths

Recurrence Interval (years)	Rainfall Depth (inches)
2	2.8
5	3.5
10	4.1
25	5.0
50	5.7
100	6.6
500	8.8

   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.

10. Hydrology (SWMM Method with Horton Infiltration) (References: A, B, C, J)
   - 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)
      ii. Provides information that there is or is not an issue with upstream street flooding / storm sewer capacity that would be detailed out as part of a future street improvement design project.
   b. SWMM Routing Parameters (if calibration is not available to adjust parameters)
      i. Percent Impervious - Follow Step 1 (pages 1-3) of the "HowTo_CalculateCN" document.
      ii. DCIA – 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. The single width with then be prorated based on sub area acreage for each sub area. DCIA will be prorated based on the area of the DCIA sub area compared to the total subcatchment area. The prorated width for the non-DCIA sub area and pervious sub area will be the same; it will be based on the sum of the non-DCIA plus the pervious area compared to the total subcatchment area.
It is expected Width is one of the first calibration parameters for peak flow.
Note: Round 1 calibration found using the same width for all three sub-areas (not prorating) resulted in closer calibration.

iv. Slope – Computed manually or estimated based on LiDAR. Computation or estimation methodology shall be documented.

v. 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.

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]
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

[a]For 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).
[b]Use 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
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.

11. 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: 18” Pipes and Larger
2. Process for Exceptions: Provide justification for reason that a pipe 18” and

larger does not need to be modeled.

3. Process for requiring inclusion of pipes less than 18": Necessary when they are the only pipes draining parts of the street or drainage system. For example, a 15" pipe stubbing out to a greenway from the street or a long trunk-line that is less than 18".

ii. Private
   1. Standard: Not included
   2. Process for requiring inclusion of private pipes:
      a. Stormwater management detention facilities
      b. When necessary to understand the functioning of the public system. For example, the West Towne Mall parking lot drainage system.

iii. All greenways and major surface drainages

iv. All stormwater detention facilities (public and private). Private systems may be simplified if serving a single site.

v. Street surface drainage, but not necessary to the block level unless needed to understand major overflow routes

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) straight-thru = 0.05
      3. Storm Sewer (internal at MHs) at 45 degree bend = 0.25
      4. Storm Sewer (internal at MHs) 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) straight-thru = 0.05
      3. Storm Sewer (internal at MHs) at 45 degree bend = 0.25
      4. Storm Sewer (internal at MHs) 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. All 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 Wingra (100-year): 848.0
    g. Inlet Clogging Factors
        i. Continuous Slopes
            1. Street slope < 1% - 25% Clogging
            2. Street slope >= 1% - No Clogging
        ii. Sags – 50% Clogging

12. 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.

13. 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.

14. 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
d. Overlay TIP map with inundation mapping to understand where immediate project opportunities are
e. Freeboard – City does not have a minimum freeboard requirement
f. 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. Help File
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D. SWMM reference manual volume volume II – hydraulics (Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100S9AS.PDF?Dockey=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.
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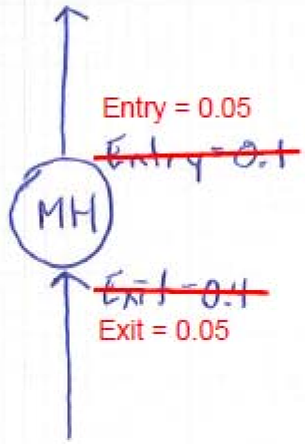
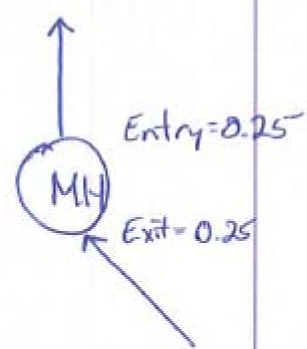
References/Notes

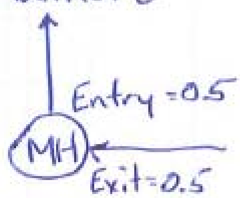
Straight-Through Manhole



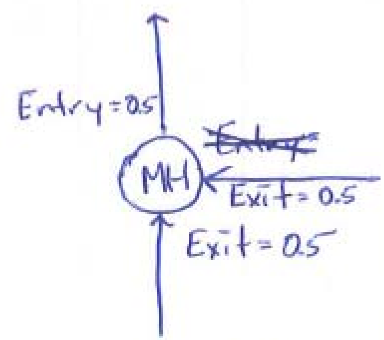
45° Bend Manhole

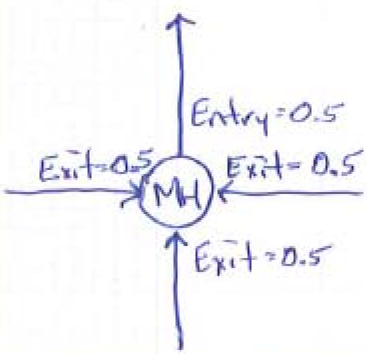


90° Bend Manhole

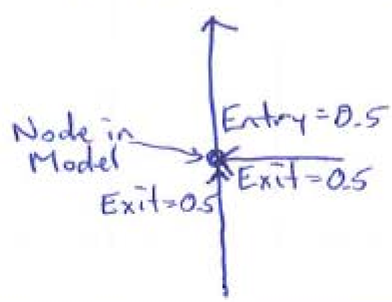


TEE Manhole





TEE (No Manhole)



Appendix B. – Hydrologic Input Parameters

Subcatchment Name	Rain Gage	Outlet	Area (ac)	Width (ft)	Flow Length (ft)	Slope (%)	Imperv (%)	N Imperv	N Perv	Dstore Imperv (in)	Dstore Perv (in)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Max. Infil. Rate (in/hr)	Min. Infil. Rate (in/hr)
AE2672-021-S	Walthum_Park_RG	991	10.739	548.5	852.9	4.160	19.50	0.016	0.2	0.05	0.15	25	PERVIOUS	60.778	2.00	0.50
AE2868-010-S	Walthum_Park_RG	J55605	3.385	129.8	1135.6	2.647	31.60	0.016	0.2	0.05	0.15	25	PERVIOUS	53.662	1.53	0.36
AE2870-006-S	Walthum_Park_RG	998	2.946	486.2	264.0	14.093	17.64	0.016	0.2	0.05	0.15	25	PERVIOUS	69.514	2.00	0.50
AE3064-015-S	Greentree_Park_RG	995	18.762	367.4	2224.4	3.821	29.58	0.016	0.2	0.05	0.15	25	PERVIOUS	58.185	1.26	0.28
AE3066-017-S	Meadowood_Park_RG	996	14.517	1024.8	617.0	2.368	13.11	0.016	0.2	0.05	0.15	25	PERVIOUS	75.865	0.86	0.20
AS2669-007-S	Walthum_Park_RG	AS2669-007	19.224	404.6	2069.7	5.184	30.29	0.016	0.2	0.05	0.15	25	PERVIOUS	31.695	1.49	0.35
AS2669-019-S	Walthum_Park_RG	AS2669-019	10.107	347.9	1265.3	6.938	24.52	0.016	0.2	0.05	0.15	25	PERVIOUS	37.935	1.57	0.37
AS2669-027-S	Walthum_Park_RG	AS2669-027	13.837	275.3	2189.4	5.246	30.89	0.016	0.2	0.05	0.15	25	PERVIOUS	39.39	1.87	0.46
AS2670-032-S	Walthum_Park_RG	AS2670-032	8.071	351.8	999.4	9.408	43.34	0.016	0.2	0.05	0.15	25	PERVIOUS	36.009	1.87	0.46
AS2670-044-S	Walthum_Park_RG	AS2670-044	12.871	275.3	2036.3	3.960	34.90	0.016	0.2	0.05	0.15	25	PERVIOUS	49.521	2.00	0.50
AS2671-006-S	Walthum_Park_RG	AS2671-006	12.243	255.5	2086.9	7.300	32.32	0.016	0.2	0.05	0.15	25	PERVIOUS	44.615	1.57	0.37
AS2671-014-S	Walthum_Park_RG	AS2671-014	5.696	211.1	1175.5	2.995	44.47	0.016	0.2	0.05	0.15	25	PERVIOUS	36.627	2.00	0.50
AS2672-011-S	Walthum_Park_RG	AS2672-011	23.453	327.6	3118.5	3.937	41.98	0.016	0.2	0.05	0.15	25	PERVIOUS	38.833	1.66	0.40
AS2672-031-S	Walthum_Park_RG	AS2672-031	14.705	488.7	1310.8	10.282	34.41	0.016	0.2	0.05	0.15	25	PERVIOUS	43.94	1.43	0.33
AS2673-2018-S	Manchester_Park_RG	AS2673-2018	5.390	153.9	1525.2	2.873	60.16	0.016	0.2	0.05	0.15	25	PERVIOUS	26.173	2.00	0.50
AS2768-005-S	Walthum_Park_RG	AS2768-005	8.813	234.1	1639.6	4.903	44.12	0.016	0.2	0.05	0.15	25	PERVIOUS	38.209	1.89	0.47
AS2770-005-S	Walthum_Park_RG	AS2770-005	14.429	291.3	2157.4	6.491	34.96	0.016	0.2	0.05	0.15	25	PERVIOUS	36.676	1.59	0.39
AS2771-001-S	Walthum_Park_RG	AS2771-001	7.700	247.6	1354.7	2.464	31.43	0.016	0.2	0.05	0.15	25	PERVIOUS	49.388	2.00	0.50
AS2773-012-S	Manchester_Park_RG	AS2773-012	8.033	302.1	1158.3	3.446	70.16	0.016	0.2	0.05	0.15	25	PERVIOUS	31.892	2.00	0.50
AS2865-004-S	Greentree_Park_RG	AS2865-004	7.850	254.3	1344.5	3.390	35.10	0.016	0.2	0.05	0.15	25	PERVIOUS	43.117	1.80	0.44
AS2866-004-S	Greentree_Park_RG	AS2866-004	11.442	377.1	1321.6	2.395	34.20	0.016	0.2	0.05	0.15	25	PERVIOUS	40.269	1.89	0.47
AS2867-004-S	Greentree_Park_RG	AS2867-004	14.934	453.6	1434.3	2.216	53.94	0.016	0.2	0.05	0.15	25	PERVIOUS	31.792	2.00	0.50
AS2867-019-S	Greentree_Park_RG	AS2867-019	13.249	261.7	2205.1	6.999	28.19	0.016	0.2	0.05	0.15	25	PERVIOUS	20.145	2.00	0.50
AS2867-025-S	Greentree_Park_RG	AS2867-025	8.923	329.5	1179.7	6.450	40.04	0.016	0.2	0.05	0.15	25	PERVIOUS	3.094	2.00	0.50
AS2868-009-S	Walthum_Park_RG	AS2868-009	9.017	337.2	1164.7	3.911	64.40	0.016	0.2	0.05	0.15	25	PERVIOUS	30.844	1.89	0.47
AS2868-025-S	Walthum_Park_RG	AS2868-025	9.796	351.7	1213.4	8.222	41.70	0.016	0.2	0.05	0.15	25	PERVIOUS	35.016	1.58	0.39
AS2868-035-S	Walthum_Park_RG	AS2868-035	3.804	180.1	919.9	6.210	43.35	0.016	0.2	0.05	0.15	25	PERVIOUS	32.568	1.22	0.27
AS2873-010-S	Walthum_Park_RG	AS2873-010	11.449	265.2	1880.9	3.823	42.06	0.016	0.2	0.05	0.15	25	PERVIOUS	35.738	2.00	0.50
AS2874-019-S	Manchester_Park_RG	AS2874-019	3.847	204.9	818.1	0.837	77.16	0.016	0.2	0.05	0.15	25	PERVIOUS	5.142	2.00	0.50
AS2965-007-S	Greentree_Park_RG	AS2965-007	19.409	354.7	2383.5	2.218	40.74	0.016	0.2	0.05	0.15	25	PERVIOUS	34.148	1.81	0.44
AS2965-008-S	Meadowood_Park_RG	AS2965-008	2.303	68.5	1463.9	2.908	58.60	0.016	0.2	0.05	0.15	25	PERVIOUS	25.386	2.00	0.50
AS2965-2022-S	Greentree_Park_RG	AS2965-2022	5.616	204.0	1199.2	3.864	44.80	0.016	0.2	0.05	0.15	25	PERVIOUS	37.959	2.00	0.50
AS2966-009-S	Greentree_Park_RG	AS2966-009	15.643	520.6	1308.9	2.318	31.95	0.016	0.2	0.05	0.15	25	PERVIOUS	34.388	2.00	0.50
AS2967-006-S	Meadowood_Park_RG	IN2967-002	5.476	165.6	1440.7	2.293	58.68	0.016	0.2	0.05	0.15	25	PERVIOUS	21.871	2.00	0.50
AS2967-007-S	Meadowood_Park_RG	AS2967-007	14.316	380.7	1638.2	1.097	44.15	0.016	0.2	0.05	0.15	25	PERVIOUS	38.028	2.00	0.50
AS2968-011-S	Meadowood_Park_RG	AS2968-011	11.465	355.3	1405.6	0.604	47.21	0.016	0.2	0.05	0.15	25	PERVIOUS	38.409	1.81	0.44
AS2968-019-S	Meadowood_Park_RG	AS2968-019	9.258	368.3	1094.9	1.354	36.61	0.016	0.2	0.05	0.15	25	PERVIOUS	49.697	2.00	0.50
AS2969-002-S	Meadowood_Park_RG	993	16.649	682.1	1063.2	2.042	11.76	0.016	0.2	0.05	0.15	25	PERVIOUS	67.312	0.82	0.18
AS2969-004-S	Meadowood_Park_RG	AS2969-004	6.802	201.6	1469.7	0.750	38.37	0.016	0.2	0.05	0.15	25	PERVIOUS	38.23	2.00	0.50
AS2969-008-S	Walthum_Park_RG	AS2969-008	21.828	312.4	3043.5	4.432	43.82	0.016	0.2	0.05	0.15	25	PERVIOUS	33.609	2.00	0.50
AS2969-024-S	Walthum_Park_RG	AS2969-024	20.566	310.0	2890.3	4.820	38.17	0.016	0.2	0.05	0.15	25	PERVIOUS	43.143	1.94	0.48
AS2969-035-S	Walthum_Park_RG	AS2969-035	20.870	469.4	1936.8	0.563	43.24	0.016	0.2	0.05	0.15	25	PERVIOUS	37.155	1.59	0.38
AS3067-005-S	Meadowood_Park_RG	AS3067-005	10.437	346.4	1312.3	1.150	42.95	0.016	0.2	0.05	0.15	25	PERVIOUS	35.682	1.26	0.30
AS3068-007-S	Meadowood_Park_RG	AS3068-007	10.648	320.6	1446.7	2.110	31.20	0.016	0.2	0.05	0.15	25	PERVIOUS	46.724	2.00	0.50

Subcatchment Name	Rain Gage	Outlet	Area (ac)	Width (ft)	Flow Length (ft)	Slope (%)	Imperv (%)	N Imperv	N Perv	Dstore Imperv (in)	Dstore Perv (in)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Max. Infil. Rate (in/hr)	Min. Infil. Rate (in/hr)
AS3068-068-S	Meadowood_Park_RG	AS3068-068	10.298	358.5	1251.2	2.443	34.89	0.016	0.2	0.05	0.15	25	PERVIOUS	32.278	2.00	0.50
AS3068-069-S	Meadowood_Park_RG	AS3068-069	2.670	102.3	1136.6	0.585	42.89	0.016	0.2	0.05	0.15	25	PERVIOUS	24.573	2.00	0.50
AS3068-072-S	Meadowood_Park_RG	AS3068-072	5.078	136.4	1622.3	1.074	25.80	0.016	0.2	0.05	0.15	25	PERVIOUS	58.625	2.00	0.50
AS3069-011-S	Meadowood_Park_RG	AS3069-011	10.111	462.3	952.7	1.734	46.35	0.016	0.2	0.05	0.15	25	PERVIOUS	33.016	2.00	0.50
AS3069-014-S	Meadowood_Park_RG	AS3069-014	7.726	197.4	1704.6	1.753	33.10	0.016	0.2	0.05	0.15	25	PERVIOUS	40.072	2.00	0.50
AS3069-019-S	Meadowood_Park_RG	AS3069-019	7.744	268.2	1257.9	2.629	38.23	0.016	0.2	0.05	0.15	25	PERVIOUS	38.752	2.00	0.50
AS3071-005-S	Meadowood_Park_RG	AS3071-005	14.868	324.7	1994.5	4.309	35.60	0.016	0.2	0.05	0.15	25	PERVIOUS	37.37	1.99	0.50
AS3166-010-S	Meadowood_Park_RG	AS3166-010	12.024	207.6	2522.5	0.882	29.37	0.016	0.2	0.05	0.15	25	PERVIOUS	42.898	2.00	0.50
AS3166-018-S	Meadowood_Park_RG	AS3166-018	18.758	333.1	2453.0	0.948	30.63	0.016	0.2	0.05	0.15	25	PERVIOUS	37.22	2.00	0.50
AS3167-010-S	Meadowood_Park_RG	AS3167-010	11.997	388.6	1344.8	1.164	69.54	0.016	0.2	0.05	0.15	25	PERVIOUS	14.788	1.80	0.45
AS3167-011-S	Meadowood_Park_RG	AS3167-016	23.709	405.6	2546.5	1.017	36.82	0.016	0.2	0.05	0.15	25	PERVIOUS	39.435	1.94	0.49
AS3168-024-S	Meadowood_Park_RG	AS3168-024	5.264	201.5	1138.2	1.599	22.98	0.016	0.2	0.05	0.15	25	PERVIOUS	38.104	2.00	0.50
AS3168-043-S	Meadowood_Park_RG	AS3168-043	8.621	209.6	1791.2	1.828	45.90	0.016	0.2	0.05	0.15	25	PERVIOUS	28.688	2.00	0.50
AS3169-009-S	Meadowood_Park_RG	AS3169-009	24.202	403.6	2611.9	0.880	44.38	0.016	0.2	0.05	0.15	25	PERVIOUS	23.085	1.97	0.49
AS3266-002-S	Meadowood_Park_RG	AS3266-002	23.936	424.1	2458.6	0.364	32.73	0.016	0.2	0.05	0.15	25	PERVIOUS	35.987	2.00	0.50
CB3068-070-S	Meadowood_Park_RG	CB3068-070	7.888	253.4	1356.3	1.172	34.14	0.016	0.2	0.05	0.15	25	PERVIOUS	31.804	2.00	0.50
GR2673-025-S	Walthum_Park_RG	990	11.004	687.9	696.8	4.935	18.34	0.016	0.2	0.05	0.15	25	PERVIOUS	66.419	2.00	0.50
GR2770-014-S	Walthum_Park_RG	J2953	10.416	359.1	1263.5	5.273	10.05	0.016	0.2	0.05	0.15	25	PERVIOUS	72.507	1.95	0.49
GR2771-017-S	Walthum_Park_RG	J7457	8.102	272.4	1295.7	3.351	19.86	0.016	0.2	0.05	0.15	25	PERVIOUS	59.399	1.85	0.46
GR2775-016-S	Manchester_Park_RG	989	8.802	725.5	528.5	4.045	20.65	0.016	0.2	0.05	0.15	25	PERVIOUS	67.869	2.00	0.50
GR2869-008-S	Walthum_Park_RG	992	14.716	826.3	775.8	4.373	7.12	0.016	0.2	0.05	0.15	25	PERVIOUS	64.355	1.03	0.24
GR2967-004-S	Greentree_Park_RG	994	22.305	1684.8	576.7	5.391	9.87	0.016	0.2	0.05	0.15	25	PERVIOUS	90.007	1.82	0.45
IN2669-012-S	Walthum_Park_RG	IN2669-012	22.962	446.1	2241.9	5.452	16.73	0.016	0.2	0.05	0.15	25	PERVIOUS	25.108	1.71	0.41
IN2669-016-S	Walthum_Park_RG	IN2669-016	4.637	127.9	1579.5	5.884	42.25	0.016	0.2	0.05	0.15	25	PERVIOUS	37.765	2.00	0.50
IN2672-014-S	Walthum_Park_RG	IN2672-014	13.324	183.4	3164.7	2.654	41.91	0.016	0.2	0.05	0.15	25	PERVIOUS	34.107	2.00	0.50
IN2672-024-S	Walthum_Park_RG	IN2672-024	12.270	219.9	2430.9	3.510	35.62	0.016	0.2	0.05	0.15	25	PERVIOUS	42.359	2.00	0.50
IN2672-029-S	Walthum_Park_RG	IN2672-029	4.056	242.6	728.2	4.498	40.00	0.016	0.2	0.05	0.15	25	PERVIOUS	42.688	2.00	0.50
IN2673-001-S	Walthum_Park_RG	IN2673-001	2.226	151.7	639.3	3.860	40.21	0.016	0.2	0.05	0.15	25	PERVIOUS	45.391	2.00	0.50
IN2673-007-S	Walthum_Park_RG	IN2673-007	15.484	291.9	2310.4	2.468	41.18	0.016	0.2	0.05	0.15	25	PERVIOUS	40.216	2.00	0.50
IN2673-029-S	Walthum_Park_RG	IN2673-029	19.172	333.8	2502.1	3.398	37.45	0.016	0.2	0.05	0.15	25	PERVIOUS	36.307	2.00	0.50
IN2674-001-S	Manchester_Park_RG	IN2674-001	2.856	139.3	893.3	1.940	43.95	0.016	0.2	0.05	0.15	25	PERVIOUS	41.149	2.00	0.50
IN2674-007-S	Manchester_Park_RG	IN2674-007	4.812	157.2	1333.6	5.010	41.64	0.016	0.2	0.05	0.15	25	PERVIOUS	37.986	2.00	0.50
IN2674-008-S	Manchester_Park_RG	IN2674-008	2.684	159.7	732.1	5.457	43.60	0.016	0.2	0.05	0.15	25	PERVIOUS	33.465	2.00	0.50
IN2768-001-S	Walthum_Park_RG	IN2768-001	2.368	106.7	966.8	2.828	54.21	0.016	0.2	0.05	0.15	25	PERVIOUS	34.548	2.00	0.50
IN2768-009-S	Walthum_Park_RG	IN2768-010	10.827	325.9	1447.0	6.685	46.15	0.016	0.2	0.05	0.15	25	PERVIOUS	29.186	1.76	0.43
IN2768-012-S	Greentree_Park_RG	IN2768-012	30.028	560.8	2332.3	3.606	16.07	0.016	0.2	0.05	0.15	25	PERVIOUS	30.741	1.58	0.37
IN2770-007-S	Walthum_Park_RG	IN2770-007	22.161	336.3	2870.3	4.869	34.75	0.016	0.2	0.05	0.15	25	PERVIOUS	40.73	1.69	0.41
IN2770-018-S	Walthum_Park_RG	TP2770-017	6.183	115.2	2338.4	3.495	59.89	0.016	0.2	0.05	0.15	25	PERVIOUS	28.968	1.92	0.48
IN2771-006-S	Walthum_Park_RG	IN2771-006	31.610	548.9	2508.4	4.424	37.55	0.016	0.2	0.05	0.15	25	PERVIOUS	40.986	2.00	0.50
IN2774-002-S	Manchester_Park_RG	IN2774-002	4.246	166.0	1114.4	2.342	61.43	0.016	0.2	0.05	0.15	25	PERVIOUS	27.818	2.00	0.50
IN2774-014-S	Manchester_Park_RG	IN2774-014	1.984	64.2	1345.2	2.202	71.34	0.016	0.2	0.05	0.15	25	PERVIOUS	7.58	2.00	0.50
IN2775-010-S	Manchester_Park_RG	IN2775-010	16.966	479.4	1541.7	1.220	57.73	0.016	0.2	0.05	0.15	25	PERVIOUS	42.432	2.00	0.50
IN2866-011-S	Greentree_Park_RG	IN2866-011	3.911	150.4	1132.3	2.601	53.65	0.016	0.2	0.05	0.15	25	PERVIOUS	29.256	2.00	0.50
IN2868-031-S	Walthum_Park_RG	IN2868-031	7.938	223.5	1547.3	3.189	52.80	0.016	0.2	0.05	0.15	25	PERVIOUS	40.992	1.81	0.44

Subcatchment Name	Rain Gage	Outlet	Area (ac)	Width (ft)	Flow Length (ft)	Slope (%)	Imperv (%)	N Imperv	N Perv	Dstore Imperv (in)	Dstore Perv (in)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Max. Infil. Rate (in/hr)	Min. Infil. Rate (in/hr)
IN2869-003-S	Walthum_Park_RG	IN2869-003	16.389	413.8	1725.3	6.360	33.51	0.016	0.2	0.05	0.15	25	PERVIOUS	36.444	1.42	0.34
IN2870-001-S	Walthum_Park_RG	IN2870-001	11.793	357.3	1438.0	1.246	35.07	0.016	0.2	0.05	0.15	25	PERVIOUS	41.751	1.58	0.39
IN2870-013-S	Walthum_Park_RG	IN2870-013	7.894	210.6	1632.6	3.621	38.56	0.016	0.2	0.05	0.15	25	PERVIOUS	34.798	1.95	0.49
IN2966-004-S	Greentree_Park_RG	IN2966-004	7.006	201.6	1513.5	0.556	35.69	0.016	0.2	0.05	0.15	25	PERVIOUS	43.098	1.49	0.37
IN2966-015-S	Meadowood_Park_RG	IN2966-015	4.078	132.8	1338.1	2.220	42.10	0.016	0.2	0.05	0.15	25	PERVIOUS	35.246	2.00	0.50
IN2966-026-S	Meadowood_Park_RG	IN2966-026	2.241	159.9	610.7	3.076	49.03	0.016	0.2	0.05	0.15	25	PERVIOUS	32.572	2.00	0.50
IN2966-032-S	Meadowood_Park_RG	TP2966-025	3.095	126.2	1068.6	1.750	57.98	0.016	0.2	0.05	0.15	25	PERVIOUS	24.729	1.61	0.40
IN2968-021-S	Meadowood_Park_RG	997	11.054	404.7	1189.7	2.441	37.15	0.016	0.2	0.05	0.15	25	PERVIOUS	38.246	0.93	0.19
IN2968-026-S	Meadowood_Park_RG	MI3068-028	6.561	210.7	1356.6	2.205	41.26	0.016	0.2	0.05	0.15	25	PERVIOUS	28.986	1.83	0.45
IN2969-025-S	Walthum_Park_RG	IN2969-025	20.390	303.6	2925.6	4.722	34.27	0.016	0.2	0.05	0.15	25	PERVIOUS	39.808	1.98	0.49
IN2969-027-S	Walthum_Park_RG	IN2969-027	9.179	212.3	1883.2	2.644	40.88	0.016	0.2	0.05	0.15	25	PERVIOUS	37.491	1.87	0.47
IN3066-002-S	Meadowood_Park_RG	IN3066-002	16.082	380.1	1842.9	0.638	38.86	0.016	0.2	0.05	0.15	25	PERVIOUS	42.083	1.75	0.43
IN3066-005-S	Meadowood_Park_RG	IN3066-005	15.362	356.8	1875.8	2.994	36.89	0.016	0.2	0.05	0.15	25	PERVIOUS	40.114	1.70	0.42
IN3066-019-S	Meadowood_Park_RG	IN3066-019	14.208	327.2	1891.4	1.002	42.42	0.016	0.2	0.05	0.15	25	PERVIOUS	43.472	1.99	0.50
IN3066-020-S	Meadowood_Park_RG	IN3066-020	8.255	238.4	1508.1	2.239	50.77	0.016	0.2	0.05	0.15	25	PERVIOUS	34.637	1.95	0.49
IN3070-008-S	Meadowood_Park_RG	IN3070-008	18.317	381.7	2090.3	2.971	31.36	0.016	0.2	0.05	0.15	25	PERVIOUS	36.086	2.00	0.50
IN3168-018-S	Meadowood_Park_RG	IN3168-018	3.390	209.6	704.5	1.877	27.93	0.016	0.2	0.05	0.15	25	PERVIOUS	41.422	2.00	0.50
IN3168-026-S	Meadowood_Park_RG	IN3168-026	5.475	128.2	1859.7	1.382	54.84	0.016	0.2	0.05	0.15	25	PERVIOUS	24.708	2.00	0.50
IN3169-001-S	Meadowood_Park_RG	IN3169-001	21.711	283.0	3341.9	0.904	36.43	0.016	0.2	0.05	0.15	25	PERVIOUS	40.013	2.00	0.50
IN3169-006-S	Meadowood_Park_RG	IN3169-006	17.943	366.5	2132.5	0.858	32.67	0.016	0.2	0.05	0.15	25	PERVIOUS	44.311	2.00	0.50
IN3266-024-S	Meadowood_Park_RG	IN3266-024	16.635	507.7	1427.1	0.621	33.77	0.016	0.2	0.05	0.15	25	PERVIOUS	14.6	1.98	0.50
PD-3204GCL-S	Manchester_Park_RG	GoldenCopper	10.472	458.8	994.3	4.935	31.35	0.016	0.2	0.05	0.15	25	PERVIOUS	44.709	2.00	0.50
PVT-3069-012-S	Meadowood_Park_RG	999	35.827	1039.2	1501.7	4.342	12.92	0.016	0.2	0.05	0.15	25	PERVIOUS	78.546	2.00	0.50

Appendix C. – Hydraulic Input Parameters

Existing Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
AE2672-020_IN2672-014	J5557	IN2672-014		35.2	0.013	0	0	0.2	0	HORIZ_ELLIPSE	5.25	8.17	32	0.00764
AE2672-021_AE2672-018	J5552	J2928		72.5	0.013	0	0	0.2	0.5	HORIZ_ELLIPSE	5.25	8.17	32	0.00888
AE2869-013_GR2869-014	J58018	J4131		87.4	0.013	0	0	0.5	0.5	CIRCULAR	6	0	2	0.00510
AE2869-015_IN2869-003	J58013	IN2869-003		43.7	0.013	0	0	0.5	0	CIRCULAR	6	0	2	0.00252
AE2966-023_AE2966-024	J1	J53970		14.2	0.013	0	0	0.5	0.5	CIRCULAR	3.5	0	2	0.00014
AE2966-US_AE2966-DS	J53751	J54093		39.0	0.013	0	0	0.5	0.5	HORIZ_ELLIPSE	2.83	4.42	31	0.00213
*AE2968-035_AE2968-037	J6691	J52905		70.0	0.022	0	0	0.5	0.5	HORIZ_ELLIPSE	4	6.33	45	0.00357
*AE2968-036_AE2968-038	J6690	J52904		70.0	0.022	0	0	0.5	0.5	HORIZ_ELLIPSE	4	6.33	45	0.00357
AE3064-015_AE3065-003	J94283	J63797		90.0	0.013	0	0	0.5	0.5	CIRCULAR	2.5	0	5	0.07142
AE3066-017_TP2966-025	J53021	TP2966-025		68.9	0.013	0	0	0.5	0	CIRCULAR	3.5	0	2	0.00235
AE3066-US_AE3066-DS	J94325	J53514		31.7	0.013	0	0	0.5	0.5	HORIZ_ELLIPSE	2.83	4.42	31	0.00063
AEPVT-PR01_IN3069-012	J57367	IN3069-012		153.1	0.013	0	0	0.5	0.05	CIRCULAR	2.5	0		0.00307
AS2669-007_AS2669-008	AS2669-007	AS2669-008		31.5	0.013	0	0	0.5	0.05	CIRCULAR	1.75	0		0.05724
AS2669-008_AS2669-019	AS2669-008	AS2669-019		328.1	0.013	0	0	0.05	0.05	CIRCULAR	1.75	0		0.03871
AS2669-019_AS2669-020	AS2669-019	AS2669-020		239.2	0.013	0	0	0.05	0.05	CIRCULAR	2.25	0		0.03346
AS2669-020_AS2669-027	AS2669-020	AS2669-027		144.6	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00671
AS2669-027_AS2670-031	AS2669-027	AS2670-031		283.3	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00568
AS2670-031_AS2670-032	AS2670-031	AS2670-032		376.0	0.013	0	0.04	0.05	0.5	CIRCULAR	3	0		0.00505
AS2670-032_AS2670-043	AS2670-032	AS2670-043		294.7	0.013	0	0	0.5	0.05	CIRCULAR	3	0		0.04335
AS2670-043_AS2670-044	AS2670-043	AS2670-044		25.8	0.013	0	0	0.05	0.5	CIRCULAR	3	0		0.02717
AS2670-044_AS2670-046	AS2670-044	AS2670-046		348.9	0.013	0	0.5	0.5	0.05	CIRCULAR	3	0		0.01522
AS2670-046_AS2671-014	AS2670-046	AS2671-014		288.9	0.013	0	0	0.05	0.5	CIRCULAR	3.5	0		0.00651
AS2671-006_IN2671-015	AS2671-006	IN2671-015		296.0	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.01102
AS2671-013_AE2671-007	AS2671-013	J6656		33.2	0.013	0	0	0.25	0.5	CIRCULAR	3.5	0		0.01809
AS2671-014_AS2671-013	AS2671-014	AS2671-013		110.0	0.013	0	0	0.5	0.25	CIRCULAR	3.5	0		0.01100
AS2672-010_AS2672-011	AS2672-010	AS2672-011		43.2	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.01876
AS2672-011_AS2672-016	AS2672-011	AS2672-016		285.8	0.013	0	0	0.5	0.5	CIRCULAR	2.25	0		0.01851
AS2672-016_AE2672-017	AS2672-016	J2929		20.3	0.013	0	0	0.5	0.5	CIRCULAR	2.5	0		0.04875
AS2672-031_AS2672-010	AS2672-031	AS2672-010		312.6	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.00646
AS2673-022_TP2673-023	AS2673-022	TP2673-023		45.0	0.013	0	0.78	0.05	0.5	CIRCULAR	2.25	0		0.08294
AS2768-005_IN2768-015	AS2768-005	IN2768-015		229.6	0.013	0	0	0.5	0.25	CIRCULAR	1.5	0		0.04928
AS2770-005_TP2770-017	AS2770-005	TP2770-017		235.1	0.013	0	3	0.05	0.5	CIRCULAR	1.75	0		0.01999
AS2771-001_TP2771-015	AS2771-001	TP2771-015		192.7	0.013	0	3.48	0.05	0.5	CIRCULAR	1.5	0		0.01022
AS2771-014_AE2671-022	AS2771-014	J6415		119.5	0.013	0	0	0.25	0.5	CIRCULAR	2	0		0.02863
AS2773-008_AS2673-022	AS2773-008	AS2673-022		36.0	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.00778
AS2773-009_AS2773-008	AS2773-009	AS2773-008		275.0	0.013	0	0	0.05	0.05	CIRCULAR	1.75	0		0.02815
AS2773-012_AS2773-009	AS2773-012	AS2773-009		156.8	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.02060
AS2774-012_TP2674-025	AS2774-012	TP2674-025		260.5	0.013	0	0.78	0.05	0.5	CIRCULAR	3	0		0.02838
AS2865-004_AS2866-004	AS2865-004	AS2866-004		282.4	0.013	0	0	0.5	0.25	CIRCULAR	2	0		0.03742
AS2866-003_IN2865-001	AS2866-003	IN2865-001		149.1	0.013	0	0	0.25	0.25	CIRCULAR	2	0		0.00590
AS2866-004_IN2866-008	AS2866-004	IN2866-008		78.1	0.013	0	0	0.25	0.25	CIRCULAR	2.25	0		0.00602
AS2867-004_AS2867-005	AS2867-004	AS2867-005		68.3	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.02212
AS2867-005_AS2867-013	AS2867-005	AS2867-013		232.5	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.00301
AS2867-013_AS2867-018	AS2867-013	AS2867-018		75.5	0.013	0	0	0.05	0.5	CIRCULAR	2.5	0		0.00993

Existing Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
AS2867-016_AS2867-018	AS2867-016	AS2867-018		78.3	0.013	0	0	0.25	0.5	CIRCULAR	2.5	0		0.07493
AS2867-018_AS2868-004	AS2867-018	AS2868-004		70.6	0.013	0	0	0.5	0.05	CIRCULAR	3	0		0.03386
AS2867-019_AS2867-016	AS2867-019	AS2867-016		222.4	0.013	0	0	0.05	0.25	CIRCULAR	2	0		0.02217
AS2867-024_AS2867-018	AS2867-024	AS2867-018		70.2	0.013	0	1.53	0.05	0.05	CIRCULAR	1.5	0		0.02093
AS2867-025_AS2867-024	AS2867-025	AS2867-024		231.2	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.05102
AS2868-004_AS2868-009	AS2868-004	AS2868-009		330.1	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.01357
AS2868-009_TP2868-037	AS2868-009	TP2868-037		117.6	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00800
AS2868-011_TP2868-038	AS2868-011	TP2868-038		58.3	0.013	0	0	0.05	0.05	CIRCULAR	3.5	0		0.00635
AS2868-018_TP2868-038	AS2868-018	TP2868-038		59.1	0.013	0	0.75	0.05	0.5	CIRCULAR	2	0		0.01912
AS2868-025_GR2869-001	AS2868-025	J58532		485.8	0.013	0	0	0.05	0.5	CIRCULAR	3.5	0		0.00838
AS2868-035_AS2868-018	AS2868-035	AS2868-018		290.7	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.01634
AS2873-010_AS2873-024	AS2873-010	AS2873-024		335.7	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.02295
AS2873-022_AS2874-017	AS2873-022	AS2874-017		35.6	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.07219
AS2873-023_AS2873-022	AS2873-023	AS2873-022		87.7	0.013	0	0	0.05	0.05	CIRCULAR	1.75	0		0.01072
AS2873-024_AS2873-023	AS2873-024	AS2873-023		24.5	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.06369
AS2874-017_IN2774-015	AS2874-017	IN2774-015		489.4	0.013	0	0	0.5	0.05	CIRCULAR	3	0		0.01850
AS2874-019_IN2874-018	AS2874-019	IN2874-018		7.1	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.00701
AS2965-007_AS2966-008	AS2965-007	AS2966-008		302.0	0.013	0	0	0.05	0.05	CIRCULAR	1.75	0		0.00540
AS2965-008_TP2966-025	AS2965-008	TP2966-025		263.8	0.013	0	1.27	0.05	0.5	CIRCULAR	1.25	0		0.00500
AS2966-008/009_AS2966-009	AS2966-008/009	AS2966-009		187.5	0.013	0	0	0.05	0.5	HORIZ_ELLIPSE	2.83	4.58		0.00472
AS2966-008_AS2966-008/009	AS2966-008	AS2966-008/009		39.3	0.013	0	0	0.05	0.05	HORIZ_ELLIPSE	2.83	4.58		0.00471
AS2966-009_GR2966-014	AS2966-009	J53940		79.5	0.013	0	0	0.5	0.5	HORIZ_ELLIPSE	2.83	4.58		0.00440
AS2967-007_AS2967-006	AS2967-007	IN2967-002		361.0	0.013	0	4.73	0.05	0.5	CIRCULAR	1.25	0		0.00687
AS2968-010_AS2968-011	AS2968-010	AS2968-011		78.9	0.013	0	0	0.5	0.05	CIRCULAR	2.25	0		0.00494
AS2968-011_AE2968-039	AS2968-011	J52912		326.6	0.013	0	0	0.05	0.5	CIRCULAR	2.75	0		0.00513
AS2968-019_GR2968-020	AS2968-019	J7416		255.3	0.013	0	0	0.05	0.5	CIRCULAR	3.5	0		0.00302
AS2968-031_IN2968-029	AS2968-031	IN2968-029		42.4	0.013	0	0	0	0	CIRCULAR	4	0		0.00660
AS2969-003_AS2968-010	AS2969-003	AS2968-010		362.1	0.013	0	0	0.05	0.5	CIRCULAR	2.25	0		0.00519
AS2969-004_AS2968-019	AS2969-004	AS2968-019		401.9	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00550
AS2969-006_AS2969-004	AS2969-006	AS2969-004		364.6	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00713
AS2969-008_AS2969-006	AS2969-008	AS2969-006		404.3	0.013	0	0	0.5	0.05	CIRCULAR	3	0		0.00712
AS2969-015_AS2969-003	AS2969-015	AS2969-003		418.7	0.013	0	0	0.05	0.05	CIRCULAR	2.25	0		0.00554
AS2969-024_AS2969-015	AS2969-024	AS2969-015		268.0	0.013	0	0	0.05	0.05	CIRCULAR	2.25	0		0.01392
AS2969-028_AS2969-029	AS2969-028	AS2969-029		64.4	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.02391
AS2969-029_AE2969-030	AS2969-029	J59668		191.4	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.01296
AS2969-035_IN2969-034	AS2969-035	IN2969-034		297.8	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.00393
AS3067-005_AS3067-006	AS3067-005	AS3067-006		215.5	0.013	0	0.19	0.05	0.25	CIRCULAR	1.5	0		0.00501
AS3067-006_AS3167-002	AS3067-006	AS3167-002		35.3	0.022	0	0	0.25	0.05	ARCH	24	0		0.07897
AS3068-007_AS3068-009	AS3068-007	AS3068-009		276.1	0.013	0	0	0.05	0.25	CIRCULAR	3	0		0.00348
AS3068-009_CB3068-066	AS3068-009	CB3068-066		82.1	0.013	0	0	0.25	0.25	CIRCULAR	3	0		0.00816
AS3068-068_CB3068-066	AS3068-068	CB3068-066		98.0	0.013	0	0	0.05	0.05	HORIZ_ELLIPSE	4	6.33		0.00500
AS3068-069_AS3068-068	AS3068-069	AS3068-068		406.9	0.013	0	0	0.05	0.05	RECT_CLOSED	5	6		0.00140
AS3068-072_CB3068-071	AS3068-072	CB3068-071		78.9	0.013	0.18	0.36	0.05	0.05	HORIZ_ELLIPSE	4	6.33		0.00279
AS3069-008_AS2969-008	AS3069-008	AS2969-008		76.0	0.013	0	0	0.05	0.5	CIRCULAR	3	0		0.01251

Existing Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
AS3069-011_AS3069-008	AS3069-011	AS3069-008		284.2	0.013	0	0	0.25	0.05	CIRCULAR	2.75	0		0.00215
AS3069-014_AS3069-019	AS3069-014	AS3069-019		339.7	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00400
AS3069-019_AS3069-029	AS3069-019	AS3069-029		349.0	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00390
AS3069-029_AS3068-007	AS3069-029	AS3068-007		54.1	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00444
AS3070-003_AS3069-011	AS3070-003	AS3069-011		402.9	0.013	0	0	0.05	0.25	CIRCULAR	2.5	0		0.00509
AS3070-007_IN3070-006	AS3070-007	IN3070-006		336.5	0.013	0	0	0.25	0.25	CIRCULAR	2	0		0.01459
AS3070-010_IN3070-012	AS3070-010	IN3070-012		18.8	0.013	0	0	0.5	0.05	CIRCULAR	2	0		0.02071
AS3070-014_IN3070-011	AS3070-014	IN3070-011		5.2	0.013	0	0	0.5	0.05	CIRCULAR	2	0		0.01341
AS3071-001_IN3071-003	AS3071-001	IN3071-003		19.4	0.013	0	0	0.05	0.25	CIRCULAR	1.75	0		0.03253
AS3071-004_AS3071-001	AS3071-004	AS3071-001		312.2	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.03956
AS3071-005_AS3071-004	AS3071-005	AS3071-004		31.0	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.04849
AS3166-008_AS3166-018	AS3166-008	AS3166-018		456.9	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.00899
AS3166-009_AS3166-008	AS3166-009	AS3166-008		450.1	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.00789
AS3166-010_AS3167-016	AS3166-010	AS3167-016		359.8	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.00208
AS3166-018_AS3166-010	AS3166-018	AS3166-010		378.2	0.013	0	0	0.5	0.05	CIRCULAR	2.5	0		0.00177
AS3167-001_MI3168-013	AS3167-001	MI3168-013		129.0	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.00868
**AS3167-002_MI3168-013	AS3167-002	MI3168-013		189.3	0.022	0	0	0.05	0.25	ARCH	24	0		0.00343
AS3167-003_AS3167-001	AS3167-003	AS3167-001		25.8	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.11978
AS3167-009_AS3167-003	AS3167-009	AS3167-003		442.8	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.02295
AS3167-010_AS3167-009	AS3167-010	AS3167-009		454.4	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.01259
AS3167-011_AS3167-003	AS3167-011	AS3167-003		262.9	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.00510
AS3167-016_AS3167-011	AS3167-016	AS3167-011		359.7	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.00706
AS3168-024_CB3168-023	AS3168-024	CB3168-023		301.0	0.013	0	0.12	0.05	0.05	CIRCULAR	1.75	0		0.00502
AS3168-034_AS3168-024	AS3168-034	AS3168-024		167.9	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.00697
AS3168-035_AS3168-034	AS3168-035	AS3168-034		135.0	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.01311
AS3168-043_AS3068-072	AS3168-043	AS3068-072		169.1	0.013	0	0	0.05	0.05	RECT_CLOSED	4.5	6		0.00254
AS3168-044_AS3168-043	AS3168-044	AS3168-043		77.9	0.013	0	0	0.05	0.05	HORIZ_ELLIPSE	4	6.33		0.00526
AS3168-045_AS3168-043	AS3168-045	AS3168-043		48.7	0.013	0	1.95	0.25	0.25	CIRCULAR	2	0		0.00904
AS3169-009_AS3168-035	AS3169-009	AS3168-035		254.0	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.01752
AS3266-002_IN3266-023	IN3266-023	AS3266-002		63.6	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.00534
AS3266-003_AS3166-009	AS3266-003	AS3166-009		440.1	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.00789
AS3266-003_AS3266-002	AS3266-002	AS3266-003		66.7	0.013	0	0	0.5	0.05	CIRCULAR	2	0		0.00465
ASPVT-MD01_IN2774-003	ASPVT-MD01	IN2774-003		148.4	0.013	0	0	0.25	0.05	HORIZ_ELLIPSE	1.17	1.92		0.00606
C839	AS2673-2018	TP2673-028		98.0	0.013	0	1.73	0.05	0.5	CIRCULAR	2	0		0.00602
CB3068-066_MI3068-028	CB3068-066	MI3068-028		270.9	0.013	0	0	0.05	0.05	RECT_CLOSED	5	6		0.00495
CB3068-070_AS3068-069	CB3068-070	AS3068-069		79.3	0.013	0	0	0.05	0.05	HORIZ_ELLIPSE	4	6.33		0.00529
CB3068-071_CB3068-070	CB3068-071	CB3068-070		259.2	0.013	0	0	0.05	0.05	RECT_CLOSED	5	6		0.00309
CB3168-023_AS3168-045	CB3168-023	AS3168-045		57.8	0.013	0	0	0.05	0.25	CIRCULAR	1.75	0		0.02459
GR2673-020_TP2673-028	J1595	TP2673-028		47.3	0.013	0	0	0.4	0.25	RECT_CLOSED	6	10	9	0.00508
GR2673-025_TP2673-023	J1598	TP2673-023		58.8	0.013	0	0	0.4	0.25	RECT_CLOSED	6	10	9	0.00321
GR2770-014_GR2770-013	J2953	J7936		109.6	0.013	0	0	0.5	0.5	CIRCULAR	6	0	2	0.00159
GR2770-015_TP2770-017	J2957	TP2770-017		59.6	0.013	0	0	0.5	0	CIRCULAR	6	0	2	0.00181
GR2771-016_TP2771-015	J7456	TP2771-015		70.0	0.013	0	0	0.5	0	CIRCULAR	6	0	2	0.01357
GR2771-017_AE2671-023	J7457	J6655		139.8	0.013	0	0	0.5	0.5	CIRCULAR	6	0	2	0.01532

Existing Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
GR2775-015_GR2775-017	J4161	J1538		119.1	0.013	0	0	0.2	0.5	RECT_CLOSED	4	8	9	0.00512
GR2775-016_GR2775-018	J4159	J1543		119.0	0.013	0	0	0.2	0.5	RECT_CLOSED	5	8	9	0.00513
GR2775-031_GR2775-033	J4160	J1537		120.0	0.013	0	0	0.2	0.5	RECT_CLOSED	4	8	9	0.00508
GR2775-032_GR2775-034	J4164	J1544		120.0	0.013	0	0	0.2	0.5	RECT_CLOSED	4	8	9	0.00508
GR2869-008_AE2869-011	J58687	J58560		120.0	0.013	0	0	0.5	0.5	CIRCULAR	6	0	2	0.00332
GR2869-010_AE2869-012	J58679	J58552		120.5	0.013	0	0	0.5	0.5	CIRCULAR	6	0	2	0.00213
GR2967-004_IN2967-002	J54236	IN2967-002		25.2	0.013	0	0	0.2	0	CIRCULAR	4	0	2	0.01192
IN2669-012_AS2669-007	IN2669-012	AS2669-007		55.9	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		0.00949
IN2669-016_AS2669-019	IN2669-016	AS2669-019		56.7	0.013	0	0	0.05	0.5	CIRCULAR	1.25	0		0.02947
IN2671-015_AS2671-014	IN2671-015	AS2671-014		35.2	0.013	0	1.99	0.05	0.05	CIRCULAR	1.5	0		0.01987
IN2672-014_AE2672-019	IN2672-014	J2933		35.5	0.013	0	0	0	0.5	HORIZ_ELLIPSE	5.25	8.17		0.00914
IN2672-024_AE2672-027	IN2672-024	J2698		141.8	0.013	0	0	0.05	0.5	CIRCULAR	1.75	0		0.01142
IN2672-029_AE2672-030	IN2672-029	J2704		146.0	0.013	0	0	0.05	0.5	CIRCULAR	1.25	0		0.03062
IN2673-001_AE2673-002	IN2673-001	J2155		144.1	0.013	0	0	0.05	0.5	CIRCULAR	1.25	0		0.02148
IN2673-007_IN2673-008	IN2673-007	IN2673-008		46.8	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.01282
IN2673-008_AE2673-009	IN2673-008	J2081		139.4	0.013	0	0	0.05	0.5	CIRCULAR	1.75	0		0.01320
IN2673-029_AE2673-013	IN2673-029	J1828		97.5	0.013	0	0	0.05	0.5	CIRCULAR	1.75	0		0.03658
IN2674-001_AE2674-003	IN2674-001	J4897		231.1	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		0.02190
IN2674-007_IN2674-008	IN2674-007	IN2674-008		69.1	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		0.01071
IN2674-008_IN2674-009	IN2674-008	IN2674-009		10.1	0.013	0	0	0.5	0.5	CIRCULAR	1.75	0		0.01389
IN2674-009_AE2674-010	IN2674-009	J5215		171.4	0.013	0	0	0.5	0.5	CIRCULAR	1.75	0		0.01458
IN2767-003_AS2867-019	IN2767-003	AS2867-019		246.5	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.05020
IN2768-001_IN2768-002	IN2768-001	IN2768-002		297.6	0.013	0	0	0.05	0.25	CIRCULAR	1.25	0		0.08330
IN2768-002_IN2768-003	IN2768-002	IN2768-003		225.1	0.013	0	0	0.25	0.05	CIRCULAR	1.25	0		0.03824
IN2768-003_AS2768-005	IN2768-003	AS2768-005		29.4	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		0.01805
IN2768-010_IN2768-014	IN2768-010	IN2768-014		59.4	0.013	0	0	0.05	0.25	CIRCULAR	1.25	0		0.03706
IN2768-012_IN2767-003	IN2768-012	IN2767-003		390.2	0.013	0	0	0.05	0.05	CIRCULAR	1.75	0		0.01669
IN2768-014_IN2768-012	IN2768-014	IN2768-012		347.6	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.01683
IN2768-015_AS2868-035	IN2768-015	AS2868-035		196.6	0.013	0	0	0.25	0.05	CIRCULAR	1.5	0		0.07638
IN2770-007_IN2770-010	IN2770-007	IN2770-010		30.0	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.00999
IN2770-010_AE2770-009	IN2770-010	J3385		169.5	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.00814
IN2771-006_AS2771-014	IN2771-006	AS2771-014		146.3	0.013	0	0	0.05	0.25	CIRCULAR	2	0		0.02857
IN2774-002_AE2674-013	IN2774-002	J4683		258.2	0.013	0	0	0.05	0.5	HORIZ_ELLIPSE	1.17	1.92		0.00511
IN2774-003_IN2774-002	IN2774-003	IN2774-002		31.7	0.013	0	0	0.05	0.05	HORIZ_ELLIPSE	1.17	1.92		0.00567
IN2774-013_AS2774-012	IN2774-013	AS2774-012		81.8	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.03805
IN2774-014_IN2774-013	IN2774-014	IN2774-013		222.5	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.02032
IN2774-015_IN2774-014	IN2774-015	IN2774-014		385.2	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.02015
IN2775-010_AE2775-012	IN2775-010	J1498		197.5	0.013	0	0	0.05	0.5	HORIZ_ELLIPSE	6	0		0.00506
IN2865-001_AS2865-004	IN2865-001	AS2865-004		351.0	0.013	0	0	0.25	0.5	CIRCULAR	2	0		0.00607
IN2866-008_AS2966-008	IN2866-008	AS2966-008		209.2	0.013	0	0	0.25	0.5	CIRCULAR	2.25	0		0.00660
IN2866-011_AS2866-003	IN2866-011	AS2866-003		136.4	0.013	0	0	0.05	0.25	CIRCULAR	2	0		0.02905
IN2868-031_AS2868-035	IN2868-031	AS2868-035		54.7	0.013	0	0	0.05	0.5	CIRCULAR	1.25	0		0.03698
IN2869-003_GR2869-005	IN2869-003	J4128		44.0	0.013	0	0	0	0.5	CIRCULAR	6	0		0.00650
IN2870-001_AE2870-006	IN2870-001	J3735		172.0	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		0.06216

Existing Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
IN2870-002_IN2870-001	IN2870-002	IN2870-001		46.7	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.01500
IN2870-013_IN2870-002	IN2870-013	IN2870-002		177.2	0.013	0	0	0.05	0.05	CIRCULAR	1.25	0		0.10705
IN2874-018_AS2874-017	IN2874-018	AS2874-017		48.6	0.013	0	0	0.5	0.05	CIRCULAR	2	0		0.08543
IN2966-004_AS2966-008_AS2966-009	IN2966-004	AS2966-008/009		15.5	0.013	0	0.725	0.05	0.5	CIRCULAR	1.5	0		0.05628
IN2966-015_GR2966-016	IN2966-015	J396		219.8	0.013	0	0	0.05	0.5	CIRCULAR	1.75	0		0.00294
IN2966-026_IN2966-030	IN2966-026	IN2966-030		176.0	0.013	0	0	0.05	0.25	CIRCULAR	1.25	0		0.01284
IN2966-030_AE2966-031	IN2966-030	J55411		91.1	0.013	0	0	0.25	0.5	CIRCULAR	1.25	0		0.01593
IN2967-002_AS2968-031	IN2967-002	AS2968-031		49.3	0.013	0	0	0	0	CIRCULAR	4	0		0.00527
IN2968-029_GR2968-032	IN2968-029	J62054		22.5	0.013	0	0	0	0.5	CIRCULAR	4	0		0.00000
IN2969-025_IN2969-027	IN2969-025	IN2969-027		62.1	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		-0.00032
IN2969-027_AS2969-028	IN2969-027	AS2969-028		277.2	0.013	0	0	0.5	0.05	CIRCULAR	1.5	0		0.02613
IN2969-034_AE2969-002	IN2969-034	J59673		84.1	0.013	0	0	0.05	0.5	CIRCULAR	1.75	0		0.00000
IN3066-002_IN3066-005	IN3066-002	IN3066-005		219.5	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.00483
IN3066-005_GR3066-010	IN3066-005	J53685		26.0	0.013	0	0	0.5	0.5	HORIZ_ELLIPSE	2	3.17		0.01962
***IN3066-019_GR3066-014	IN3066-019	J94335		162.3	0.022	0	0	0.05	0.5	HORIZ_ELLIPSE	1.417	2.25		0.00594
****IN3066-020_AE3066-021	IN3066-020	J52969		139.0	0.013	0	0	0.05	0.5	RECT_CLOSED	2	3		0.00124
IN3068-035_IN3068-036	IN3068-035	IN3068-036		229.3	0.013	0	0	0.25	0.25	HORIZ_ELLIPSE	1.58	2.5		0.00576
IN3068-036_CB3068-071	IN3068-036	CB3068-071		45.6	0.013	0	0	0.25	0.25	HORIZ_ELLIPSE	1.58	2.5		0.07724
IN3069-012_AS3069-011	IN3069-012	AS3069-011		7.6	0.013	0	0	0.05	0.5	CIRCULAR	2.75	0		0.00263
IN3070-006_IN3070-016	IN3070-006	IN3070-016		218.4	0.013	0	0	0.25	0.5	CIRCULAR	2.5	0		0.00449
IN3070-008_AS3070-007	IN3070-008	AS3070-007		251.2	0.013	0	0	0.05	0.25	CIRCULAR	2	0		0.02059
IN3070-011_AS3070-010	IN3070-011	AS3070-010		125.8	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.01225
IN3070-012_IN3070-008	IN3070-012	IN3070-008		38.2	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.02044
IN3070-016_AS3070-003	IN3070-016	AS3070-003		311.3	0.013	0	0	0.5	0.05	CIRCULAR	2.5	0		0.00405
IN3071-003_AS3070-014	IN3071-003	AS3070-014		188.5	0.013	0	0	0.25	0.5	CIRCULAR	1.75	0		0.03945
IN3168-018_IN3068-035	IN3168-018	IN3068-035		77.2	0.013	0	0	0.05	0.25	HORIZ_ELLIPSE	1.58	2.5		0.00622
IN3168-026_AS3168-024	IN3168-026	AS3168-024		41.7	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		0.00480
IN3169-001_IN3169-006	IN3169-001	IN3169-006		23.5	0.013	0	0	0.05	0.5	CIRCULAR	1.25	0		0.04049
IN3169-006_TE3168-017	IN3169-006	TE3168-017		332.4	0.013	0	0	0.5	0.05	CIRCULAR	1.5	0		0.00626
IN3266-024_IN3266-023	IN3266-024	IN3266-023		361.2	0.013	0	0	0.05	0.05	CIRCULAR	1.75	0		0.00504
INPVT-MD02_ASPVT-MD01	INPVT-MD02	ASPVT-MD01		24.3	0.013	0	0	0.05	0.25	CIRCULAR	1.5	0		0.02511
MI3068-028_GR2968-028	MI3068-028	J7406		88.0	0.022	0	0	0.05	0.5	ARCH	3.17	4.75		0.00490
MI3168-013_AS3168-020	MI3168-013	AS3168-044		499.4	0.013	0	0	0.05	0.05	RECT_CLOSED	5.5	6		0.00300
OSPVT-MD03_INPVT-MD02	OSPVT-MD03	INPVT-MD02		59.4	0.013	0	0	0.5	0.05	CIRCULAR	1.5	0		0.01078
TE3168-016_IN3168-018	TE3168-016	IN3168-018		24.8	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.00606
TE3168-017_TE3168-016	TE3168-017	TE3168-016		14.4	0.013	0	0	0.05	0.05	CIRCULAR	1.5	0		0.00624
TP2673-023_TP2674-025	TP2673-023	TP2674-025		81.4	0.013	0	0	0.25	0	RECT_CLOSED	6	10		0.00479
TP2673-028_TP2674-019	TP2673-028	TP2674-019		113.0	0.013	0	0	0.25	0	RECT_CLOSED	6	10		0.00504
TP2674-019_GR2674-015	TP2674-019	J5489		22.1	0.013	0	0	0	0.5	RECT_CLOSED	6	10		0.01288
TP2674-025_GR2674-020	TP2674-025	J5488		53.2	0.013	0	0	0	0.5	RECT_CLOSED	6	10		0.00710
TP2770-017_GR2770-016	TP2770-017	J7940		49.7	0.013	0	0	0	0.5	CIRCULAR	6	0		0.00465
TP2771-015_AE2671-021	TP2771-015	J6654		70.0	0.013	0	0	0	0.5	CIRCULAR	6	0		0.01744
TP2868-037_AE2868-010	J55605	TP2868-037		304.4	0.013	0	0.74	0.5	0.5	CIRCULAR	1.5	0		0.00455
TP2868-037_AS2868-011	TP2868-037	AS2868-011		124.2	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00805

Existing Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
TP2868-038_AS2868-025	TP2868-038	AS2868-025		268.4	0.013	0	0	0.05	0.05	CIRCULAR	3.5	0		0.00578
TP2966-025_AE2966-021	TP2966-025	J1245		36.3	0.013	0	0	0	0.5	CIRCULAR	3.5	0		0.00085

*included in City records as 48"x76" CMPA; after existing conditions model was finalized, field measurement confirmed as 47"x71" CMPA

**included in City records as 48" CMPA with no second dimension so model sees it as 48" round; manually adjusted to corrugated pipe arch (code 24)

***included in City records as 10x5 box; confirmed at inlet end as 17"x27" HE, manually adjusted

****included in City records as 3x2 box; confirmed at outlet end as low arch shape with no bottom, height less than 2' and width greater than 3'; no better approximation of open area, left as box

Existing Conditions Hydraulic Input Parameters - Junctions

Name	Tag	Invert Elev. (ft)	Rim Elev. (ft)	Depth (ft)	Surcharge Depth (ft)
989	Connect2D	978	979	1	0
990	Connect2D	983.621	984.621	1	0
991	Connect2D	987.702	988.702	1	0
992	Connect2D	1004.71	1005.71	1	0
993	Connect2D	1006.671	1007.671	1	0
994	Connect2D	1016.564	1017.564	1	0
995	Connect2D	1033.967	1034.967	1	0
996	Connect2D	1020.616	1021.616	1	0
997	Connect2D	1009.623	1010.623	1	0
998	Connect2D	1002	1003	1	0
999	Connect2D	1025.886	1026.886	1	0
AS2669-007	Connect2D	1043.07	1046.9	3.83	0
AS2669-008	Connect2D	1041.27	1045.2	3.93	0
AS2669-019	Connect2D	1028.58	1032.6	4.02	0
AS2669-020	Connect2D	1020.58	1025.4	4.82	0
AS2669-027	Connect2D	1019.61	1024.1	4.49	0
AS2670-031	Connect2D	1018	1022.7	4.7	0
AS2670-032	Connect2D	1016.06	1020.8	4.74	0
AS2670-043	Connect2D	1003.3	1007.6	4.3	0
AS2670-044	Connect2D	1002.6	1007.4	4.8	0
AS2670-046	Connect2D	996.79	1001.6	4.81	0
AS2671-006	Connect2D	1000.86	1004.3	3.44	0
AS2671-013	Connect2D	993.7	1000	6.3	0
AS2671-014	Connect2D	994.91	1000.4	5.49	0
AS2672-010	Connect2D	992.65	997.42	4.77	0
AS2672-011	Connect2D	991.84	996.5	4.66	0
AS2672-016	Connect2D	986.55	990.8	4.25	0
AS2672-031	Connect2D	994.67	998.94	4.27	0
AS2673-022	Connect2D	985.82	990	4.18	0
AS2673-2018	Connect2D	983.68	989.54	5.86	0
AS2768-005	Connect2D	1044.87	1048.8	3.93	0
AS2770-005	Connect2D	1006.39	1009.4	3.01	0
AS2771-001	Connect2D	998.5	1001.6	3.1	0
AS2771-014	Connect2D	995.42	1003	7.58	0
AS2773-008	Connect2D	986.1	991.87	5.77	0
AS2773-009	Connect2D	993.84	998.34	4.5	0
AS2773-012	Connect2D	997.07	1001.57	4.5	0
AS2774-012	Connect2D	989.1	994.87	5.77	0
AS2865-004	Connect2D	1031.43	1034.9	3.47	0
AS2866-003	Connect2D	1034.44	1037.6	3.16	0
AS2866-004	Connect2D	1020.87	1024.3	3.43	0
AS2867-004	Connect2D	1024.11	1027.1	2.99	0
AS2867-005	Connect2D	1022.6	1026.9	4.3	0
AS2867-013	Connect2D	1021.9	1028.8	6.9	0

Existing Conditions Hydraulic Input Parameters - Junctions

Name	Tag	Invert Elev. (ft)	Rim Elev. (ft)	Depth (ft)	Surcharge Depth (ft)
AS2867-016	Connect2D	1027	1030.7	3.7	0
AS2867-018	Connect2D	1021.15	1029.6	8.45	0
AS2867-019	Connect2D	1031.93	1036.11	4.18	0
AS2867-024	Connect2D	1024.15	1030.39	6.24	0
AS2867-025	Connect2D	1035.93	1041.81	5.88	0
AS2868-004	Connect2D	1018.76	1027.2	8.44	0
AS2868-009	Connect2D	1014.28	1019.62	5.34	0
AS2868-011	Connect2D	1012.34	1018.1	5.76	0
AS2868-018	Connect2D	1013.85	1017.1	3.25	0
AS2868-025	Connect2D	1010.42	1015.4	4.98	0
AS2868-035	Connect2D	1018.6	1022	3.4	0
AS2873-010	Connect2D	1026.3	1029.5	3.2	0
AS2873-022	Connect2D	1016.1	1021.8	5.7	0
AS2873-023	Connect2D	1017.04	1021.61	4.57	0
AS2873-024	Connect2D	1018.6	1023.91	5.31	0
AS2874-017	Connect2D	1013.54	1019.54	6	0
AS2874-019	Connect2D	1017.73	1021.96	4.23	0
AS2965-007	Connect2D	1020.65	1023.34	2.69	0
AS2965-008	Connect2D	1022	1026	4	0
AS2965-2022	Connect2D	1028.76	1029.76	1	0
AS2966-008	Connect2D	1019.02	1022.95	3.93	0
AS2966-008/009		1018.835	1023.5	4.665	20
AS2966-009	Connect2D	1017.95	1021.87	3.92	0
AS2967-007	Connect2D	1019.64	1024.24	4.6	0
AS2968-010	Connect2D	1011.42	1016.5	5.08	0
AS2968-011	Connect2D	1011.03	1016	4.97	0
AS2968-019	Connect2D	1011.76	1016.71	4.95	0
AS2968-031	Connect2D	1012.17	1022.56	10.39	0
AS2969-003	Connect2D	1013.3	1018.47	5.17	0
AS2969-004	Connect2D	1013.97	1019.22	5.25	0
AS2969-006	Connect2D	1016.57	1022	5.43	0
AS2969-008	Connect2D	1019.45	1024.45	5	0
AS2969-015	Connect2D	1015.62	1020.65	5.03	0
AS2969-024	Connect2D	1019.35	1022	2.65	0
AS2969-028	Connect2D	1012.02	1016.5	4.48	0
AS2969-029	Connect2D	1010.48	1015	4.52	0
AS2969-035	Connect2D	1007.6	1010.6	3	0
AS3067-005	Connect2D	1021.73	1028.5	6.77	0
AS3067-006	Connect2D	1020.46	1025.89	5.43	0
AS3068-007	Connect2D	1013.64	1017.6	3.96	0
AS3068-009	Connect2D	1012.68	1016.6	3.92	0
AS3068-068	Connect2D	1012.5	1017.5	5	0
AS3068-069	Connect2D	1013.07	1018.94	5.87	0
AS3068-072	Connect2D	1014.69	1020.4	5.71	0

Existing Conditions Hydraulic Input Parameters - Junctions

Name	Tag	Invert Elev. (ft)	Rim Elev. (ft)	Depth (ft)	Surcharge Depth (ft)
AS3069-008	Connect2D	1020.4	1025	4.6	0
AS3069-011	Connect2D	1021.01	1026	4.99	0
AS3069-014	Connect2D	1016.6	1020.8	4.2	0
AS3069-019	Connect2D	1015.24	1019.2	3.96	0
AS3069-029	Connect2D	1013.88	1017.58	3.7	0
AS3070-003	Connect2D	1023.06	1026.5	3.44	0
AS3070-007		1030.21	1035	4.79	20
AS3070-010	Connect2D	1036.55	1041	4.45	0
AS3070-014	Connect2D	1038.16	1042.7	4.54	0
AS3071-001	Connect2D	1046.22	1049.6	3.38	0
AS3071-004	Connect2D	1058.56	1062.2	3.64	0
AS3071-005	Connect2D	1060.06	1063.6	3.54	0
AS3166-008	Connect2D	1030.63	1036	5.37	0
AS3166-009	Connect2D	1034.18	1039	4.82	0
AS3166-010	Connect2D	1025.85	1031	5.15	0
AS3166-018	Connect2D	1026.52	1032.62	6.1	0
AS3167-001	Connect2D	1018.15	1024.1	5.95	0
AS3167-002	Connect2D	1017.68	1025.79	8.11	0
AS3167-003	Connect2D	1021.22	1025.5	4.28	0
AS3167-009	Connect2D	1031.38	1037	5.62	0
AS3167-010	Connect2D	1037.1	1042	4.9	0
AS3167-011	Connect2D	1022.56	1026.4	3.84	0
AS3167-016	Connect2D	1025.1	1028.6	3.5	0
AS3168-024	Connect2D	1020.56	1023.97	3.41	0
AS3168-034	Connect2D	1021.73	1026	4.27	0
AS3168-035	Connect2D	1023.5	1028	4.5	0
AS3168-043	Connect2D	1015.12	1021.82	6.7	0
AS3168-044	Connect2D	1015.53	1022.15	6.62	0
AS3168-045	Connect2D	1017.51	1021.99	4.48	0
AS3169-009	Connect2D	1027.95	1032.45	4.5	0
AS3266-002	Connect2D	1037.96	1042.53	4.57	0
AS3266-003	Connect2D	1037.65	1041.78	4.13	0
ASPVT-MD01	Connect2D	981.25	985.03	3.78	0
CB3068-066	Connect2D	1012.01	1017.01	5	0
CB3068-070	Connect2D	1013.49	1019.19	5.7	0
CB3068-071	Connect2D	1014.29	1020.94	6.65	0
CB3168-023	Connect2D	1018.93	1022.29	3.36	0
IN2669-012	Connect2D	1043.6	1048.16	4.56	0
IN2669-016	Connect2D	1030.25	1033.7	3.45	0
IN2671-015	Connect2D	997.6	1001.92	4.32	0
IN2672-014	Connect2D	984.65	992	7.35	0
IN2672-024	Connect2D	986.91	991.59	4.68	0
IN2672-029	Connect2D	991	994.3	3.3	0
IN2673-001	Connect2D	988.5	991.5	3	0

Existing Conditions Hydraulic Input Parameters - Junctions

Name	Tag	Invert Elev. (ft)	Rim Elev. (ft)	Depth (ft)	Surcharge Depth (ft)
IN2673-007	Connect2D	987	990.55	3.55	0
IN2673-008	Connect2D	986.4	990.6	4.2	0
IN2673-029	Connect2D	988.12	992.06	3.94	0
IN2674-001	Connect2D	984.76	988.37	3.61	0
IN2674-007	Connect2D	983.68	986.94	3.26	0
IN2674-008	Connect2D	982.94	987.44	4.5	0
IN2674-009	Connect2D	982.8	987.54	4.74	0
IN2767-003	Connect2D	1044.29	1048.77	4.48	0
IN2768-001	Connect2D	1078.7	1082.5	3.8	0
IN2768-002	Connect2D	1054	1056.8	2.8	0
IN2768-003	Connect2D	1045.4	1050.6	5.2	0
IN2768-010	Connect2D	1058.85	1062.8	3.95	0
IN2768-012	Connect2D	1050.8	1055	4.2	0
IN2768-014	Connect2D	1056.65	1060.5	3.85	0
IN2768-015	Connect2D	1033.57	1037.2	3.63	0
IN2770-007	Connect2D	1002.4	1006.1	3.7	0
IN2770-010	Connect2D	1002.1	1006.1	4	0
IN2771-006	Connect2D	999.6	1004.45	4.85	0
IN2774-002	Connect2D	980.17	983.82	3.65	0
IN2774-003	Connect2D	980.35	983.77	3.42	0
IN2774-013	Connect2D	992.21	997.35	5.14	0
IN2774-014	Connect2D	996.73	1001.95	5.22	0
IN2774-015	Connect2D	1004.49	1009.74	5.25	0
IN2775-010	Connect2D	977.1	981.78	4.68	0
IN2865-001	Connect2D	1033.56	1038.13	4.57	0
IN2866-008	Connect2D	1020.4	1024.5	4.1	0
IN2866-011	Connect2D	1038.4	1043.85	5.45	0
IN2868-031	Connect2D	1020.62	1023.7	3.08	0
IN2869-003	Connect2D	1003.1	1016	12.9	0
IN2870-001	Connect2D	1014.2	1018.11	3.91	0
IN2870-002	Connect2D	1014.9	1018.11	3.21	0
IN2870-013	Connect2D	1033.76	1040.66	6.9	0
IN2874-018	Connect2D	1017.68	1022.18	4.5	0
IN2966-004	Connect2D	1020.43	1023.77	3.34	0
IN2966-015	Connect2D	1018.65	1022.05	3.4	0
IN2966-026	Connect2D	1020.79	1025.83	5.04	0
IN2966-030	Connect2D	1018.53	1021.53	3	0
IN2967-002	Connect2D	1012.43	1022.05	9.62	0
IN2968-029	Connect2D	1011.89	1022.18	10.29	0
IN2969-025	Connect2D	1019.24	1022.39	3.15	0
IN2969-027	Connect2D	1019.26	1022.74	3.48	0
IN2969-034	Connect2D	1006.43	1009.64	3.21	0
IN3066-002	Connect2D	1022.97	1026.6	3.63	0
IN3066-005	Connect2D	1021.91	1025.6	3.69	0

Existing Conditions Hydraulic Input Parameters - Junctions

Name	Tag	Invert Elev. (ft)	Rim Elev. (ft)	Depth (ft)	Surcharge Depth (ft)
IN3066-019	Connect2D	1021.28	1024.36	3.08	0
IN3066-020	Connect2D	1020.23	1023.1	2.87	0
IN3068-035	Connect2D	1019.12	1021.6	2.48	0
IN3068-036	Connect2D	1017.8	1020.6	2.8	0
IN3069-012	Connect2D	1021.03	1026.03	5	0
IN3070-006	Connect2D	1025.3	1027.8	2.5	0
IN3070-008	Connect2D	1035.38	1040	4.62	0
IN3070-011	Connect2D	1038.09	1042.9	4.81	0
IN3070-012	Connect2D	1036.16	1040.5	4.34	0
IN3070-016	Connect2D	1024.32	1028.3	3.98	0
IN3071-003	Connect2D	1045.59	1050.18	4.59	0
IN3168-018	Connect2D	1019.6	1022.2	2.6	0
IN3168-026	Connect2D	1020.76	1024.02	3.26	0
IN3169-001	Connect2D	1022.87	1025.87	3	0
IN3169-006	Connect2D	1021.92	1025	3.08	0
IN3266-023	Connect2D	1038.3	1042.3	4	0
IN3266-024	Connect2D	1040.12	1044.12	4	0
INPVT-MD02	Connect2D	981.86	985.46	3.6	0
MI3068-028	Connect2D	1010.67	1016.111	5.441	0
MI3168-013		1017.03	1025.27	8.24	20
OSPVT-MD03		982.5	987.3	4.8	20
TE3168-016		1019.75	1023.07	3.32	20
TE3168-017	Connect2D	1019.84	1023.3	3.46	0
TP2673-023		981.32	989.55	8.23	20
TP2673-028		981.36	989.39	8.03	20
TP2674-019		980.79	989.65	8.86	20
TP2674-025		980.93	989.9	8.97	20
TP2770-017	Connect2D	998.69	1008.2	9.51	0
TP2771-015		993.05	1001.3	8.25	20
TP2868-037	Connect2D	1013.34	1019	5.66	0
TP2868-038	Connect2D	1011.97	1018	6.03	0
TP2966-025	Connect2D	1019.41	1024.111	4.701	0

Proposed Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
AE2672-020_IN2672-014	J5557	IN2672-014		35.2	0.013	0	0	0.2	0	RECT_CLOSED	5	11	24	0.00426
AE2672-021_AE2672-018	J5552	J2928		72.5	0.013	0	0	0.2	0.5	RECT_CLOSED	5	11	24	0.00414
AE2869-013_GR2869-014	McKennaBend3	J4131		179.8	0.013	0	0	0.25	0.5	RECT_CLOSED	5	8		0.00189
AE2869-015_IN2869-003	McKennaBend4	IN2869-003		135.1	0.013	0	0	0.25	0	RECT_CLOSED	5	8		0.00192
AE2966-023_AE2966-024	J1	J53970		14.2	0.013	0	0	0.5	0.5	CIRCULAR	3.5	0	2	0.00014
AE2966-US_AE2966-DS	J53751	J54093		39.0	0.013	0	0	0.5	0.5	RECT_CLOSED	4	10	31	0.00213
AE2968-035_AE2968-037	J6691	J52905		70.0	0.022	0	0	0.2	0.5	RECT_CLOSED	4	14	21	0.00357
AE2968-036_AE2968-038	J6690	J52904		70.0	0.022	0	0	0.2	0.5	RECT_CLOSED	4	14	21	0.00357
AE3064-015_AE3065-003	J94283	J63797		90.0	0.013	0	0	0.5	0.5	CIRCULAR	2.5	0	5	0.07142
AE3066-017_TP2966-025	J53021	TP2966-025		68.9	0.013	0	0	0.2	0	RECT_CLOSED	3	6	21	0.00235
AE3066-US_AE3066-DS	J94325	J53514		31.7	0.013	0	0	0.5	0.5	HORIZ_ELLIPSE	2.83	4.42	31	0.00063
AEPVT-PR01_IN3069-012	J57367	IN3069-012		153.1	0.013	0	0	0.5	0.05	CIRCULAR	3	0		0.00307
AS2669-007_AS2669-008	AS2669-007	AS2669-008		31.5	0.013	0	0	0.5	0.05	CIRCULAR	2.5	0		0.05724
AS2669-008_AS2669-019	AS2669-008	AS2669-019		328.1	0.013	0	1	0.05	0.05	CIRCULAR	2.5	0		0.03871
AS2669-019_AS2669-020	AS2669-019	AS2669-020		239.2	0.013	0	0.5	0.05	0.05	CIRCULAR	3.5	0		0.02961
AS2669-020_AS2669-027	AS2669-020	AS2669-027		144.6	0.013	0	0.5	0.05	0.05	CIRCULAR	4	0		0.00982
AS2669-027_AS2670-031	AS2669-027	AS2670-031		283.3	0.013	0	0	0.05	0.05	CIRCULAR	4	0		0.00801
AS2670-031_AS2670-032	AS2670-031	AS2670-032		376.0	0.013	0	0.04	0.05	0.5	CIRCULAR	4	0		0.0079
AS2670-032_AS2670-043	AS2670-032	AS2670-044		294.7	0.013	0	0	0.5	0.05	CIRCULAR	4	0		0.04212
AS2670-044_AS2670-046	AS2670-044	AS2670-046		348.9	0.013	0	0	0.5	0.05	CIRCULAR	4	0		0.0131
AS2670-046_AS2671-014	AS2670-046	AS2671-014		288.9	0.013	0	0	0.05	0.5	RECT_CLOSED	4	4		0.00498
AS2671-006_IN2671-015	AS2671-006	IN2671-015		296.0	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.015
AS2671-013_AE2671-007	AS2671-013	J6656		33.2	0.013	0	0	0.25	0.5	RECT_CLOSED	4	4		0.00904
AS2671-014_AS2671-013	AS2671-014	AS2671-013		110.0	0.013	0	0	0.5	0.25	RECT_CLOSED	4	4		0.009
AS2672-010_AS2672-011	AS2672-010	AS2672-011		43.2	0.013	0	0	0.05	0.5	CIRCULAR	3	0		0.00996
AS2672-011_AS2672-016	AS2672-011	AS2672-016		285.8	0.013	0	0	0.5	0.5	RECT_CLOSED	3	3		0.01708
AS2672-016_AE2672-017	AS2672-016	J2929		20.3	0.013	0	0	0.5	0.5	RECT_CLOSED	3	3		0.01968
AS2672-031_AS2672-010	AS2672-031	AS2672-010		312.6	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00998
AS2673-022_TP2673-023	AS2673-022	TP2673-023		45.0	0.013	0	0.78	0.05	0.5	CIRCULAR	2.5	0		0.08294
AS2768-005_IN2768-015	AS2768-005	IN2768-015		229.6	0.013	0	0	0.5	0.25	CIRCULAR	1.5	0		0.04928
AS2770-005_TP2770-017	AS2770-005	TP2770-017		235.1	0.013	0	2.43	0.05	0.5	CIRCULAR	1.75	0		0.02369
AS2771-001_TP2771-015	AS2771-001	TP2771-015		192.7	0.013	0	4.27	0.05	0.5	CIRCULAR	1.5	0		0.01002
AS2771-014_AE2671-022	AS2771-014	J6415		119.5	0.013	0	0	0.25	0.5	CIRCULAR	2.5	0		0.02863
AS2773-008_AS2673-022	AS2773-008	AS2673-022		36.0	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.00778
AS2773-009_AS2773-008	AS2773-009	AS2773-008		275.0	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.02815
AS2773-012_AS2773-009	AS2773-012	AS2773-009		156.8	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.0206
AS2774-012_TP2674-025	AS2774-012	TP2674-025		260.5	0.013	0	0.78	0.05	0.5	CIRCULAR	3	0		0.02838
AS2865-004_AS2866-004	AS2865-004	AS2866-004		282.4	0.013	0	0.6	0.5	0.25	CIRCULAR	2	0		0.03742
AS2866-003_IN2865-001	AS2866-003	IN2865-001		149.1	0.013	0	0	0.25	0.25	CIRCULAR	2	0		0.0059
AS2866-004_IN2866-008	AS2866-004	IN2866-008		78.1	0.013	0	0	0.25	0.25	RECT_CLOSED	2	4		0.00499
AS2867-005_AS2867-013	AS2867-005	AS2867-013		232.5	0.013	0	0	0.5	0.05	RECT_CLOSED	2	4		0.00499
AS2867-013_AS2867-018	AS2867-013	AS2867-018		75.5	0.013	0	1.5	0.05	0.5	RECT_CLOSED	2	4		0.00503
AS2867-016_AS2867-018	AS2867-016	AS2867-018		78.3	0.013	0	0.5	0.25	0.5	CIRCULAR	3	0		0.03361
AS2867-018_AS2868-004	AS2867-018	AS2868-004		70.6	0.013	0	0	0.5	0.05	RECT_CLOSED	4	4		0.01501

Proposed Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
AS2867-019_AS2867-016	AS2867-019	AS2867-016		222.4	0.013	0	0.5	0.05	0.25	CIRCULAR	2.5	0		0.03973
AS2867-024_AS2867-018	AS2867-024	AS2867-018		70.2	0.013	0	1.5	0.05	0.05	CIRCULAR	2	0		0.04033
AS2867-025_AS2867-024	AS2867-025	AS2867-024		231.2	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.05102
AS2868-004_AS2868-009	AS2868-004	AS2868-009		330.1	0.013	0	0	0.05	0.05	RECT_CLOSED	4	4		0.01357
AS2868-009_TP2868-037	AS2868-009	TP2868-037		117.6	0.013	0	0	0.05	0.05	RECT_CLOSED	4	4		0.008
AS2868-011_TP2868-038	AS2868-011	TP2868-038		58.3	0.013	0	0	0.05	0.05	RECT_CLOSED	4	4		0.00635
AS2868-018_TP2868-038	AS2868-018	TP2868-038		59.1	0.013	0	0.65	0.05	0.5	CIRCULAR	2.5	0		0.01404
AS2868-025_GR2869-001	AS2868-025	McKennaBend2		485.8	0.013	0	0.5	0.05	0.5	RECT_CLOSED	4	4		0.01073
AS2868-035_AS2868-018	AS2868-035	AS2868-018		290.7	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.01634
AS2873-010_AS2873-024	AS2873-010	AS2873-024		335.7	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.02295
AS2873-022_AS2874-017	AS2873-022	AS2874-017		35.6	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.07219
AS2873-023_AS2873-022	AS2873-023	AS2873-022		87.7	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.01072
AS2873-024_AS2873-023	AS2873-024	AS2873-023		24.5	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.06369
AS2874-017_IN2774-015	AS2874-017	IN2774-015		489.4	0.013	0	0	0.5	0.05	CIRCULAR	3	0		0.0185
AS2874-019_IN2874-018	AS2874-019	IN2874-018		7.1	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.00701
AS2965-007_AS2966-008	AS2965-007	AS2966-008		302.0	0.013	0	0.5	0.05	0.05	RECT_CLOSED	2	4		0.00301
AS2965-008_TP2966-025	AS2965-008	TP2966-025		263.8	0.013	0	0.5	0.5	0.5	CIRCULAR	2	0		0.0069
AS2965-2022_AS2965-2022A	AS2965-2022	AS2965-2022A		121.7	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.00501
AS2965-2022A_AS2965-008	AS2965-2022A	AS2965-008		317.1	0.013	0	0	0.5	0.5	CIRCULAR	2	0		0.00659
AS2966-008/009_AS2966-009	AS2966-008/009	AS2966-009		187.5	0.013	0	0	0.05	0.5	RECT_CLOSED	3	6		0.00299
AS2966-008_AS2966-008/009	AS2966-008	AS2966-008/009		39.3	0.013	0	0	0.05	0.05	RECT_CLOSED	3	6		0.00306
AS2966-009_GR2966-014	AS2966-009	J53940		79.5	0.013	0	0	0.5	0.5	RECT_CLOSED	3	8		0.00327
AS2967-007_AS2967-006	AS2967-007	IN2967-002		361.0	0.013	0	4.73	0.05	0.5	CIRCULAR	2	0		0.01
AS2968-010_AS2968-011	AS2968-010	AS2968-011		78.9	0.013	0	0	0.5	0.05	CIRCULAR	2.25	0		0.00494
AS2968-011_AE2968-039	AS2968-011	J52912		326.6	0.013	0	0	0.05	0.5	CIRCULAR	2.75	0		0.00513
AS2968-019_GR2968-020	AS2968-019	J7416		255.3	0.013	0	0	0.05	0.5	HORIZ_ELLIPSE	9	0		0.00302
AS2968-031_IN2968-029	AS2968-031	IN2968-029		42.4	0.013	0	0	0	0	CIRCULAR	4	0		0.0066
AS2969-003_AS2968-010	AS2969-003	AS2968-010		362.1	0.013	0	0	0.05	0.5	CIRCULAR	2.25	0		0.00519
AS2969-004_AS2968-019	AS2969-004	AS2968-019		401.9	0.013	0	0.333	0.05	0.05	HORIZ_ELLIPSE	8	0		0.00621
AS2969-006_AS2969-004	AS2969-006	AS2969-004		364.6	0.013	0	0	0.05	0.05	HORIZ_ELLIPSE	8	0		0.00601
AS2969-008_AS2969-006	AS2969-008	AS2969-006		404.3	0.013	0	0	0.5	0.05	HORIZ_ELLIPSE	8	0		0.00601
AS2969-015_AS2969-003	AS2969-015	AS2969-003		418.7	0.013	0	0	0.05	0.05	CIRCULAR	2.25	0		0.00554
AS2969-024_AS2969-015	AS2969-024	AS2969-015		268.0	0.013	0	0	0.05	0.05	CIRCULAR	2.25	0		0.00798
AS2969-028_AS2969-029	AS2969-028	AS2969-029		64.4	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.01801
AS2969-029_AE2969-030	AS2969-029	J59668		191.4	0.013	0	0	0.05	0.5	CIRCULAR	2.5	0		0.01803
AS2969-035_IN2969-034	AS2969-035	IN2969-034		297.8	0.013	0	0	0.05	0.05	RECT_CLOSED	2	4		0.00306
AS3067-005_AS3067-006	AS3067-005	AS3067-006		215.5	0.013	0	0.5	0.05	0.25	CIRCULAR	2	0		0.01002
AS3067-006_AS3167-002	AS3067-006	AS3167-002		35.3	0.013	0	0	0.25	0.05	CIRCULAR	2.5	0		0.00991
AS3068-007_AS3068-009	AS3068-007	AS3068-009		276.1	0.013	0	0	0.05	0.25	HORIZ_ELLIPSE	8	0		0.00351
AS3068-009_CB3068-066	AS3068-009	CB3068-066		82.1	0.013	0	0.3	0.25	0.25	HORIZ_ELLIPSE	8	0		0.00353
AS3068-068_CB3068-066	AS3068-068	CB3068-066		98.0	0.013	0	0	0.05	0.05	RECT_CLOSED	4	8		0.005
AS3068-069_AS3068-068	AS3068-069	AS3068-068		406.9	0.013	0	0	0.05	0.05	RECT_CLOSED	5	6		0.00143
AS3068-072_CB3068-071	AS3068-072	CB3068-071		78.9	0.013	0	0	0.05	0.05	RECT_CLOSED	4	8		0.00507
AS3069-008_AS2969-008	AS3069-008	AS2969-008		76.0	0.013	0	0	0.05	0.5	HORIZ_ELLIPSE	8	0		0.00606

Proposed Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
AS3069-011_AS3069-008	AS3069-011	AS3069-008		284.2	0.013	0	0	0.25	0.05	HORIZ_ELLIPSE	8	0		0.00471
AS3069-014_AS3069-019	AS3069-014	AS3069-019		339.7	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.004
AS3069-019_AS3069-029	AS3069-019	AS3069-029		349.0	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.0039
AS3069-029_AS3068-007	AS3069-029	AS3068-007		54.1	0.013	0	0.08	0.05	0.05	CIRCULAR	3	0		0.00444
AS3070-003_AS3069-011	AS3070-003	AS3069-011		402.9	0.013	0	0	0.05	0.25	CIRCULAR	2.5	0		0.00509
AS3070-007_IN3070-006	AS3070-007	IN3070-006		336.5	0.013	0	0	0.25	0.25	CIRCULAR	2.5	0		0.01459
AS3070-010_IN3070-012	AS3070-010	IN3070-012		18.8	0.013	0	0	0.5	0.05	CIRCULAR	2	0		0.02071
AS3070-014_IN3070-011	AS3070-014	IN3070-011		5.2	0.013	0	0	0.5	0.05	CIRCULAR	2	0		0.02108
AS3071-001_IN3071-003	AS3071-001	IN3071-003		19.4	0.013	0	0	0.05	0.25	CIRCULAR	2	0		0.03253
AS3071-004_AS3071-001	AS3071-004	AS3071-001		312.2	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.03956
AS3071-005_AS3071-004	AS3071-005	AS3071-004		31.0	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.04849
AS3166-008_AS3166-018	AS3166-008	AS3166-018		456.9	0.013	0	0.5	0.05	0.5	CIRCULAR	3	0		0.00565
AS3166-009_AS3166-008	AS3166-009	AS3166-008		450.1	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00564
AS3166-010_AS3167-016	AS3166-010	AS3167-016		359.8	0.013	0	0.5	0.05	0.05	CIRCULAR	3.5	0		0.006
AS3166-018_AS3166-010	AS3166-018	AS3166-010		378.2	0.013	0	0	0.5	0.05	CIRCULAR	3.5	0		0.005
AS3167-001_MI3168-013	AS3167-001	MI3168-013		129.0	0.013	0	0.76	0.05	0.05	CIRCULAR	4	0		0.00705
AS3167-002_MI3168-013	AS3167-002	MI3168-013		189.3	0.013	0	2	0.05	0.25	CIRCULAR	2.5	0		0.00999
AS3167-003_AS3167-001	AS3167-003	AS3167-001		25.8	0.013	0	0	0.05	0.05	CIRCULAR	4	0		0.00697
AS3167-004_AS3167-001	AS3167-004	AS3167-001		44.8	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		0.04689
AS3167-009_AS3167-003	AS3167-009	AS3167-003		442.8	0.013	0	1.5	0.05	0.5	CIRCULAR	2.5	0		0.02485
AS3167-010_AS3167-009	AS3167-010	AS3167-009		454.4	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.01259
AS3167-011_AS3167-003	AS3167-011	AS3167-003		262.9	0.013	0	0	0.05	0.05	CIRCULAR	4	0		0.007
AS3167-016_AS3167-011	AS3167-016	AS3167-011		359.7	0.013	0	0	0.05	0.05	CIRCULAR	4	0		0.00701
AS3168-024_CB3168-023	AS3168-024	CB3168-023		301.0	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00801
AS3168-034_AS3168-024	AS3168-034	AS3168-024		167.9	0.013	0	0.5	0.05	0.05	CIRCULAR	2	0		0.01299
AS3168-035_AS3168-034	AS3168-035	AS3168-034		135.0	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.01437
AS3168-043_AS3068-072	AS3168-043	AS3068-072		169.1	0.013	0	0	0.05	0.05	RECT_CLOSED	4.5	6		0.00254
AS3168-044_AS3168-043	AS3168-044	AS3168-043		77.9	0.013	0	0	0.05	0.05	RECT_CLOSED	5	6		0.00526
AS3168-045_AS3168-043	AS3168-045	AS3168-043		48.7	0.013	0	0.5	0.25	0.25	CIRCULAR	3	0		0.00801
AS3169-009_AS3168-035	AS3169-009	AS3168-035		254.0	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.01752
AS3266-002_AS3266-002A	AS3266-002A	AS3266-002		50.4	0.013	0	1.5	0.05	0.05	CIRCULAR	2	0		0.00516
AS3266-002_IN3266-023	IN3266-023	AS3266-002		63.6	0.013	0	1	0.05	0.5	CIRCULAR	2.5	0		0.00707
AS3266-003_AS3166-009	AS3266-003	AS3166-009		440.1	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00566
AS3266-003_AS3266-002	AS3266-002	AS3266-003		66.7	0.013	0	0	0.5	0.05	CIRCULAR	3	0		0.00555
ASPVT-MD01_IN2774-003	ASPVT-MD01	IN2774-003		148.4	0.013	0	0	0.25	0.05	HORIZ_ELLIPSE	1.17	1.92		0.00606
CB3068-066_MI3068-028	CB3068-066	MI3068-028		270.9	0.013	0	0	0.05	0.05	RECT_CLOSED	5	6		0.00491
CB3068-070_AS3068-069	CB3068-070	AS3068-069		79.3	0.013	0	0	0.05	0.05	RECT_CLOSED	4	8		0.00529
CB3068-071_CB3068-070	CB3068-071	CB3068-070		259.2	0.013	0	0	0.05	0.05	RECT_CLOSED	5	6		0.00309
CB3168-023_AS3168-045	CB3168-023	AS3168-045		57.8	0.013	0	0	0.05	0.25	CIRCULAR	3	0		0.00796
GR2673-020_TP2673-028	J1595	TP2673-028		47.3	0.013	0	0	0.2	0.25	RECT_CLOSED	6	10	24	0.00508
GR2673-025_TP2673-023	J1598	TP2673-023		58.8	0.013	0	0	0.2	0.25	RECT_CLOSED	6	10	24	0.00321
GR2770-014_GR2770-013	J2953	J7936		109.6	0.013	0	0	0.2	0.5	RECT_CLOSED	6	7	24	0.00183
GR2770-015_TP2770-017	J2957	TP2770-017		59.6	0.013	0	0	0.2	0	RECT_CLOSED	6	7	24	0.00185
GR2771-016_TP2771-015	J7456	TP2771-015		70.0	0.013	0	0	0.2	0	RECT_CLOSED	6	7	24	0.00429

Proposed Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
GR2771-017_AE2671-023	J7457	J6655		139.8	0.013	0	0	0.2	0.5	RECT_CLOSED	6	7	24	0.00429
GR2775-015_GR2775-017	J4161	J1538		119.1	0.013	0	0	0.2	0.5	RECT_CLOSED	4	8	21	0.00512
GR2775-016_GR2775-018	J4159	J1543		119.0	0.013	0	0	0.2	0.5	RECT_CLOSED	5	8	21	0.00513
GR2775-031_GR2775-033	J4160	J1537		120.0	0.013	0	0	0.2	0.5	RECT_CLOSED	4	8	21	0.00508
GR2775-032_GR2775-034	J4164	J1544		120.0	0.013	0	0	0.2	0.5	RECT_CLOSED	4	8	21	0.00508
GR2869-008_AE2869-011	J58687	McKennaBend1		176.5	0.013	0	0	0.2	0.25	RECT_CLOSED	5	8	24	0.00204
GR2869-010_AE2869-012	J58679	McKennaBend2		178.3	0.013	0	0	0.2	0.25	RECT_CLOSED	5	8	24	0.00204
GR2967-004_IN2967-002	J54236	IN2967-002		25.2	0.013	0	0	0.2	0	CIRCULAR	4	0	2	0.01192
IN2669-012_AS2669-007	IN2669-012	AS2669-007		55.9	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.00949
IN2669-016_AS2669-019	IN2669-016	AS2669-019		56.7	0.013	0	2	0.05	0.5	CIRCULAR	1.5	0		0.01182
IN2671-015_AS2671-014	IN2671-015	AS2671-014		35.2	0.013	0	1.5	0.05	0.05	CIRCULAR	2	0		0.01504
IN2672-014_AE2672-019	IN2672-014	J2933		35.5	0.013	0	0	0	0.5	RECT_CLOSED	5	11		0.00422
IN2672-024_AE2672-027	IN2672-024	J2698		141.8	0.013	0	0	0.05	0.5	CIRCULAR	1.75	0		0.01142
IN2672-029_AE2672-030	IN2672-029	J2704		146.0	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.03062
IN2673-001_AE2673-002	IN2673-001	J2155		144.1	0.013	0	0	0.05	0.5	CIRCULAR	1.25	0		0.02148
IN2673-007_IN2673-008	IN2673-007	IN2673-008		46.8	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.01282
IN2673-008_AE2673-009	IN2673-008	J2081		139.4	0.013	0	0	0.05	0.5	CIRCULAR	2.5	0		0.0132
IN2673-029_AE2673-013	IN2673-029	J1829		97.5	0.013	0	0	0.05	0.5	HORIZ_ELLIPSE	6	0		0.01245
IN2674-001_AE2674-003	IN2674-001	J4897		231.1	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		0.0219
IN2674-007_IN2674-008	IN2674-007	IN2674-008		69.1	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.01071
IN2674-008_IN2674-009	IN2674-008	IN2674-009		10.1	0.013	0	0	0.5	0.5	CIRCULAR	2	0		0.01389
IN2674-009_AE2674-010	IN2674-009	J5215		171.4	0.013	0	0	0.5	0.5	CIRCULAR	2	0		0.01458
IN2767-003_AS2867-019	IN2767-003	AS2867-019		246.5	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.03003
IN2768-001_IN2768-002	IN2768-001	IN2768-002		297.6	0.013	0	0	0.05	0.25	CIRCULAR	1.25	0		0.0833
IN2768-002_IN2768-003	IN2768-002	IN2768-003		225.1	0.013	0	0	0.25	0.05	CIRCULAR	1.25	0		0.03824
IN2768-003_AS2768-005	IN2768-003	AS2768-005		29.4	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		0.01805
IN2768-010_IN2768-014	IN2768-010	IN2768-014		59.4	0.013	0	0	0.05	0.25	CIRCULAR	2	0		0.03706
IN2768-012_IN2767-003	IN2768-012	IN2767-003		390.2	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.0292
IN2768-014_IN2768-012	IN2768-014	IN2768-012		347.633	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.01692
IN2768-015_AS2868-035	IN2768-015	AS2868-035		196.567	0.013	0	0.5	0.25	0.05	CIRCULAR	1.5	0		0.07587
IN2770-007_IN2770-010	IN2770-007	IN2770-010		30.017	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.00999
IN2770-010_AE2770-009	IN2770-010	J3385		169.54	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.00814
IN2771-006_AS2771-014	IN2771-006	AS2771-014		146.344	0.013	0	0	0.05	0.25	CIRCULAR	2.5	0		0.02857
IN2774-002_AE2674-013	IN2774-002	J4683		258.17	0.013	0	0	0.05	0.5	HORIZ_ELLIPSE	2	0		0.00511
IN2774-003_IN2774-002	IN2774-003	IN2774-002		31.747	0.013	0	0	0.05	0.05	HORIZ_ELLIPSE	1.17	1.92		0.00567
IN2774-013_AS2774-012	IN2774-013	AS2774-012		81.791	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.03805
IN2774-014_IN2774-013	IN2774-014	IN2774-013		222.53	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.02032
IN2774-015_IN2774-014	IN2774-015	IN2774-014		385.24	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.02015
IN2775-010_AE2775-012	IN2775-010	J1498		197.5	0.013	0	0	0.05	0.5	RECT_CLOSED	3	6		0.00506
IN2865-001_AS2865-004	IN2865-001	AS2865-004		351.002	0.013	0	0	0.25	0.5	CIRCULAR	2	0		0.00607
IN2866-008_AS2966-008	IN2866-008	AS2966-008		209.21	0.013	0	0.3	0.25	0.5	RECT_CLOSED	2	4		0.00497
IN2866-011_AS2866-003	IN2866-011	AS2866-003		136.365	0.013	0	0	0.05	0.25	CIRCULAR	2	0		0.02905
IN2867-020A_AS2867-005	IN2867-020A	AS2867-005		37.873	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		0.00502
IN2868-031_AS2868-035	IN2868-031	AS2868-035		54.662	0.013	0	0.5	0.05	0.5	CIRCULAR	2	0		0.03112

Proposed Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
IN2868-044A_AS2867-005	IN2868-044A	AS2867-005		48.696	0.013	0	0	0.05	0.5	CIRCULAR	1.5	0		0.00493
IN2869-003_GR2869-005	IN2869-003	J4128		44.027	0.013	0	0	0	0.5	RECT_CLOSED	5	8		0.00182
IN2870-001_AE2870-006	IN2870-001	J3735		171.994	0.013	0	0	0.05	0.5	CIRCULAR	2.25	0		0.06216
IN2870-002_IN2870-001	IN2870-002	IN2870-001		46.68	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.015
IN2870-013_IN2870-002	IN2870-013	IN2870-002		177.178	0.013	0	0	0.05	0.05	CIRCULAR	1.25	0		0.10705
IN2874-018_AS2874-017	IN2874-018	AS2874-017		48.637	0.013	0	0	0.5	0.05	CIRCULAR	2	0		0.08543
IN2966-004_AS2966-008_AS2966-009	IN2966-004	AS2966-008/009		15.483	0.013	0	1	0.05	0.5	CIRCULAR	1.5	0		0.06537
IN2966-015_GR2966-016	IN2966-015	J396		219.768	0.013	0	0	0.05	0.5	CIRCULAR	1.75	0		0.00294
IN2966-026_IN2966-030	IN2966-026	IN2966-030		175.974	0.013	0	0	0.05	0.25	CIRCULAR	1.25	0		0.01284
IN2966-030_AE2966-031	IN2966-030	J55411		91.116	0.013	0	0	0.25	0.5	CIRCULAR	1.25	0		0.01593
IN2967-002_AS2968-031	IN2967-002	AS2968-031		49.324	0.013	0	0	0	0	CIRCULAR	4	0		0.00527
IN2968-029_GR2968-032	IN2968-029	J62054		22.456	0.013	0	0	0	0.5	CIRCULAR	4	0		0
IN2969-025_IN2969-027	IN2969-025	IN2969-027		62.068	0.013	0	0.5	0.05	0.5	CIRCULAR	2	0		0.02401
IN2969-027_AS2969-028	IN2969-027	AS2969-028		277.197	0.013	0	0	0.5	0.05	CIRCULAR	2.5	0		0.018
IN2969-034_AE2969-002	IN2969-034	J59673		84.144	0.013	0	0	0.05	0.5	RECT_CLOSED	2	4		0.00309
IN3066-002_IN3066-005	IN3066-002	IN3066-005		219.509	0.013	0	0	0.05	0.5	CIRCULAR	2.5	0		0.00483
IN3066-005_GR3066-010	IN3066-005	J53685		26.002	0.013	0	0	0.5	0.5	CIRCULAR	2.5	0		0.01962
IN3066-019_GR3066-014	IN3066-019	J94335		162.255	0.022	0	0	0.05	0.5	RECT_CLOSED	2	3		0.00594
IN3066-020_AE3066-021	IN3066-020	J52969		139.005	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.00124
IN3068-035_IN3068-036	IN3068-035	IN3068-036		229.332	0.013	0	0	0.25	0.25	CIRCULAR	3	0		0.00798
IN3068-036_CB3068-071	IN3068-036	CB3068-071		45.578	0.013	0	1	0.25	0.25	CIRCULAR	3	0		0.01009
IN3069-012_AS3069-011	IN3069-012	AS3069-011		7.613	0.013	0	0	0.05	0.5	CIRCULAR	3	0		0.00263
IN3070-006_IN3070-016	IN3070-006	IN3070-016		218.398	0.013	0	0	0.25	0.5	CIRCULAR	2.5	0		0.00449
IN3070-008_AS3070-007	IN3070-008	AS3070-007		251.187	0.013	0	0	0.05	0.25	CIRCULAR	2.5	0		0.02059
IN3070-011_AS3070-010	IN3070-011	AS3070-010		125.754	0.013	0	0	0.05	0.5	CIRCULAR	2	0		0.02004
IN3070-012_IN3070-008	IN3070-012	IN3070-008		38.173	0.013	0	0	0.05	0.05	CIRCULAR	2	0		0.02044
IN3070-016_AS3070-003	IN3070-016	AS3070-003		311.278	0.013	0	0	0.5	0.05	CIRCULAR	2.5	0		0.00405
IN3071-003_AS3070-014	IN3071-003	AS3070-014		188.499	0.013	0	0	0.25	0.5	CIRCULAR	2	0		0.03403
IN3168-018_IN3068-035	IN3168-018	IN3068-035		77.162	0.013	0	0	0.05	0.25	CIRCULAR	3	0		0.00804
IN3168-026_AS3168-024	IN3168-026	AS3168-024		41.695	0.013	0	1.04	0.05	0.5	CIRCULAR	2	0		0.02015
IN3169-001_IN3169-006	IN3169-001	IN3169-006		23.483	0.013	0	1	0.05	0.5	CIRCULAR	2	0		0.02215
IN3169-006_TE3168-017	IN3169-006	TE3168-017		332.415	0.013	0	0	0.5	0.05	CIRCULAR	3	0		0.00701
IN3266-024_IN3266-023	IN3266-024	IN3266-023		361.163	0.013	0	0	0.05	0.05	CIRCULAR	2.5	0		0.00698
INPVT-MD02_ASPVT-MD01	INPVT-MD02	ASPVT-MD01		24.3	0.013	0	0	0.05	0.25	CIRCULAR	1.5	0		0.02511
McKenna1-3	McKennaBend1	McKennaBend3		114.609	0.013	0	0	0.25	0.25	RECT_CLOSED	5	8		0.00209
McKenna2-4	McKennaBend2	McKennaBend4		120.546	0.013	0	0	0.25	0.25	RECT_CLOSED	5	8		0.00199
MI3068-028_GR2968-028	MI3068-028	J7406		88.04	0.022	0	0	0.05	0.5	RECT_CLOSED	4	10		0.0049
MI3168-013_AS3168-020	MI3168-013	AS3168-044		499.351	0.013	0	0	0.05	0.05	RECT_CLOSED	5.5	6		0.003
OSPVT-MD03_INPVT-MD02	OSPVT-MD03	INPVT-MD02		59.4	0.013	0	0	0.5	0.05	CIRCULAR	1.5	0		0.01078
TE3168-016_IN3168-018	TE3168-016	IN3168-018		24.756	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00808
TE3168-017_TE3168-016	TE3168-017	TE3168-016		14.419	0.013	0	0	0.05	0.05	CIRCULAR	3	0		0.00832
TP2673-023_TP2674-025	TP2673-023	TP2674-025		81.365	0.013	0	0	0.25	0	RECT_CLOSED	6	10		0.00479
TP2673-028_TP2674-019	TP2673-028	TP2674-019		113.021	0.013	0	0	0.25	0	RECT_CLOSED	6	10		0.00504
TP2674-019_GR2674-015	TP2674-019	J5489		22.124	0.013	0	0	0	0.5	RECT_CLOSED	6	10		0.01288

Proposed Conditions Hydraulic Input Parameters - Conduits

Name	Inlet Node	Outlet Node	Tag	Length (ft)	Roughness	Inlet Offset (ft)	Outlet Offset (ft)	Entry Loss Coeff.	Exit Loss Coeff.	Cross-Section	Geom1 (ft)	Geom2 (ft)	Culvert Code	Slope (ft/ft)
TP2674-025_GR2674-020	TP2674-025	J5488		53.242	0.013	0	0	0	0.5	RECT_CLOSED	6	10		0.0071
TP2770-017_GR2770-016	TP2770-017	J7940		49.71	0.013	0	0	0	0.5	RECT_CLOSED	6	7		0.00181
TP2771-015_AE2671-021	TP2771-015	J6654		70.008	0.013	0	0	0	0.5	RECT_CLOSED	6	7		0.00429
TP2868-037_AE2868-010	J55605	TP2868-037		304.354	0.013	0	0.74	0.5	0.5	CIRCULAR	1.5	0		0.00455
TP2868-037_AS2868-011	TP2868-037	AS2868-011		124.217	0.013	0	0	0.05	0.05	RECT_CLOSED	4	4		0.00805
TP2868-038_AS2868-025	TP2868-038	AS2868-025		268.391	0.013	0	0	0.05	0.05	RECT_CLOSED	4	4		0.00999
TP2966-025_AE2966-021	TP2966-025	J1245		36.281	0.013	0	0	0	0.5	RECT_CLOSED	3	6		0.00085
WalthamOUT1_WalthamOUT2	WalthamOUT1	WalthamOUT2		149.66	0.013	0	0	0.05	0.5	HORIZ_ELLIPSE	6	0		0.00401
WalthamOUT2_GWY	WalthamOUT2	J3148		286.904	0.013	0	0	0.5	0.5	HORIZ_ELLIPSE	6	0		0.00401

Proposed Conditions Hydraulic Input Parameters - Junctions

Name	Tag	Invert Elev. (ft)	Rim Elev. (ft)	Depth (ft)	Surcharge Depth (ft)
989	Connect2D	978	979	1	0
990	Connect2D	983.621	984.621	1	0
991	Connect2D	987.702	988.702	1	0
992	Connect2D	1004.71	1005.71	1	0
993	Connect2D	1006.671	1007.671	1	0
994	Connect2D	1016.564	1017.564	1	0
995	Connect2D	1033.967	1034.967	1	0
996	Connect2D	1020.616	1021.616	1	0
997	Connect2D	1009.623	1010.623	1	0
998	Connect2D	1002	1003	1	0
999	Connect2D	1025.886	1026.886	1	0
AS2669-007	Connect2D	1043.07	1046.9	3.83	0
AS2669-008	Connect2D	1041.27	1045.2	3.93	0
AS2669-019	Connect2D	1027.58	1032.6	5.02	0
AS2669-020	Connect2D	1020	1025.4	5.4	0
AS2669-027	Connect2D	1018.08	1024.1	6.02	0
AS2670-031	Connect2D	1015.81	1022.7	6.89	0
AS2670-032	Connect2D	1012.8	1020.8	8	0
AS2670-043	Connect2D	1003.3	1007.6	4.3	0
AS2670-044	Connect2D	1000.4	1007.4	7	0
AS2670-046	Connect2D	995.83	1001.6	5.77	0
AS2671-006	Connect2D	1000.86	1004.3	3.44	0
AS2671-013	Connect2D	993.4	1000	6.6	0
AS2671-014	Connect2D	994.39	1000.4	6.01	0
AS2672-010	Connect2D	991.27	997.42	6.15	0
AS2672-011	Connect2D	990.84	996.5	5.66	0
AS2672-016	Connect2D	985.96	990.8	4.84	0
AS2672-031	Connect2D	994.39	998.94	4.55	0
AS2673-022	Connect2D	985.82	990	4.18	0
AS2673-2018	Connect2D	983.68	989.54	5.86	0
AS2768-005	Connect2D	1044.87	1048.8	3.93	0
AS2770-005	Connect2D	1006.39	1009.4	3.01	0
AS2771-001	Connect2D	998.4	1001.6	3.2	0
AS2771-014	Connect2D	995.42	1003	7.58	0
AS2773-008	Connect2D	986.1	991.87	5.77	0
AS2773-009	Connect2D	993.84	998.34	4.5	0
AS2773-012	Connect2D	997.07	1001.57	4.5	0
AS2774-012	Connect2D	989.1	994.87	5.77	0
AS2865-004	Connect2D	1031.43	1034.9	3.47	0
AS2866-003	Connect2D	1034.44	1037.6	3.16	0
AS2866-004	Connect2D	1020.27	1024.3	4.03	0
AS2867-004		1023.96	1027.1	3.14	0
AS2867-005	Connect2D	1022.86	1026.9	4.04	0
AS2867-013	Connect2D	1021.7	1028.8	7.1	0

Proposed Conditions Hydraulic Input Parameters - Junctions

Name	Tag	Invert Elev. (ft)	Rim Elev. (ft)	Depth (ft)	Surcharge Depth (ft)
AS2867-016	Connect2D	1022.95	1030.7	7.75	0
AS2867-018	Connect2D	1019.82	1029.6	9.78	0
AS2867-019	Connect2D	1032.28	1036.11	3.83	0
AS2867-024	Connect2D	1024.15	1030.39	6.24	0
AS2867-025	Connect2D	1035.93	1041.81	5.88	0
AS2868-004	Connect2D	1018.76	1027.2	8.44	0
AS2868-009	Connect2D	1014.28	1019.62	5.34	0
AS2868-011	Connect2D	1012.34	1018.1	5.76	0
AS2868-018	Connect2D	1013.45	1017.1	3.65	0
AS2868-025	Connect2D	1009.29	1015.4	6.11	0
AS2868-035	Connect2D	1018.2	1022	3.8	0
AS2873-010	Connect2D	1026.3	1029.5	3.2	0
AS2873-022	Connect2D	1016.1	1021.8	5.7	0
AS2873-023	Connect2D	1017.04	1021.61	4.57	0
AS2873-024	Connect2D	1018.6	1023.91	5.31	0
AS2874-017	Connect2D	1013.54	1019.54	6	0
AS2874-019	Connect2D	1017.73	1021.96	4.23	0
AS2965-007	Connect2D	1019.95	1023.34	3.39	0
AS2965-008	Connect2D	1021.73	1026	4.27	0
AS2965-2022	Connect2D	1024.43	1028.76	4.33	0
AS2965-2022A	Connect2D	1023.82	1028.18	4.36	0
AS2966-008	Connect2D	1018.54	1022.95	4.41	0
AS2966-009	Connect2D	1017.86	1021.87	4.01	0
AS2967-007	Connect2D	1020.77	1024.24	3.47	0
AS2968-010	Connect2D	1011.42	1016.5	5.08	0
AS2968-011	Connect2D	1011.03	1016	4.97	0
AS2968-019	Connect2D	1011.76	1016.71	4.95	0
AS2968-031	Connect2D	1012.17	1022.56	10.39	0
AS2969-003	Connect2D	1013.3	1018.47	5.17	0
AS2969-004	Connect2D	1014.59	1019.22	4.63	0
AS2969-006	Connect2D	1016.78	1022	5.22	0
AS2969-008	Connect2D	1019.21	1024.45	5.24	0
AS2969-015	Connect2D	1015.62	1020.65	5.03	0
AS2969-024	Connect2D	1017.76	1022	4.24	0
AS2969-028	Connect2D	1012.61	1016.5	3.89	0
AS2969-029	Connect2D	1011.45	1015	3.55	0
AS2969-035	Connect2D	1007.6	1010.6	3	0
AS3067-005	Connect2D	1023.93	1028.5	4.57	0
AS3067-006	Connect2D	1021.27	1025.89	4.62	0
AS3068-007	Connect2D	1013.56	1017.6	4.04	0
AS3068-009	Connect2D	1012.59	1016.6	4.01	0
AS3068-068	Connect2D	1012.49	1017.5	5.01	0
AS3068-069	Connect2D	1013.07	1018.94	5.87	0
AS3068-072	Connect2D	1014.69	1020.4	5.71	0

Proposed Conditions Hydraulic Input Parameters - Junctions

Name	Tag	Invert Elev. (ft)	Rim Elev. (ft)	Depth (ft)	Surcharge Depth (ft)
AS3069-008	Connect2D	1019.67	1025	5.33	0
AS3069-011	Connect2D	1021.01	1026	4.99	0
AS3069-014	Connect2D	1016.6	1020.8	4.2	0
AS3069-019	Connect2D	1015.24	1019.2	3.96	0
AS3069-029	Connect2D	1013.88	1017.58	3.7	0
AS3070-003	Connect2D	1023.06	1026.5	3.44	0
AS3070-010	Connect2D	1036.55	1041	4.45	0
AS3070-014	Connect2D	1039.18	1042.7	3.52	0
AS3071-001	Connect2D	1046.22	1049.6	3.38	0
AS3071-004	Connect2D	1058.56	1062.2	3.64	0
AS3071-005	Connect2D	1060.06	1063.6	3.54	0
AS3166-008	Connect2D	1030.87	1036	5.13	0
AS3166-009	Connect2D	1033.41	1039	5.59	0
AS3166-010	Connect2D	1025.9	1031	5.1	0
AS3166-018	Connect2D	1027.79	1032.62	4.83	0
AS3167-001	Connect2D	1018.7	1024.1	5.4	0
AS3167-002	Connect2D	1020.92	1025.79	4.87	0
AS3167-003	Connect2D	1018.88	1025.5	6.62	0
AS3167-004	Connect2D	1020.8	1024.3	3.5	0
AS3167-009	Connect2D	1031.38	1037	5.62	0
AS3167-010	Connect2D	1037.1	1042	4.9	0
AS3167-011	Connect2D	1020.72	1026.4	5.68	0
AS3167-016	Connect2D	1023.24	1028.6	5.36	0
AS3168-024	Connect2D	1018.88	1023.97	5.09	0
AS3168-034	Connect2D	1021.56	1026	4.44	0
AS3168-035	Connect2D	1023.5	1028	4.5	0
AS3168-043	Connect2D	1015.12	1021.82	6.7	0
AS3168-044	Connect2D	1015.53	1022.15	6.62	0
AS3168-045	Connect2D	1016.01	1021.99	5.98	0
AS3169-009	Connect2D	1027.95	1032.45	4.5	0
AS3266-002	Connect2D	1036.27	1042.53	6.26	0
AS3266-002A	Connect2D	1038.03	1041.12	3.09	0
AS3266-003	Connect2D	1035.9	1041.78	5.88	0
ASPVT-MD01	Connect2D	981.25	985.03	3.78	0
CB3068-066	Connect2D	1012	1017.01	5.01	0
CB3068-070	Connect2D	1013.49	1019.19	5.7	0
CB3068-071	Connect2D	1014.29	1020.94	6.65	0
CB3168-023	Connect2D	1016.47	1022.29	5.82	0
IN2669-012	Connect2D	1043.6	1048.16	4.56	0
IN2669-016	Connect2D	1030.25	1033.7	3.45	0
IN2671-015	Connect2D	996.42	1001.92	5.5	0
IN2672-014	Connect2D	984.45	992	7.55	0
IN2672-024	Connect2D	986.91	991.59	4.68	0
IN2672-029	Connect2D	991	994.3	3.3	0

Proposed Conditions Hydraulic Input Parameters - Junctions

Name	Tag	Invert Elev. (ft)	Rim Elev. (ft)	Depth (ft)	Surcharge Depth (ft)
IN2673-001	Connect2D	988.5	991.5	3	0
IN2673-007	Connect2D	987	990.55	3.55	0
IN2673-008	Connect2D	986.4	990.6	4.2	0
IN2673-029	Connect2D	988.12	991.6	3.48	0
IN2674-001	Connect2D	984.76	988.37	3.61	0
IN2674-007	Connect2D	983.68	986.94	3.26	0
IN2674-008	Connect2D	982.94	987.44	4.5	0
IN2674-009	Connect2D	982.8	987.54	4.74	0
IN2767-003	Connect2D	1039.68	1048.77	9.09	0
IN2768-001	Connect2D	1078.7	1082.5	3.8	0
IN2768-002	Connect2D	1054	1056.8	2.8	0
IN2768-003	Connect2D	1045.4	1050.6	5.2	0
IN2768-010	Connect2D	1059.15	1062.8	3.65	0
IN2768-012	Connect2D	1051.07	1055	3.93	0
IN2768-014	Connect2D	1056.95	1060.5	3.55	0
IN2768-015	Connect2D	1033.57	1037.2	3.63	0
IN2770-007	Connect2D	1002.4	1005.9	3.5	0
IN2770-010	Connect2D	1002.1	1005.9	3.8	0
IN2771-006	Connect2D	999.6	1004.45	4.85	0
IN2774-002	Connect2D	980.17	983.82	3.65	0
IN2774-003	Connect2D	980.35	983.77	3.42	0
IN2774-013	Connect2D	992.21	997.35	5.14	0
IN2774-014	Connect2D	996.73	1001.95	5.22	0
IN2774-015	Connect2D	1004.49	1009.74	5.25	0
IN2775-010	Connect2D	977.1	981.78	4.68	0
IN2865-001	Connect2D	1033.56	1038.13	4.57	0
IN2866-008	Connect2D	1019.88	1024.5	4.62	0
IN2866-011	Connect2D	1038.4	1043.85	5.45	0
IN2867-020A	Connect2D	1023.05	1026.828	3.778	0
IN2868-031	Connect2D	1020.4	1023.7	3.3	0
IN2868-044A	Connect2D	1023.1	1025.887	2.787	0
IN2869-003	Connect2D	1003.08	1016	12.92	0
IN2870-001	Connect2D	1014.2	1018.11	3.91	0
IN2870-002	Connect2D	1014.9	1018.11	3.21	0
IN2870-013	Connect2D	1033.76	1040.66	6.9	0
IN2874-018	Connect2D	1017.68	1022.18	4.5	0
IN2966-004	Connect2D	1020.43	1023.77	3.34	0
IN2966-015	Connect2D	1018.65	1022.05	3.4	0
IN2966-026	Connect2D	1020.79	1025.83	5.04	0
IN2966-030	Connect2D	1018.53	1021.53	3	0
IN2967-002	Connect2D	1012.43	1022.05	9.62	0
IN2968-029	Connect2D	1011.89	1022.18	10.29	0
IN2969-025	Connect2D	1019.59	1022.39	2.8	0
IN2969-027	Connect2D	1017.6	1022.74	5.14	0

Proposed Conditions Hydraulic Input Parameters - Junctions

Name	Tag	Invert Elev. (ft)	Rim Elev. (ft)	Depth (ft)	Surcharge Depth (ft)
IN2969-034	Connect2D	1006.69	1009.64	2.95	0
IN3066-002	Connect2D	1022.97	1026.6	3.63	0
IN3066-005	Connect2D	1021.91	1025.6	3.69	0
IN3066-019	Connect2D	1021.28	1024.36	3.08	0
IN3066-020	Connect2D	1020.23	1023.1	2.87	0
IN3068-035	Connect2D	1017.58	1021.6	4.02	0
IN3068-036	Connect2D	1015.75	1020.6	4.85	0
IN3069-012	Connect2D	1021.03	1026.03	5	0
IN3070-006	Connect2D	1025.3	1027.8	2.5	0
IN3070-008	Connect2D	1035.38	1040	4.62	0
IN3070-011	Connect2D	1039.07	1042.9	3.83	0
IN3070-012	Connect2D	1036.16	1040.5	4.34	0
IN3070-016	Connect2D	1024.32	1028.3	3.98	0
IN3071-003	Connect2D	1045.59	1050.18	4.59	0
IN3168-018	Connect2D	1018.2	1022.2	4	0
IN3168-026	Connect2D	1020.76	1024.02	3.26	0
IN3169-001	Connect2D	1022.37	1025.87	3.5	0
IN3169-006	Connect2D	1020.85	1025	4.15	0
IN3266-023	Connect2D	1037.72	1042.3	4.58	0
IN3266-024	Connect2D	1040.24	1044.12	3.88	0
INPVT-MD02	Connect2D	981.86	985.46	3.6	0
MI3068-028	Connect2D	1010.67	1016.111	5.441	0
TE3168-017	Connect2D	1018.52	1023.3	4.78	0
TP2770-017	Connect2D	998.39	1008.2	9.81	0
TP2868-037	Connect2D	1013.34	1019	5.66	0
TP2868-038	Connect2D	1011.97	1018	6.03	0
TP2966-025	Connect2D	1019.41	1024.111	4.701	0
WalthamOUT1	Connect2D	1002.87	1005.9	3.03	0
WalthamOUT2	Connect2D	1002.27	1008.54	6.27	0
McKennaBend1		1003.58	1015	11.42	12
McKennaBend2		1003.58	1015	11.42	12
McKennaBend3		1003.34	1015	11.66	12
McKennaBend4		1003.34	1015	11.66	12
AS2966-008/009		1018.42	1023.5	5.08	20
AS3070-007		1030.21	1035	4.79	20
MI3168-013		1017.03	1025.27	8.24	20
OSPVT-MD03		982.5	987.3	4.8	20
TE3168-016		1018.4	1023.07	4.67	20
TP2673-023		981.32	989.55	8.23	20
TP2673-028		981.36	989.39	8.03	20
TP2674-019		980.79	989.65	8.86	20
TP2674-025		980.93	989.9	8.97	20
TP2771-015		992.2	1001.3	9.1	20

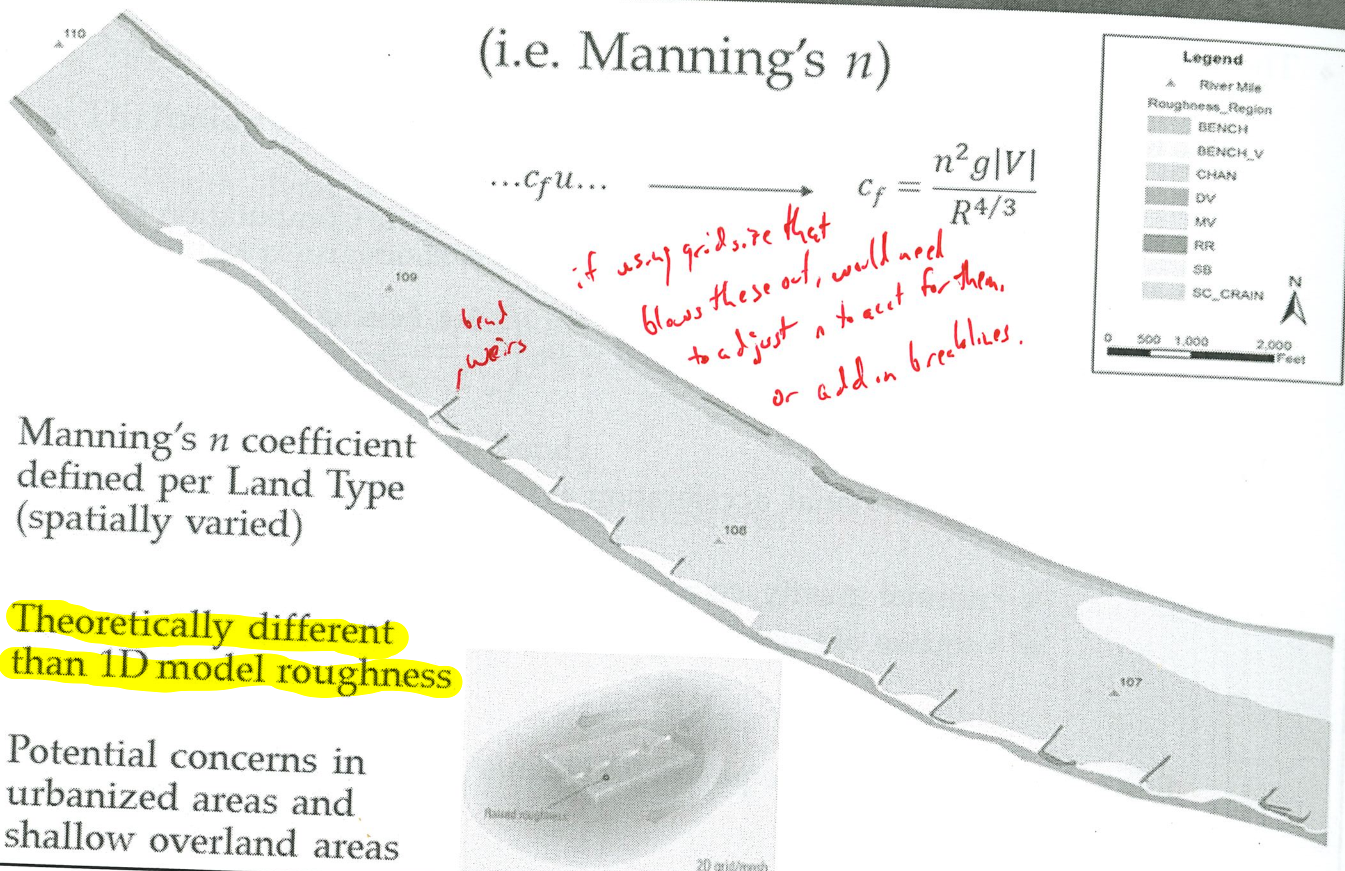
Appendix D. – HEC-RAS 2D Manning’s n Reference Document

Form Roughness

(i.e. Manning's n)

$$\ldots c_f u \ldots \longrightarrow c_f = \frac{n^2 g |V|}{R^{4/3}}$$

if using grid size that blows these out, would need to adjust n to acct for them, or add in breaklines.



- Manning's n coefficient defined per Land Type (spatially varied)
- Theoretically different than 1D model roughness
- Potential concerns in urbanized areas and shallow overland areas

It is important to note that the loss processes embedded in hydraulic roughness parameters for 1D and 2D models, while closely related, are not exactly the same.

In a 1D model the roughness parameter can account for:
* Friction losses associated with the bed material of a channel/floodplain,
* Drag losses associated with vegetation or other obstructions in the channel/floodplain,
* Form losses due to turbulence in a channel/floodplain due to channel geometry,
* Variations in geometry and associated form losses between cross-sections,
* Bend losses in a channel,
* Other losses not explicitly considered.

In a 2D model, some of the above losses are to some degree accounted for by the numerical scheme.

can't do vertically varied n values in 2D like you can in 1D.

Typical nValues

Valid Manning's 'n' Ranges for Different Land Use Types

Land Use Type	Manning's 'n'
Residential areas – high density	0.2 – 0.5
Residential areas – low density	0.1 – 0.2
Industrial/commercial	0.2 – 0.5
Open pervious areas, minimal vegetation (grassed)	0.03 – 0.05
Open pervious areas, moderate vegetation (shrubs)	0.05 – 0.07
Open pervious areas, thick vegetation (trees)	0.07 – 0.12
Waterways/channels – minimal vegetation	0.02 - 0.04
Waterways/channels – vegetated	0.04 – 0.1
Concrete lined channels	0.015 – 0.02
Paved roads/car park/driveways	0.02 – 0.03
Lakes (no emergent vegetation)	0.015 – 0.35
Wetlands (emergent vegetation)	0.05 – 0.08
Estuaries/Oceans	0.02 – 0.04

Source: Australian Rainfall & Runoff Revision Projects, Project 15: Two Dimensional Modelling in Urban rand Rural Floodplains, November 2012

Above table is recommended for 2D modeling of non-shallow flow conditions. Note the high n values for residential areas. Alternatively, individual buildings can be simulated with even higher n values (e.g in the 1 to 10 range) to simulate water leaking and storing inside of buildings but not conveying.

there isn't a lot of guidance out there.

WEST Consultants, Inc.

Typical n Values

Manning's n for Shallow Flow Conditions

Surface	n-value
Dense turf	0.17 - 0.80
Bermuda and dense grass, dense vegetation	0.17 - 0.48
Shrubs and forest litter, pasture	0.30 - 0.40
Average grass cover	0.20 - 0.40
Poor grass cover on rough surface	0.20 - 0.30
Short prairie grass	0.10 - 0.20
Sparse vegetation	0.05 - 0.13
Sparse rangeland with debris	0.09 - 0.34
0% cover	0.05 - 0.25
20 % cover	
Plowed or tilled fields	0.008 - 0.012
Fallow - no residue	0.06 - 0.22
Conventional tillage	0.06 - 0.16
Chisel plow	0.30 - 0.50
Fall disking	0.04 - 0.10
No till - no residue	0.07 - 0.17
No till (20 - 40% residue cover)	0.17 - 0.47
No till (60 - 100% residue cover)	
Open ground with debris	0.10 - 0.20
Shallow glow on asphalt or concrete (0.25" to 1.0")	0.10 - 0.15
Fallow fields	0.08 - 0.12
Open ground, no debris	0.04 - 0.10
Asphalt or concrete	0.02 - 0.05

[1]Adapted from COE, HEC-1 Manual, 1990 and the COE, Technical Engineering and Design Guide, No. 19, 1997 with modifications.

Source: FLO-2D Reference Manual, FLO-2D Software, 2012

Above table is recommended for 2D modeling of shallow flow conditions. These n values should typically not be used unless the modeler is interested only in the results at shallow flow conditions.

ASCE

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Two-Dimensional Modeling Using HEC-RAS

2017

1D/2D Connection Problems

Problem: Weir Coefficient not correct

Common problem HEC-RAS users have with 1D/2D

What is being modeled with the Lateral Structure	Description	Range of Weir Coefficients
Levee/Roadway – 3ft or higher above natural ground	Broad crested weir shape, flow over levee/road acts like weir flow	**1.5 to 2.6** (2.0 default) SI Units: 0.83 to 1.43
Levee/Roadway – 1 to 3 ft elevated above ground	Broad crested weir shape, flow over levee/road acts like weir flow, but becomes submerged easily.	**1.0 to 2.0** SI Units: 0.55 to 1.1
Natural high ground barrier – 1 to 3 ft high	Does not really act like a weir, but water must flow over high ground to get into 2D flow area.	**0.5 to 1.0** SI Units: 0.28 to 0.55
Non elevated overbank terrain. Lat Structure not elevated above ground	Overland flow escaping the main river.	**0.2 to 0.5** SI Units: 0.11 to 0.28

Fix:

Use values in Table

A common problem HEC-RAS users have when interfacing 1D river reaches with 2D flow areas, is using too high of a weir coefficient for the situation being modeled. If the lateral structure is really just overland flow interface between the 1D river and the 2D floodplain, then a weir coefficient of 0.2 to 0.5 (0.11 to 0.28 for SI Units) must be used to get the right flow transfer and keep the model stable.

What to look for: The user should check all lateral structures and verify if the correct coefficient is used against what is being modeled as there is no warnings or errors provided by the model.

Appendix E. – Culvert Inlet Treatments

East Pass

3-8’x4’ & 1-8’x5’ Box Culverts with 45° Wingwalls and Beveled Top Edge (0.2 entrance loss coefficient)

McKee Road

2-10'x6' Box Culverts with 45° Wingwalls and Square Top Edge (0.4 entrance loss coefficient)

Carnwood Road
2-63”x98” HERCP with socket ends (0.2 entrance loss coefficient)

Lancaster Lane
2-72” RCP with apron end (0.5 entrance loss coefficient)

Canterbury Road
2-72” RCP with apron end (0.5 entrance loss coefficient)

Pilgrim Road

2-72” RCP with apron end (0.5 entrance loss coefficient)

McKenna Boulevard
2-72” RCP with apron end (0.5 entrance loss coefficient)

Westbrook Lane
2-47”x71” CMPA with vertical headwall and square edge (0.5 entrance loss coefficient)

Raymond Road

48” RCP with vertical headwall and socket end (0.2 entrance loss coefficient)

Prairie Road

42” RCP with apron end (0.5 entrance loss coefficient)

Appendix F. – Uncalibrated Model Peer Review Comments

From:	Burger, Caroline
To:	Allie, Matthew
Cc:	Fries, Gregory; Schmidt, Janet
Subject:	RE: East Badger Mill Creek QC Review
Date:	October 28, 2020 2:21:28 PM

Hi Matt,

I completed my review of the 1D results and 2D input and results. I have the following comments:

1. The continuity is good and water is not being lost from the model. (this is very good)
2. I checked the junctions with relatively high depths – sometimes this can indicate unreasonable results. Where the relatively high depths occur, it appears that the pipe is relatively large and there overland flow above the pipe. Based on this, the results make sense.
3. I played the animation for the 500-yr event. It was pretty fun to watch (yes, I know I need more hobbies). It looks reasonable.
4. I imported the 2D results into GIS and color coded the max depths. The mapping looks reasonable.

I think the next steps are to:

1. Calibrate the model (which you indicated you already started)
2. Print out a flood map to show Janet and Greg following the calibration so they can comment on if the results look like what they expect.

Please let me know if you have questions.

Thanks,

Caroline Burger, PE, ENV SP
(she/her/hers)
Engineer 4
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Madison, WI 53703
Desk: 608-266-4913
cburger@cityofmadison.com

From: Allie, Matthew
Sent: Friday, October 23, 2020 9:18 AM
To: Burger, Caroline
Cc: Fries, Gregory ; Schmidt, Janet
Subject: RE: East Badger Mill Creek QC Review

Hi Caroline,

Thanks again for your review and for getting to it quickly after your vacation. I'll start working on these comments and then hold tight until I hear back about the 2D portions.

Matt

From: Burger, Caroline <CBurger@cityofmadison.com>
Sent: Thursday, October 22, 2020 5:16 PM
To: Allie, Matthew <MAllie@cityofmadison.com>
Cc: Fries, Gregory <GFries@cityofmadison.com>; Schmidt, Janet <jschmidt@cityofmadison.com>

Subject: RE: East Badger Mill Creek QC Review

Hi Matt,

I was able to get through the Hydrology and 1D hydraulics of the model noted below. I the following comments. The items in green are the ones you need to address. Others are noting what I checked. If I did not comment on something, I did not check it. If you want me to review an item I did not comment on, please let me know.

Overall it looks beautiful and very well put together.

1. I previously reviewed the subbasin and flow path delineation, I did not re-review that.
2. The area in GIS matches the overall watershed area in the model. There are some discrepancies between the Subcatchment file Richie created and the PC-SWMM model hydrology. You indicated you did some manual changes after the import. Please check the areas flagged in yellow in the attached spreadsheet to see that those are the ones you changed. If those are the changes you meant to make then the hydrology in the model matches the hydrology in the GIS file.
3. It looks like the model has 0.013 for concrete pipes and 0.022 for CMP pipes. This makes sense to me.
4. Theoretically gravity storm sewer should not have negative slopes. It can happen.
    a. AS2968-019_GR2968-020 has a slight negative slope. There is no downstream invert in GIS. Please check that this should be negative based on the data you have.
    b. AE3066-US_AE3066-DS has a slight negative slope, there is no data in GIS or GT-Viewer. Please check that this should be negative based on the data you have.
    c. IN2969-025_IN2969-027 has a negative slope. The data in GIS shows a positive slope. Please check that this should be negative based on the data you have.
    d. IN2968-029_GR2968-032 has a negative slope. There is no invert data in GIS. Please check that this should be negative based on the data you have.
5. Pipes with slopes greater than 4% are relatively steep for this area. They can happen. I checked the pipes with a slope greater than 4% and found the following:
    a. AS2670-032_AS2670-043 – the upstream invert does not match what is in GIS. Please check that the data in the model is correct.
    b. AE2966-023_AE2966-024 – the upstream invert does not match what is in GIS. GIS has no downstream invert. Please check that the data in the model is correct.
    c. IN2870-001_AE2870-006 – the downstream invert does not match what is in GIS. Please check that the data in the model is correct.
    d. AE3064-015_AE3065-003 – the downstream invert does not match what is in GIS. Please check that the data in the model is correct.
6. I reviewed the profiles and they look reasonable. Some look to have minimum cover, but, given the scale of this model, that is likely ok. If there are areas of excess ponding, the DEM may need to be adjusted to add more cover. I will look at that when I look at the 2D portions.
7. The entrance and exit loss coefficients look reasonable.

I will look at the 2D portion and the output next week.

Please let me know if you have questions.

Caroline Burger, PE, ENV SP

(she/her/hers)

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✉ cburger@cityofmadison.com
Please note some City offices currently closed to the public due to COVID-19, but most staff is still working. See our website (link below) for the most up to date information on how to best continue working with each department.
https://www.cityofmadison.com/health-safety/coronavirus/service-updates

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From: Allie, Matthew <MAllie@cityofmadison.com>
Sent: Thursday, October 15, 2020 4:08 PM
To: Burger, Caroline <CBurger@cityofmadison.com>
Subject: East Badger Mill Creek QC Review

Hi Caroline,

I have all of my uncalibrated existing conditions model files and related input organized for review.

- The mxd and all shapefiles I've been using to prepare model inputs are saved here: M:\DESIGN\Projects\12491\GIS
- List of all the shapefile layers and descriptions in the mxd: M:\DESIGN\Projects\12491\GIS\EBMC GIS Layer Summary.xlsx (bold layer names – I imported these directly to PCSWMM when building the model)
- PCSWMM model files are here: M:\DESIGN\Projects\12491\Deliverables\Task 3 Uncalibrated Existing Conditions Model\QC Review

I only moved the base model, 10-year, and 500-year files to the M drive. It's taking a long time for the files to transfer and I know our M drive space has been running low, so I figured these show the high and lower ends of simulations. I revised the mesh extents to contain all inundation and I have boundary condition/outfalls at three locations where flow leaves the watershed (main channel outfall, East Pass overflow to west, Williamsburg Way overflow to east/Fitchburg). If you need any of the other scenario files we can work that out while you're reviewing. I've also been unable to add a field to my mesh extents shapefile in GIS. I added the mesh resolution and 2D surface roughness directly in PCSWMM, but the shapefile doesn't currently document those parameters so I'm working on fixing that.

I already noticed two things I'll want to change before starting calibration, but I didn't want to spend time running the model again before review. I'll incorporate these changes along with your review comments. First, in the shapefiles I adjusted the configuration and loading nodes of three subcatchments along McKee Rd. I noticed that I was loading a fair amount of runoff to two structures on McKee in a way that wasn't realistic, so my revisions will make it more representative of the existing conditions. Second, there are a handful of junctions in the model that represent taps into culverts and therefore have no surface connection. I overlooked these when connecting junctions to the 2D mesh, so I'll need to disconnect these from the mesh to prevent water from surcharging onto the surface where it shouldn't.

I've started looking at output for a few of the calibration events since the curiosity was killing me. I realize I'll need to address any review comments and re-run before that data is good to use. The results are looking pretty good so far, but I figure we can have a calibration discussion before I get into turning knobs.

Thanks for making time to review this!

Matt Allie

From:	Burger, Caroline
To:	Allie, Matthew
Subject:	RE: EBMC Calibration
Date:	December 18, 2020 1:43:02 PM
Attachments:	RAS 2D Training - Mannings n Reference.pdf RAS 2D Training - Weir Coeff Reference.pdf

Hi Matt,

Please see below.

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From: Allie, Matthew
Sent: Wednesday, December 16, 2020 7:44 AM
To: Burger, Caroline
Subject: RE: EBMC Calibration

Thanks! I wasn’t trying to rush a response and hope I didn’t come off short.

I know my first email was pretty dense and then I found some clarity once I had additional results. I realized that writing that email was partly me processing what I was seeing. I’ll definitely still value any input you have!

From: Burger, Caroline <CBurger@cityofmadison.com>
Sent: Tuesday, December 15, 2020 5:12 PM
To: Allie, Matthew <MAllie@cityofmadison.com>
Subject: RE: EBMC Calibration

Hi,

I did read it. I was letting it digest before I replied.

I think your results sounds really good. For the largest events, if I’m within a foot, I feel like that’s success.

I will do some more digestion and fully respond tomorrow. ☺

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From: Allie, Matthew <MAllie@cityofmadison.com>
Sent: Tuesday, December 15, 2020 4:07 PM
To: Burger, Caroline <CBurger@cityofmadison.com>
Subject: RE: EBMC Calibration

If you haven’t read my email from yesterday yet, I’ll save you some time. The August 2018 storm ran quicker than I expected and has slightly smaller flows in EBMC than the 500-year event, which accounts for some of the

remaining discrepancies. There are a couple of small tweaks I want to check tomorrow, but the model is looking great!
Main takeaway is that it's within 0.8 feet of observed water level at the two downstream crossings and well within half a foot at all other locations with observations. I think that's pretty good!
Matt

From: Allie, Matthew
Sent: Monday, December 14, 2020 2:19 PM
To: Burger, Caroline <CBurger@cityofmadison.com>
Subject: RE: EBMC Calibration

Hi Caroline,
Here are a few more things I've found during calibration when I started focusing on large events. All inundation below pertains to the 500-year modeled flow since I need to get the August 2018 event set up to run this week. 500-year should be a decent proxy for August 2018 in this watershed.
Changes made:

- The model doesn't seem to be nearly as sensitive to changes in Manning's n values as PB was. For context, when I created the polygon to define mesh roughness I joined a street R/W file and the greenways parcel shapefile. I initially had the impervious and pervious areas set high, but mostly in line with modeling guidance for overland flow (n=0.1 & n=0.2).

I think I miscommunicated. The part of pheasant branch I was referring to was just the greenways. In the pheasant branch model, the greenways are a separate land use. In XP-SWMM you can vary the manning's n value by depth for the 2D land uses, so, for the greenways I started out with the higher/middle range of mannings and ended up at the lower end. For example, my grassed greenways have a mannings of 0.1 at the lowest elevations to 0.027 at the highest. The landscaped areas and streets are what is in the modeling guidance.

- Pervious areas – while the above seems reasonable for shallow flow (e.g. between homes), the pervious areas also include locations that are greenway adjacent and become inundated during high flows. Since those areas are conveying channel flow and we're more focused on large events, I **decreased the n value** and eventually got down to 0.05.

That seems consistent with what I found/did for pheasant branch

- Impervious areas – I noticed a few spots where we received input on August 2018 street flooding and the model was overestimating inundation depth. I **decreased the n value** of streets and eventually got down to 0.03. On the streets where inundation seemed inaccurate, flow is deep enough that I think it behaves less like overland than channel flow in large events.

That makes sense to me.

- I double checked and **corrected culvert inlet loss coefficients**.

OK

- I had a feeling that flow was being over estimated, so I tried increasing min and max soil infiltration parameters by 25% and then by 50%. This seemed like a large adjustment that I'd have a hard time justifying (especially assuming soils become more compact over time) and it only improved inundation depths by a couple tenths of a foot at most. At this point I'm leaning towards not including an infiltration adjustment.

OK. I was hit or miss with Pheasant Branch. Some places it was sensitive and others it was not. I did not spend the time to determine if there was a relationship between the areas that were sensitive and were not.
Conclusions:

- The table below gives an approximate snapshot comparing the model to what we heard from residents at focus groups and in emails if they couldn't make the focus group. This is based on 2018 observed elevations to the nearest foot or half foot, but I converted to depth for ease of comparison.
- Most of these locations are very close. Riva has a large percent error, but flow depths are only about 1' after calibration revisions. The inundation extents are still a bit wider than what we heard from residents. However, I don't have big concerns here if the inundation in August 2018 was ~0.5-1.5 feet deep and the model is within half a foot of that.
- McKee and Carnwood are the only locations still making me scratch my head a bit. The model still shows

depths about 1.5 feet too deep, even though percent error isn't eye popping. Residents who live close to these crossings were very clear that the road didn't overtop and water didn't come that close to their homes in August 2018. There are a handful of homes near both crossings that would definitely give us feedback at the PIM that the model shows the water higher than it actually was. However, one hundred feet or so upstream of the crossings the high water elevations are pretty well in line with resident observations. **I'll look into further decreasing inlet coefficients at these two locations**.

This could be an area to reduce the greenway manning's n more. Also, I'm not super familiar with how PC-SWMM does inlet types. With XP-SWMM, for culverts, you select the inlet type and it's different based on the shape/material of the culvert, if it has wingwalls and what their flare is, if they are beveled etc. You could try different inlet types (assuming it's not outlet controlled) to see if that is a significant factor.

- Another possibility is that elevation could be overestimated if the model allows some contributing pipes to flow full and dump more water in the greenway where inlet capacity actually prevents that from happening.
- **Do you have an opinion on how much I've lowered Manning's n values?** I would rather be more accurate with channel flow levels and run the risk of underestimating some of the smaller overland flow areas.

I've been lowering my manning's n values for my 2D land uses to almost uncomfortable levels. I feel sort of okay doing this because of a presentation for HEC-RAS 2D Amber from AE2S shared. It more or less states that manning's n need to be adjusted to be more like channel-flow manning's n when the flow depths get above a certain level and it can no longer be considered to act like sheet flow. I attached the pdfs she sent.

	McKee	Carnwood	Lancaster	Canterbury	Brompton	Riva	Barton
2018 Observed Depth	7.5	5.8	8.3	9.7	4.3	0.7	2.2
500-yr Uncal. Depth	9.5	7.9	9.0	10.1	4.2	1.5	1.9
500-yr Uncal. % Error	27	36	9	4	-2	100	-12
500-yr Calib. Depth	8.9	7.3	8.7	9.6	4.3	1.0	2.0
500-yr Calib. % Error	20	26	5	-1	-1	40	-7

I'll let you know what I see if I make any further tweaks and once I run the August 2018 event. If McKee and Carnwood are still the only areas where the model is off, I may be inclined to say that the model is close enough and will still provide good comparison for proposed conditions. Getting closer!

I think it's looking good. It seems like it will be a reasonable tool for making decisions for the larger storm events. We, as a group, need to figure out our messaging if we're expected to use these for the smaller events someday…

Thanks!

Matt

From: Burger, Caroline <CBurger@cityofmadison.com>
Sent: Friday, November 27, 2020 10:20 AM
To: Allie, Matthew <MAllie@cityofmadison.com>
Subject: RE: EBMC Calibration

Hi!

Sorry I'm just getting back to you now. See my discussion below in green.

Caroline Burger, PE, ENV SP
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From: Allie, Matthew <MAllie@cityofmadison.com>

Sent: Thursday, November 19, 2020 9:58 AM
To: Burger, Caroline <CBurger@cityofmadison.com>
Subject: RE: EBMC Calibration
Thanks for the feedback Caroline! I've been pondering more too and I think I've made a little progress. My thoughts back are in bold below. Let me know if they bring anything else to mind for you.
Matt

From: Burger, Caroline <CBurger@cityofmadison.com>
Sent: Wednesday, November 18, 2020 1:57 PM
To: Allie, Matthew <MAllie@cityofmadison.com>
Subject: RE: EBMC Calibration
Hi Matt,
I've been thinking about this. This is not my strong suit. If we can't figure it out, I think I could talk Jim Bachhuber into some help from the goodness of his heart, or, we could see what Nic or Bill at the USGS say.
Regarding the volume question – all I can think of is creating a unit section – say 1' or 10' of pipe and calculate the volume over the event in that section for both the modeled flows and the observed flows. **This is a good idea. I'll make the unit section the width of a mesh cell since PCSWMM makes it easy to check cumulative volume by cell. I think I'll still need to make some assumptions to do the calculation for the observed flows, but I have a couple ideas to try.**
OK
Regarding what you found with some over-estimating and some under-estimating. That's a total bummer. Since you're using 2D, you're taking some of the guess work out of elevations and depths… It doesn't make sense to globally adjust a parameter because you'll make one of them worse. **It just occurred to me that the two locations overpredicting level are channel sections. I currently have Manning's n for greenway areas set to 0.035. I think it would be worth lowering this to 0.025 or 0.03 and seeing how it improves modeled water levels at those locations.**
I found Pheasant Branch was very sensitive to the manning's n in the greenways. I started out with what I felt were reasonable manning's n and ended up with values that were on the low end of the range. So, perhaps the SWMM hydrology/SWMM equations is consistently a touch high as compared to HEC-RAS type calcs? I'm not sure. But, I'm very interested to see what you find when you adjust.
Which means you get to be more strategic. Have you looked at the Prairie du Chein geologic layer to see if that could impact your infiltration in areas? Or, could there be soils more compact than the HSG is estimating in areas? **I looked at that geologic layer when you first sent it to me to share with MSA. The only overlap in EBMC is in the south portion of the watershed, but the monitored locations are in the north part of the watershed. My thought is that soils being more compact than I've already considered would further increase runoff and wouldn't help lower the overpredicted flows.**
OK
Because it's not consistent, I'm also curious about your %DCIA. We're soooooooooooo close to having our Citywide impervious layer and that should be identifying areas of DCIA. I'm wondering if the data used has bad underlying assumptions in it…. **Great point, now I'm getting more curious about that too. I think it's worth seeing what story the more accurate DCIA information tells. The next question is: do we push the PIM into January to give a bit more time to review the impervious layer and finish calibrating? I was going to follow up with the alders today. Otherwise, we run the risk of sharing partially calibrated results at the PIM, maybe not the end of the world.**
I think pushing back the PIM is okay. Janet doesn't seem to be super concerned with when we do the PIMs as long as they ultimately finish around the same time. She's also told me for Pheasant Branch that it's okay I'm not on the same schedule as the consultants; which, I'm guessing is the same feedback you'd receive for this watershed.
How do the models depths/extents compare to the anecdotal information you've received? **On the whole they compare pretty well, but lead me to believe the model is overestimating flows/water levels in more locations than where the gages are installed. This is primarily happening in the downstream portion of the greenway. Accounts from residents adjacent to the greenway near the Carnwood Road and McKee Road greenway crossings made clear that water came just into their yards in August 2018, but the model shows the 500-year**

event coming up to their homes, which they said did not happen. Even though the Riva Road gage (installed in a pipe) observed water levels higher than what the model predicts, inundation in the street during the 500-year event is higher than what residents said they saw in August 2018.
OK
Now that I see all three of those locations described together, I'd be a little more comfortable adjusting a parameter globally to reduce flows. Even though it sacrifices accuracy at the Riva gage in smaller events, it should help produce more realistic result for large events. What are your thoughts on a parameter to try adjusting? Focus adjusting infiltration parameters first or is it worth looking closer at subcatchment width too?
Yes, this is super common for model calibration. It's really hard to get both large and small flows to match with the same hydrologic parameters. Since our studies are focusing on the larger events, trying to get your calibration to match for the smaller events isn't as important. For Pheasant Branch, I was almost exactly replicating a peak WSE for the August 2018 event in a couple places (honestly, I think this is due more to luck than anything), but I was pretty far off for our smaller calibration events. Which is why I ultimately gave up and only used the high water survey elevations from the August 2018 to calibration. Well, that, and the data from the equipment was not that great – we definitely did not pay it the attention it needed at that time.
We were also blessed with a decent storm a week ago, so I might add that storm into my calibration mix to see how the model responds to that.
I'll keep pondering….
It sounds like you're on the right track and using the data we have in a defensible manner. ☺

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From: Allie, Matthew <MAllie@cityofmadison.com>
Sent: Thursday, November 12, 2020 1:42 PM
To: Burger, Caroline <CBurger@cityofmadison.com>
Subject: EBMC Calibration

Hi Caroline,
I've summarized measured and modeled hydrographs in the attachment. Each plot is shown twice, once grouped by event and once grouped by gaging location. They're separated by a blank page, but I've found myself wanting to look at them both ways as I think about calibrating. Gage locations and contributing subcatchments are shown on the first page. I realize that calibration won't lead to perfect results and it's an art, but I also don't want to assume the model is already performing well enough. I'm looking for feedback specifically on the bold items below. Let me know if you'd rather do a quick call to discuss.
Calibration approach:

- Peak stage at Raymond, Riva, Westbrook LLs – calculated error at each location for each event
- Peak flow rate at Riva FLW – calculated error for each event
- Cumulative volume at Riva FLW – summed volume over time, calculated error for each event
- Correlation between observed and modeled values – time series plotted against each other (not shown here)
- **Yet to do:**
    - **Volume comparison?** MSA did this at the one gage that had good results in their watershed. I'm having trouble thinking of how to do this, aside from creating an approximate stage-area curve for the Raymond and Westbrook LLs measured values and estimating velocity. Am I overthinking this? Is there any easier way to estimate cumulative volume from observed stage?

- **Any other calibration metrics you would recommend?**

Overall performance:

- Average LL error for each event ranges from 16-26%
- Westbrook LL average absolute error = 14% (6-26%)
- Raymond LL average absolute error = 33% (8-48%)
- Riva LL average absolute error = 16% (2-30%)
- Riva flow average absolute error = 40% (38-43%) *most of these values are negative*
- Riva flow volume average absolute error = 28% (3-48%)

The model seems like it's performing well with two exceptions: 1) Raymond LL has some irregularities and the highest model error (overestimating), 2) Riva FLW measured higher flow rates or model is underestimating flow rate at this location. Westbrook (slightly) and Raymond overestimate stage and Riva (slightly) underestimates stage. Focusing on Westbrook and Riva LLs and excluding the May 17th event, all peaks are already within 25% of measured values.

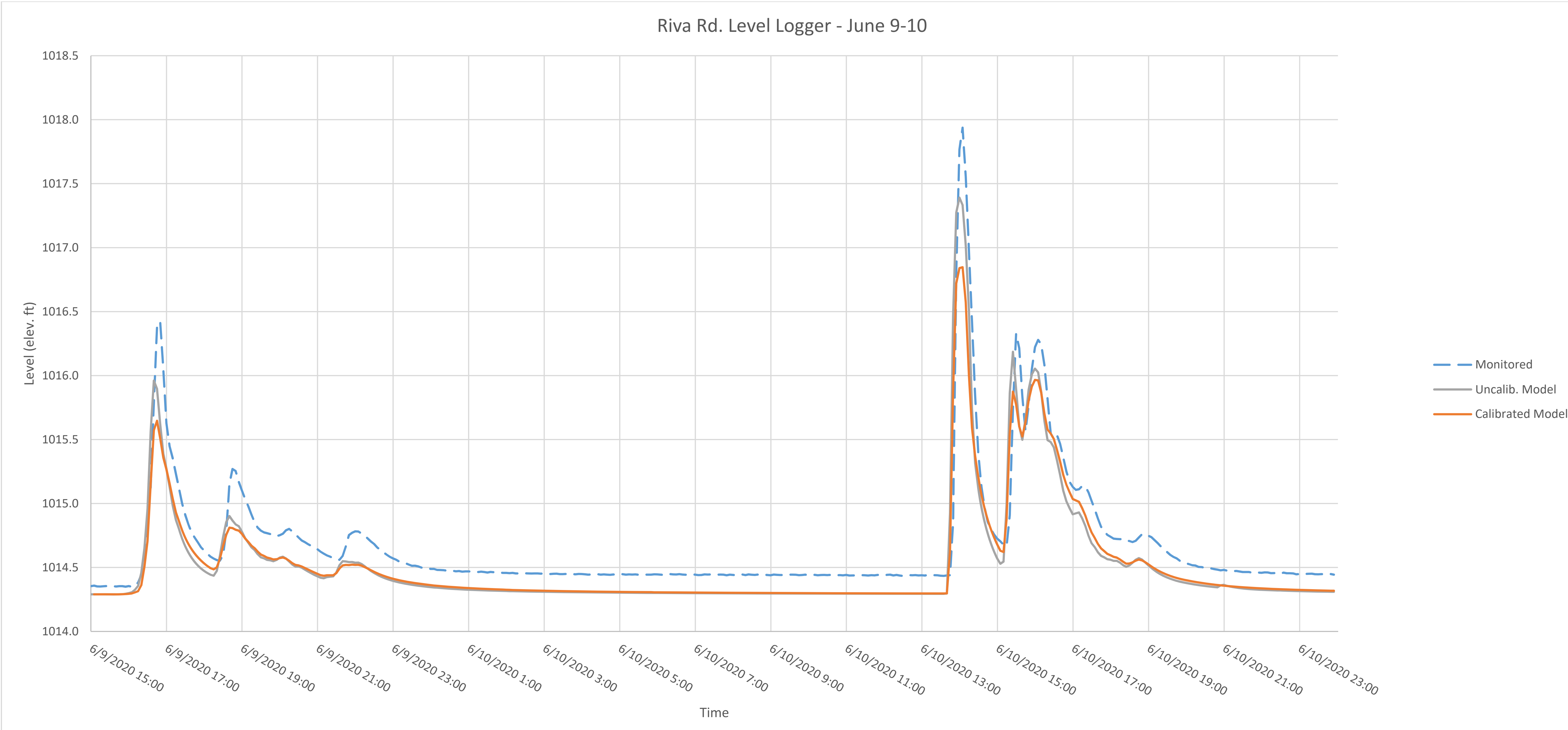
To calibrate, I've been thinking about subcatchment width and/or infiltration parameters, **please let me know if there are others I should be considering.**

- Width: Since modeled peak timing appears to be good, I've been leaning away from adjusting width. However, would slowing runoff slightly also dampen the modeled peaks? Drawback here is that it would help Raymond and Westbrook perform better but hurt Riva LL.
- Infiltration: The area contributing to the Riva gage is 35% impervious (83% DCIA), while the unique areas contributing to the other two gages are 29% impervious (76% DCIA). If I increase infiltration parameters, modeled peaks should be reduced slightly and more so at the two gages currently underestimating since they have more pervious area for increased infiltration.

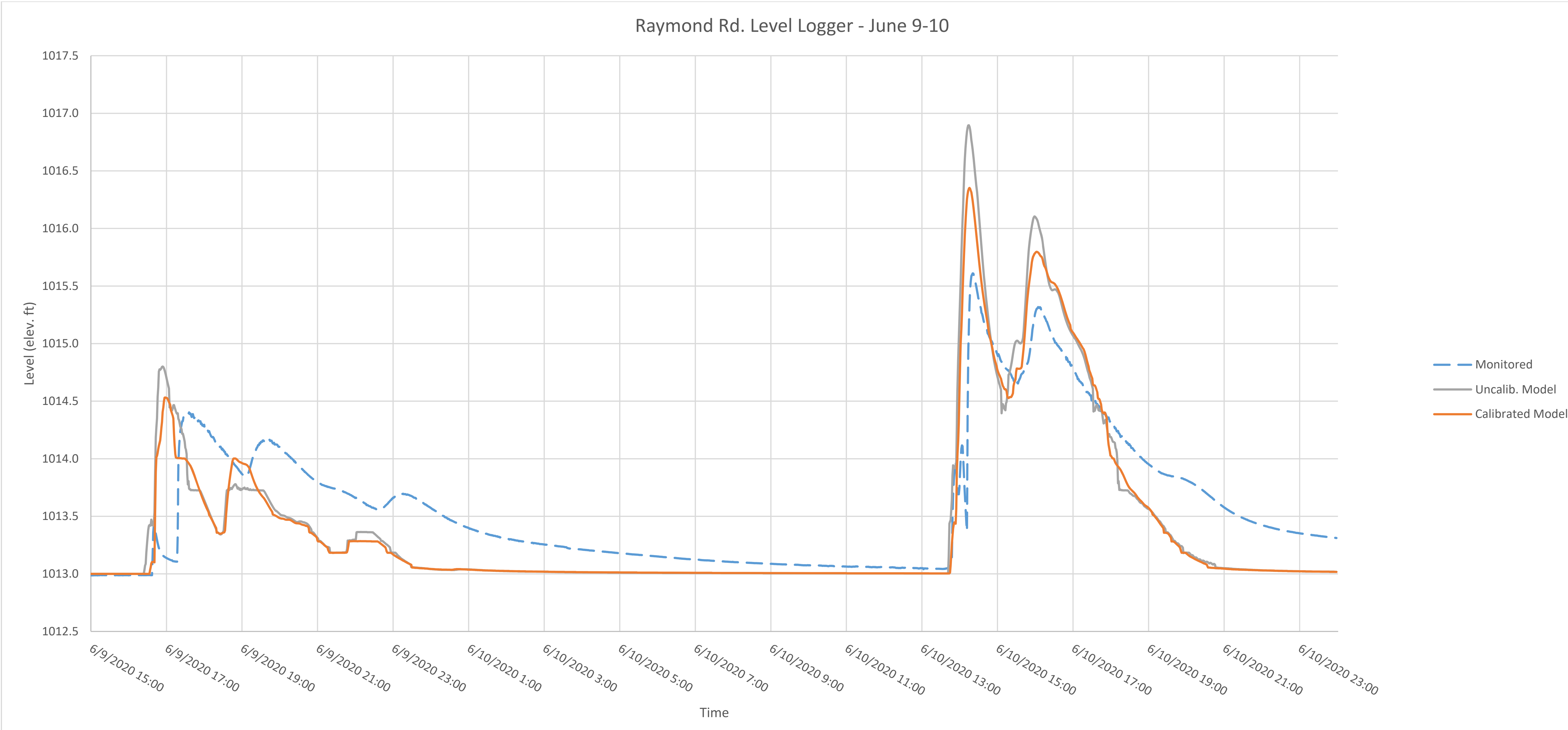
Thanks!

Matt

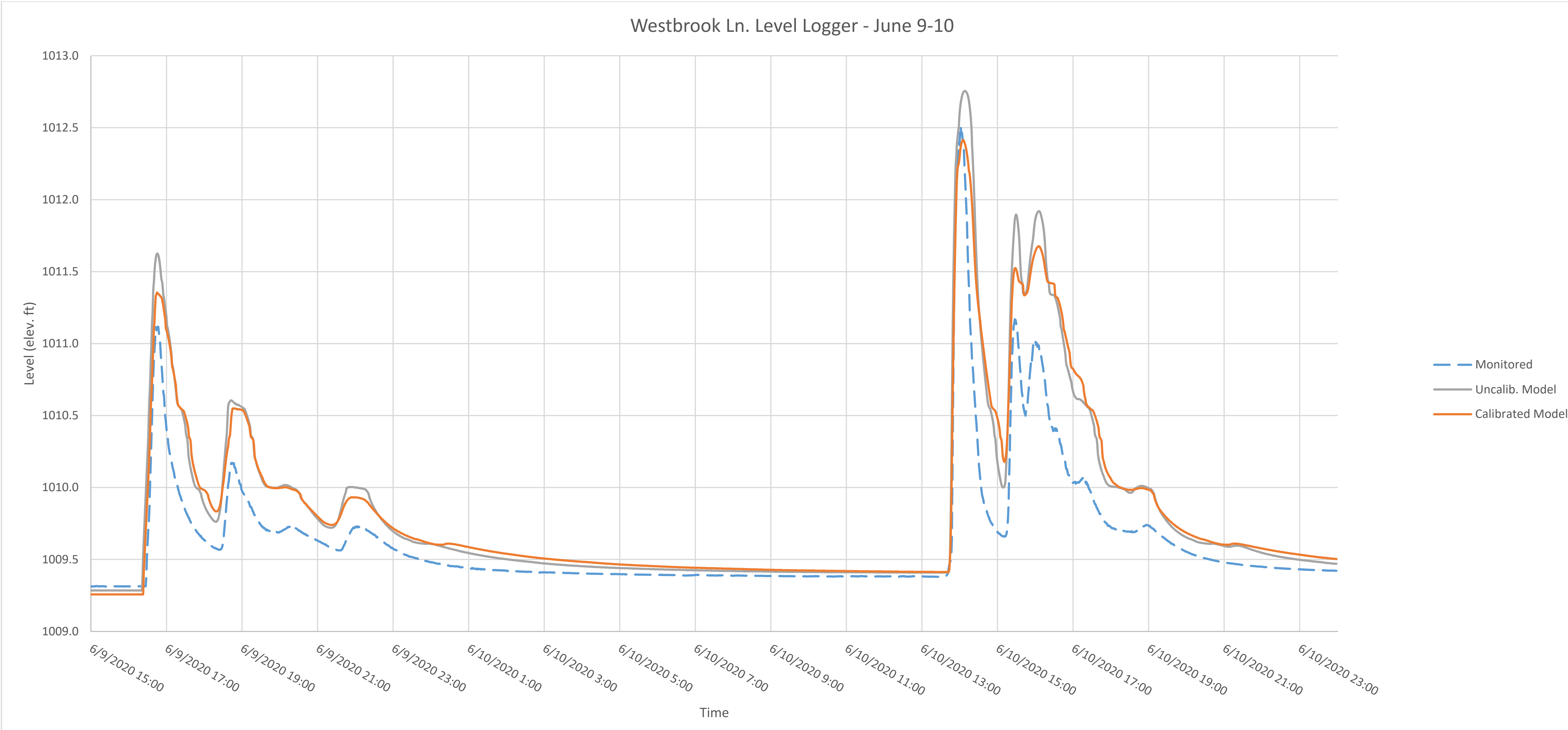
Appendix G. – Calibration Event Monitored and Modeled Time Series Graphs



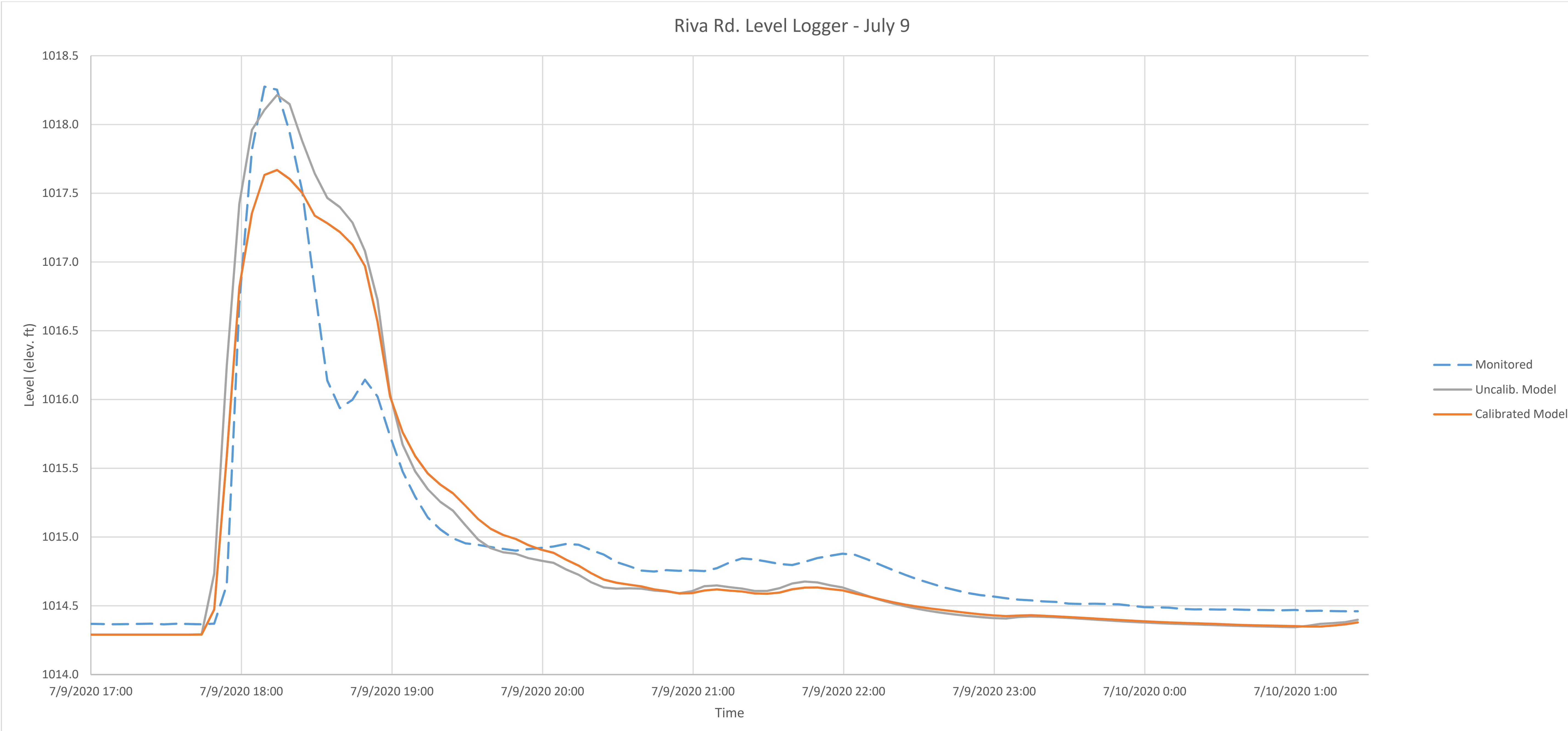
Riva Rd. Level Logger - June 9-10
Level (elev. ft)
1018.5
1018.0
1017.5
1017.0
1016.5
1016.0
1015.5
1015.0
1014.5
1014.0
6/9/2020 15:00
6/9/2020 17:00
6/9/2020 19:00
6/9/2020 21:00
6/9/2020 23:00
6/10/2020 1:00
6/10/2020 3:00
6/10/2020 5:00
6/10/2020 7:00
6/10/2020 9:00
6/10/2020 11:00
6/10/2020 13:00
6/10/2020 15:00
6/10/2020 17:00
6/10/2020 19:00
6/10/2020 21:00
6/10/2020 23:00
Time
Monitored
Uncalib. Model
Calibrated Model



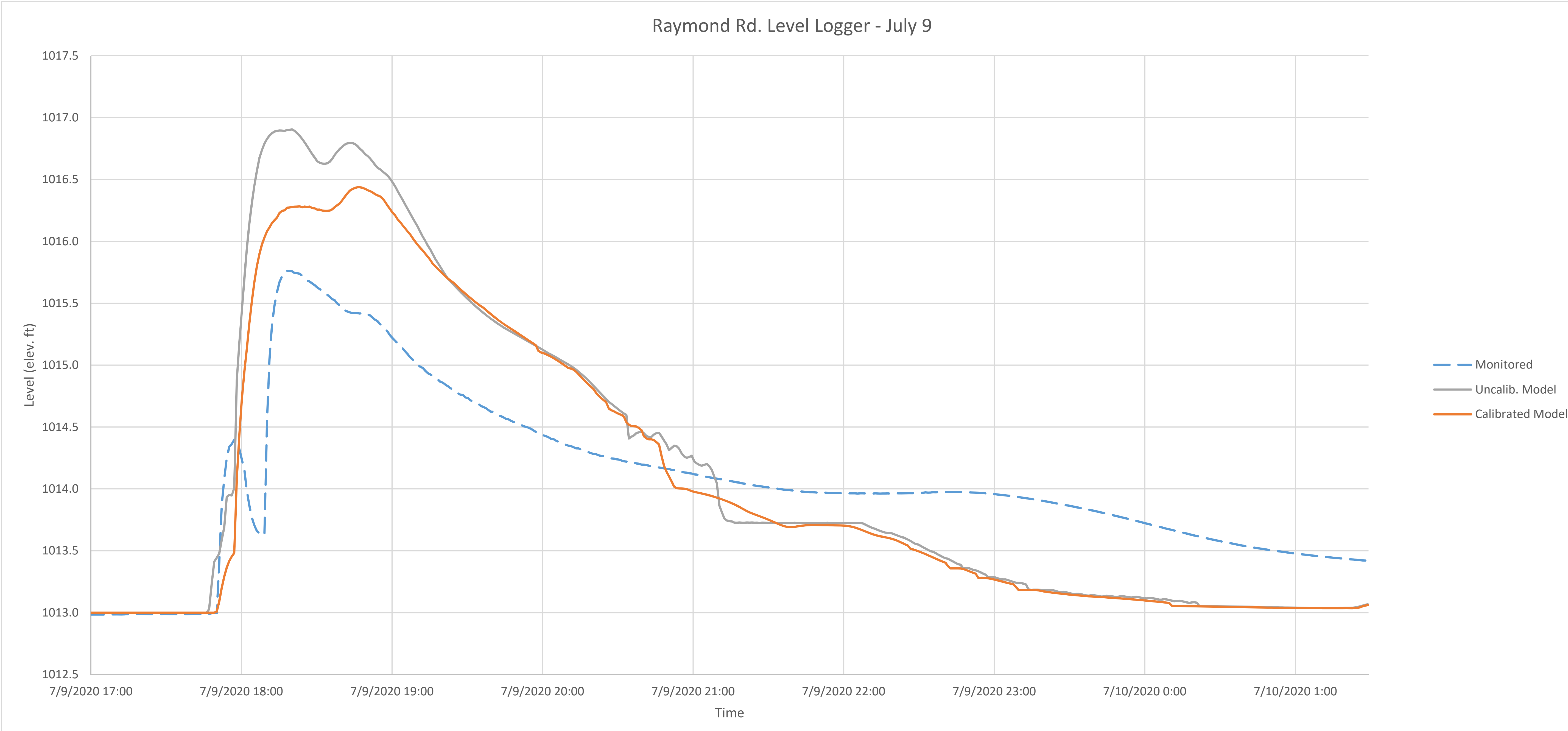
Raymond Rd. Level Logger - June 9-10
Level (elev. ft)
1017.5
1017.0
1016.5
1016.0
1015.5
1015.0
1014.5
1014.0
1013.5
1013.0
1012.5
6/9/2020 15:00
6/9/2020 17:00
6/9/2020 19:00
6/9/2020 21:00
6/9/2020 23:00
6/10/2020 1:00
6/10/2020 3:00
6/10/2020 5:00
6/10/2020 7:00
6/10/2020 9:00
6/10/2020 11:00
6/10/2020 13:00
6/10/2020 15:00
6/10/2020 17:00
6/10/2020 19:00
6/10/2020 21:00
6/10/2020 23:00
Time
Monitored
Uncalib. Model
Calibrated Model



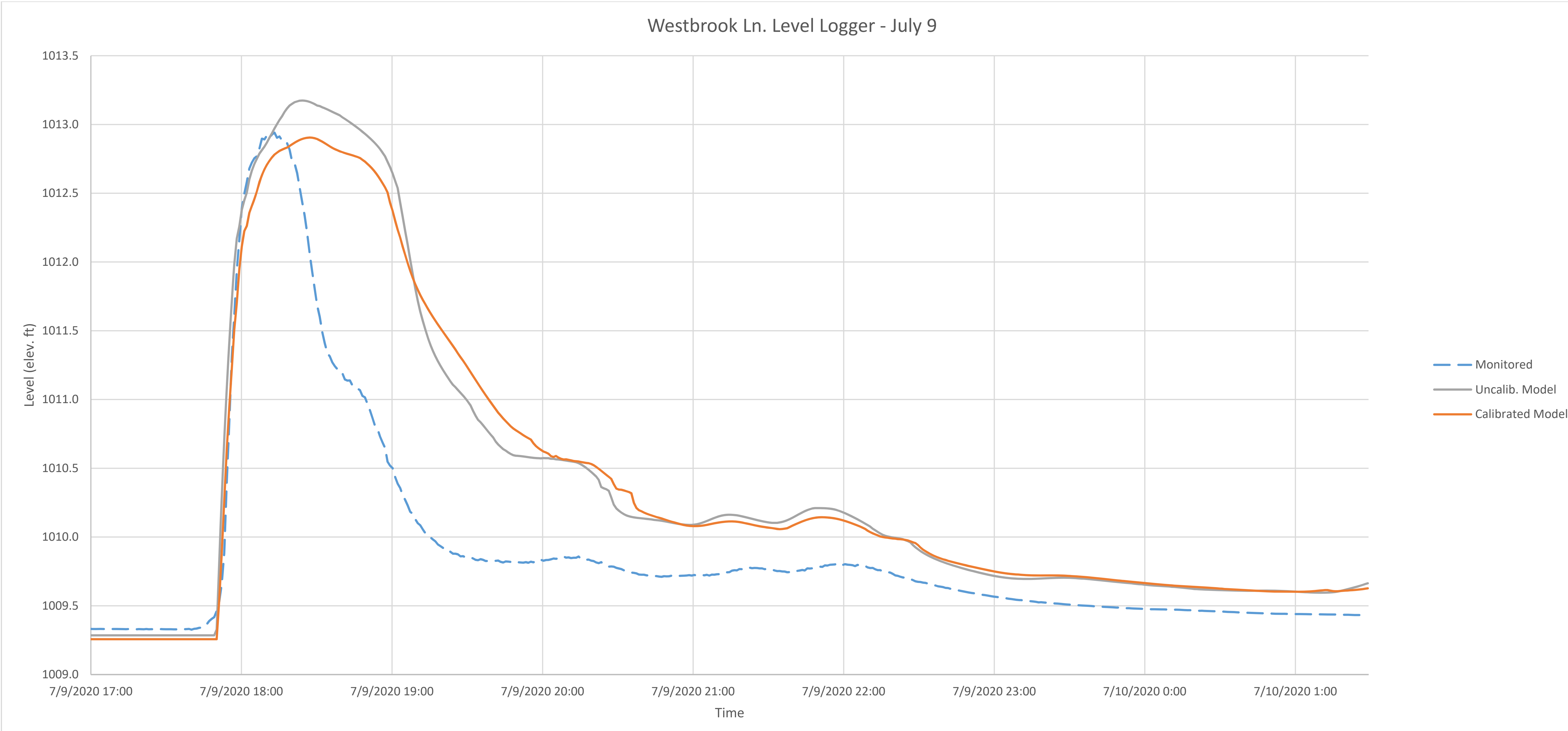
Westbrook Ln. Level Logger - June 9-10
Level (elev. ft)
1013.0
1012.5
1012.0
1011.5
1011.0
1010.5
1010.0
1009.5
1009.0
6/9/2020 15:00
6/9/2020 17:00
6/9/2020 19:00
6/9/2020 21:00
6/9/2020 23:00
6/10/2020 1:00
6/10/2020 3:00
6/10/2020 5:00
6/10/2020 7:00
6/10/2020 9:00
6/10/2020 11:00
6/10/2020 13:00
6/10/2020 15:00
6/10/2020 17:00
6/10/2020 19:00
6/10/2020 21:00
6/10/2020 23:00
Time
Monitored
Uncalib. Model
Calibrated Model

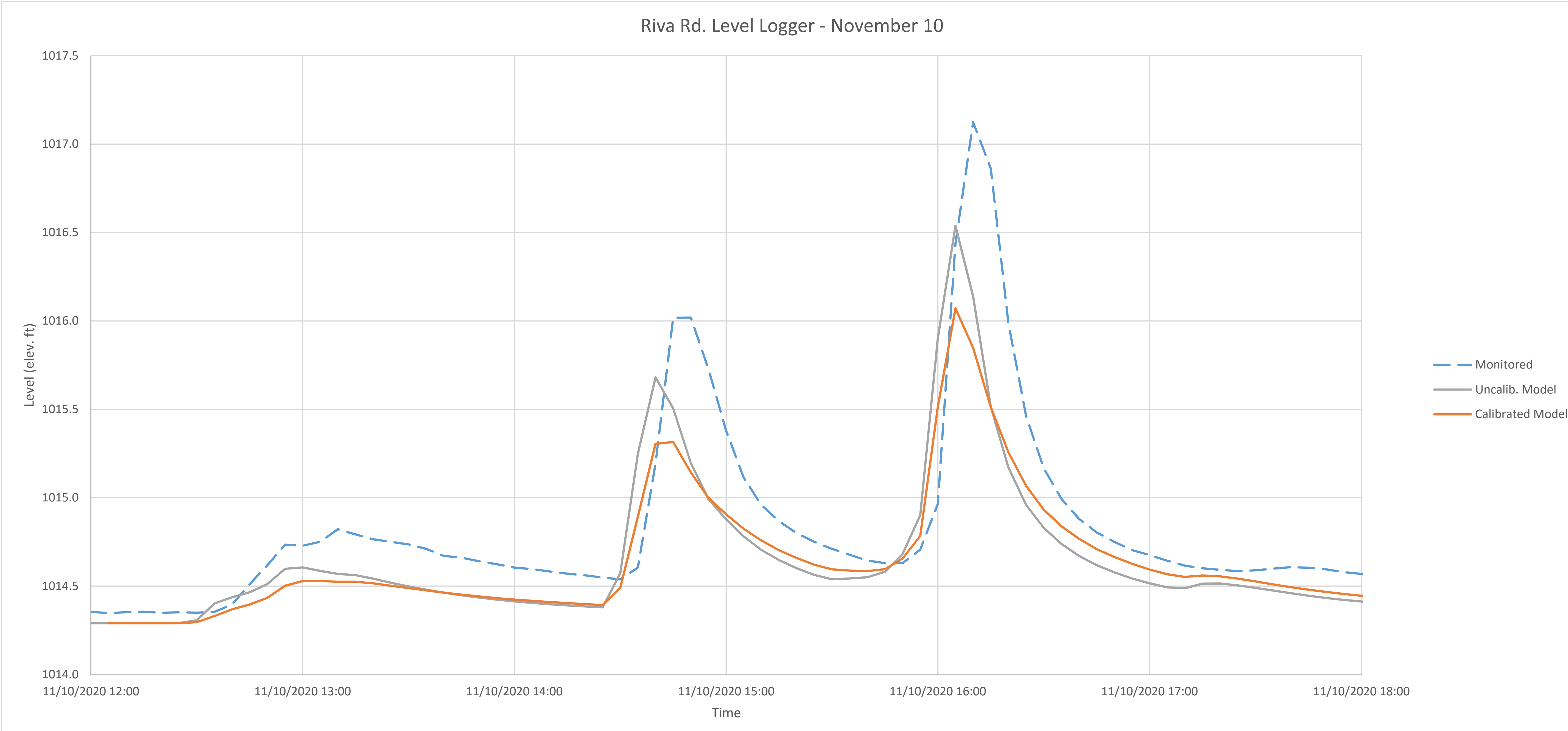


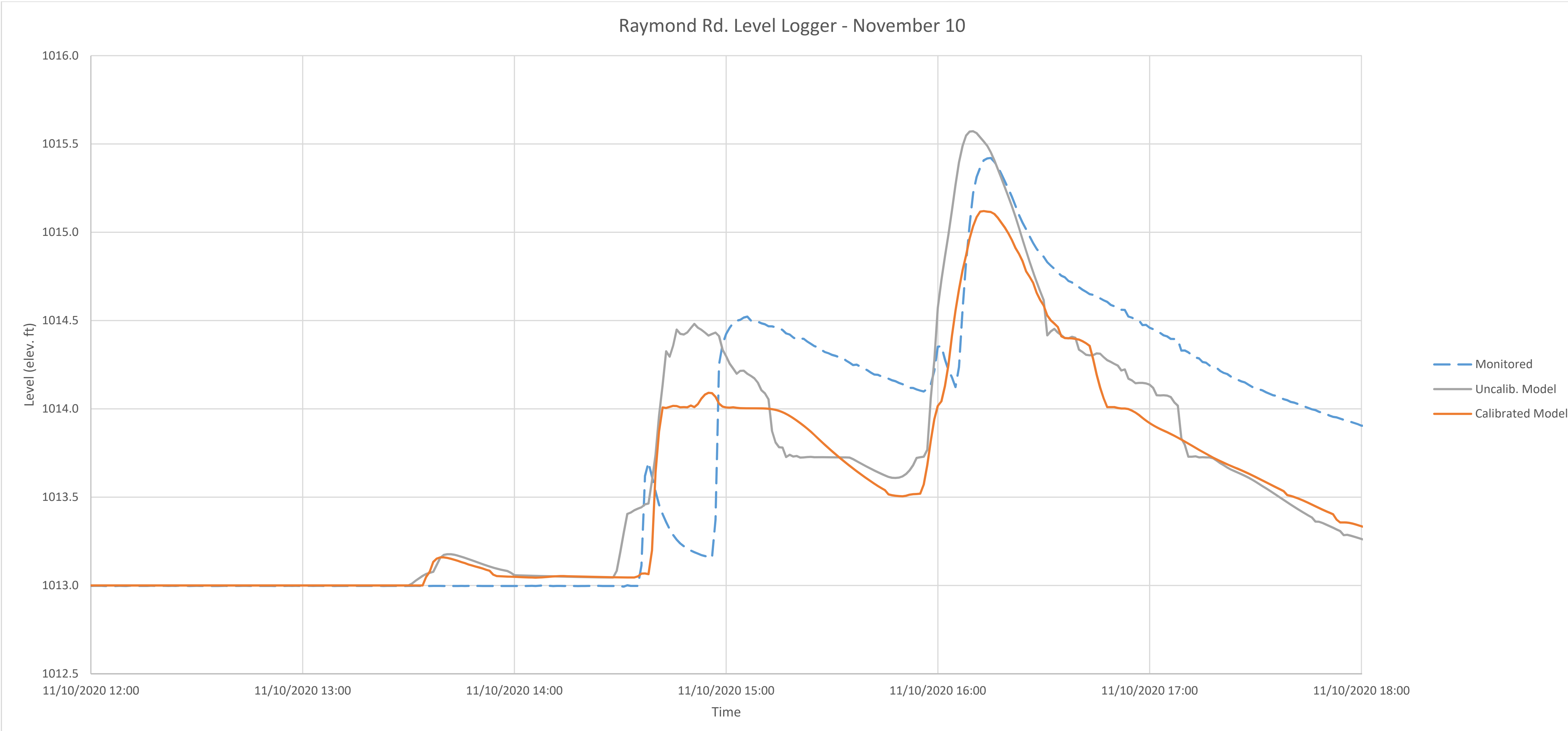
Riva Rd. Level Logger - July 9
1018.5
1018.0
1017.5
1017.0
1016.5
1016.0
1015.5
1015.0
1014.5
1014.0
Level (elev. ft)
7/9/2020 17:00
7/9/2020 18:00
7/9/2020 19:00
7/9/2020 20:00
7/9/2020 21:00
7/9/2020 22:00
7/9/2020 23:00
7/10/2020 0:00
7/10/2020 1:00
Time
Monitored
Uncalib. Model
Calibrated Model



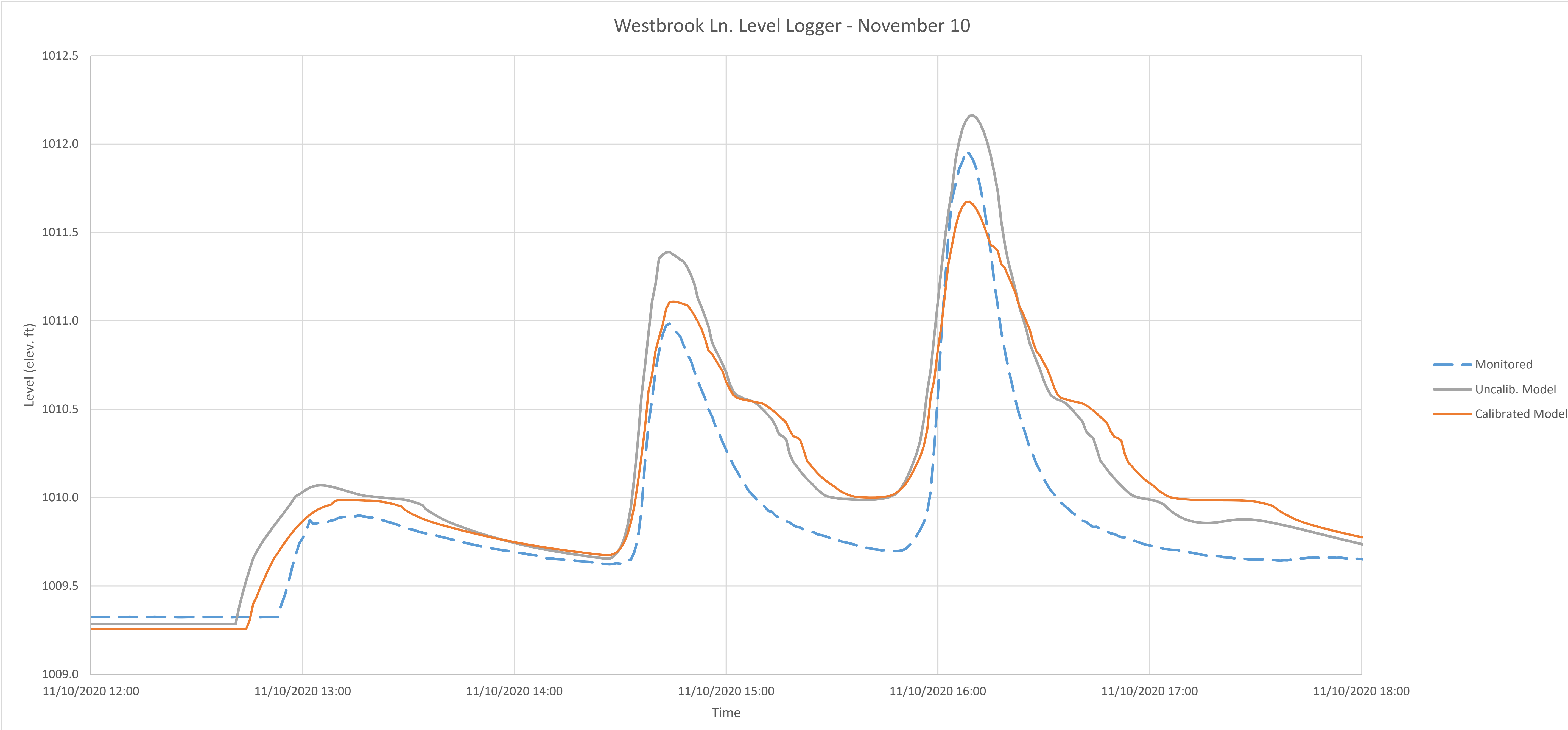
Raymond Rd. Level Logger - July 9
Level (elev. ft)
1017.5
1017.0
1016.5
1016.0
1015.5
1015.0
1014.5
1014.0
1013.5
1013.0
1012.5
7/9/2020 17:00
7/9/2020 18:00
7/9/2020 19:00
7/9/2020 20:00
7/9/2020 21:00
7/9/2020 22:00
7/9/2020 23:00
7/10/2020 0:00
7/10/2020 1:00
Time
Monitored
Uncalib. Model
Calibrated Model


Westbrook Ln. Level Logger - July 9
1013.5
1013.0
1012.5
1012.0
1011.5
1011.0
1010.5
1010.0
1009.5
1009.0
Level (elev. ft)
7/9/2020 17:00
7/9/2020 18:00
7/9/2020 19:00
7/9/2020 20:00
7/9/2020 21:00
7/9/2020 22:00
7/9/2020 23:00
7/10/2020 0:00
7/10/2020 1:00
Time
Monitored
Uncalib. Model
Calibrated Model


Riva Rd. Level Logger - November 10
Level (elev. ft)
1017.5
1017.0
1016.5
1016.0
1015.5
1015.0
1014.5
1014.0
11/10/2020 12:00
11/10/2020 13:00
11/10/2020 14:00
11/10/2020 15:00
11/10/2020 16:00
11/10/2020 17:00
11/10/2020 18:00
Time
Monitored
Uncalib. Model
Calibrated Model



Raymond Rd. Level Logger - November 10
Level (elev. ft)
1016.0
1015.5
1015.0
1014.5
1014.0
1013.5
1013.0
1012.5
11/10/2020 12:00
11/10/2020 13:00
11/10/2020 14:00
11/10/2020 15:00
11/10/2020 16:00
11/10/2020 17:00
11/10/2020 18:00
Time
Monitored
Uncalib. Model
Calibrated Model



Westbrook Ln. Level Logger - November 10
Level (elev. ft)
1012.5
1012.0
1011.5
1011.0
1010.5
1010.0
1009.5
1009.0
11/10/2020 12:00
11/10/2020 13:00
11/10/2020 14:00
11/10/2020 15:00
11/10/2020 16:00
11/10/2020 17:00
11/10/2020 18:00
Time
Monitored
Uncalib. Model
Calibrated Model

Appendix H. – Existing Conditions Flood Depth, Water Surface Elevation, and Peak Flow Model Results

Location Number	Description	*Reporting Junction*	*Surface Elevation*	10% Chance Event		4% Chance Event		1% Chance Event	
				Existing WSE	Existing Depth	Existing WSE	Existing Depth	Existing WSE	Existing Depth
1	Watershed outlet	*SJ1314*	*976.22*	978.82	2.60	979.16	2.94	979.66	3.44
2	East Pass culverts US (983.23 L.O.)	*SJ4206*	*977.92*	981.56	3.64	982.21	4.29	983.21	5.29
3	McKee Road culverts US (988.48 L.O.)	*SJ1634*	*981.53*	986.81	5.28	987.65	6.12	988.90	7.37
4	Carnwood Road culverts US	*SJ5642*	*986.21*	990.50	4.29	990.91	4.70	992.16	5.95
5	Lancaster Lane culverts US (999.60 L.O.)	*SJ7518*	*993.50*	1000.26	6.76	1001.00	7.50	1001.96	8.46
6	Canterbury Road culverts US (1006.42 L.O.)	*SJ2993*	*999.06*	1004.99	5.93	1005.73	6.67	1006.99	7.93
7	Pilgrim Road culverts US	*SJ58055*	*1003.04*	1009.53	6.49	1010.15	7.11	1011.28	8.24
8	McKenna Boulevard culverts US (1011.04 L.O.)	*SJ58692*	*1003.94*	1012.57	8.63	1013.43	9.49	1014.92	10.98
9	Westbrook Lane culverts US (1013.15 L.O.)	*SJ6731*	*1009.31*	1013.81	4.50	1014.78	5.47	1015.55	6.24
10	Raymond Road culverts US	*SJ54306*	*1013.20*	1018.36	5.16	1019.72	6.52	1021.99	8.79
11	Prairie Road culverts US	*SJ53068*	*1019.63*	1022.70	3.07	1023.14	3.51	1024.41	4.78
12	Stonecreek Drive N or East Pass	*SJ12834*	*982.12*	982.12	0.00	982.12	0.00	982.25	0.13
13	Tanglewood Drive-Timberwood Drive	*SJ11475*	*986.64*	986.86	0.22	987.50	0.86	987.97	1.33
14	McKee Road-Maple Grove Drive	*SJ9674*	*1019.45*	1019.65	0.20	1019.81	0.36	1019.93	0.48
15	McKee Road E of greenway	*SJ9731*	*989.94*	990.84	0.90	991.06	1.12	991.22	1.28
16	Chester Drive cul-de-sac	*SJ8976*	*991.49*	992.21	0.72	992.40	0.91	992.63	1.14
17	Silverton Trail-Tempe Drive*	*SJ8741*	*990.01*	990.69	0.68	990.99	0.98	991.80	1.79
18	3145 Silverton Trail (back, along greenway)	*SJ67473*	*987.48*	987.48	0.00	987.95	0.47	989.08	1.60
19	Laramie Court cul-de-sac*	*SJ13879*	*993.84*	992.87	0.00	994.31	0.47	994.59	0.75
20	Greenway Trail-Chelsea Street*	*SJ49307*	*991.16*	990.04	0.00	991.54	0.38	992.30	1.14
21	Muir Field Road N of Carnwood Road	*SJ48501*	*998.44*	998.64	0.20	998.74	0.30	998.91	0.47
22	McKenna Boulevard-Stratford Drive*	*SJ47601*	*1004.16*	1004.84	0.68	1005.06	0.90	1005.40	1.24
23	Lancaster Lane-Whitlock Road	*SJ46844*	*1000.82*	1001.56	0.74	1002.07	1.25	1002.61	1.79
24	Muir Field Road-Gladstone Drive	*SJ44927*	*1021.29*	1021.74	0.45	1021.96	0.67	1022.27	0.98
25	McKenna Boulevard-Canterbury Road	*SJ46200*	*1010.62*	1010.73	0.11	1011.19	0.57	1011.42	0.80
26	Waltham Road-Lambeth Circle	*SJ43968*	*1005.40*	1006.39	0.99	1007.31	1.91	1008.75	3.35
27	McKenna Boulevard low pt N of Yorktown Circle*	*SJ43015*	*1017.38*	1018.12	0.74	1018.63	1.25	1019.44	2.06
28	McKenna Boulevard low pt S of Tottenham Road	*SJ34364*	*1015.73*	1016.95	1.22	1017.58	1.85	1018.34	2.61
29	McKenna Boulevard-Raymond Road	*SJ26709*	*1025.89*	1028.77	2.88	1028.90	3.01	1029.06	3.17
30	Raymond Road W of McKenna Boulevard	*SJ26323*	*1046.01*	1046.46	0.45	1046.56	0.55	1046.70	0.69

Location Number	Description	*Reporting Junction*	*Surface Elevation*	10% Chance Event		4% Chance Event		1% Chance Event	
				Existing WSE	Existing Depth	Existing WSE	Existing Depth	Existing WSE	Existing Depth
31	Raymond Road low pt E of McKenna Boulevard	*SJ26117*	*1025.91*	1027.17	1.26	1027.29	1.38	1027.58	1.67
32	Tottenham Road-Adderbury Circle	*SJ32637*	*1014.38*	1015.10	0.72	1015.36	0.98	1015.76	1.38
33	Frisch Rd cul-de-sac S of Tottenham Road	*SJ36961*	*1009.25*	1012.60	3.35	1013.44	4.19	1014.92	5.67
34	Pilgrim Road-Homestead Road	*SJ40768*	*1022.18*	1023.04	0.86	1023.19	1.01	1023.39	1.21
35	Huegel School ditch	*SJ57368*	*1022.50*	1027.34	4.84	1027.74	5.24	1028.10	5.60
36	Prairie Road-Riva Road	*SJ31106*	*1014.78*	1016.58	1.80	1016.81	2.03	1017.17	2.39
37	Jonquil Road-Riva Road	*SJ32481*	*1016.40*	1017.23	0.83	1017.62	1.22	1018.20	1.80
38	Thrush Lane-Balsam Road	*SJ31654*	*1022.85*	1024.14	1.29	1024.33	1.48	1024.60	1.75
39	Raymond Road-Cameron Drive	*SJ21641*	*1024.30*	1025.43	1.13	1026.12	1.82	1026.51	2.21
40	Raymond Road E of greenway crossing*	*SJ22322*	*1022.79*	1023.54	0.75	1023.63	0.84	1023.76	0.97
41	Barton Road-Cameron Drive	*SJ17126*	*1032.54*	1033.28	0.74	1033.45	0.91	1033.66	1.12
42	Whitney Way-Barton Road*	*SJ17238*	*1041.12*	1042.37	1.25	1042.45	1.33	1042.55	1.43
43	Frisch Road-Jacobs Way	*SJ51910*	*1022.97*	1023.91	0.94	1024.31	1.34	1024.76	1.79
44	Frisch Road low pt S of Jacobs Way	*SJ52254*	*1022.08*	1022.84	0.76	1023.74	1.66	1024.19	2.11
45	Jacobs Way-Theresa Terrace	*SJ50564*	*1027.98*	1028.51	0.53	1028.55	0.57	1028.61	0.63
46	Loreen Drive-Jacobs Way low pt	*SJ50911*	*1022.24*	1022.24	0.00	1023.17	0.93	1024.43	2.19
47	Prairie Road low pt at greenway crossing	*SJ51589*	*1023.76*	1023.76	0.00	1023.76	0.00	1024.32	0.56
48	Barton Road-Golden Oak Lane-Redwood Lane	*SJ17895*	*1023.93*	1024.73	0.80	1024.86	0.93	1025.10	1.17
49	Lynndale Road low pt N of Barton Road*	*SJ15864*	*1025.31*	1024.66	0.00	1025.38	0.07	1025.98	0.67

* reporting point is located at a 2D cell where mesh is connected to 1D pipe network; the reported water surface elevation (WSE) is in the structure, below grade

L.O. structure low opening elevation

Greenway Crossing	10-Percent Chance Q (cfs)	4-Percent Chance Q (cfs)	1-Percent Chance Q (cfs)
	Existing	Existing	Existing
EBMC Watershed Outlet	673	842	1114
East Pass	657	823	1080
McKee Road	623	776	1014
Carnwood Road	546	660	851
Lancaster Lane	461	531	649
Canterbury Road	447	521	641
Pilgrim Road	430	498	614
McKenna Boulevard	378	448	555
Westbrook Lane	273	344	523
Raymond Road	141	165	203
Prairie Road	47	57	89

Appendix I. – Focus Group Meeting Summaries

<u>Lancaster Lane-Carnwood Road</u>

Lancaster Lane-Carnwood Road Focus Group for the East Badger Mill Creek Watershed Study

In-person

July 28, 2020, 6:30 PM – 7:30 PM

Attendees: 8

- Canterbury Road at greenway crossing fills with water (E side first) at low point during most heavy rains, but not up to crown unless it's something large like 2018 or more than 3-4 inches.
- Canterbury Road overtops at the greenway during the largest events ~50-year or larger; it overtopped in August 2018 and roughly six times since 1980s
- Residents wanted to know if we could put a “highwater” or “intersection floods” or “do not play during highwater” sign at the greenway crossings. They have concerns that children play in the water and could get hurt or cars could stall from driving through.
- In August 2018 high water got within 10 ft (laterally) of City’s property line along these greenway sections.
- House at the NE corner of Lancaster Lane and Whitlock Road has year round sandbags in their backyard to protect their lower level; contours show that their yard is lower than anyone else's along greenway
- Residents observed Lancaster Lane overtopping in August 2018 and provided pictures and video.
- Water at Lancaster Lane and McKenna Boulevard gets up to curb in hard rain (~3"+ of rain, hasn't happened in summer 2020).
- There is wild parsnip and woody vegetation in the greenway between Lancaster Lane and Carnwood Road. Debris gets hung up on the woody vegetation. Residents would like both removed. Request has been forwarded to Greenway Vegetation Coordinator (Dumas).
- The concrete channel needs some maintenance in various locations, especially between Carnwood Road and Lancaster Lane.
- Water overtops the concrete part of the channel in rain events that are about 2 inches or larger.
- There’s a home on Tuscon Trail that now floods because their neighbor regraded their driveway and now their neighbor’s water comes to their home. Address not provided.
- One resident pointed out a spot, just north of Yorktown Circle, where water frequently fills road. The crown is usually just barely passable when this happens. This location appears to be inlet capacity limited and this is at the bottom of hill where a steep pipe runs down from a cul-de-sac and out to greenway.

After PIM #3 – Resident asked if greenway crossing replacements would require full closures of the corresponding street and how long a closure would last. Matt Allie responded that it’s possible to stage culvert replacement, but it can take longer to construct this way. The City would either make an effort to maintain one-way traffic during construction or complete construction as quickly as the contractor is able. If a full closure is necessary, a detour would be marked.

Looking SW from Lancaster Lane – August 20, 2018

Looking NE at Lancaster Lane and culvert outlet ends – August 20, 2018

<u>Frisch Road-Theresa Terrace</u>

Frisch Road-Theresa Terrace Focus Group for the East Badger Mill Creek Watershed Study

August 5, 2020, 11:00 AM – 12:00 PM

Attendees: 6

August 13, 2020, 6:30 PM – 7:30 PM

Attendees: 1

- Any time it rains hard, water piles up at Theresa Terrace-Jacobs Way intersection and doesn't drain.
- Water up to driveways at intersection of Theresa Terrace and Jacobs Way. Water spills down driveways if it gets high enough.
- Tara Kennan from the Prairie Hill’s Neighborhood Association was in attendance. She lives at 6325 Jacobs Way and hasn’t experienced flooding issues. She was there to represent the neighborhood.
- When the Theresa Terrace Neighborhood Center was constructed a low spot was added near the fence opening that now directs runoff to 1431 Theresa Terrace. They’ve needed to replace basement drywall several times in past prior to 2020 as a result (none this year).
- There are private area drains in the back/side yard between Jacobs Way and Lucy Lane near Frisch Road. These do not show up in our records. They appear to have 8” PVC coming out of them. There was no inlet/manhole in the street where this pipe would connect.
- In August 2018 buses needed to be re-routed around the low point on Frisch Road at outfall to greenway.
- Water often ponds on the low point on Frisch Road (above), but hasn’t occurred during summer of 2020. Inlets clog here and water can get up to sidewalk and extend 4' further out laterally, perhaps 4 ft deep water in road (resident estimate).
- The house across from this outfall to the greenway (1610 Frisch Road) often gets water in their driveway since they're at the low point.
- In August 2018 the water was up to the tree in the front yard of 1501 Frisch Road (~1.5-2 ft deep in intersection). Summer 2020 storms have deposited debris on the terrace. Three inlets at the corner of Lucy Lane and Frisch Road always plug with debris and ice; snow plows dump snow right over these inlets and the fire hydrant.
- There are more frequent and significant drainage issues at 1509 Frisch Road. Ponding often occurs in their front yard and between their lot and next one south.
- Check if inlets at the intersections of Lucy Lane and Frisch Road and Jacobs Way and Frisch Road are on Ops’ priority list.
- Water flows curb to curb coming down the hill on Lucy Lane towards Frisch Road.
- 1421 Lucy has flooding in the backyard from becoming a low spot and the drainage way downstream being filled in over time. Backyard is lower than the road at front of house. We discussed potential private drainage solutions with this resident.

After PIM #3 – Resident asked if the Frisch Road low point at greenway is candidate for terrace inlets. Matt Allie responded that it is, see report.

McKee Road-Silverton Trail

McKee Road-Silverton Trail Focus Group for the East Badger Mill Creek Watershed Study

August 5, 2020, 4:00 PM – 5:00 PM

Attendees: 2

- In August 2018, Lancaster Lane overtopped, but Carnwood Road did not overtop.
- No issues observed in August 2018 or more recently at Tempe Drive and Silverton Trail intersection.
- Resident in second house on east side of Silverton Trail (3169) moved in after August 2018, but heard that the home stayed dry.
- In August 2018, high water in the greenway blocked the pipe outlet from Greenway Trail.
- In August 2018, Greenway Trail cul-de-sac water was about 1-2 feet deep and starting to come up driveways.
- Regularly, standing water collects up to curb in most heavy rains, but goes down quickly at the intersection of Tempe Drive and Silverton Trail.

After PIM #3 – No questions

Tottenham Road-McKenna Boulevard

Tottenham Road-McKenna Boulevard Focus Group for the East Badger Mill Creek Watershed Study

August 5, 2020, 6:30 PM – 7:30 PM

Attendees: 8

- The low spot on Raymond Road in front of the McKenna Rowhouses condos is impassable a couple times a year. Ponding has been up to the curb twice during summer 2020 storm alone; came up to terrace at driveway to McKenna Rowhouses off of Raymond Road.
- In June 2018 and August 2018, the water in Raymond Road near the condos crested the driveway and rushed south through the parking lot, adding to flooding in the underground garages. Residents provided pictures.
- The condo association installed a curb to prevent floodwater from their complex overflowing to the adjacent complex.
- Water flowing south to Tottenham Road from low point behind McKenna Rowhouses has been 1-2 feet deep in summer 2020 storms and 2-4 feet deep, at edge of foundation, in August 2018. Along the side of the house at 6606 Tottenham Road water got up to the landscaping mulch in August 2018.
- Water flowed down Tottenham Road from McKenna Boulevard from curb to curb and was standing overnight.
- Water up to sidewalk and terrace at Adderbury Lane and Tottenham Road intersection part way through the August 2018 storm, and in smaller storms. Water probably got up close to their garage at peak of August 2018 storm (rough estimate).
- Tottenham Road and Frisch Road intersection fills pretty frequently, including a couple times in summer 2020. Inlets will also occasionally surcharge, but this hasn't happened in summer 2020.
- The water elevation in the greenway at the end of Frisch Road rises at the same time that water can be seen coming out of the inlets on Frisch Road at Tottenham Road.
- In August 2018, Frisch Road was flooded to just past Brompton Circle all the way from Frisch cul-de-sac end.
- In August 2018, water came up to the fourth step of the garage at 2113/2115 Frisch Road. Home had water coming in through both the garage in front and the patio door in back. The overflow of the water from the greenway is very close to the level of this home’s patio. Greenway does not have slopes going up to homes like other sections do. Home appears to be approximately 2 ft above the bottom of the concrete cunette. They installed flood gates so they could protect their home when the water starts rising.
- The water on Frisch Road usually recedes pretty quickly once the rain stops.
- 2025/2027 Frisch resident stated that in August 2018 street water came up to his house along driveway and water came into the ground floor/basement from greenway at the back of his property. He said low opening is not very high above greenway flow line.
- Matt Allie explained to residents that the City has limited options to lower the greenway since it requires lowering channel a long way downstream. There is potential to make improvements downstream that would lower high water elevations adjacent to their property.

After PIM #3 – Condos located at 6754 to 6806 Raymond Road (Park Hill Condominium) and Deer Point Trail Condominium have routinely experienced standing water in backyards that comes from uphill in Elver Park. This is outside of the mapped focus group limits, but is nearby. Greg Fries contact info was provided during the meeting. On January 25, 2023, Matt Allie followed up with another resident here that we received a call from before the PIM. Visit confirmed that water comes from Elver Park, but grading on condo property and downspout extension discharge points are significant factors in the drainage issues present. The condo association hired an engineering firm to prepare a plan to improve drainage on site, but the construction cost estimate is exorbitant ($371,000). Resident asked if Parks is willing to help improve drainage in any way, but realizes that they may choose not to do anything.

Looking west into underground parking at McKenna Rowhouses – August 20, 2018

Cameron Drive-Russett Road

Cameron Drive-Russett Road Focus Group for the East Badger Mill Creek Watershed Study

August 6, 2020, 11:00 AM – 12:00 PM

Attendees: 0

August 12, 2020, 6:30 PM – 7:30 PM

Attendees: 0

- No meeting held
- On Saturday, July 4th an email was received from a resident stating: "I live on the corner of Leland and Balsam and last week rainfall caused flooding. On the corner of Balsam and Leland. I don't know if the draining system needed to be cleaned."
- The rainfall referenced above likely occurred on 6/29/20 when just over 1" of rain fell in a short period of time. It's not apparent that inundation was sustained and may have been water flowing to inlets. If storm sewer is extended here, inlet location and capacity needs to be evaluated.

After PIM #3 – No questions

<u>Barton Road-Lynndale Road</u>

Barton Road-Lynndale Road Focus Group for the East Badger Mill Creek Watershed Study

August 6, 2020, 4:00 PM – 5:00 PM

Attendees: 12

- Resident stated that the neighborhood was noted as a historical landfill and as such, lots are experiencing differential settlement.
- In August 2018, the water was just over the sidewalk at Barton Road and Rae Lane (near 1602 Rae Lane).
- Water can get deep enough on Barton Road where the street looks impassable during heavier rain events.
- Check if inlets at Barton Road and Lynndale Road are on Ops' priority list. Clogging is a frequent problem here. No structural damage, but cars can't pass.
- Water often rushes south on Rae Lane towards the intersection with Barton Road from curb to curb, even 2020 summer storms.
- Water often flows down Barton Road, from curb to curb, starting west of Cameron Drive to the low point on Barton Road. In August 2018, water was up to the terrace at this location. Resident thinks this happened again in 2019.
- Back lot line drainage issues between Lynndale Road and Rae Lane as flow works south to Barton Road.
- Inlets in front of 1510 Lynndale Road that connect to greenway outfall clog frequently. Water came up to the terrace once in summer 2020. Water was 3 squares up driveway in August 2018, June 2018, twice in 2017, and in 2016.
- Water can't flow down the flume/cunette that connects the outfall above to the greenway. Flow in the flume is obstructed by deposited street sand and vegetation that grows in the deposits. Within the past year the resident at 1510 Lynndale Road saw City crews come to clear out the sand and she said 10 dump truck loads were removed. More frequent maintenance needed to avoid reduced capacity.
- Clogging and overtopping of bike path over greenway and Prairie Drive over greenway occurs with some frequency.
- There is ice frequently on the sidewalk at the southeast corner of Golden Oak Lane and Barton Road.
- Terrace inlet at Redwood Lane-Barton Road-Golden Oak Lane clogs with ice multiple times each winter and with debris. This has also happened at least once during summer 2020. Ponding extends one property east, west, and south of the intersection and makes intersection impassible. Pipe coming out the back of terrace inlet at Redwood-Barton-Golden Oak is a ~24x15 CMHE.
- In August 2018, water was estimated to be knee deep in this intersection (see picture). Water overflowed terrace to the greenway and came halfway up the exposed portion of foundation at 6114 Barton Road and entered the home through the window wells.
- Matt Allie visited 1705 Lynndale previously on November 21, 2019 and discussed the situation with a couple of the neighbors. There is an obvious low area in the backyard. The homeowner said the water in the backyard came to within 10 ft of her home during August 2018. Water ponds at the end of her driveway after storm events; there's a raised area holding water in the curb line.

After PIM #3 – A resident asked if flooding at Redwood Lane-Barton Road-Golden Oak Lane intersection would be addressed by recommended solutions (pipes and inlets). Inundation mapping shows reduced flooding due to recommended local sewer improvements.

Riva Road-Balsam Road

Riva Road-Balsam Road Focus Group for the East Badger Mill Creek Watershed Study

August 6, 2020, 6:30 PM – 7:30 PM

Attendees: 1

August 12, 2020, 11:00 AM – 12:00 PM

Attendees: 2

- Inlets at Balsam Road and Thrush Lane plug with ice and snow. The plowing along Balsam Road and Thrush Lane is almost non-existent, according to a resident who rents near that intersection. The road also fills with ice over the course of the winter.
- Residents say the inlets at Cameron Drive and Raymond Road, on the north side of street, are filled with street sand. This was checked in late 2022 and was found not to be the case. However, these are saddled inlets, so it is very likely they do become clogged from time to time and do not have capacity at critical times of the year.
- Lot line drainage issues along the back of Balsam Road and Cameron Drive lots.
- A lot of water running down Balsam Road in heavy rains. Thrush Lane flows with water from each curb almost all the way to the crown in most heavy rains. Flow did stretch from curb to curb, to the top of the curb, in August 2018.
- In August 2018, water came up to the curbs on Riva Road and the median was an island.
- A resident has heard from neighbors that flooding used to be worse before a street project a few years ago (in 2015).
- Water used to come halfway up driveway at 5910 Riva Road and the median used to be open ditch. However, after the project, including in August 2018, water came only a few feet up driveway at 5910 Riva Road.
- Backyard drainage issues between lots behind 5910 Riva Road since there's no relief to the street. 5910 Riva Road runs a sump pump which helps a lot.
- Resident from 5925 Riva Road also noted back lot line drainage issue, but stated that flow finds its way to end of block at Jonquil Road.

After PIM #3 – No questions

Pilgrim Road-Monticello Way

Pilgrim Road-Monticello Way Focus Group for the East Badger Mill Creek Watershed Study

August 13, 2020, 4:00 PM – 5:00 PM

Attendees: 3

- Water up to curb at intersection of Prairie Road and Monticello Way in July 2020 storm.
- Resident at the southwest corner of Prairie Road and Monticello Way has issue with ice on sidewalk coming down hill along Monticello Way. Sidewalk has slight bump in grade, but nothing significant. Edge of road pavement in front of inlets is in rough shape, but gets patched each year. Inlets in front of this house (2502 Prairie Road) clog with leafs.
- There are pervious sidewalk squares along Pilgrim Road where sidewalk inlets are shown in storm layer and can be seen near 2502 Homestead Road.
- Spring snow melt fills up the better part of Sara Road and Pilgrim Road intersection, but doesn't get over crown along Pilgrim Road.
- In August 2018, inundation on Pilgrim Road extended from almost as far to the west as Pilgrim Circle and as far to the east as Ravenswood Road.
- Resident states that inundation on Pilgrim Road occurs in most heavy rains, can spill down path into Pilgrim Park.
- A resident has observed that the upstream side of the culverts under McKenna Boulevard sometimes clog with branches and debris.

After PIM #3 – No questions

Appendix J. – Recommended Inlet Capacity Increases

Location	Subcatchment	Existing Inlet Capacity (cfs)	Required Added Capacity (cfs)	Inlet Type	Notes
East Pass at Stonecreek Drive	IN2775-010	42	6	H	<Null>
Muir Field Road at Pagham Drive	AS2669-007	18	27	H	Extend storm NW on Muir Field to add inlets
Pagham Drive at Muir Field Road	IN2669-012	12	17	H	<Null>
Muir Field Road at Linfield Road	AS2669-019	15	14	H	<Null>
Muir Field Road south of Carnwood Road	AS2672-011	12	42	Both	Extend storm SW on Muir Field to add inlets
Muir Field Road north of Carnwood Road	AS2672-031	36	14	H	<Null>
Laramie Court cul-de-sac end	IN2672-029	6	18	Terrace	Only install terrace inlet if replacing pipe
Silverton Trail at Tempe Drive	IN2673-007	27	7	Terrace	Replace existing H inlets with terrace inlets
Chester Drive cul-de-sac end	IN2673-029	12	42	Terrace	Replace existing H inlets with terrace inlets
Greenway Trail cul-de-sac end	IN2673-001	3	3	H	<Null>
Tottenham Road at Singleton Court	AS2768-005	12	9	H	<Null>
N Wickham Court at Tottenham Road	IN2868-031	12	7	H	<Null>
McKenna Boulevard at Canterbury Road	AS2770-005	18	10	H	<Null>
Raymond Road east of McKenna Boulevard	AS2867-004	36	11	Terrace	Replace existing H inlets with terrace inlets
McKenna Boulevard north of Raymond Road	AS2867-025	21	6	H	<Null>
Frisch Road at Lucy Lane	AS2965-007	18	15	H	<Null>
Theresa Terrace at Jacobs Way	AS2965-2022	9	10	H	Extend storm N on Theresa to add inlets
Frisch Road at outfall south of Jacobs Way	AS2966-009	12	21	Terrace	Replace existing H inlets with terrace inlets
Raymond Road at greenway crossing	AS2967-006	15	6	H	<Null>
Raymond Road west of Prairie Road	AS2967-007	15	8	H	<Null>
Prairie Road south of Pilgrim Road	AS2969-008	15	25	H	Extend storm S on Prairie to add inlets
Ravenswood Road at Pilgrim Road	AS2969-024	18	15	H	<Null>
Pilgrim Road east side of Homestead Road	IN2969-025	9	22	Terrace	Replace existing H inlets with terrace inlets
Pilgrim Road west side of Homestead Road	IN2969-027	12	5	Terrace	Replace existing H inlets with terrace inlets or add Hs
Riva Road at Mulberry Lane	AS3068-068	15	13	H	<Null>
Raymond Road east of Cameron Drive	AS3167-010	39	9	H	<Null>
Barton Road at Cameron Drive	AS3166-018	23	5	H	<Null>
Cameron Drive at Bartlett Lane	AS3167-011	24	15	H	<Null>
Thrush Lane at Riva Road	AS3168-043	18	6	H	<Null>
Leland Drive at Thrush Lane	AS3169-009	27	11	H	<Null>
Canterbury Road at Raymond Road	IN2768-009	21	10	H	<Null>
Raymond Road east of Canterbury Road	IN2768-012	18	15	H	<Null>
McKenna Boulevard at Stratford Drive	IN2771-006	27	31	Both	Extend storm E on Stratford to add inlets
Canterbury Road at greenway crossing	IN2770-018	12	9	H	<Null>
Waltham Road at Lambeth Circle	IN2770-007	18	27	Terrace	Add terrace inlets or replace existing H inlets with terrace
Pilgrim Road at greenway crossing	IN2869-003	12	36	Both	Extend storm W on Pilgrim or use terrace inlets at culvert
McKenna Boulevard north of Yorktown Circle	IN2870-001	12	14	Terrace	Add terrace inlet on W side of McKenna
Piedmont Road cul-de-sac end	IN2870-013	15	7	H	Add H inlet or replace existing inlets with terrace inlet
Starr Court cul-de-sac end	IN2966-015	3	8	H	<Null>
Prairie Road at greenway crossing	IN2966-032	6	7	H	<Null>
Lynndale Road at Barton Road	IN3066-002	12	16	H	<Null>
Lynndale Road at outfall north of Barton Road	IN3066-005	6	31	Terrace	Replace existing H inlets with terrace inlet
Jacobs Way at Loreen Drive	IN3066-020	9	17	Terrace	Replace existing inlets with terrace inlet or add H inlets
Tanager Trail east of Mayhill Drive	IN3169-001	6	17	H	Extend storm SE on Tanager to add inlets
Mayhill Drive south of Tanager Trail	IN3169-006	9	18	H	Extend storm SW on Mayhill if needed to add inlets

Appendix K. – Proposed Conditions Flood Depth, Water Surface Elevation, and Peak Flow Model Results

Location Number	Description	*Reporting Junction*	*Surface Elevation*	10% Chance Event			4% Chance Event			1% Chance Event		
				Proposed WSE	WSE Δ	Proposed Depth	Proposed WSE	WSE Δ	Proposed Depth	Proposed WSE	WSE Δ	Proposed Depth
1	Watershed outlet	*SJ1314*	*976.22*	979.39	0.57	3.17	979.78	0.62	3.56	980.29	0.63	4.07
2	East Pass culverts US (983.23 L.O.)	*SJ4206*	*977.92*	981.46	-0.10	3.54	982.16	-0.05	4.24	983.23	0.02	5.31
3	McKee Road culverts US (988.48 L.O.)	*SJ1634*	*981.53*	986.64	-0.17	5.11	987.25	-0.40	5.72	988.45	-0.45	6.92
4	Carnwood Road culverts US	*SJ5642*	*986.21*	990.51	0.01	4.30	991.06	0.15	4.85	992.13	-0.03	5.92
5	Lancaster Lane culverts US (999.60 L.O.)	*SJ7518*	*993.50*	999.74	-0.52	6.24	1000.45	-0.55	6.95	1001.30	-0.66	7.80
6	Canterbury Road culverts US (1006.42 L.O.)	*SJ2993*	*999.06*	1005.58	0.59	6.52	1006.30	0.57	7.24	1007.14	0.15	8.08
7	Pilgrim Road culverts US	*SJ58055*	*1003.04*	1003.04	-6.49	0.00	1003.04	-7.11	0.00	1003.04	-8.24	0.00
8	McKenna Boulevard culverts US (1011.04 L.O.)	*SJ58692*	*1003.94*	1010.80	-1.77	6.86	1011.85	-1.58	7.91	1013.49	-1.43	9.55
9	Westbrook Lane culverts US (1013.15 L.O.)	*SJ6731*	*1009.31*	1012.85	-0.96	3.54	1013.07	-1.71	3.76	1014.17	-1.38	4.86
10	Raymond Road culverts US	*SJ54306*	*1013.20*	1018.72	0.36	5.52	1020.23	0.51	7.03	1022.42	0.43	9.22
11	Prairie Road culverts US	*SJ53068*	*1019.63*	1021.90	-0.80	2.27	1022.26	-0.88	2.63	1023.31	-1.10	3.68
12	Stonecreek Drive N or East Pass	*SJ12834*	*982.12*	982.12	0.00	0.00	982.12	0.00	0.00	982.12	-0.13	0.00
13	Tanglewood Drive-Timberwood Drive	*SJ11475*	*986.64*	986.64	-0.22	0.00	986.92	-0.58	0.28	987.72	-0.25	1.08
14	McKee Road-Maple Grove Drive	*SJ9674*	*1019.45*	1019.45	-0.20	0.00	1019.45	-0.36	0.00	1019.75	-0.18	0.30
15	McKee Road E of greenway	*SJ9731*	*989.94*	989.94	-0.90	0.00	989.94	-1.12	0.00	990.94	-0.28	1.00
16	Chester Drive cul-de-sac	*SJ8976*	*991.49*	991.49	-0.72	0.00	991.49	-0.91	0.00	992.38	-0.25	0.89
17	Silverton Trail-Tempe Drive*	*SJ8741*	*990.01*	988.44	-2.25	0.00	988.82	-2.17	0.00	990.60	-1.20	0.59
18	3145 Silverton Trail (back, along greenway)	*SJ67473*	*987.48*	987.50	0.02	0.02	987.99	0.04	0.51	988.92	-0.16	1.44
19	Laramie Court cul-de-sac*	*SJ13879*	*993.84*	991.74	-1.13	0.00	991.88	-2.43	0.00	992.22	-2.37	0.00
20	Greenway Trail-Chelsea Street*	*SJ49307*	*991.16*	990.35	0.31	0.00	991.60	0.06	0.44	992.41	0.11	1.25
21	Muir Field Road N of Carnwood Road	*SJ48501*	*998.44*	998.44	-0.20	0.00	998.44	-0.30	0.00	998.62	-0.29	0.18
22	McKenna Boulevard-Stratford Drive*	*SJ47601*	*1004.16*	1002.54	-2.30	0.00	1004.77	-0.29	0.61	1005.15	-0.25	0.99
23	Lancaster Lane-Whitlock Road	*SJ46844*	*1000.82*	1000.82	-0.74	0.00	1001.78	-0.29	0.96	1002.30	-0.31	1.48
24	Muir Field Road-Gladstone Drive	*SJ44927*	*1021.29*	1021.29	-0.45	0.00	1021.29	-0.67	0.00	1021.75	-0.52	0.46
25	McKenna Boulevard-Canterbury Road	*SJ46200*	*1010.62*	1010.62	-0.11	0.00	1011.16	-0.03	0.54	1011.41	-0.01	0.79
26	Waltham Road-Lambeth Circle	*SJ43968*	*1005.40*	1005.68	-0.71	0.28	1006.49	-0.82	1.09	1007.37	-1.38	1.97
27	McKenna Boulevard low pt N of Yorktown Circle*	*SJ43015*	*1017.38*	1015.26	-2.86	0.00	1015.49	-3.14	0.00	1015.91	-3.53	0.00
28	McKenna Boulevard low pt S of Tottenham Road	*SJ34364*	*1015.73*	1016.45	-0.50	0.72	1016.80	-0.78	1.07	1017.88	-0.46	2.15
29	McKenna Boulevard-Raymond Road	*SJ26709*	*1025.89*	1028.38	-0.39	2.49	1028.53	-0.37	2.64	1028.93	-0.13	3.04
30	Raymond Road W of McKenna Boulevard	*SJ26323*	*1046.01*	1046.01	-0.45	0.00	1046.31	-0.25	0.30	1046.54	-0.16	0.53

Location Number	Description	*Reporting Junction*	*Surface Elevation*	10% Chance Event			4% Chance Event			1% Chance Event		
				Proposed WSE	WSE Δ	Proposed Depth	Proposed WSE	WSE Δ	Proposed Depth	Proposed WSE	WSE Δ	Proposed Depth
31	Raymond Road low pt E of McKenna Boulevard	*SJ26117*	*1025.91*	1025.91	-1.26	0.00	1025.93	-1.36	0.02	1027.09	-0.49	1.18
32	Tottenham Road-Adderbury Circle	*SJ32637*	*1014.38*	1014.71	-0.39	0.33	1015.17	-0.19	0.79	1015.51	-0.25	1.13
33	Frisch Rd cul-de-sac S of Tottenham Road	*SJ36961*	*1009.25*	1011.17	-1.43	1.92	1012.05	-1.39	2.80	1013.56	-1.36	4.31
34	Pilgrim Road-Homestead Road	*SJ40768*	*1022.18*	1022.18	-0.86	0.00	1022.80	-0.39	0.62	1023.19	-0.20	1.01
35	Huegel School ditch	*SJ57368*	*1022.50*	1026.47	-0.87	3.97	1027.65	-0.09	5.15	1028.03	-0.07	5.53
36	Prairie Road-Riva Road	*SJ31106*	*1014.78*	1014.78	-1.80	0.00	1016.23	-0.58	1.45	1016.54	-0.63	1.76
37	Jonquil Road-Riva Road	*SJ32481*	*1016.40*	1016.40	-0.83	0.00	1016.96	-0.66	0.56	1017.90	-0.30	1.50
38	Thrush Lane-Balsam Road	*SJ31654*	*1022.85*	1022.93	-1.21	0.08	1023.82	-0.51	0.97	1024.28	-0.32	1.43
39	Raymond Road-Cameron Drive	*SJ21641*	*1024.30*	1024.30	-1.13	0.00	1024.30	-1.82	0.00	1025.72	-0.79	1.42
40	Raymond Road E of greenway crossing*	*SJ22322*	*1022.79*	1022.78	-0.76	0.00	1023.06	-0.57	0.27	1023.56	-0.20	0.77
41	Barton Road-Cameron Drive	*SJ17126*	*1032.54*	1032.55	-0.73	0.01	1032.55	-0.90	0.01	1033.34	-0.32	0.80
42	Whitney Way-Barton Road*	*SJ17238*	*1041.12*	1039.16	-3.21	0.00	1041.48	-0.97	0.36	1042.35	-0.20	1.23
43	Frisch Road-Jacobs Way	*SJ51910*	*1022.97*	1022.97	-0.94	0.00	1022.97	-1.34	0.00	1023.95	-0.81	0.98
44	Frisch Road low pt S of Jacobs Way	*SJ52254*	*1022.08*	1022.08	-0.76	0.00	1022.08	-1.66	0.00	1022.86	-1.33	0.78
45	Jacobs Way-Theresa Terrace	*SJ50564*	*1027.98*	1027.98	-0.53	0.00	1027.98	-0.57	0.00	1028.48	-0.13	0.50
46	Loreen Drive-Jacobs Way low pt	*SJ50911*	*1022.24*	1022.24	0.00	0.00	1022.24	-0.93	0.00	1023.41	-1.02	1.17
47	Prairie Road low pt at greenway crossing	*SJ51589*	*1023.76*	1023.76	0.00	0.00	1023.76	0.00	0.00	1024.00	-0.32	0.24
48	Barton Road-Golden Oak Lane-Redwood Lane	*SJ17895*	*1023.93*	1023.93	-0.80	0.00	1023.93	-0.93	0.00	1024.76	-0.34	0.83
49	Lynndale Road low pt N of Barton Road*	*SJ15864*	*1025.31*	1023.75	-0.91	0.00	1024.20	-1.18	0.00	1025.16	-0.82	0.00

* reporting point is located at a 2D cell where mesh is connected to 1D pipe network; the reported water surface elevation (WSE) is in the structure, below grade

L.O. structure low opening elevation

Greenway Crossing	10-Percent Chance Q (cfs)		4-Percent Chance Q (cfs)		1-Percent Chance Q (cfs)	
	Existing	Proposed	Existing	Proposed	Existing	Proposed
EBMC Watershed Outlet	673	965	842	1186	1114	1503
East Pass	657	953	823	1165	1080	1471
McKee Road	623	909	776	1103	1014	1396
Carnwood Road	546	833	660	971	851	1210
Lancaster Lane	461	731	531	826	649	934
Canterbury Road	447	712	521	803	641	914
Pilgrim Road	430	715	498	794	614	891
McKenna Boulevard	378	596	448	677	555	790
Westbrook Lane	273	426	344	478	523	596
Raymond Road	141	148	165	174	203	210
Prairie Road	47	60	57	75	89	112

Appendix L. – City Agency Meeting Summaries

From:	Allie, Matthew
To:	Laatsch, Kirstie; Linaberry, Brian; Saqqaf, Tariq; Wachter, Matthew
Cc:	Fries, Gregory; Mikolajewski, Matthew
Subject:	Theresa Terrace Drainage Discussion
Date:	December 30, 2022 9:18:02 AM
Attachments:	Theresa Terrace Drainage Discussion_122222.docx

Good Morning,

I'm following up with a summary of the discussion we had last week (attached) and to provide some answers to items I said I would investigate further.

- Engineering is not aware of chronic groundwater issues in the vicinity of Theresa Terrace, so it's more likely that instances of water in residents' basements were due to surface water runoff.
  - Brian – do you have any additional information/Building Inspection records about the flooding issues that residents here have experienced?
- Engineering is in the early stage of developing a plan to extend storm sewer along Theresa Terrace:
  - This would help with drainage in the street, but wouldn't do a lot to directly improve issues caused by runoff coming from the back of homes. Property owners could install private drainage pipes that connect to City storm sewer.
  - A project like this is the opportunity to implement a similar solution to what was done on Brentwood Parkway, however, this is different than that location for a few reasons:
    - Most homes on Brentwood already had constantly running sump pumps, caused by groundwater, before storm sewer was extended. Despite this, providing storm sewer connections to these properties was unpopular with many residents at the time it was initially installed.
    - For homes that do not already have a sump pump, retrofitting a home with one can be quite expensive (at least a few thousand dollars).
    - Sump pumps are effective at intercepting groundwater, but they only remove surface water runoff once it has already entered a basement.
  - If any property owners want to install a sump pump, it would be best to connect them to the storm sewer when the City has new sewer built. However, private storm sewer connections are assessable and are usually bid by contractors around $1,000-$2,500.
  - Surface drainage issues at these properties would be more effectively addressed by grading each lot to promote better drainage, which is more cost effective than retrofitting a sump pump. If multiple property owners are interested in re-grading, it would be productive to coordinate those plans to result in a complimentary drainage pattern.
- Regarding redevelopment of the CDA properties:
  - It's reasonable for these buildings to have basements as long as there's a proper site grading plan.
  - It would be a good idea for these buildings to have sump pumps, since installation is less expensive with new construction. These should be connected to the storm sewer when available.

- This is a good opportunity to intercept flow coming from uphill, which would help mitigate the amount of runoff seen by properties to the south. A concept like this could be incorporated into the site grading plan.
- When a design firm is selected to work on the site plan they can reach out to me and Greg if they have additional questions about drainage in the area.

I will keep you updated as a project is developed to extend storm sewer on Theresa Terrace and will take a look at any information Brian is able to provide. Don't hesitate to follow up if you have any additional questions.

Thanks,

Matt

-----Original Appointment-----

From: Allie, Matthew <MAllie@cityofmadison.com>

Sent: Thursday, December 15, 2022 12:47 PM

To: Laatsch, Kirstie; Wachter, Matthew; Mikolajewski, Matthew

Subject: Theresa Terrace Drainage Discussion

When: Thursday, December 22, 2022 2:00 PM-3:00 PM (UTC-06:00) Central Time (US & Canada).

Where: Conf Rm MMB Rm 151

Hi Kirstie, Matt, and Matt,

In response to questions raised following the watershed study presentation I gave at the PWI meeting last Thursday, I'm setting up a time to discuss drainage concerns and considerations along Theresa Terrace. I'll bring a figure showing the ground contours in this area to guide a conversation about the existing flow paths in this area and the sources of stormwater runoff.

Matt M., I'm adding you on this invite since I had a resident reach out to me during the study to tell me their basement has flooded a couple times in the years since lot grading was completed at the Theresa Terrace Neighborhood Center. Since this issue is based on the same drainage patterns that Matt W. and Kirstie are interested in learning about, this is an effective time to include you in discussion.

Let me know if there's any additional information you need prior to this meeting.

Matt

Theresa Terrace Drainage Discussion – 12/22/22

Invited: Kirstie Laatsch (Planning), Matt Wachter (Planning), Matt Mikolajewski (EDD), Tariq Saqqaf (DCR), Brian Linaberry (BI)

Attendees: Matt Allie, Kirstie Laatsch, Matt Wachter, Matt Mikolajewski

Description of known drainage issues in the neighborhood:

- Runoff flows down back lot line of properties that front Theresa Terrace and Prairie Road
    - At least a couple residents have experienced water entering their basement on more than one occasion
- Runoff from the street flows west through parcels at the south end of Theresa Terrace
- Ponding at low point where Jacobs Way meets Loreen Drive

Extending storm sewer up Theresa Terrace from Jacobs Way to Hammersley Road would help improve drainage in the area

- It wouldn't directly solve drainage issues along the backs of houses on Theresa Terrace
- Private connections to storm sewer would be assessable; costs would be a burden to renters/owners in the neighborhood
- Are sump pumps a solution to be considered here? Another burdensome added cost.
- What was done on Brentwood Parkway and can something similar/more effective be done here?
- Are there larger scale grading fixes that can be recommended or coordinated between property owners?

CDA owns two parcels at 1403 and 1311 Theresa Terrace (not adjacent to each other)

- Plan to demolish existing duplexes and build new triplexes
- Planned residences would have basements
- Parking area at the back of both lots
- Request is currently out for civil/site design services
- Selected consultant can coordinate with Engineering (Matt Allie & Greg Fries)
- Is it reasonable for CDA properties to have basements if site grading is designed properly?
- Should CDA consider installing sump pumps in the new homes?
- Would Engineering want sump pumps connected directly to storm sewer? (only if storm is already constructed, otherwise curb head discharge may be needed in the meantime)

Matt will check to see if Engineering is aware of any chronic groundwater issues in the area

Can Brian check Building Inspection records to see which properties have had flooding issues and when?

If Engineering wants to address the drainage issue just south of TTNC:

- Fixing grading to be more similar to what existed before would be one option
- Prepare a grading plan and share with Matt M. since he could sign EC permit app on behalf of EDD
- Could flow be intercepted at the CDA properties to the north to help relieve the problem?

Discuss Impacts of East Badger Mill Creek Watershed Study Recommended Solutions on Parks Property

Friday, February 3rd, 2023

Skype

Present: Matt Allie (Engineering), Ann Freiwald (Parks), Chad Hughes (Parks Division)

1. Pilgrim Park
    a. Impacts: Open trench through grassy area to remove old storm sewer pipes and to install new, larger storm sewer pipes. High water elevation in the park will be lower in the future after culverts under McKenna Boulevard are replaced.
    b. Parks response: These impacts are generally acceptable, but Parks requests that timing and details of construction are coordinated during design. Seed restored areas in fall, if possible. Avoid impacts to the path from Pilgrim Road into the park, if possible.
    c. Ann asked if Engineering has a plan to replace the concrete cunettes/channel lining. Matt said there is not a plan for that and that replacing them may run into challenges with WDNR. When the concrete lining inevitably reaches a state of disrepair, effort and consideration should be put into developing a more natural channel (e.g. rock lined with grass overbanks) that can be maintained by Engineering Operations crews.

2. Waltham Park
    a. Impacts: Open trench through grassy area to install new relief storm sewer pipes. High water elevation and inundation extents in the park will be increased slightly in the future after other improvements are implemented.
    b. Parks response: These impacts are generally acceptable, but Parks requests that timing and details of construction are coordinated during design. Seed restored areas in fall, if possible. This work would occur near playing fields and scheduling construction for off peak season or closing the fields for a season will need to be considered. Low to medium use reserve-able shelter.

Appendix M. – Planning Level Cost Estimates

Conceptual Cost Estimate - McKenna Blvd-Raymond Rd Reconstruction

2/8/2023 **See Figure 9-3**

DRAFT

Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	20,000.00	$ 20,000	
10911	MOBILIZATION	1	LUMP SUM	230,000.00	$ 230,000	10% of other bid items.
20221	TOPSOIL	100	S.Y.	8.00	$ 800	
20312	REMOVE CATCH BASIN	20	EACH	900.00	$ 18,000	
20313	REMOVE INLET	44	EACH	630.00	$ 27,720	
20314	REMOVE PIPE	3,940	L.F.	25.00	$ 98,500	
20321	REMOVE CONCRETE CURB & GUTTER	140	L.F.	8.00	$ 1,120	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	100	S.F.	5.00	$ 500	
21063	EROSION MATTING CLASS I, TYPE A - ORGANIC	100	S.Y.	6.25	$ 625	
21092	TERRACE RESTORATION	100	S.Y.	5.00	$ 500	
30201	TYPE "A" CONCRETE CURB & GUTTER	140	L.F.	35.00	$ 4,900	
30301	5 INCH CONCRETE SIDEWALK	100	S.F.	7.32	$ 732	
50211	SELECT BACKFILL FOR STORM SEWER	3,940	T.F.	39.50	$ 155,630	
50226	UTILITY TRENCH TYPE III	2,547	S.Y.	95.00	$ 241,933	
50405	24 INCH TYPE I RCP STORM SEWER PIPE	510	L.F.	125.00	$ 63,750	
50407	30 INCH TYPE I RCP STORM SEWER PIPE	1,560	L.F.	160.00	$ 249,600	
50409	36 INCH TYPE I RCP STORM SEWER PIPE	80	L.F.	175.00	$ 14,000	
50724	4' X 4' STORM SAS	8	EACH	5,500.00	$ 44,000	
50725	5' X 5' STORM SAS	3	EACH	7,000.00	$ 21,000	
50726	6' X 6' STORM SAS	9	EACH	9,500.00	$ 85,500	
50741	H INLET	50	EACH	2,900.00	$ 145,000	
50768	TERRACE INLET TYPE 3	6	EACH	7,000.00	$ 42,000	
50792	STORM SEWER TAP	1	EACH	1,500.00	$ 1,500	
	4'X4' REINFORCED CONCRETE BOX CULVERT	1480	L.F.	930.00	$ 1,376,400	$600/LF in January 2023, increased based on recent prices
	2'X4' REINFORCED CONCRETE BOX CULVERT	310	L.F.	780.00	$ 241,800	$450/LF in January 2023, increased based on recent prices
	4'X4' RCBC JUNCTION @ 8'X5' RCBC	1	EACH	20,000.00	$ 20,000	
	WATERMAIN OFFSET	1	LUMP SUM	40,000.00	$ 40,000	
	EROSION CONTROL	1	LUMP SUM	20,000.00	$ 20,000	
				Subtotal	**$ 3,165,510**	
				Contingency 25%	**$ 791,378**	
				Design 10%	**$ 316,551**	
				Total	**$ 4,273,439**	East portion of Raymond Road storm sewer is approximately $569,000 of this total
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 4,273,439**	

Conceptual Cost Estimate - Riva Rd Reconstruction

2/8/2023 **See Figure 9-4**

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	60,000.00	$ 60,000	10% of other bid items.
20221	TOPSOIL	100	S.Y.	8.00	$ 800	
20312	REMOVE CATCH BASIN	10	EACH	900.00	$ 9,000	
20313	REMOVE INLET	11	EACH	630.00	$ 6,930	
20314	REMOVE PIPE	460	L.F.	25.00	$ 11,500	
20321	REMOVE CONCRETE CURB & GUTTER	200	L.F.	8.00	$ 1,600	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	100	S.F.	5.00	$ 500	
21063	EROSION MATTING CLASS I, TYPE A - ORGANIC	100	S.Y.	6.25	$ 625	
21092	TERRACE RESTORATION	100	S.Y.	5.00	$ 500	
30201	TYPE "A" CONCRETE CURB & GUTTER	200	L.F.	35.00	$ 7,000	
30301	5 INCH CONCRETE SIDEWALK	100	S.F.	7.32	$ 732	
50211	SELECT BACKFILL FOR STORM SEWER	460	T.F.	39.50	$ 18,170	
50226	UTILITY TRENCH TYPE III	613	S.Y.	95.00	$ 58,267	
50741	H INLET	4	EACH	2,900.00	$ 11,600	
50768	TERRACE INLET TYPE 3	4	EACH	7,000.00	$ 28,000	
50792	STORM SEWER TAP	2	EACH	1,500.00	$ 3,000	
	6'X5' REINFORCED CONCRETE BOX CULVERT	90	L.F.	1,180.00	$ 106,200	$860/LF in January 2023, increased based on recent prices
	8'X4' REINFORCED CONCRETE BOX CULVERT	270	L.F.	1,210.00	$ 326,700	$900/LF in January 2023, increased based on recent prices
	10'X4' REINFORCED CONCRETE BOX CULVERT	100	L.F.	1,360.00	$ 136,000	$1040/LF in January 2023, increased based on recent prices
	RCBC WINGWALLS	1	EACH	20,000.00	$ 20,000	
	CULVERT RAILINGS	30	L.F.	180.00	$ 5,400	
	WATERMAIN OFFSET	1	LUMP SUM	20,000.00	$ 20,000	
	EROSION CONTROL	1	LUMP SUM	20,000.00	$ 20,000	
				Subtotal	**$ 862,524**	
				Contingency 25%	**$ 215,631**	
				Design 10%	**$ 86,252**	
				Total	**$ 1,164,407**	
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 1,164,407**	

Conceptual Cost Estimate - Raymond Rd-Cameron Dr-Barton Rd-Whitney Way Reconstruction

1/5/2023 **See Figure 9-5**

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	170,000.00	$ 170,000	10% of other bid items.
20312	REMOVE CATCH BASIN	18	EACH	900.00	$ 16,200	
20313	REMOVE INLET	46	EACH	630.00	$ 28,980	
20314	REMOVE PIPE	4,690	L.F.	25.00	$ 117,250	
20321	REMOVE CONCRETE CURB & GUTTER	160	L.F.	8.00	$ 1,280	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	100	S.F.	5.00	$ 500	
20711	TRENCH RESTORATION 4 INCH TOPSOIL, SEED, FERTILIZE AND MULCH	2,300	T.F.	5.00	$ 11,500	
30201	TYPE "A" CONCRETE CURB & GUTTER	160	L.F.	35.00	$ 5,600	
30301	5 INCH CONCRETE SIDEWALK	1,000	S.F.	7.32	$ 7,320	
30302	7 INCH CONCRETE SIDEWALK & DRIVE	500	S.F.	12.00	$ 6,000	
50211	SELECT BACKFILL FOR STORM SEWER	4,690	T.F.	39.50	$ 185,255	
50226	UTILITY TRENCH TYPE III	1,062	S.Y.	95.00	$ 100,911	
50405	24 INCH TYPE I RCP STORM SEWER PIPE	220	L.F.	125.00	$ 27,500	
50407	30 INCH TYPE I RCP STORM SEWER PIPE	1,540	L.F.	160.00	$ 246,400	
50409	36 INCH TYPE I RCP STORM SEWER PIPE	1,420	L.F.	175.00	$ 248,500	
50410	42 INCH TYPE I RCP STORM SEWER PIPE	740	L.F.	220.00	$ 162,800	Increased price based on recent bid prices for larger pipes
50411	48 INCH TYPE I RCP STORM SEWER PIPE	770	L.F.	250.00	$ 192,500	Increased price based on recent bid prices for larger pipes
50724	4' X 4' STORM SAS	8	EACH	5,500.00	$ 44,000	
50725	5' X 5' STORM SAS	5	EACH	7,000.00	$ 35,000	
50726	6' X 6' STORM SAS	4	EACH	9,500.00	$ 38,000	
50741	H INLET	50	EACH	2,900.00	$ 145,000	
50768	TERRACE INLET TYPE 3	4	EACH	7,000.00	$ 28,000	
50792	STORM SEWER TAP	2	EACH	1,500.00	$ 3,000	
	WATERMAIN OFFSET	1	LUMP SUM	20,000.00	$ 20,000	
	EROSION CONTROL	1	LUMP SUM	20,000.00	$ 20,000	
				Subtotal	**$ 1,871,496**	
				Contingency 25%	**$ 467,874**	
				Design 10%	**$ 187,150**	
				Total	**$ 2,526,520**	
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 2,526,520**	

Conceptual Cost Estimate - East Pass Relief Box Culvert
2/8/2023 **See Figure 9-7**

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	25,000.00	$ 25,000	10% of other bid items.
20221	TOPSOIL	300	S.Y.	8.00	$ 2,400	
20321	REMOVE CONCRETE CURB & GUTTER	60	L.F.	8.00	$ 480	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	320	S.F.	5.00	$ 1,600	
21073	EROSION MATTING CLASS II, TYPE C - ORGANIC	300	S.Y.	6.25	$ 1,875	
21092	TERRACE RESTORATION	300	S.Y.	5.00	$ 1,500	
30201	TYPE "A" CONCRETE CURB & GUTTER	60	L.F.	35.00	$ 2,100	
30301	5 INCH CONCRETE SIDEWALK	320	S.F.	7.32	$ 2,342	
40202	HMA PAVEMENT	20	TON	100.00	$ 2,000	Increased by 50% for small quantity over trench; ##SF/9X2"X.06TSI (SY X 2" X .06 TON/SY-IN)
50211	SELECT BACKFILL FOR STORM SEWER	120	T.F.	39.50	$ 4,740	
50226	UTILITY TRENCH TYPE III	170	S.Y.	95.00	$ 16,150	
	8'X4' REINFORCED CONCRETE BOX CULVERT	120	L.F.	1,210.00	$ 145,200	$900/LF in January 2023, increased based on recent prices
	RCBC WINGWALLS	2	EACH	20,000.00	$ 40,000	
	CULVERT RAILINGS	160	L.F.	180.00	$ 28,800	
	TREE REMOVAL	1	EACH	2,000.00	$ 2,000	
	STORM WATER CONTROL PLAN	1	EACH	20,000.00	$ 20,000	
	EROSION CONTROL	1	LUMP SUM	5,000.00	$ 5,000	
				Subtotal	**$ 311,187**	
				Contingency 25%	**$ 77,797**	
				Design 10%	**$ 31,119**	
				Total	**$ 420,103**	
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 420,103**	

Conceptual Cost Estimate - McKee Rd Relief Box Culvert

2/8/2023 **See Figure 9-8**

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Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	30,000.00	$ 30,000	
10911	MOBILIZATION	1	LUMP SUM	50,000.00	$ 50,000	10% of other bid items.
20221	TOPSOIL	350	S.Y.	8.00	$ 2,800	
20236	HEAVY RIPRAP - GLACIAL FIELD STONE	5	TON	75.00	$ 375	
20321	REMOVE CONCRETE CURB & GUTTER	160	L.F.	8.00	$ 1,280	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	440	S.F.	5.00	$ 2,200	
21073	EROSION MATTING CLASS II, TYPE C - ORGANIC	350	S.Y.	6.25	$ 2,188	
21092	TERRACE RESTORATION	350	S.Y.	5.00	$ 1,750	
30201	TYPE "A" CONCRETE CURB & GUTTER	160	L.F.	35.00	$ 5,600	
30301	5 INCH CONCRETE SIDEWALK	440	S.F.	7.32	$ 3,221	
40202	HMA PAVEMENT	35	TON	100.00	$ 3,500	Increased by 50% for small quantity over trench; ##SF/9X2"X.06TSI (SY X 2" X .06 TON/SY-IN)
50211	SELECT BACKFILL FOR STORM SEWER	170	T.F.	39.50	$ 6,715	
50226	UTILITY TRENCH TYPE III	300	S.Y.	95.00	$ 28,500	
50792	STORM SEWER TAP	2	EACH	1,500.00	$ 3,000	
	10'X4' REINFORCED CONCRETE BOX CULVERT	170	L.F.	1,360.00	$ 231,200	$1040/LF in January 2023, increased based on recent prices
	RCBC WINGWALLS	2	EACH	40,000.00	$ 80,000	
	CULVERT RAILINGS	140	L.F.	180.00	$ 25,200	
	TREE REMOVAL	1	EACH	2,000.00	$ 2,000	
	STORM WATER CONTROL PLAN	1	EACH	20,000.00	$ 20,000	
	EROSION CONTROL	1	LUMP SUM	5,000.00	$ 5,000	
				Subtotal	**$ 504,528**	
				Contingency 25%	**$ 126,132**	
				Design 10%	**$ 50,453**	
				Total	**$ 681,113**	
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 681,113**	

Conceptual Cost Estimate - Carnwood Rd Box Culvert Replacement

2/8/2023 **See Figure 9-9**

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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	10% of other bid items.
20221	TOPSOIL	480	S.Y.	8.00	$ 3,840	
20313	REMOVE INLET	8	EACH	630.00	$ 5,040	
20314	REMOVE PIPE	140	L.F.	25.00	$ 3,500	
20321	REMOVE CONCRETE CURB & GUTTER	100	L.F.	8.00	$ 800	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	1,760	S.F.	5.00	$ 8,800	
21073	EROSION MATTING CLASS II, TYPE C - ORGANIC	480	S.Y.	6.25	$ 3,000	
21092	TERRACE RESTORATION	480	S.Y.	5.00	$ 2,400	
30201	TYPE "A" CONCRETE CURB & GUTTER	100	L.F.	35.00	$ 3,500	
30301	5 INCH CONCRETE SIDEWALK	510	S.F.	7.32	$ 3,733	
30302	7 INCH CONCRETE SIDEWALK & DRIVE	1,250	S.F.	12.00	$ 15,000	
40202	HMA PAVEMENT	20	TON	100.00	$ 2,000	Increased by 50% for small quantity over trench; ##SF/9X2"X.06TSI (SY X 2" X .06 TON/SY-IN)
50211	SELECT BACKFILL FOR STORM SEWER	200	T.F.	39.50	$ 7,900	
50226	UTILITY TRENCH TYPE III	170	S.Y.	95.00	$ 16,150	
50403	18 INCH TYPE I RCP STORM SEWER PIPE	20	L.F.	115.00	$ 2,300	
50741	H INLET	8	EACH	2,600.00	$ 20,800	
50792	STORM SEWER TAP	1	EACH	1,500.00	$ 1,500	
	11'X5' REINFORCED CONCRETE BOX CULVERT	200	L.F.	1,630.00	$ 326,000	$1320/LF in January 2023, increased based on recent prices
	RCBC WINGWALLS	2	EACH	40,000.00	$ 80,000	
	CULVERT RAILINGS	100	L.F.	180.00	$ 18,000	
	TREE REMOVAL	4	EACH	2,000.00	$ 8,000	
	STORM WATER CONTROL PLAN	1	EACH	20,000.00	$ 20,000	
	WATERMAIN OFFSET	1	LUMP SUM	20,000.00	$ 20,000	
	EROSION CONTROL	1	LUMP SUM	5,000.00	$ 5,000	
				Subtotal	**$ 637,263**	
				Contingency 25%	**$ 159,316**	
				Design 10%	**$ 63,726**	
				Total	**$ 860,305**	
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 860,305**	

Conceptual Cost Estimate - Lancaster Ln Box Culvert Replacement

2/8/2023 **See Figure 9-10**

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Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	10,000.00	$ 10,000	
10911	MOBILIZATION	1	LUMP SUM	60,000.00	$ 60,000	10% of other bid items.
20221	TOPSOIL	500	S.Y.	8.00	$ 4,000	
20314	REMOVE PIPE	220	L.F.	25.00	$ 5,500	
20314	REMOVE PIPE (SANITARY)	70	L.F.	50.00	$ 3,500	
20321	REMOVE CONCRETE CURB & GUTTER	90	L.F.	8.00	$ 720	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	1,360	S.F.	5.00	$ 6,800	
21073	EROSION MATTING CLASS II, TYPE C - ORGANIC	500	S.Y.	6.25	$ 3,125	
21092	TERRACE RESTORATION	500	S.Y.	5.00	$ 2,500	
30201	TYPE "A" CONCRETE CURB & GUTTER	90	L.F.	35.00	$ 3,150	
30301	5 INCH CONCRETE SIDEWALK	460	S.F.	7.32	$ 3,367	
30302	7 INCH CONCRETE SIDEWALK & DRIVE	900	S.F.	12.00	$ 10,800	
40202	HMA PAVEMENT	20	TON	100.00	$ 2,000	Increased by 50% for small quantity over trench; ##SF/9X2"X.06TSI (SY X 2" X .06 TON/SY-IN)
50103	RECONSTRUCT BENCH AND FLOWLINE(S)	1	EACH	1,000.00	$ 1,000	
50211	SELECT BACKFILL FOR STORM SEWER	280	T.F.	39.50	$ 11,060	
50212	SELECT BACKFILL FOR SANITARY SEWER	70	T.F.	8.00	$ 560	
50226	UTILITY TRENCH TYPE III	170	S.Y.	95.00	$ 16,150	
50321	8 INCH PVC PRESSURE SANITARY SEWER PIPE	70	L.F.	380.00	$ 26,600	
50361	WASTEWATER CONTROL	1	L.S.	5,000.00	$ 5,000	
50390	SEWER ELECTRONIC MARKERS	1	EACH	50.00	$ 50	
50701	4' DIA. SANITARY SAS	1	EACH	5,500.00	$ 5,500	
50781	8 INCH SANITARY SEWER OUTSIDE DROP	4	V.F.	150.00	$ 600	
50791	SANITARY SEWER TAP	1	EACH	2,000.00	$ 2,000	
50792	STORM SEWER TAP	1	EACH	1,500.00	$ 1,500	
	7'X6' REINFORCED CONCRETE BOX CULVERT	280	L.F.	1,400.00	$ 392,000	$1080/LF in January 2023, increased based on recent prices
	RCBC WINGWALLS	2	EACH	40,000.00	$ 80,000	
	CULVERT RAILINGS	90	L.F.	180.00	$ 16,200	
	TREE REMOVAL	4	EACH	2,000.00	$ 8,000	
	STORM WATER CONTROL PLAN	1	EACH	20,000.00	$ 20,000	
	WATERMAIN OFFSET	1	LUMP SUM	20,000.00	$ 20,000	
	EROSION CONTROL	1	LUMP SUM	5,000.00	$ 5,000	
				Subtotal	**$ 726,682**	
				Contingency 25%	**$ 181,671**	
				Design 10%	**$ 72,668**	
				Total	**$ 981,021**	
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 981,021**	

Conceptual Cost Estimate - Canterbury Rd Box Culvert Replacement

2/8/2023 **See Figure 9-11**

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Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	10,000.00	$ 10,000	
10911	MOBILIZATION	1	LUMP SUM	45,000.00	$ 45,000	10% of other bid items.
20221	TOPSOIL	390	S.Y.	8.00	$ 3,120	
20313	REMOVE INLET	4	EACH	630.00	$ 2,520	
20314	REMOVE PIPE	220	L.F.	25.00	$ 5,500	
20321	REMOVE CONCRETE CURB & GUTTER	70	L.F.	8.00	$ 560	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	1,390	S.F.	5.00	$ 6,950	
21073	EROSION MATTING CLASS II, TYPE C - ORGANIC	390	S.Y.	6.25	$ 2,438	
21092	TERRACE RESTORATION	390	S.Y.	5.00	$ 1,950	
30201	TYPE "A" CONCRETE CURB & GUTTER	70	L.F.	35.00	$ 2,450	
30301	5 INCH CONCRETE SIDEWALK	390	S.F.	7.32	$ 2,855	
30302	7 INCH CONCRETE SIDEWALK & DRIVE	1,000	S.F.	12.00	$ 12,000	
40202	HMA PAVEMENT	20	TON	100.00	$ 2,000	Increased by 50% for small quantity over trench; ##SF/9X2"X.06TSI (SY X 2" X .06 TON/SY-IN)
50211	SELECT BACKFILL FOR STORM SEWER	200	T.F.	39.50	$ 7,900	
50226	UTILITY TRENCH TYPE III	170	S.Y.	95.00	$ 16,150	
50741	H INLET	4	EACH	2,900.00	$ 11,600	
50792	STORM SEWER TAP	1	EACH	1,500.00	$ 1,500	
	7'X6' REINFORCED CONCRETE BOX CULVERT	200	L.F.	1,400.00	$ 280,000	$1080/LF in January 2023, increased based on recent prices
	RCBC WINGWALLS	2	EACH	40,000.00	$ 80,000	
	CULVERT RAILINGS	90	L.F.	180.00	$ 16,200	
	TREE REMOVAL	6	EACH	2,000.00	$ 12,000	
	STORM WATER CONTROL PLAN	1	EACH	20,000.00	$ 20,000	
	WATERMAIN OFFSET	1	LUMP SUM	20,000.00	$ 20,000	
	EROSION CONTROL	1	LUMP SUM	5,000.00	$ 5,000	
				Subtotal	**$ 567,692**	
				Contingency 25%	**$ 141,923**	
				Design 10%	**$ 56,769**	
				Total	**$ 766,385**	
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 766,385**	

Conceptual Cost Estimate - McKenna Blvd-Pilgrim Rd Box Culvert Replacement

2/8/2023 **See Figure 9-12**

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Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	20,000.00	$ 20,000	
10911	MOBILIZATION	1	LUMP SUM	180,000.00	$ 180,000	10% of other bid items.
20221	TOPSOIL	1,550	S.Y.	8.00	$ 12,400	
20313	REMOVE INLET	6	EACH	630.00	$ 3,780	
20314	REMOVE PIPE	420	L.F.	25.00	$ 10,500	
20314	REMOVE PIPE (SANITARY)	340	L.F.	50.00	$ 17,000	
20321	REMOVE CONCRETE CURB & GUTTER	160	L.F.	8.00	$ 1,280	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	2,190	S.F.	5.00	$ 10,950	
21073	EROSION MATTING CLASS II, TYPE C - ORGANIC	1,550	S.Y.	6.25	$ 9,688	
21092	TERRACE RESTORATION	1,550	S.Y.	5.00	$ 7,750	
30201	TYPE "A" CONCRETE CURB & GUTTER	160	L.F.	35.00	$ 5,600	
30301	5 INCH CONCRETE SIDEWALK	790	S.F.	7.32	$ 5,783	
30302	7 INCH CONCRETE SIDEWALK & DRIVE	1,400	S.F.	12.00	$ 16,800	
40202	HMA PAVEMENT	20	TON	100.00	$ 2,000	Increased by 50% for small quantity over trench; ##SF/9X2"X.06TSI (SY X 2" X .06 TON/SY-IN)
50103	RECONSTRUCT BENCH AND FLOWLINE(S)	2	EACH	1,000.00	$ 2,000	
50211	SELECT BACKFILL FOR STORM SEWER	940	T.F.	39.50	$ 37,130	
50212	SELECT BACKFILL FOR SANITARY SEWER	370	T.F.	8.00	$ 2,960	
50226	UTILITY TRENCH TYPE III	170	S.Y.	95.00	$ 16,150	
50335	18 INCH RCP SANITARY SEWER PIPE	370	L.F.	200.00	$ 74,000	
50361	WASTEWATER CONTROL	1	L.S.	10,000.00	$ 10,000	
50390	SEWER ELECTRONIC MARKERS	1	EACH	50.00	$ 50	
50701	5' DIA. SANITARY SAS	1	EACH	7,000.00	$ 7,000	
50791	SANITARY SEWER TAP	2	EACH	2,000.00	$ 4,000	
50741	H INLET	6	EACH	2,900.00	$ 17,400	
50792	STORM SEWER TAP	1	EACH	1,500.00	$ 1,500	
	8'X5' REINFORCED CONCRETE BOX CULVERT	940	L.F.	1,360.00	$ 1,278,400	$1040/LF in January 2023, increased based on recent prices
	RCBC WINGWALLS	2	EACH	40,000.00	$ 80,000	
	CULVERT RAILINGS	90	L.F.	180.00	$ 16,200	
	CULVERT GRATES	1	EACH	30,000.00	$ 30,000	
	TREE REMOVAL	20	EACH	1,000.00	$ 20,000	Unit cost lowered due to higher quantity (add efficiency)
	STORM WATER CONTROL PLAN	1	EACH	30,000.00	$ 30,000	Higher unit cost due to complexity of two inflows
	WATERMAIN OFFSET	1	LUMP SUM	40,000.00	$ 40,000	
	EROSION CONTROL	1	LUMP SUM	5,000.00	$ 5,000	
				Subtotal	**$ 1,975,320**	
				Contingency 25%	**$ 493,830**	
				Design 10%	**$ 197,532**	
				Total	**$ 2,666,682**	
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 2,666,682**	

Conceptual Cost Estimate - Westbrook Ln Box Culvert Replacement

2/8/2023 **See Figure 9-13**

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Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	10,000.00	$ 10,000	
10911	MOBILIZATION	1	LUMP SUM	45,000.00	$ 45,000	10% of other bid items.
20221	TOPSOIL	360	S.Y.	8.00	$ 2,880	
20313	REMOVE INLET	2	EACH	630.00	$ 1,260	
20314	REMOVE PIPE	140	L.F.	25.00	$ 3,500	
20321	REMOVE CONCRETE CURB & GUTTER	100	L.F.	8.00	$ 800	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	1,940	S.F.	5.00	$ 9,700	
21073	EROSION MATTING CLASS II, TYPE C - ORGANIC	360	S.Y.	6.25	$ 2,250	
21092	TERRACE RESTORATION	360	S.Y.	5.00	$ 1,800	
30201	TYPE "A" CONCRETE CURB & GUTTER	100	L.F.	35.00	$ 3,500	
30301	5 INCH CONCRETE SIDEWALK	540	S.F.	7.32	$ 3,953	
30302	7 INCH CONCRETE SIDEWALK & DRIVE	1,400	S.F.	12.00	$ 16,800	
40202	HMA PAVEMENT	20	TON	100.00	$ 2,000	Increased by 50% for small quantity over trench; ##SF/9X2"X.06TSI (SY X 2" X .06 TON/SY-IN)
50211	SELECT BACKFILL FOR STORM SEWER	160	T.F.	39.50	$ 6,320	
50226	UTILITY TRENCH TYPE III	170	S.Y.	95.00	$ 16,150	
50741	H INLET	2	EACH	2,900.00	$ 5,800	
	14'X4' REINFORCED CONCRETE BOX CULVERT	160	L.F.	1,650.00	$ 264,000	$1340/LF in January 2023, increased based on recent prices
	RCBC WINGWALLS	2	EACH	40,000.00	$ 80,000	
	CULVERT RAILINGS	120	L.F.	180.00	$ 21,600	
	TREE REMOVAL	4	EACH	2,000.00	$ 8,000	
	STORM WATER CONTROL PLAN	1	EACH	20,000.00	$ 20,000	
	WATERMAIN OFFSET	1	LUMP SUM	20,000.00	$ 20,000	
	EROSION CONTROL	1	LUMP SUM	5,000.00	$ 5,000	
				Subtotal	**$ 550,313**	
				Contingency 25%	**$ 137,578**	
				Design 10%	**$ 55,031**	
				Total	**$ 742,922**	
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 742,922**	

Conceptual Cost Estimate - Lucy Lincoln Hiestand Park Box Culvert and Frisch Road Storm Sewer

2/8/2023 **See Figure 9-14**

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Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	10,000.00	$ 10,000	
10911	MOBILIZATION	1	LUMP SUM	85,000.00	$ 85,000	10% of other bid items.
20221	TOPSOIL	800	S.Y.	8.00	$ 6,400	
20312	REMOVE CATCH BASIN	6	EACH	900.00	$ 5,400	
20313	REMOVE INLET	21	EACH	630.00	$ 13,230	
20314	REMOVE PIPE	1,050	L.F.	25.00	$ 26,250	
20321	REMOVE CONCRETE CURB & GUTTER	80	L.F.	8.00	$ 640	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	100	S.F.	5.00	$ 500	
21063	EROSION MATTING CLASS I, TYPE A - ORGANIC	100	S.Y.	6.25	$ 625	
21073	EROSION MATTING CLASS II, TYPE C - ORGANIC	700	S.Y.	6.25	$ 4,375	
21092	TERRACE RESTORATION	800	S.Y.	5.00	$ 4,000	
30201	TYPE "A" CONCRETE CURB & GUTTER	80	L.F.	35.00	$ 2,800	
30301	5 INCH CONCRETE SIDEWALK	100	S.F.	7.32	$ 732	
40202	HMA PAVEMENT	10	TON	100.00	$ 1,000	Increased by 50% for small quantity over trench; ##SF/9X2"X.06TSI (SY X 2" X .06 TON/SY-IN)
50211	SELECT BACKFILL FOR STORM SEWER	1,050	T.F.	39.50	$ 41,475	
50226	UTILITY TRENCH TYPE III	933	S.Y.	95.00	$ 88,667	
50726	6' X 6' STORM SAS	4	EACH	9,500.00	$ 38,000	
50741	H INLET	24	EACH	2,900.00	$ 69,600	
50768	TERRACE INLET TYPE 3	2	EACH	7,000.00	$ 14,000	
50792	STORM SEWER TAP	2	EACH	1,500.00	$ 3,000	
	4'X2' REINFORCED CONCRETE BOX CULVERT	600	L.F.	300.00	$ 180,000	used a lower unit cost since HERCP may be an alternative to box sections
	4'X3' REINFORCED CONCRETE BOX CULVERT	160	L.F.	350.00	$ 56,000	used a lower unit cost since HERCP may be an alternative to box sections
	6'X3' REINFORCED CONCRETE BOX CULVERT	230	L.F.	420.00	$ 96,600	used a lower unit cost since HERCP may be an alternative to box sections
	10'X4' REINFORCED CONCRETE BOX CULVERT	60	L.F.	1,360.00	$ 81,600	$1040/LF in January 2023, increased based on recent prices
	CULVERT RAILINGS	30	L.F.	180.00	$ 5,400	
	RCBC WINGWALLS	3	EACH	20,000.00	$ 60,000	
	STORM WATER CONTROL PLAN	1	EACH	5,000.00	$ 5,000	
	WATERMAIN OFFSET	1	LUMP SUM	20,000.00	$ 20,000	
	EROSION CONTROL	1	LUMP SUM	10,000.00	$ 10,000	
				Subtotal	**$ 930,294**	
				Contingency 25%	**$ 232,573**	
				Design 10%	**$ 93,029**	
				Total	**$ 1,255,896**	Lucy Lincoln Hiestand Park Box Culvert is approximately $243,000 of this total
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 1,255,896**	

Conceptual Cost Estimate - Prairie Rd Box Culvert and Theresa Terrace Storm Sewer

2/8/2023 **See Figure 9-15**

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Item #	Item	Quantity	Unit	Unit Cost	Cost	Comments
10701	TRAFFIC CONTROL	1	LUMP SUM	10,000.00	$ 10,000	
10911	MOBILIZATION	1	LUMP SUM	70,000.00	$ 70,000	10% of other bid items.
20221	TOPSOIL	810	S.Y.	8.00	$ 6,480	
20313	REMOVE INLET	4	EACH	630.00	$ 2,520	
20314	REMOVE PIPE	820	L.F.	25.00	$ 20,500	
20321	REMOVE CONCRETE CURB & GUTTER	1,200	L.F.	8.00	$ 9,600	
20323	REMOVE CONCRETE SIDEWALK AND DRIVE	770	S.F.	5.00	$ 3,850	
21073	EROSION MATTING CLASS II, TYPE C - ORGANIC	810	S.Y.	6.25	$ 5,063	
21092	TERRACE RESTORATION	810	S.Y.	5.00	$ 4,050	
30201	TYPE "A" CONCRETE CURB & GUTTER	1,200	L.F.	35.00	$ 42,000	
30301	5 INCH CONCRETE SIDEWALK	260	S.F.	7.32	$ 1,903	
30302	7 INCH CONCRETE SIDEWALK & DRIVE	510	S.F.	12.00	$ 6,120	
40202	HMA PAVEMENT	650	TON	65.00	$ 42,250	##SF/9X2"X.06TSI (SY X 2" X .06 TON/SY-IN)
50211	SELECT BACKFILL FOR STORM SEWER	1,540	T.F.	39.50	$ 60,830	
50226	UTILITY TRENCH TYPE III	700	S.Y.	95.00	$ 66,500	pipe trench area=1440*4/9, culvert trench area=50*10/9
50402	15 INCH TYPE I RCP STORM SEWER PIPE	720	L.F.	105.00	$ 75,600	
50405	24 INCH TYPE I RCP STORM SEWER PIPE	720	L.F.	125.00	$ 90,000	
50741	H INLET	16	EACH	2,900.00	$ 46,400	
50768	TERRACE INLET TYPE 3	1	EACH	7,000.00	$ 7,000	
50792	STORM SEWER TAP	1	EACH	1,500.00	$ 1,500	
	6'X3' REINFORCED CONCRETE BOX CULVERT	100	L.F.	960.00	$ 96,000	$630/LF in January 2023, increased based on recent prices
	CULVERT RAILINGS	50	L.F.	180.00	$ 9,000	
	RCBC WINGWALLS	2	EACH	20,000.00	$ 40,000	
	TREE REMOVAL	4	EACH	2,000.00	$ 8,000	
	STORM WATER CONTROL PLAN	1	EACH	20,000.00	$ 20,000	
	WATERMAIN OFFSET	1	LUMP SUM	20,000.00	$ 20,000	
	EROSION CONTROL	1	LUMP SUM	5,000.00	$ 5,000	
				Subtotal	**$ 770,166**	
				Contingency 25%	**$ 192,541**	
				Design 10%	**$ 77,017**	
				Total	**$ 1,039,724**	
				Land Acquisition	**$ -**	
				Wetland Mitigation	**$ -**	
				Total Total	**$ 1,039,724**	

Appendix N. – Public Comments and Responses to Comments