LOCALIZED FLOOD MITIGATION ASSESSMENT REPORT

CITY OF MEDFORD, MASSACHUSETTS
MARCH 2023

KLEINFELDER PROJECT #20230276.001A

TABLE OF CONTENTS

Section **Page**

TABLES

FIGURES

APPENDICES

1 EXECUTIVE SUMMARY

The City of Medford Department of Public Works and Engineering Department identified five locations (Figure 1) where localized flooding was observed during large storms on June 2nd, August 19th, and September 1st of 2021. This report describes Kleinfelder's hydraulic modeling analysis and evaluation of design alternatives to mitigate flooding at four of the five locations. At one of the five locations (Newbern Avenue), the City implemented a solution to mitigate the observed flooding and will continue to monitor the location.

Kleinfelder updated the City's existing hydraulic model with improved catchment delineations and updated input parameters using the latest information from GIS data, record drawings, and field investigations. Kleinfelder used the updated model to identify hydraulic issues in the existing drainage system and validate observed flooding.

Kleinfelder developed design alternatives to mitigate flooding for the 10-year, 24-hour design storm. Kleinfelder evaluated the design alternatives based on the following criteria: effectiveness at mitigating flooding, cost, constructability, and ability to incorporate green infrastructure. Kleinfelder's analysis and recommended design alternatives for each flood location are summarized in this executive summary.

Flood comparison figures are provided to show the modeled flood mitigation benefits. Flood comparison figures show the modeled extent and depth of flooding under existing infrastructure conditions (red) and after implementation of the recommended alternative (blue). All flood comparison figures presented in this report show the maximum modeled flood depths for a particular storm and infrastructure scenario. The maximum modeled flood depths represent a snapshot in time of the worst flooding conditions. Depending on the specific location and distribution of rainfall in a storm, the maximum modeled flood depths may only occur for a short duration of time shortly after the peak rainfall intensity of the storm. Kleinfelder recommends that the City consider evaluating the flood mitigation effectiveness of recommended alternatives for different storm frequencies, durations and/or distributions (for example, a 10-year, 2-hour storm) in a future design phase, as these considerations may impact effectiveness of recommended alternatives.

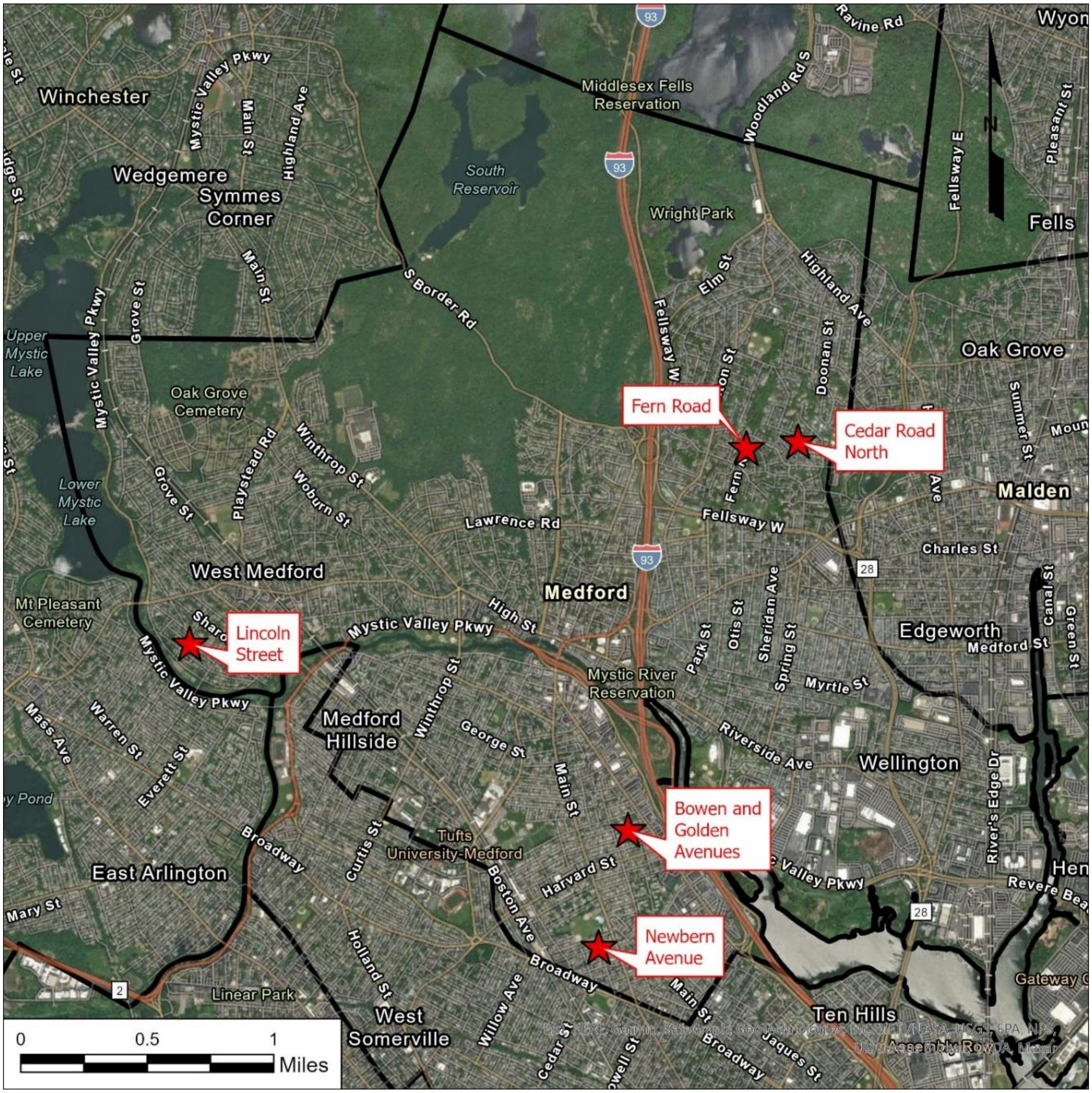

Figure 1: Localized flood locations overview map

Fern Road: The City confirmed residents' reports of stormwater overflow at a shallow depth manhole (MH-655) in the vicinity of 146 Fern Road on the Cranberry Brook culvert pipe. The pipe conveys stormwater from a moderately sized catchment upstream of the observed flood location including flow from the undeveloped, open channel, portion of the Cranberry Brook. Field investigations identified a reduction in the culvert pipe diameter from 30-inch to 24-inch at the shallow depth manhole and another reduction from 30-inch to 18-inch at a manhole just upstream of the flood location in the vicinity of 3 Hickory Avenue. Modeling analysis indicates that the size and slope of the upstream catchment area, the reductions in the culvert pipe diameter and a change in pipe slope (from steep to shallow) at the shallow depth manhole, result in elevated hydraulic grades and stormwater overflows at the manholes upstream of the reductions in the culvert pipe diameter. Increasing the pipe diameters at the existing reductions mitigates simulated stormwater overflow at the manhole just upstream of the flood location in the vicinity of 3 Hickory Avenue but only partially mitigates the stormwater overflow at the observed flood location. Kleinfelder recommends modifying the existing Cranberry Brook headwall structure upstream of the flood location with a weir and orifices to utilize the natural storage within the undeveloped, open channel portion of Cranberry Brook and reduce the peak flow in the downstream culvert pipe portion. This alternative mostly eliminates flooding at the observed location during the 10-year, 24-hour, present day design storm, at a substantially lower cost compared to increasing the pipe diameters at the existing reductions (Figure 2). This alternative provides a green infrastructure benefit by increasing the volume of stormwater that is stored in the undeveloped area upstream of the headwall and infiltrated to groundwater as opposed to being conveyed through the drainage system. Kleinfelder's preliminary opinion of probable cost for this alternative is $196,900 for construction costs and $197,000 for engineering design, engineering services during construction and construction contingency for a total project cost of $393,900. This alternative requires environmental permitting. This alternative could be supplemented with additional improvements in the future including the creation of constructed wetland storage upstream of the headwall structure and increasing the pipe diameters at the existing reductions.

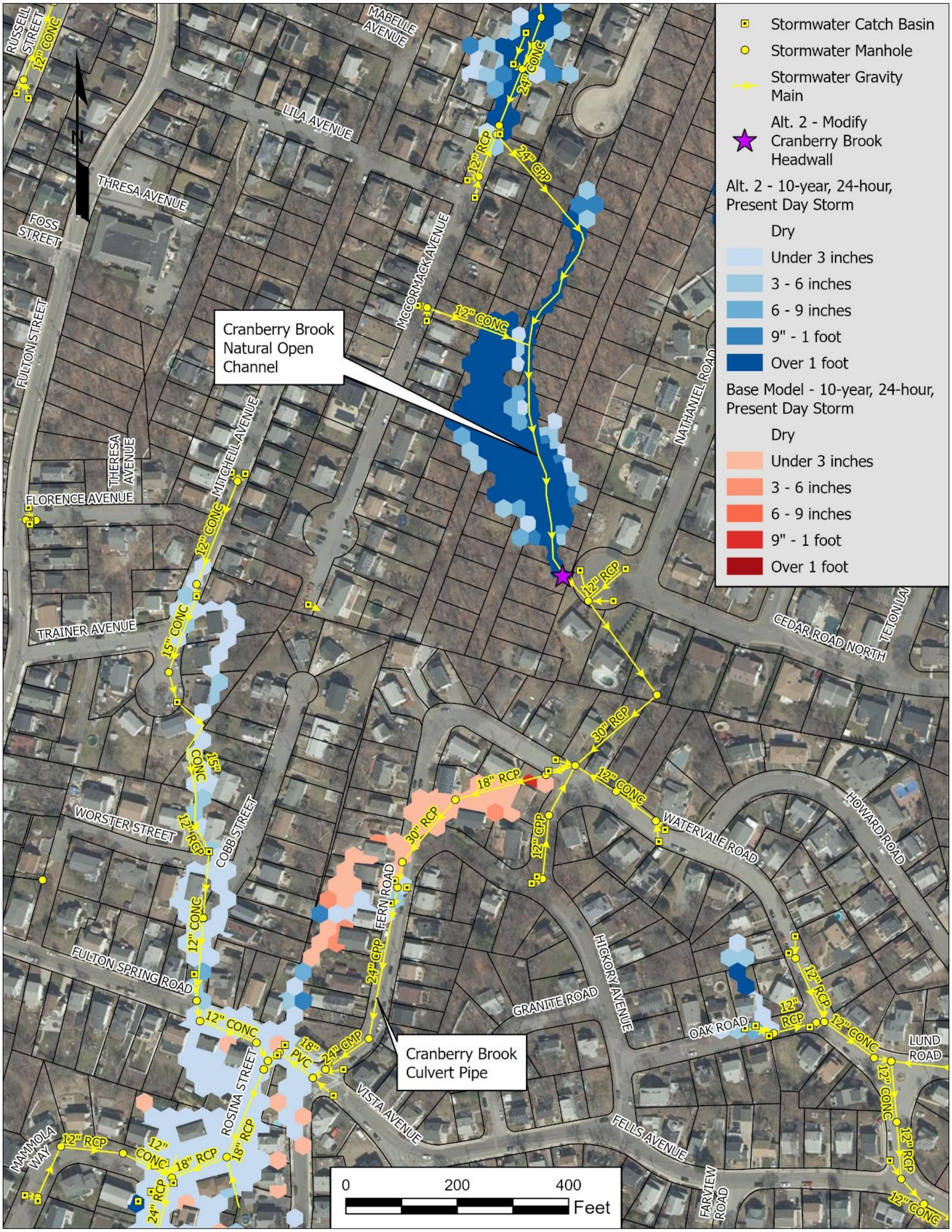

Figure 2: Fern Road flood mitigation for recommended alternative

Cedar Road North: The City has received reports of flooding at a local low point in elevation near 81 and 83 Cedar Road North. The four catch basins in this vicinity are hydraulically linked to a wetland detention area north of Grover Road which contains an inlet to the Grover Road Easement drainage system consisting of a 24-inch pipe that travels behind 97-107 Grover Road in a cross-country easement. During large storm events, water levels in the wetland detention area exceed the rim elevations of the catch basins near 81 and 83 Cedar Road North resulting stormwater backing up through the catch basins and causing flooding in this area. Kleinfelder recommends rerouting flow from the four catch basins on Cedar Road North, through the existing sewer easement, to the existing drainage system on Frye Road and Grover Road. This alternative involves installation of pipe at a reasonable depth (approximately 10 feet) and replacement of a portion of the existing drainage on Frye Road and Grover Road to maintain minimum slopes and to connect to the existing drainage system downstream. This alternative eliminates flooding during the 10-year, 24-hour, 2070 design storm using 15-inch and 18-inch pipe to reroute flow from the catch basins (Figure 3). Kleinfelder's preliminary opinion of probable cost for this alternative is $608,900 for construction costs and $334,900 for engineering design, engineering services during construction and construction contingency for a total project cost of $943,800. Kleinfelder recommends the City evaluates the cost benefit under future design phases for the replacement of the existing catch basins along the recommended reroute alignment with leaching catch basins to increase infiltration in this area with favorable soils.

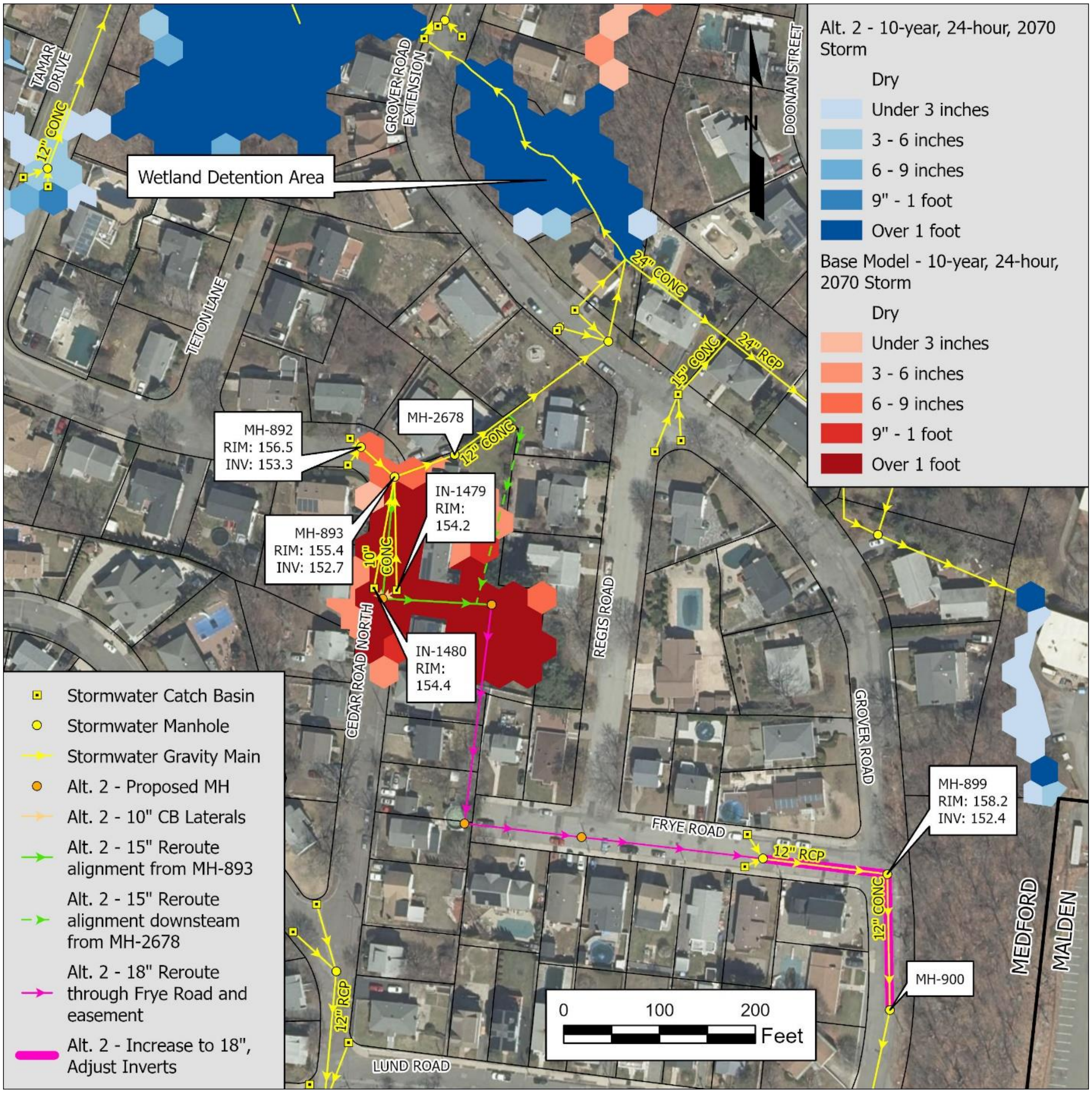

Figure 3: Cedar Road North flood mitigation for recommended alternative

Bowen and Golden Avenues: The location at Bowen and Golden Avenues between Mystic Avenue and Willis Avenue is a low point in elevation with a history of flooding during large storm events. Drainage along both Avenues connects to a 15-inch pipe in Willis Avenue, which connects to the 72-inch Two Penny Brook culvert pipe. Modeling analysis indicates that the relative size and slope of the Willis Avenue catchment, the shallow slopes of the Bowen and Golden Avenue drainage pipes, and the limited conveyance capacity of the 15-inch pipe in Willis Avenue result in elevated hydraulic grades causing flooding at this location. Modeling analysis shows that even significantly increasing the diameter of the Willis Avenue drain to 30-inch only partially mitigates flooding during the 10-year, 24-hour, present day design storm. Kleinfelder recommends installing 18-inch connections between the existing drains on Bowen and Golden Avenues and the existing drain on Mystic Avenue. The Mystic Avenue drain catchment is a similar area but flatter topography than the Willis Avenue catchment and the Mystic Avenue drain pipe is 36-inch at its downstream connection to the Two Penny Brook culvert pipe as opposed to the 15-inch pipe in Willis Avenue. These existing conditions result in a shorter time of concentration and smaller hydraulic capacity for the Mystic Avenue catchment compared to the Willis Avenue catchment. The recommended 18-inch connections allow the existing drains on Bowen and Golden Avenue to remain in place and create a hydraulic link between the Willis Avenue and Mystic Avenue drains. The connections act as overflow outlets, allowing stormwater to be conveyed to both the Mystic Avenue and Willis Avenue drains when the hydraulic grade in the area is elevated. This alternative provides moderate flood mitigation during the 10-year, 24-hour, present day design storm (Figure 4), at a significantly lower cost compared to increasing the pipe diameter of the Willis Avenue drain. Kleinfelder's preliminary opinion of probable cost for this alternative is $508,500 for construction costs and $279,700 for engineering design, engineering services during construction and construction contingency for a total project cost of $788,200. This recommended alternative could be supplemented with additional improvements in the future including increasing the pipe diameters of the Willis Avenue and Mystic Avenue drains downstream of the observed flooding.

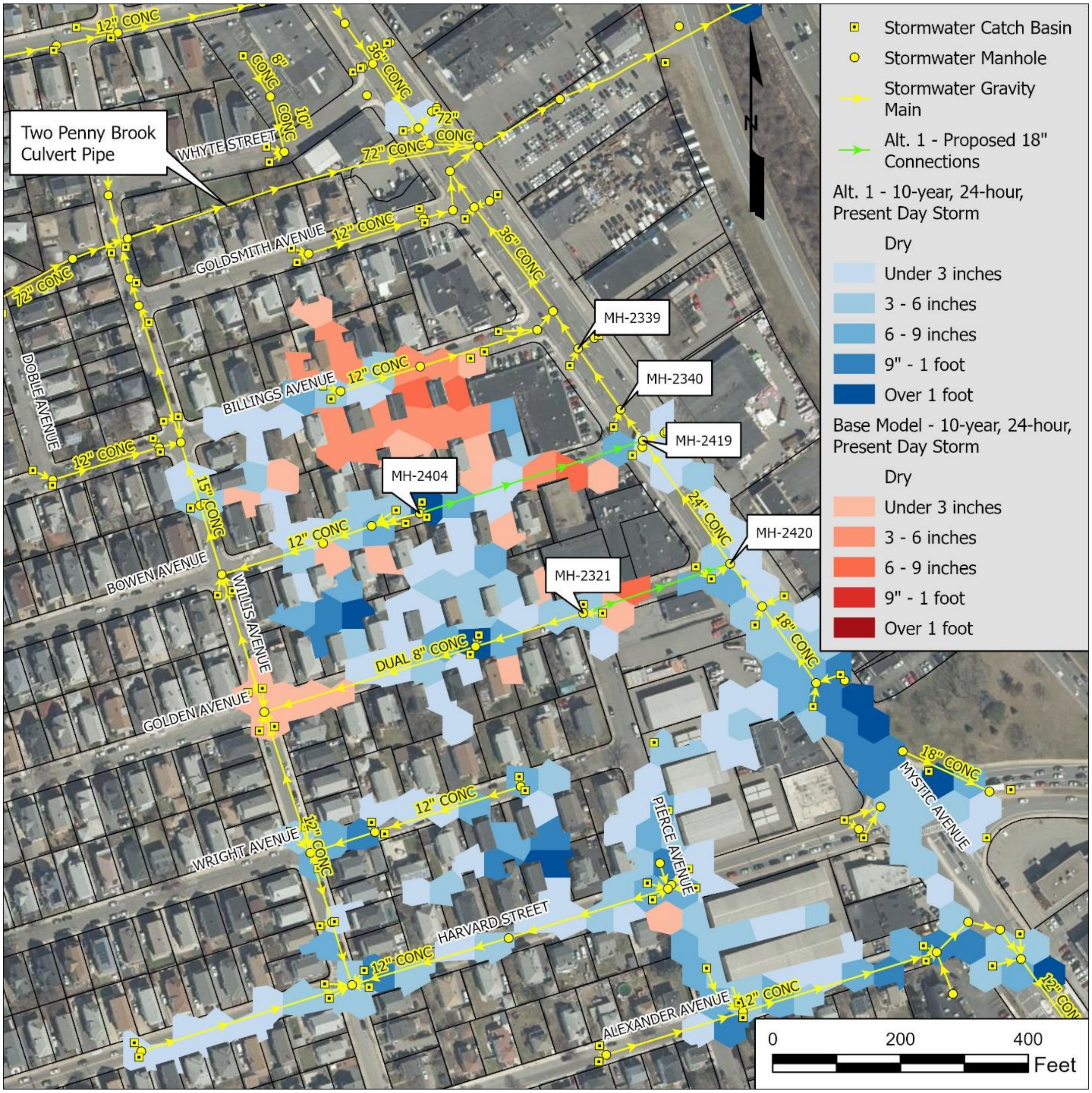

Figure 4: Bowen and Golden Avenue flood mitigation for recommended alternative

Lincoln Street: Residents have reported flooding near 35/37 Lincoln Street during large storm events. The driveway of the 35/37 and 55 Lincoln Street properties slopes down from the roadway elevation to basement garages which have private infiltration drainage systems in front of the garages. These properties are impacted by stormwater overflows from the City's drainage catch basins in the roadway directly in front of the properties. Drainage along Lincoln Street consists of 12-inch pipes with shallow slopes that connect to a 15-inch drain in Fairfield Street which increases downstream to 18-inch at Arlington Street and then 24-inch in the vicinity of Mystic River Road before discharging to the Mystic River at an outfall. The Fairfield Street drain conveys stormwater flows for a relatively small upstream catchment area. Modeling analysis indicates that the shallow slopes of the 12-inch drain in Lincoln Street, the shallow slopes of the Fairfield Street drains, and a tailwater condition at the Mystic River outfall during larger storm events result in flooding at this location. Kleinfelder recommends increasing the pipe diameters of the Lincoln Street and Fairfield Street drains to Mystic River Road and replacing catch basins along Lincoln Street with leaching catch basins. This alternative does not require increasing the size of the outfall and provides some green infrastructure benefit by increasing infiltration. This alternative eliminates flooding in the vicinity of 35/37 Lincoln Street for the 10-year, 24-hour, present day design storm (Figure 5). The remaining modeled flooding on Lincoln Street is primarily the result of stormwater overflows at the Harvard Avenue and Lincoln Street intersection. Modeling analysis indicates that overflows from the Harvard Avenue drain could be contributing additional stormwater flow to the Lincoln Street drain and worsening flooding impacts on Lincoln Street. Kleinfelder recommends the City investigate this further to confirm if the modeled conditions match observed conditions during large storm events. If this is the case, the City could consider additional measures to mitigate flooding on Lincoln Street and Harvard Avenue such as increasing the pipe diameter of Harvard Avenue drain or replacing catch basins connected to the Harvard Avenue drain with leaching catch basins. Kleinfelder's preliminary opinion of probable cost for this alternative is $851,800 for construction costs and $468,500 for engineering design, engineering services during construction and construction contingency for a total project cost of $1,320,300. This recommended alternative requires DCR permitting for work within Mystic River Road.

Figure 5: Lincoln Street flood mitigation for recommended alternative

Newbern Avenue: The City observed water backing up into the basements of 19/21, 10/12 and 9/11 Newbern Avenue during a storm event in July 2021 that may have impacted as many as 10 buildings. Water was observed entering basements from sanitary sewer connections with the characteristics of the water indicating that stormwater and/or groundwater was contributing to the flow. The underdrain system for the sanitary sewer in this area has a significant tributary area that collects at the underdrain overflow manhole just upstream of where the sewer service backups were observed. A 12-inch overflow pipe conveys underdrain flow from the overflow manhole, between 19/21 and 23 Newbern Avenue, across Morton Avenue, and discharges to the Winter Brook Culvert in Tufts Park. The City removed debris from the overflow manhole and jetted the 12-inch pipe. The sanitary sewer overflows (SSOs) observed appear to have resulted from blockage of the underdrain overflow pipe and underdrain flow entering the sanitary sewer. To rectify the problem, the City connected the underdrain pipe to the existing drain on Morton Avenue by excavating down to the underdrain pipe and installing a new manhole along the existing drain alignment (Figure 6). The portion of underdrain pipe in Tufts Park was abandoned. The City will monitor the Newbern Avenue area and perform additional investigative activities if SSOs continue in this area.

Figure 6: Newbern Avenue underdrain connection

2 INTRODUCTION

2.1 BACKGROUND

In 2018, the City engaged Kleinfelder to develop a city-wide stormwater model and conduct model simulations with current and future predicted design storms. The purpose of the study was to help the City gain a better understanding of which areas are more prone to future flood risks from storms that are likely to be more frequent and intense because of climate change. The City's model was developed in PCSWMM, a software developed by Computational Hydraulics International (CHI, Inc.) that is based on the same computation engine as the EPA Stormwater Management Model (EPA SWMM), with an improved user interface. The model is an integrated 1D-2D model with City's drainage network modeled as 1D pipe conduits connected to a 2D mesh surface to model flooding over the ground surface topography. The 2018 model represented the City's piped drainage infrastructure through carefully selected simplified conduits draining large catchments, which balanced the need for realistic flood simulation with computational efficiency. After the initial study, the City received two 2018 Municipal Vulnerability Preparedness Action Grants from the State to continue its climate change preparedness and resiliency efforts. One of those grants was used to fund an additional study completed by Kleinfelder in 2019. This 2019 study involved further refinement of the stormwater model in South Medford and evaluation of flood reduction strategies to mitigate future flooding impacts.

The City has received reports of localized flooding at five locations throughout the City during large storm events. Specifically, the City received and confirmed reports of flooding on August 19, 2021 and when the remnants of Hurricane Ida crossed the region on September 1 – 2, 2021. In 2022, the City engaged Kleinfelder to update the previously prepared city-wide drainage model and use the updated model to identify hydraulic issues in the existing drainage system, validate observed flooding, and develop design alternatives to mitigate localized flooding at the five identified locations. The analysis described in this report builds on the previous analyses and continues the City's efforts of climate change preparedness and resiliency.

2.2 LOCALIZED FLOOD LOCATIONS

The five localized flooding locations identified by the City are described below. Reports of observed flooding are described in further detail in memoranda prepared by the City (Appendix A). Refer to Figures 7-11 for detailed overview maps of each flood location area including approximate catchment boundaries, existing stormwater and sewer infrastructure, and ground surface elevation contours (vertical datum NAVD88 in feet). Note that the existing stormwater and sewer infrastructure shown on the maps represents the latest information from the City's GIS and field investigations performed as part of this project. The existing stormwater and sewer infrastructure shown on the maps may be missing information or contain inaccuracies.

2.2.1 Fern Road

The City's Engineering Division documented a manhole (MH-655) overflowing near 146 Fern Road after intense rainfall on August 19, 2021. The manhole is located on the Cranberry Brook culvert pipe. This portion of the Cranberry Brook was converted to a culvert pipe during the urbanization of the area with a headwall structure in the vicinity of 124 Cedar Road North. The pipe conveys stormwater from a moderately sized catchment upstream of the observed flood location including inlets on McCormack Avenue, Cedar Road North, Watervale Road and Hickory Avenue and flow from the undeveloped, open channel, portion of Cranberry Brook (Figure 7). The manhole is located on a shallow sloped section of the Cranberry Brook culvert pipe immediately downstream of a steep section and immediately upstream of a reduction in the culvert pipe diameter from 30-inch to 24-inch. Upstream of the flood location is another reduction in the culvert pipe diameter from 30-inch to 18-inch at a manhole in the vicinity of 3 Hickory Avenue. The City has noted that shallow subsurface ledge (bedrock) may be present in this area. The soils in this area are classified as hydrologic soil group A and have high infiltration rates based on NRCS soil data.

2.2.2 Cedar Road North

The City has received reports of flooding at a local low point in elevation near 81 and 83 Cedar Road North. The four catch basins in this vicinity are hydraulically linked to a wetland detention area north of Grover Road which contains an inlet to the Grover Road easement drainage system consisting of a 24-inch pipe that travels behind 97-107 Grover Road in a cross country easement (Figure 8). The City has noted that shallow subsurface ledge (bedrock) may be present in this area. The soils in this area are classified as hydrologic soil group A and have high infiltration rates based on NRCS soil data.

2.2.3 Lincoln Street

Lincoln Street residents reported stormwater accumulating at a low point in the road near 35/37 Lincoln Street during the intense rainfall on August 19, 2021. Residents' photos documented surcharged catch basins at this location. The Lincoln Street drainage connects to a mainline drain on Fairfield Street that conveys stormwater from a small urban catchment area to an outfall on the Mystic River (Figure 9). The soils in this area are classified as hydrologic soil group A and have high infiltration rates based on NRCS soil data. This flood location is within an Environmental Justice block group with a minority population.

2.2.4 Bowen and Golden Avenues

The City's Engineering Division received reports that Bowen Avenue and Golden Avenue flooded between Mystic Avenue and Willis Avenue on August 19, 2021. Bowen and Golden Avenues between Mystic Avenue and Willis Avenue is a local low point in elevation with a history of flooding during large storm events. Drainage pipes on both Avenues connect to a trunk line on Willis Avenue which conveys stormwater for a small urban catchment area (Figure 10). The trunk line on Willis Avenue connects to the Two Penny Brook culvert which discharges to the Mystic River. This flood location is within an Environmental Justice block group with a minority population.

2.2.5 Newbern Avenue

The City observed water backing up into the basements of 19/21, 10/12 and 9/11 Newbern Avenue during a heavy, intense rain event in July 2021 that may have impacted as many as 10 buildings. Water was observed entering basements from sanitary sewer connections with the characteristics of the water indicating that stormwater and/or groundwater was contributing. There is separate storm drainage in this area. The underdrain system for the sanitary sewer in this area has a significant tributary area that collects at an "overflow manhole" just upstream of where the sanitary sewer overflows were observed (Figure 11). Records indicate that a 12-inch pipe conveys underdrain flow from the overflow manhole, between 19/21 and 23 Newbern Avenue, across Morton Avenue, and discharges to the Winter Brook Culvert in Tufts Park.

Kleinfelder did not perform hydraulic model updates, hydraulic evaluations or develop alternatives for this site location since field investigations determined that the likely cause of the SSOs was a maintenance issue with the underdrain. See section 3.3 for additional information related to this site location. Kleinfelder recommends a comprehensive field investigation of the sewer, drain and underdrain be undertaken if SSOs continue on Newbern Avenue. The investigations would focus on potential interconnections between the three systems and the ground water table, in addition to capacity issues with the underdrain.

LEGEND

- Stormwater Manhole
- Stormwater Catch Basin
- Stormwater Gravity Main
- Flood Locations
- Stormwater Outlet
- Sewer Manhole
- Sanitary Sewer Gravity Main
- Underdrain
- Elevation Contour (ft)
- Municipal Boundaries
- Parcels
- Fern Road Catchment Area Upstream of Flooding

N

0 100 200
Feet

KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com

PROJECT NO.	20230276
CREATED:	3/3/2023
CREATED BY:	ASilveri
CHECKED BY:	DScott
FILE NAME:	StormwaterGIS.mxd

Fern Road Overview Map

Localized Flood Mitigation Project
City of Medford, MA

FIGURE
7

LEGEND

- Flood Locations
- Stormwater Outlet
- Stormwater Manhole
- Stormwater Catch Basin
- Stormwater Gravity Main
- Sewer Manhole
- Sanitary Sewer Gravity Main
- Underdrain
- Elevation Contour (ft)
- Municipal Boundaries
- Parcels
- Cedar Road North Catchment Area
- Frye and Grover Road Catchment Area

N

0 100 200
Feet

KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com

PROJECT NO.	20230276
CREATED:	3/3/2023
CREATED BY:	ASilveri
CHECKED BY:	DScott
FILE NAME:	StormwaterGIS.mxd

Cedar Road North Overview Map

Localized Flood Mitigation Project
City of Medford, MA

FIGURE
8

LEGEND

- Stormwater Manhole
- Stormwater Catch Basin
- Stormwater Gravity Main
- Stormwater Outlet
- Flood Locations
- Sewer Manhole
- Sanitary Sewer Gravity Main
- Underdrain
- Elevation Contour (ft)
- Municipal Boundaries
- Parcels
- Fairfield Street Outfall Catchment Area

0 50 100 200
Feet

KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com

PROJECT NO.	20230276
CREATED:	3/3/2023
CREATED BY:	ASilveri
CHECKED BY:	DScott
FILE NAME:	StormwaterGIS.mxd

Lincoln Street Overview Map

Localized Flood Mitigation Project
City of Medford, MA

FIGURE

9

LEGEND

- Stormwater Manhole
- Stormwater Catch Basin
- Stormwater Gravity Main
- Stormwater Outlet
- Flood Locations
- Sewer Manhole
- Sanitary Sewer Gravity Main
- Underdrain
- Elevation Contour (ft)
- Municipal Boundaries
- Parcels
- Mystic Avenue Catchment Area
- Willis Avenue Catchment Area

N

0 50 100 200
Feet

The information included on this graphic representation has been compiled from a variety of sources and is subject to change without notice. Kleinfelder makes no representations or warranties, express or implied, as to accuracy, completeness, timeliness, or rights to the use of such information. This document is not intended for use as a land survey product nor is it designed or intended as a construction design document. The use or misuse of the information contained on this graphic representation is at the sole risk of the party using or misusing the information.

KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com

PROJECT NO.	20230276
CREATED:	3/3/2023
CREATED BY:	ASilveri
CHECKED BY:	DScott
FILE NAME:	StormwaterGIS.mxd

Bowen and Golden Avenues Overview Map

Localized Flood Mitigation Project
City of Medford, MA

FIGURE
10

LEGEND

- Stormwater Manhole
- Stormwater Catch Basin
- Stormwater Gravity Main
- Stormwater Outlet
- Flood Locations
- Sewer Manhole
- Sanitary Sewer Gravity Main
- Underdrain
- Elevation Contour (ft)
- Municipal Boundaries
- Parcels

0 50 100 200
Feet

KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com

PROJECT NO.	20230276	**Newbern Avenue Overview Map**	FIGURE
CREATED:	3/3/2023		**11**
CREATED BY:	ASilveri		
CHECKED BY:	DScott	Localized Flood Mitigation Project City of Medford, MA	
FILE NAME:	StormwaterGIS.mxd		

3 FIELD INVESTIGATIONS AND GIS UPDATES

The City provided Kleinfelder with its latest GIS data representing stormwater, sanitary sewer and drinking water infrastructure. Additionally, the City provided Kleinfelder with available records in the five identified flood locations. Kleinfelder used the information provided to conduct field investigations and then update the City's GIS and hydraulic model as described in the following sections.

3.1 RECORD REVIEW

Kleinfelder reviewed records provided by the City and compared rim and invert elevations, pipe diameters, materials, and other key information as shown in the record drawings with the corresponding information in the City's GIS. Where record information was not provided or conflicted with the City's GIS, Kleinfelder used the information in the City's GIS or conducted field investigations to obtain updated information.

3.2 FIELD INVESTIGATIONS

Kleinfelder reviewed the records and GIS data provided by the City and identified pipe lengths and manholes which either lacked necessary information (pipe diameter, pipe material, invert elevations) to establishing a complete hydraulic model of the system or which appeared to be potentially inaccurate. Kleinfelder developed a priority list of manholes and catch basins for field inspection. Kleinfelder staff conducted surface (non-entry) manhole inspections and recorded manhole rim and invert elevations as well as pipe invert elevations and diameters using a GPS unit and a survey rod. Kleinfelder also recorded pipe sizes and pipe materials. Refer to Appendix B and C for manhole inspection information and photos. Kleinfelder identified one manhole on the Cranberry Brook culvert pipe that was not previously shown in the City's GIS. This manhole is located just upstream of the Fern Road flood location in the vicinity of 3 Hickory Avenue and shows a reduction in pipe diameter from 30-inch to 18-inch (Figure 12). Kleinfelder was unable to locate one manhole (MH-2676) that appears to be on the Cranberry Brook culvert pipe and may be buried. Additionally, Kleinfelder was unable to inspect one manhole (MH-2677) on the Cranberry Brook culvert pipe that is located on private property that may be buried.

Figure 12: Photograph of manhole in the vicinity of 3 Hickory Avenue showing a reduction in pipe diameter from 30-inch to 18-inch

3.3 NEWBERN AVENUE FIELD INVESTIGATION

In the summer of 2022, the City removed a large volume of debris from the overflow manhole near 23 Newbern Avenue and jetted the 12-inch outlet pipe, prior to hitting a blockage approximately 90’ downstream. The blockage of the underdrain pipe downstream of the “overflow” manhole and underdrain flow entering the sanitary sewer are suspected to be the main contributing factors of the SSOs observed in the area. The observed sanitary sewer overflows do not appear to have been related to the separate storm drainage network in this area.

Kleinfelder performed a field investigation in this area on September 15, 2022, with the assistance of the City. The purpose of the investigation was to attempt to identify the downstream tie in point of the underdrain pipe. The team first tried to locate a drain manhole shown on record plans on Morton Ave that may have been paved over but were unsuccessful using a metal detector. The team then opened up the nearest manhole on the Winter Brook Culvert in Tufts Park and utilized man entry to determine if an underdrain connection was visible downstream of the manhole but were unable to identify a connection.

To rectify the problem, the City connected the underdrain pipe to the existing drain on Morton Avenue by excavating down to the underdrain pipe and installing a new manhole along the existing drain alignment (Figure 6). The portion of underdrain pipe in Tufts Park was abandoned. The exact alignment of this portion of underdrain is unknown. The City will monitor the Newbern Avenue area and perform additional investigative activities if SSOs continue in this area.

It should be noted that the material of the sewer on Newbern Avenue is shown on records as unreinforced concrete which is extremely susceptible to structural deterioration from hydrogen sulfide damage. Structural defects on the concrete sewer pipes would create a pathway for groundwater to enter the sewer, reducing capacity and increasing the risk of SSOs. Kleinfelder recommends the City evaluate the condition of the sewer system on Newbern Avenue to determine the condition of the pipe.

3.4 GIS UPDATES

Kleinfelder updated rim and invert elevations of features in the City's GIS if the elevations recorded in the field investigations differed from elevations in the City's GIS by more than three inches. Kleinfelder updated pipe sizes and materials and added new pipe lengths, manholes, and catch basins that were not previously shown in the City's GIS. Kleinfelder labeled each updated feature in the GIS by setting "DATA_SOURCE" attribute to "Kleinfelder" and provided the updated GIS database to the City's GIS administrator.

4 HYDRAULIC MODEL UPDATES

4.1 MODEL UPDATES

Kleinfelder updated the City's existing integrated 1D-2D model in the flood location area to include the following:

- Smaller subcatchments with improved delineations, routing, and input land cover parameters (impervious %, infiltration parameters based on soil data, etc.)
- Precipitation data for validating observed flooding
- Additional, finer resolution, 2D mesh representing the ground surface topography including a 2D directional mesh to model the Cranberry Brook open channel
- Improved 1D drain pipe diameters, elevations and connectivity based on City's GIS, record review and field investigations

After updating the city-wide model, Kleinfelder extracted sub-models for each of the flood location areas to allow for model simulations of the individual areas with lower computational burden. The boundaries of the sub-models were chosen such that all catchment area upstream of the flood locations was represented and any downstream tailwater impacts affecting the observed flood locations were accurately represented. The detailed sub-models allowed for more refined characterization of flood issues in each area as well as assessment of flood mitigation alternatives. The model updates are described in greater detail in Appendix D. Refer to Figures 13 and 14 below showing the stormwater model in the Lincoln Street area before and after model updates were performed.

Figure 13: Lincoln Street flood location before model updates.

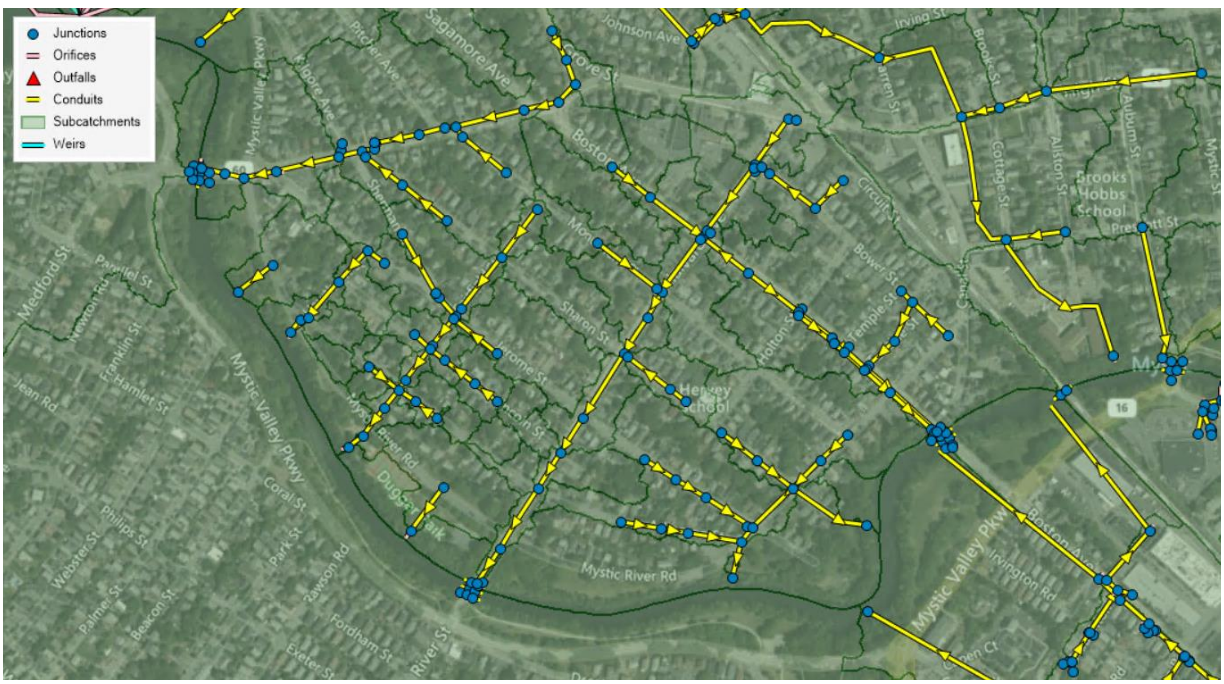

Figure 14: Lincoln Street flood location after model updates.

4.2 MODEL VALIDATION

Kleinfelder validated the updated model by running simulations of the existing infrastructure conditions with input rain gauge data from periods when flooding was observed (August 19, 2021 and September 1-2, 2021). Kleinfelder obtained data from several rain gauge locations used in the previous South Medford study and assigned rainfall for each subcatchment to the closest rain gauge location. Kleinfelder compared the rain gauge data to NOAA Atlas 14 Partial Duration Series (PDS)-based depth-duration-frequency (DDF) curves for the Medford area (Figure 15). The highest intensity interval of the August 19, 2021 storm corresponds to approximately a 10-year, 3-hour storm, while the highest intensity interval of the September 1-2, 2021 event corresponds to approximately a 5-year, 12-hour storm. While the storm curves have some variation throughout the different rain gauge locations, generally the curves are similar for the same storm event.

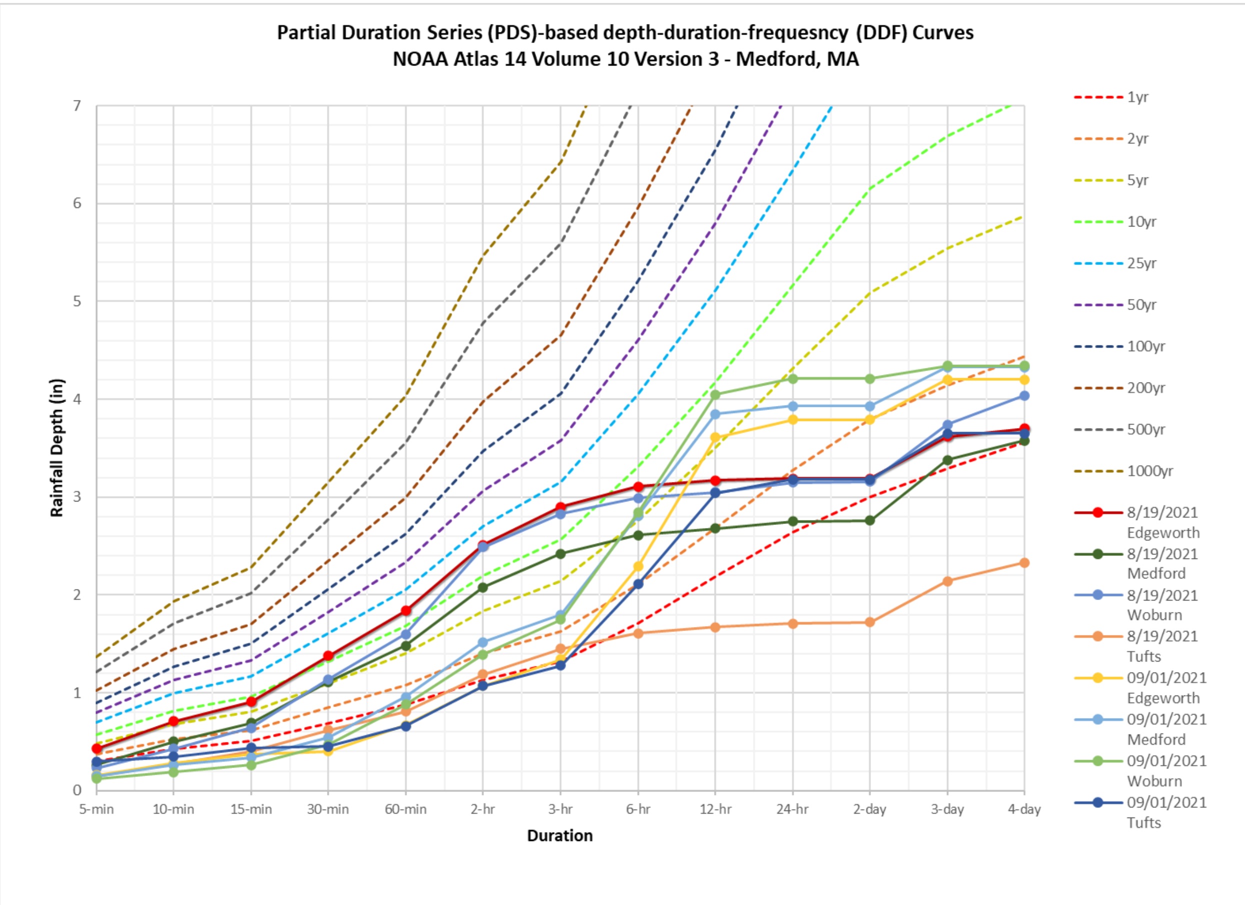

Figure 15: Rain gauge data compared to NOAA Atlas 14 partial duration series (PDS)-based depth-duration-frequency (DDF) curves for the Medford, MA

Refer to Figures 16-19 below comparing modeled flood depths to observed flooding at each location. Modeled flooding matches the observed flooding providing a validation of the updated model.

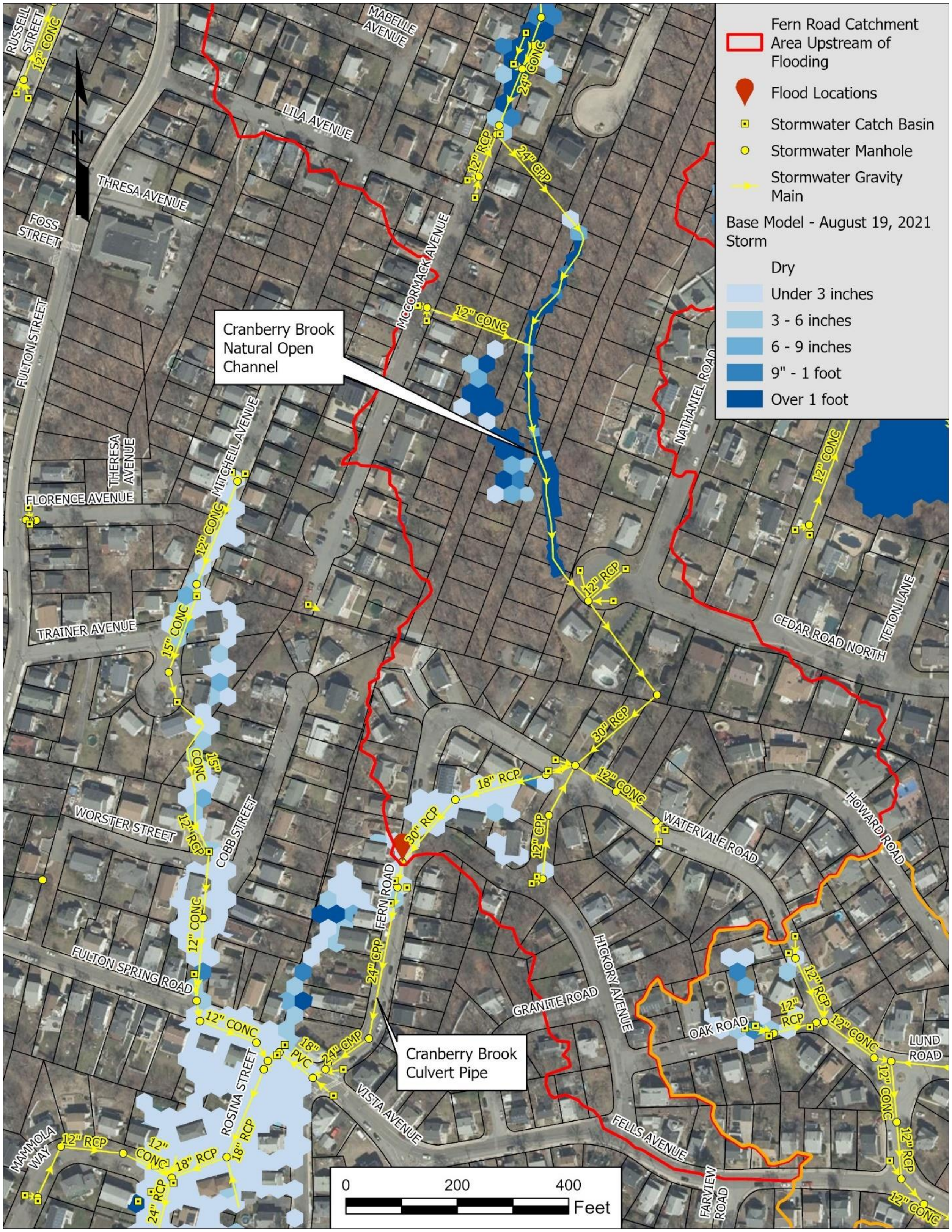

Figure 16: Fern Road modeled flood depths compared to observed flood locations for August 19, 2021 storm

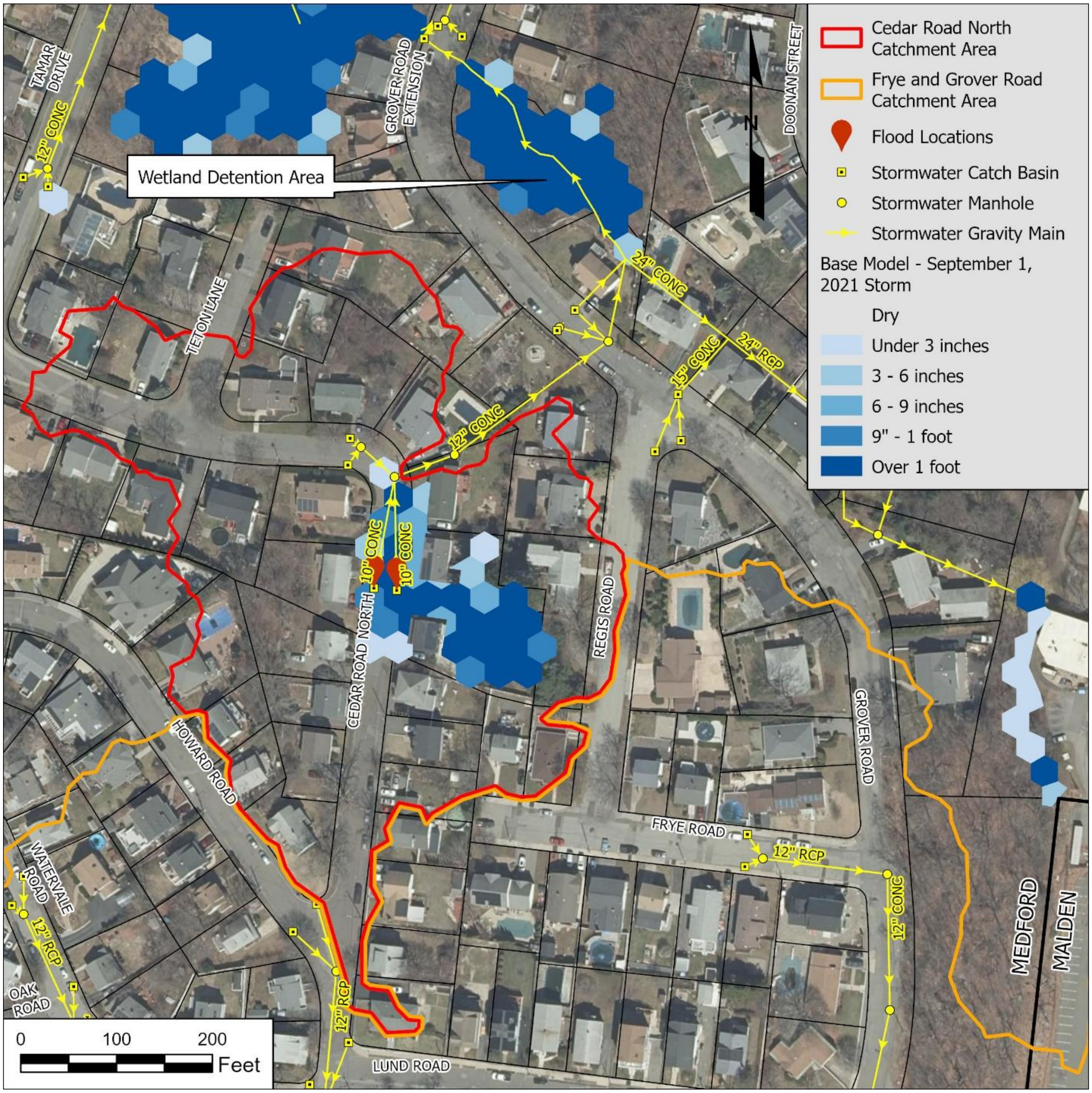

Figure 17: Cedar Road North modeled flood depths compared to observed flood locations for September 1, 2021 storm

Figure 18: Lincoln Street modeled flood depths compared to observed flood locations for August 19, 2021 storm

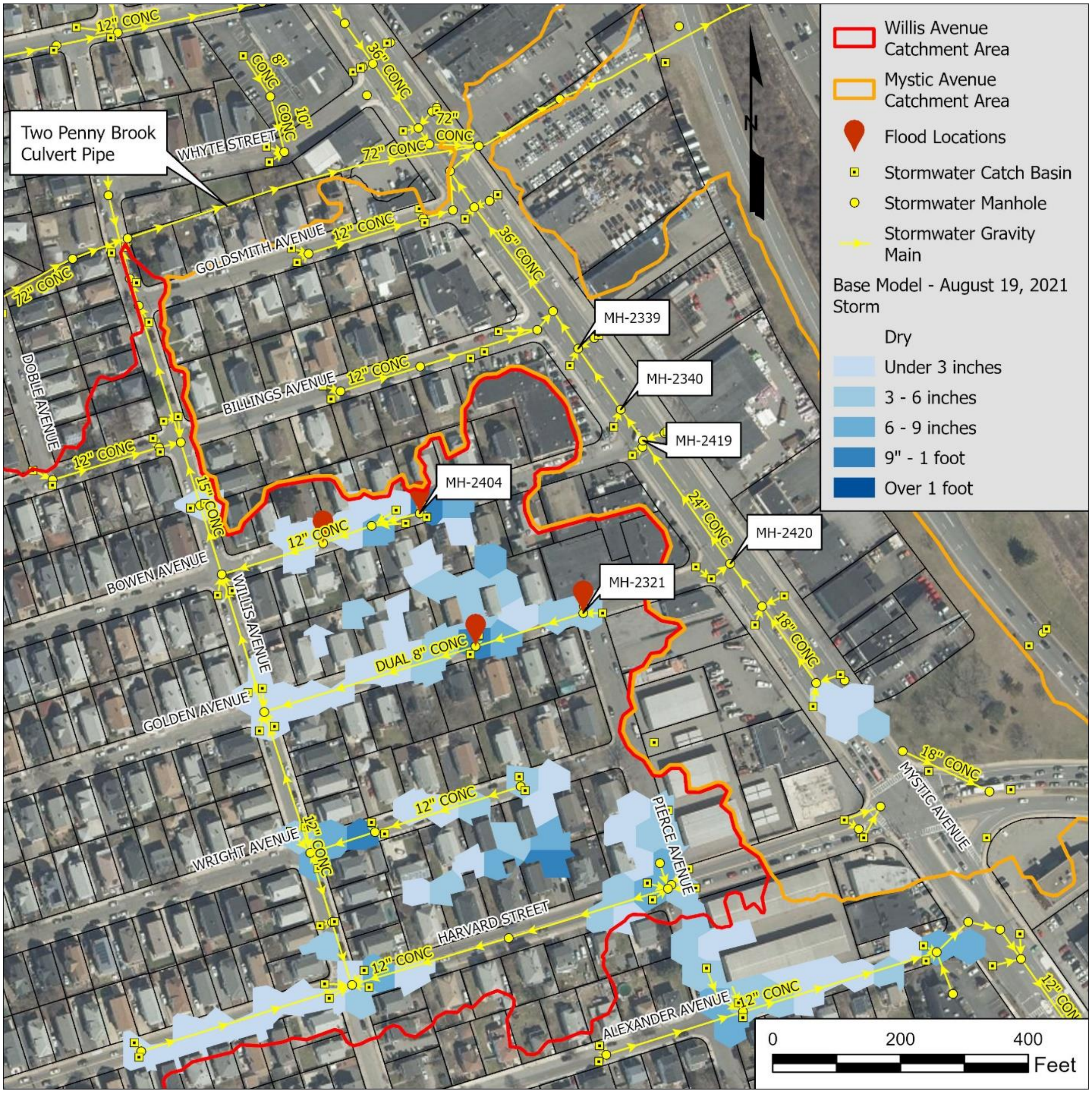

Figure 19: Bowen and Golden Avenues modeled flood depths compared to observed flood locations for August 19, 2021 storm

5 HYDRAULIC EVALUATION, ALTERNATIVES ASSESSMENT, AND RECOMMENDATIONS

In each flood area, Kleinfelder modeled the performance of the existing drainage infrastructure for the validation storm events and for a 10-year, 24-hour storm. Kleinfelder then examined the modeled depth, velocity, and hydraulic grade of flow in the pipes as well as the depth of surface flooding at and near each flood location during and after each simulated rain event. Kleinfelder analyzed this information to identify hydraulic issues in the existing drainage system. Kleinfelder evaluated three design alternatives to address the identified hydraulic issues and mitigate flooding at each location. Kleinfelder iteratively evaluated variations of each alternative (for example, using different pipe diameters, slopes, or elevations) to refine the alternatives. Table 1 summarizes the minimum pipe slopes used for proposed pipes in evaluated alternatives. Note that some of the proposed pipes in evaluated alternatives use slopes higher than the minimum slopes when judged to be appropriate. For some of the flood locations, Kleinfelder determined that designing alternatives to mitigate flooding for the 10-year, 24-hour, present day design storm is more realistically feasible than designing for the 10-year, 24-hour, 2070 storm. Kleinfelder used an SCS Type III storm distribution with rainfall depths summarized at 1-hour time intervals matching previous modeling efforts City-wide and in South Medford. Kleinfelder recommends that the City consider evaluating the flood mitigation effectiveness of alternatives for different storm frequencies, durations and/or distributions in future design phases.

Kleinfelder evaluated the design alternatives based on the following criteria and weighting:

- Effectiveness at mitigating flooding (35% weighting)
- Cost (35% weighting)
- Constructability (15% weighting)
- Ability to incorporate green infrastructure (15% weighting)

Kleinfelder developed a preliminary opinion of probable cost for each alternative including costs for construction, engineering design, engineering services during construction and construction contingency. Refer to Appendix E for the detailed preliminary opinion of probable cost for each alternative. Design alternatives were rated on a scale of 1 (least desirable) to 5 (most desirable) in each criterion according to the performance standards described in Table 2 below. The scoring of design alternatives and criteria weighting was used to calculate an overall score for each alternative and determine the recommended alternative for location.

Table 1: Minimum drain pipe slopes by diameter

Diameter (inches)	Slope (ft/ft)
10	0.0056
12	0.0044
15	0.0032
18	0.0026
21	0.0021
24	0.0017
27	0.0015
30	0.0013
33	0.0011
36	0.001

Table 2: Performance rating by criterion

Rating	Effectiveness (35%)	Cost (35%)	Constructability (15%)	Green Infrastructure (15%)
1	Minimal mitigation of flooding at identified location for 10-year, 24-hour, present day design storm	More than twice middle-cost alternative	Significant constructability challenges	No green infrastructure
2	Moderate mitigation of flooding at identified location for 10-year, 24-hour, present day design storm	Greater than the middle cost alternative	Greater than typical constructability challenges	Minor use of green infrastructure
3	Minimal or no flooding at identified location for 10-year, 24-hour, present day design storm	Middle cost alternative or within 10% of middle cost alternative	Typical constructability challenges	Combines green & grey infrastructure
4	Minimal or no flooding at identified location for 10-year, 24-hour, 2030 design storm	Less than middle cost alternative	Less than typical constructability challenges	Substantial use of green infrastructure
5	Minimal or no flooding at identified location for 10-year, 24-hour, 2070 design storm	Less than half middle-cost alternative	Minimal constructability challenges	Primarily green infrastructure solution

5.1 FERN ROAD

5.1.1 Fern Road Hydraulic Evaluation

Model simulations of the August 19, 2021 storm show overflowing at two locations directly upstream of reductions in the Cranberry Brook culvert pipe diameter. The simulated hydraulic grade rises to the ground surface level at the manholes directly upstream of both pipe diameter reductions, resulting in flooding (Figure 20). Modeling analysis indicates that the existing reductions in the culvert pipe diameter and a change pipe slope (from steep to shallow) at the shallow depth manholes near 146 Fern Road result in elevated hydraulic grades and stormwater overflows at the manholes upstream of the reductions in the culvert pipe diameter. The catchment area upstream of the flood locations contains some steep sloped topography which also contributes to higher peak flows in this area of the storm drain system.

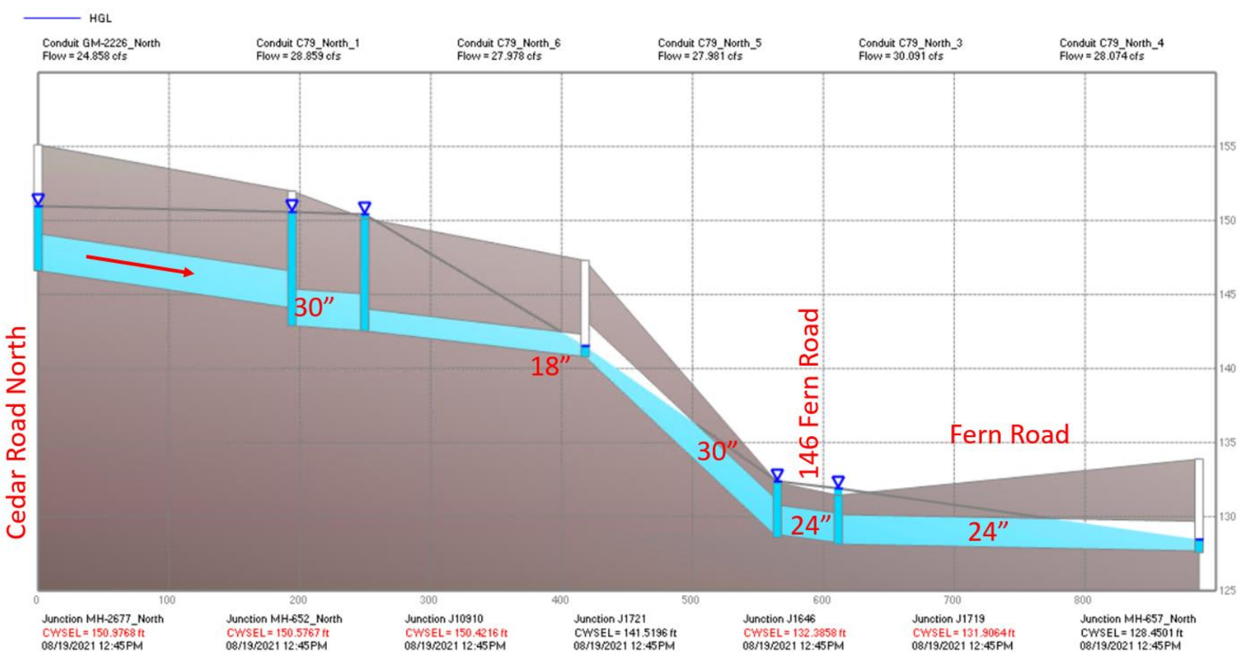

Figure 20: Simulated peak hydraulic grades along Cranberry Brook culvert pipe for August 19, 2021 storm

Kleinfelder modeled the performance of the existing drainage infrastructure for a 10-year, 24-hour storm, present day, design storm. Figure 21 shows the modeled extent and depth of flooding under this existing infrastructure scenario.

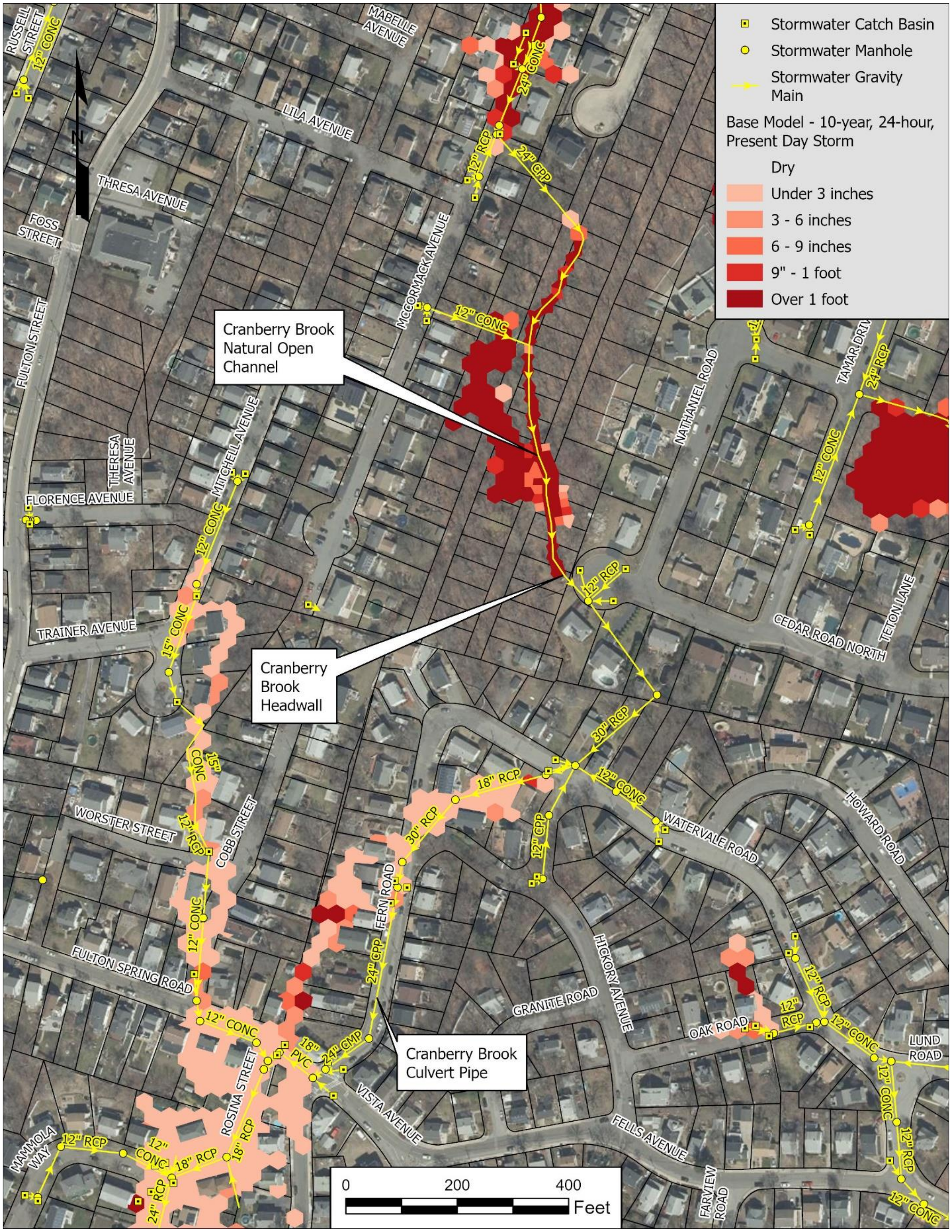

Figure 21: Fern Road existing infrastructure flooding for 10-year, 24-hour, present day storm

5.1.2 Fern Road Alternatives

Kleinfelder evaluated the following three alternatives to mitigate localized flooding at the Fern Road location:

- Alternative 1 - Increase the Cranberry Brook culvert pipe diameter at the two existing pipe size reductions
- Alternative 2 - Modify the existing Cranberry Brook headwall structure to utilize natural upstream storage in the undeveloped, open channel, portion of Cranberry Brook
- Alternative 3 - Modify the existing Cranberry Brook headwall structure and construct upstream stormwater wetland storage in the undeveloped, open channel, portion of Cranberry Brook.

Refer to Figure 22 for a map showing the evaluated alternatives. Kleinfelder evaluated each of these alternatives individually, however; the three alternatives are not mutually exclusive and multiple alternatives could be implemented in phases. For example, the modification of the existing Cranberry Brook headwall structure (Alternative 2) could be implemented first to provide some flood mitigation benefit and then the constructed stormwater wetland storage (Alternative 3) could be implemented as a separate project at a later date to provide additional flood mitigation benefits. The City noted that shallow subsurface ledge (bedrock) may be present in this area which informed the assumptions used to estimate rock excavation costs for these alternatives.

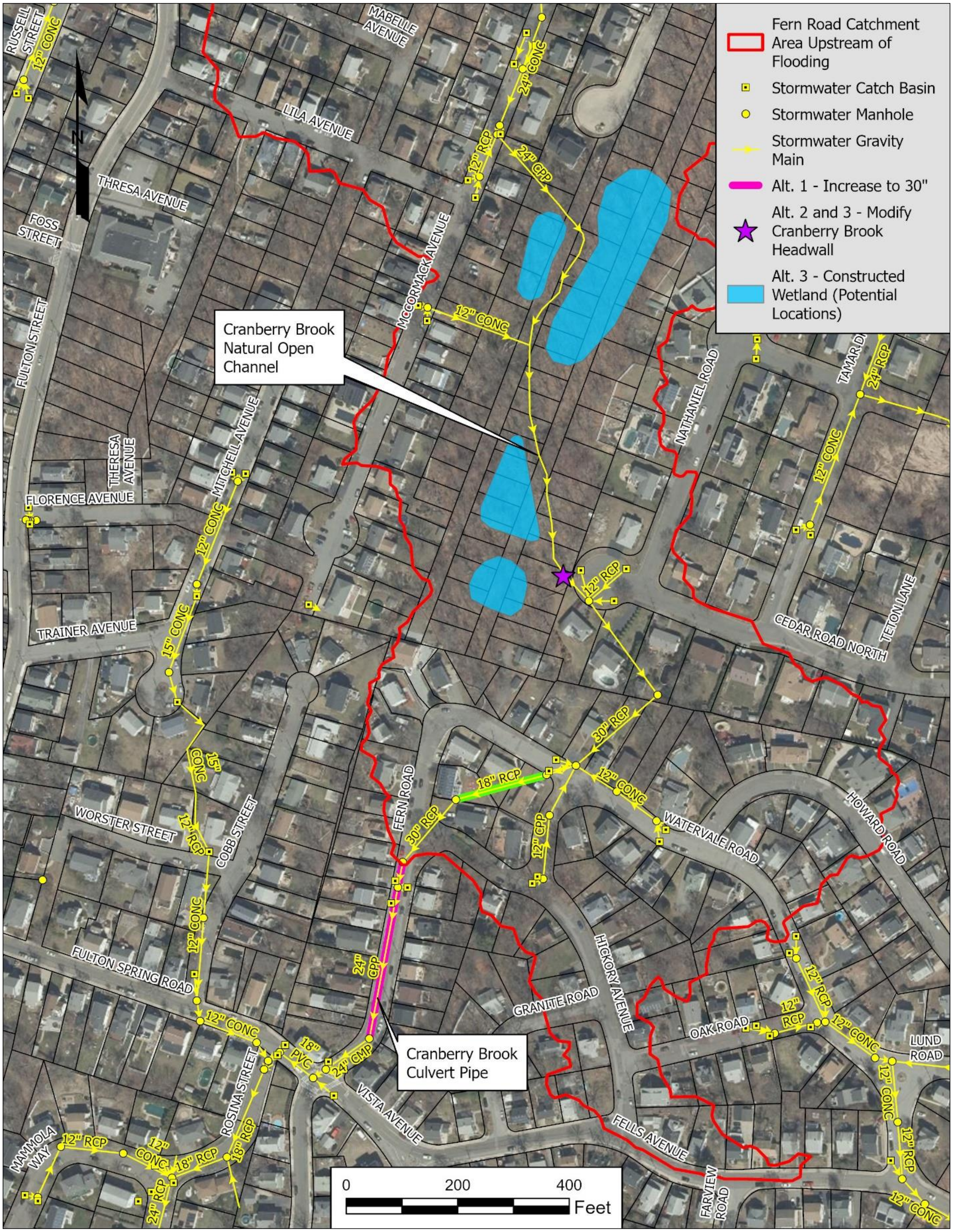

Figure 22: Fern Road Alternatives 1, 2 and 3

5.1.2.1 Alternative 1 - Increase the Cranberry Brook culvert pipe diameter at the two existing pipe size reductions

Alternative 1 involves increasing the Cranberry Brook culvert pipe diameter at the two existing pipe size reductions (18-inch and 24-inch). The existing 18-inch pipe travels through a private property easement. The portion of Fern Road with 24-inch pipe is narrow with parking on both sides of the road and other parallel utilities in the roadway which affects the cost and constructability of the alternative. Additionally, the existing 24-inch pipe has limited cover at the shallow manholes in Fern Road and the cover would be further reduced to approximately 1 foot with a 30-inch pipe.

Increasing the existing 18-inch pipe to 24-inch mitigates simulated stormwater overflow at the manhole just upstream of the flood location in the vicinity of 3 Hickory Avenue but only partially mitigates the stormwater overflow at the observed flood location near 146 Fern Road. The existing 18-inch pipe is beneficial to some degree as it raises the upstream hydraulic grade and increases upstream storage of stormwater in the undeveloped area of Cranberry Brook. Increasing the size of the existing 18-inch pipe mitigates stormwater overflows upstream by lowering the hydraulic grade but increases the amount of stormwater conveyed downstream resulting in some flooding remaining even with the increase in size of downstream Fern Road pipe. Refer to Figure 23 for a comparison of modeled flood depths in the baseline existing infrastructure scenario (red) and after implementation of Alternative 1 (blue) for the 10-year, 24-hour, present day storm. The figure shows that upstream stormwater storage and flooding are reduced but some downstream flooding at the observed flood location remains.

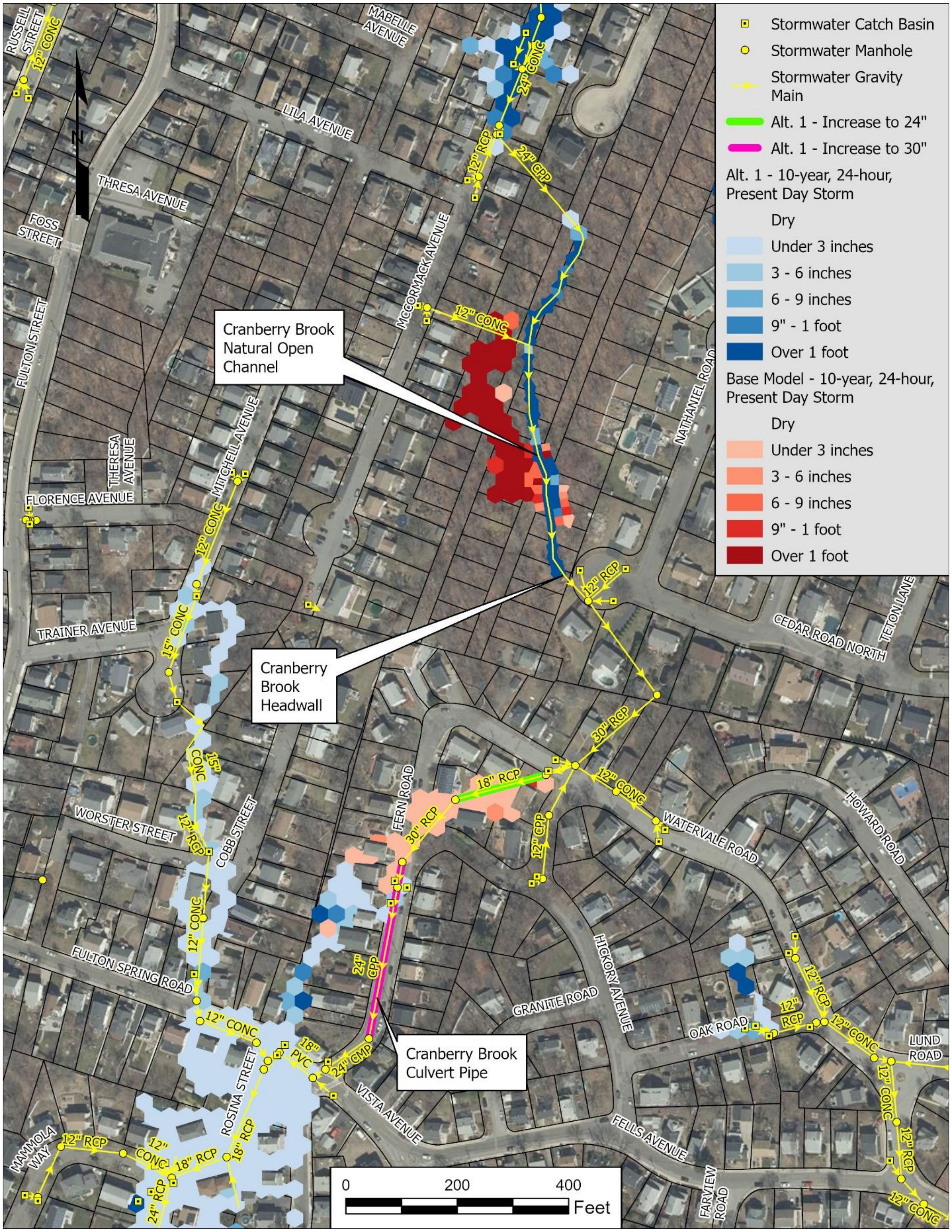

Figure 23: Fern Road Alternative 1 flood mitigation for 10-year, 24-hour, present day storm

Kleinfelder's preliminary opinion of probable cost for this alternative is $522,700 for construction costs and $287,500 for engineering design, engineering services during construction and construction contingency for a total project cost of $810,200. The construction cost estimate includes the cost of construction staging and mobilization, 170 LF of 24-inch RCP, 330 LF of 30-inch RCP, 48-inch precast drain manholes, utility support and coordination, paving, rock excavation, and traffic management. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.1.2.2 Alternative 2 – Modify the existing Cranberry Brook headwall structure

Upstream of the observed flood location on Fern Road is an undeveloped area including the open channel portion of Cranberry Brook. Most of this undeveloped area is City-owned property. The bottom of the open channel portion of Cranberry Brook is approximately elevation 149. The ground surface elevation is approximately 154-156 at the back of five properties (address numbers 83-95) on McCormack Avenue that abut the undeveloped area around the Cranberry Brook open channel. Additionally, there is a portion of McCormack Avenue where the ground surface elevation is approximately 155-156 in the vicinity of address numbers 17-42. The approximate 5 feet difference in elevation between the bottom of the Cranberry Brook open channel and low points on adjacent properties represents potential stormwater storage depth and volume that can be utilized before flooding encroaches on adjacent properties.

Alternative 2 involves modifying the Cranberry Brook headwall with a weir and orifices to utilize the natural storage within the undeveloped, open channel, portion of Cranberry Brook and reduce the peak flow in the downstream culvert pipe portion. Orifices sized smaller than the 30-inch diameter Cranberry Brook culvert pipe create a hydraulic restriction which raises the hydraulic grade elevation upstream in the Cranberry Brook open channel. During large storm events, the weir provides an overflow to ensure that the hydraulic grade upstream is not raised too high to cause flooding on adjacent properties, at least to a level that would not have occurred under the existing infrastructure conditions. Kleinfelder iteratively simulated variations of this alternative and developed a preliminary design consisting of two 12-inch orifices at offset heights and a 5 feet wide weir with a weir crest elevation of 153.75. This design balanced the raising of the hydraulic grade upstream to utilize natural storage and mitigation of flooding downstream while also minimizing flooding on properties adjacent to the Cranberry Brook open channel for the 10-year, 24-hour, present day storm (Figure 24). This design could be further refined and evaluated as necessary in a future design phase. For example, the weir could be designed as stop logs or a weir gate to allow for a range of operating weir elevations. Similarly the orifices could be designed as removable plates to allow for a range of orifice opening sizes.

Alternative 2 provides a green infrastructure benefit by increasing the volume of stormwater that is stored in the undeveloped area upstream of the headwall and infiltrated to groundwater as opposed to being conveyed through the drainage system. The soils in this area are classified as hydrologic soil group A which is favorable for infiltration of stormwater. Implementation of Alternative 2 would require environmental permitting.

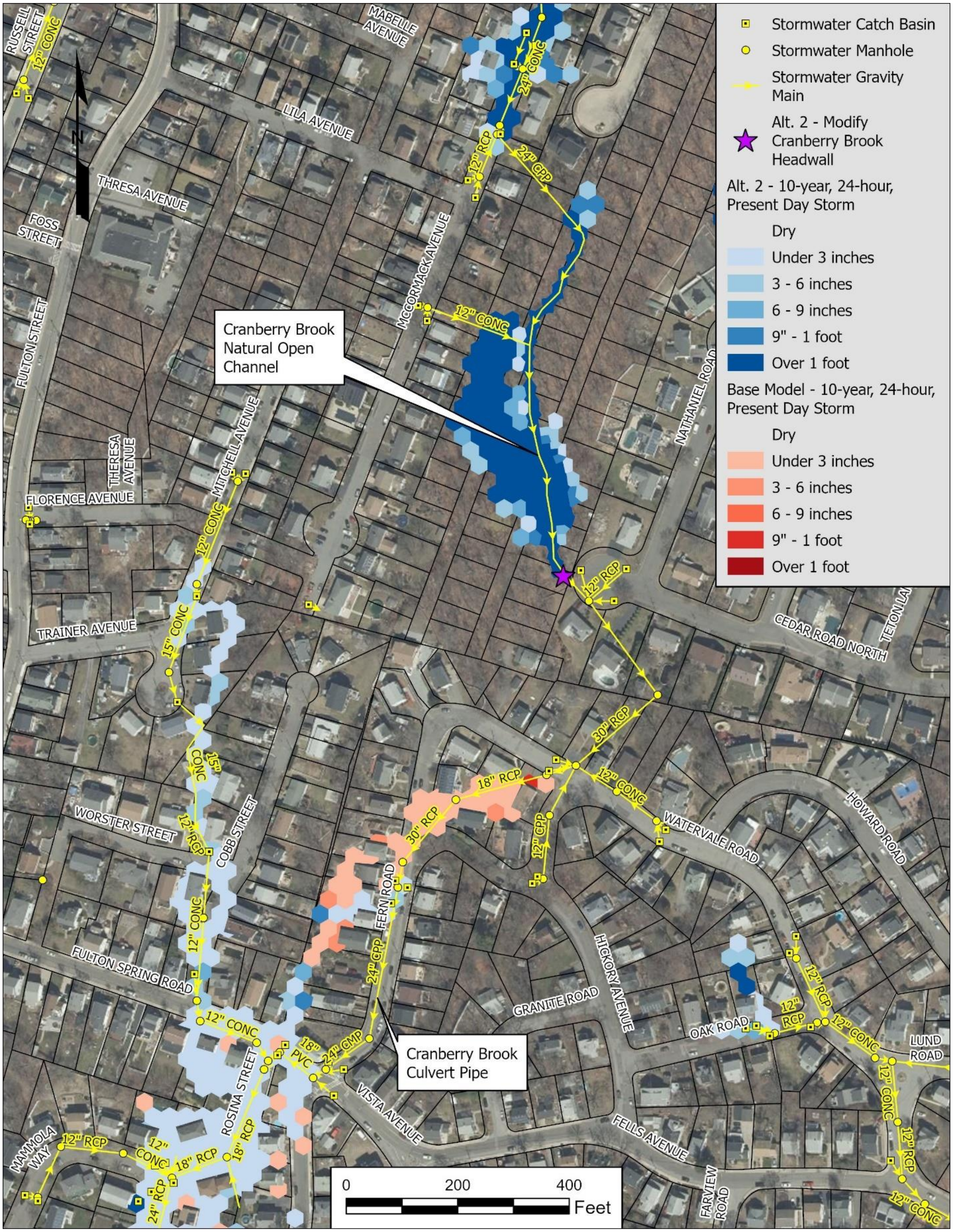

Figure 24: Fern Road Alternative 2 flood mitigation for 10-year, 24-hour, present day storm

Kleinfelder's preliminary opinion of probable cost for this alternative is $196,900 for construction costs and $197,000 for engineering design, engineering services during construction and construction contingency for a total project cost of $393,900. The construction cost estimate includes the cost of construction staging and mobilization, topographic survey, modifications to the headwall, flow management and bypass, clearing and grubbing, invasive species management, tree and stump removal, excavation, grading, soil removal and disposal, and rock excavation. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.1.2.3 Alternative 3 - Modify the existing Cranberry Brook headwall structure and construct upstream stormwater wetland storage

Alternative 3 involves the same modifications to the Cranberry Brook headwall included in Alternative 2 combined with the construction of upstream stormwater wetland storage in the undeveloped area around the Cranberry Brook open channel. Alternative 3 involves excavation and removal of existing soils to create areas where the ground surface elevation is below the Cranberry Brook headwall weir elevation resulting in these areas being filled with stormwater during rain events. Implementation of Alternative 3 would require detailed topographic survey and design to optimize the siting and grading of the constructed wetland area and ensure ground surface slopes remain adequate to meet the elevations of the surrounding developed area. Kleinfelder modeled Alternative 3 by lowering the existing ground surface elevation to 150 for approximately 1 acre of area adjacent to the Cranberry Brook open channel to represent cut removal of existing soil volume. This level of implementation was also used to inform the preliminary opinion of probable cost. This alternative mitigates flooding at the observed location for the 10-year, 24-hour, 2030 storm (Figure 25).

Alternative 3 provides a greater green infrastructure benefit than Alternative 2 by further increasing the volume of stormwater that is stored upstream of the headwall and infiltrated to groundwater as opposed to being conveyed through the drainage system. The soils in this area are classified as hydrologic soil group A which is favorable for infiltration of stormwater. Implementation of Alternative 3 would require a significant environmental permitting effort.

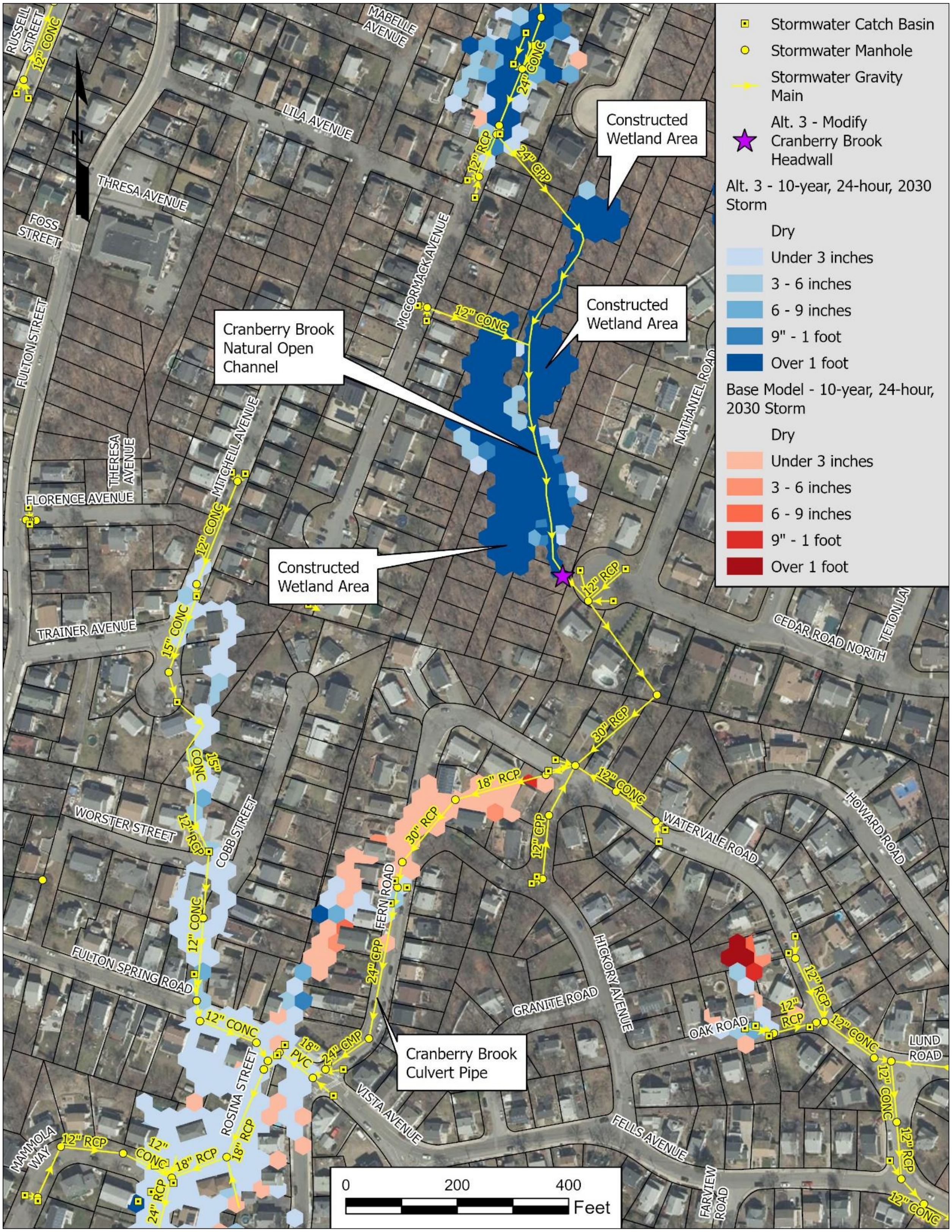

Figure 25: Fern Road Alternative 3 flood mitigation for 10-year, 24-hour, 2030 storm

Kleinfelder's preliminary opinion of probable cost for this alternative is $1,116,600 for construction costs and $614,200 for engineering design, engineering services during construction and construction contingency for a total project cost of $1,730,800. The construction cost estimate includes the cost of construction staging and mobilization, topographic survey, modifications to the headwall, flow management and bypass, clearing and grubbing, invasive species management, tree and stump removal, excavation, grading, soil removal and disposal, rock excavation and a lump sum cost for various items associated with the constructed wetland itself. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.1.3 Fern Road Alternatives Assessment

Table 3: Fern Road Alternatives Assessment and Comparison

Alternative	Effectiveness (35%)	Cost (35%)	Constructability (15%)	GI (15%)	Score
Alt. 1 - Increase pipe diameter at existing pipe size reductions	2	3	2	1	2.2
Alt. 2 - Modify Cranberry Brook headwall structure	3	5	3	3	3.7
Alt. 3 - Modify Cranberry Brook headwall structure and construct upstream stormwater wetland storage	4	1	2	5	2.8

5.1.4 Fern Road Recommendations

Kleinfelder recommends Alternative 2 which consists of modification of the existing Cranberry Brook headwall structure to utilize natural upstream storage in the undeveloped, open channel, portion of Cranberry Brook. Alternative 2 mostly eliminates flooding at the observed location for the 10-year, present day storm and can be implemented at a significantly lower cost than Alternatives 1 and 3. Kleinfelder recommends further evaluation of the orifice and weir design associated with this alternative in a future design phase. As noted previously, the three alternatives are not mutually exclusive and Alternatives 1 and 3 could also be implemented at a later date to provide additional flood mitigation benefits.

5.2 CEDAR ROAD NORTH

5.2.1 Cedar Road North Hydraulic Evaluation

The four catch basins between 81 and 93 Cedar North Road are hydraulically linked to a wetland detention area north of Grover Road. The wetland detention area contains an inlet to the Grover Road Easement drainage system consisting of a 24-inch pipe that travels behind 97-107 Grover Road in a cross-country easement. During large storm events, water levels in the wetland detention area exceed the rim elevations of the catch basins near 81 and 83 Cedar Road North resulting stormwater backing up through the catch basins and causing flooding in this area (Figure 26). The two lower catch basins on Cedar Road North have approximate rim elevations of 154-154.5. Model simulations of the September 1, 2021 storm show the water level in the wetland detention area exceeding elevation 155 and causing overflowing at the two lower catch basins.

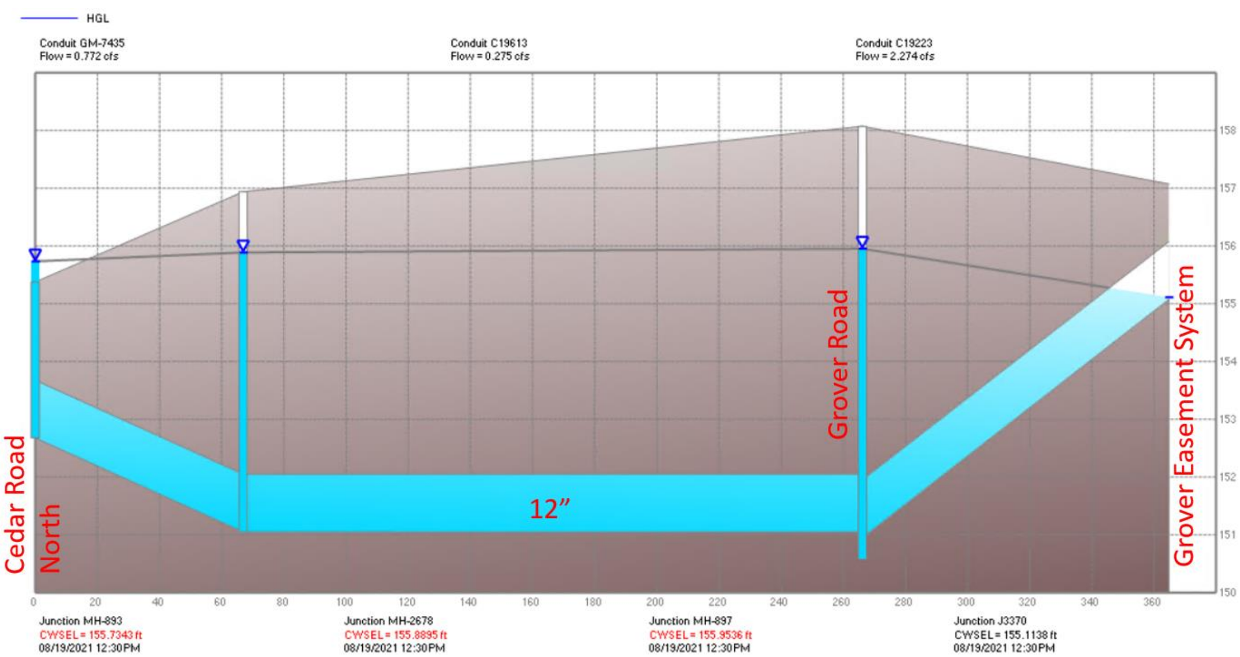

Figure 26: Simulated peak hydraulic grades along Cedar Road North pipe connection to wetland detention area and Grover Road Easement drain system for September 1, 2021 storm

Kleinfelder modeled the performance of the existing drainage infrastructure for a 10-year, 24-hour storm, 2070, design storm. Figure 27 shows the modeled extent and depth of flooding under this existing infrastructure scenario.

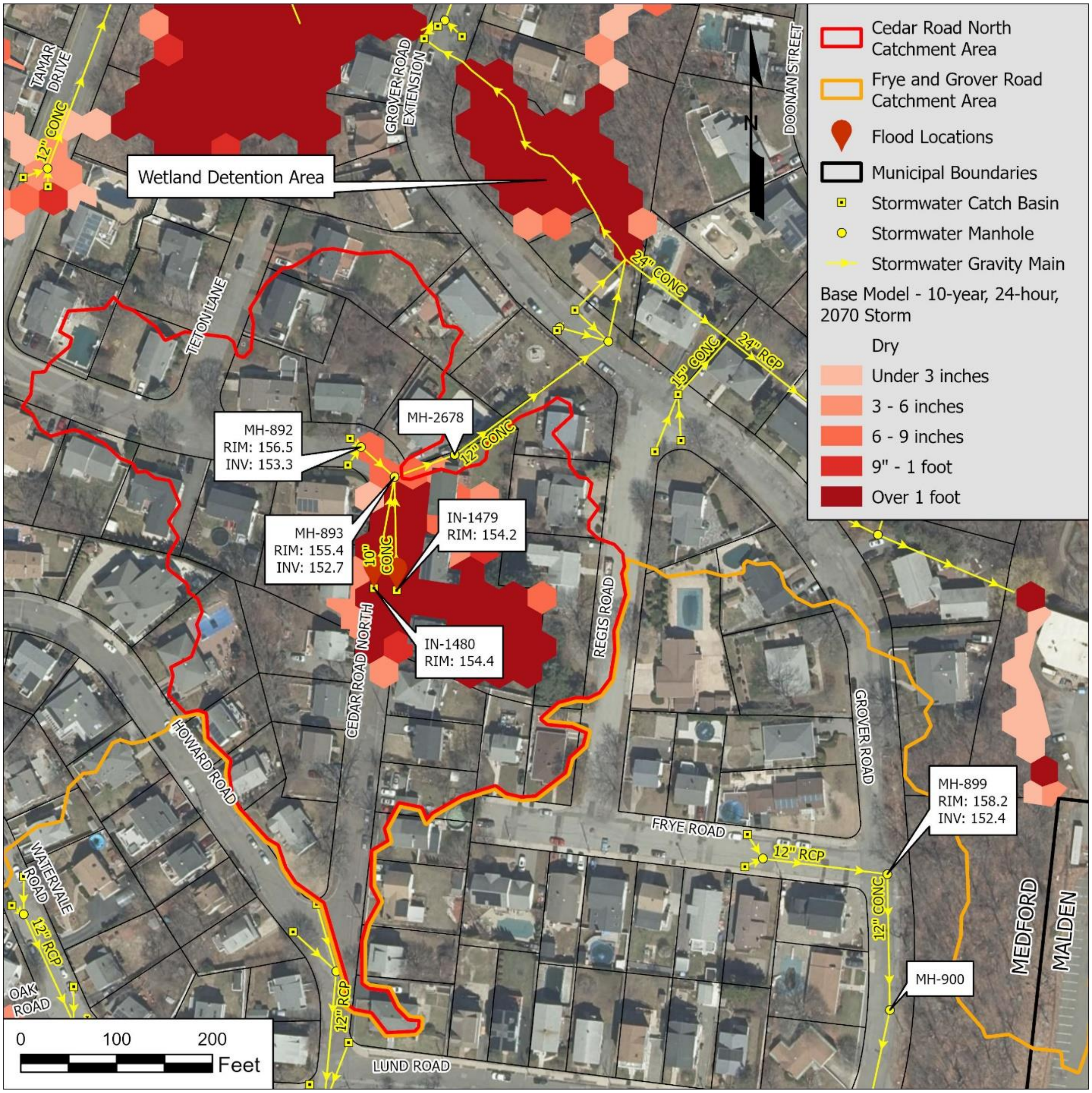

Figure 27: Cedar Road North existing infrastructure flooding for 10-year, 24-hour, 2070 storm

5.2.2 Cedar Road North Alternatives

Kleinfelder evaluated the following three alternatives to mitigate localized flooding at the Cedar Road North location:

- Alternative 1 - reroute the two lower catch basins on Cedar Road North to the existing drainage system on Grover Road through the existing sewer easement and Frye Road, retrofit two manhole covers on Cedar North Road to be pressure-tight
- Alternative 2 - reroute all four catch basins on Cedar Road North to the existing drainage system on Grover Road through the existing sewer easement and Frye Road
- Alternative 3 - reroute all four catch basins on Cedar Road North to the existing drainage system on Grover Road through Regis Road or Grover Road

Figures 28-30 detail the evaluated alternatives. These alternatives involve installation of some pipe at a reasonable depth (approximately 10 feet to invert) and replacement of some of the existing drainage on Frye Road and Grover Road to maintain minimum pipe slopes and to connect to the invert elevation of the existing drainage system downstream. These alternatives involve connecting to the existing drainage system at MH-900 where the downstream drain pipe is steeply sloped following the existing roadway grade. For alternatives 2 and 3, the existing connection to the wetland detention area would be cut and capped at the start of the reroute to sever the hydraulic link to the wetland detention area. The City noted that shallow subsurface ledge (bedrock) may be present in this area which informed the assumptions used to estimate rock excavation costs for these alternatives.

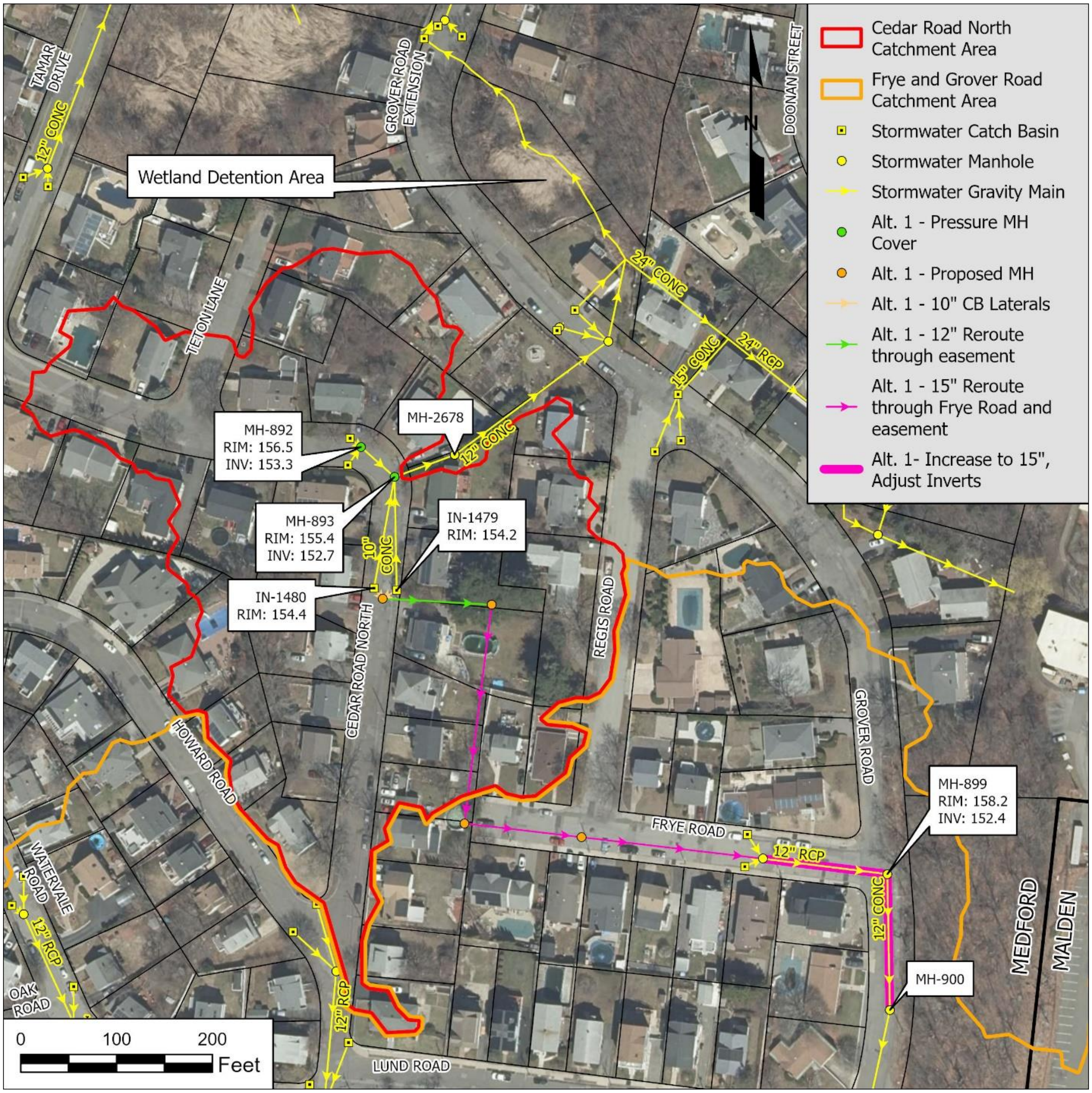

Figure 28: Cedar North Road Alternative 1

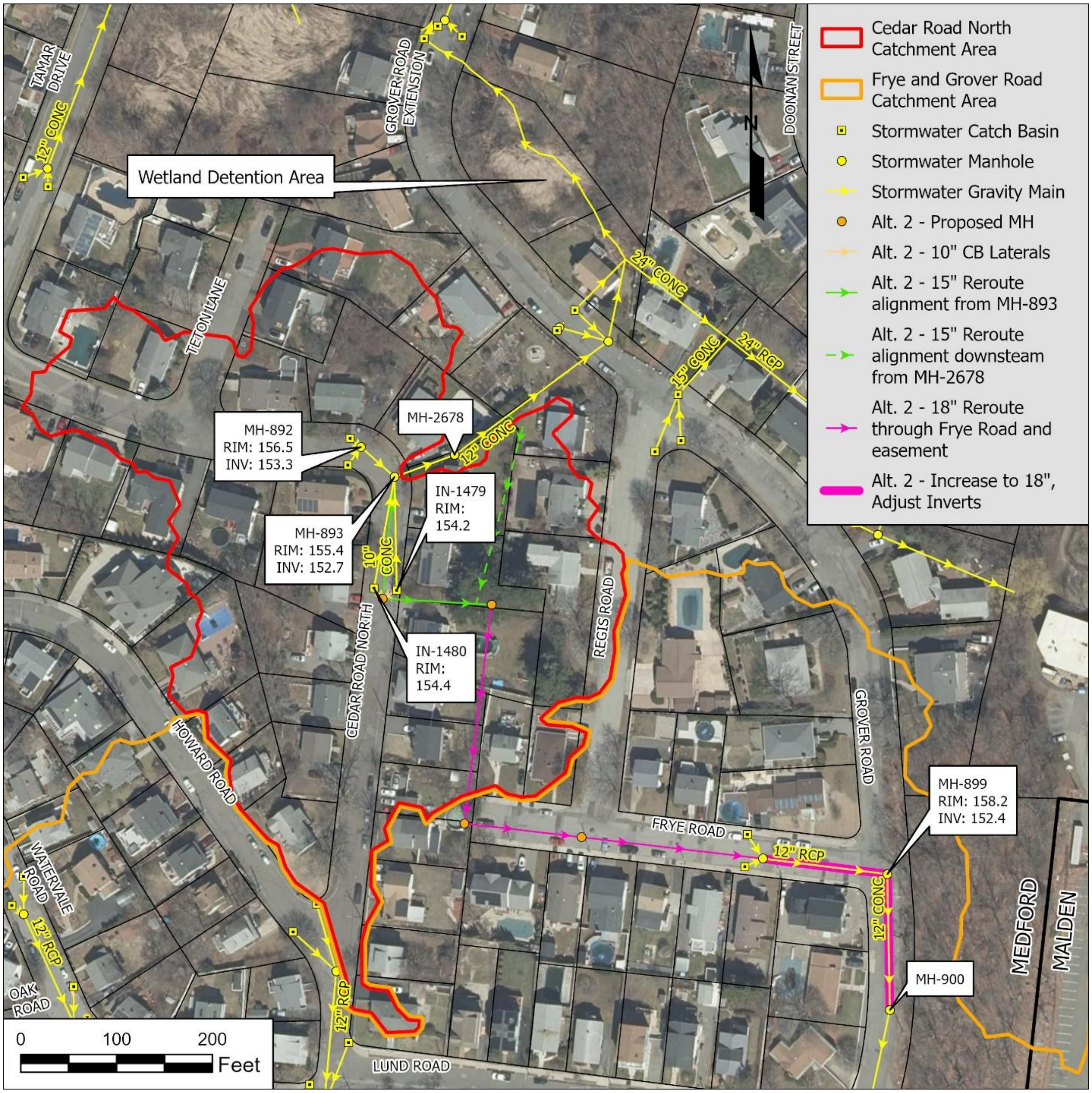

Figure 29: Cedar North Road Alternative 2

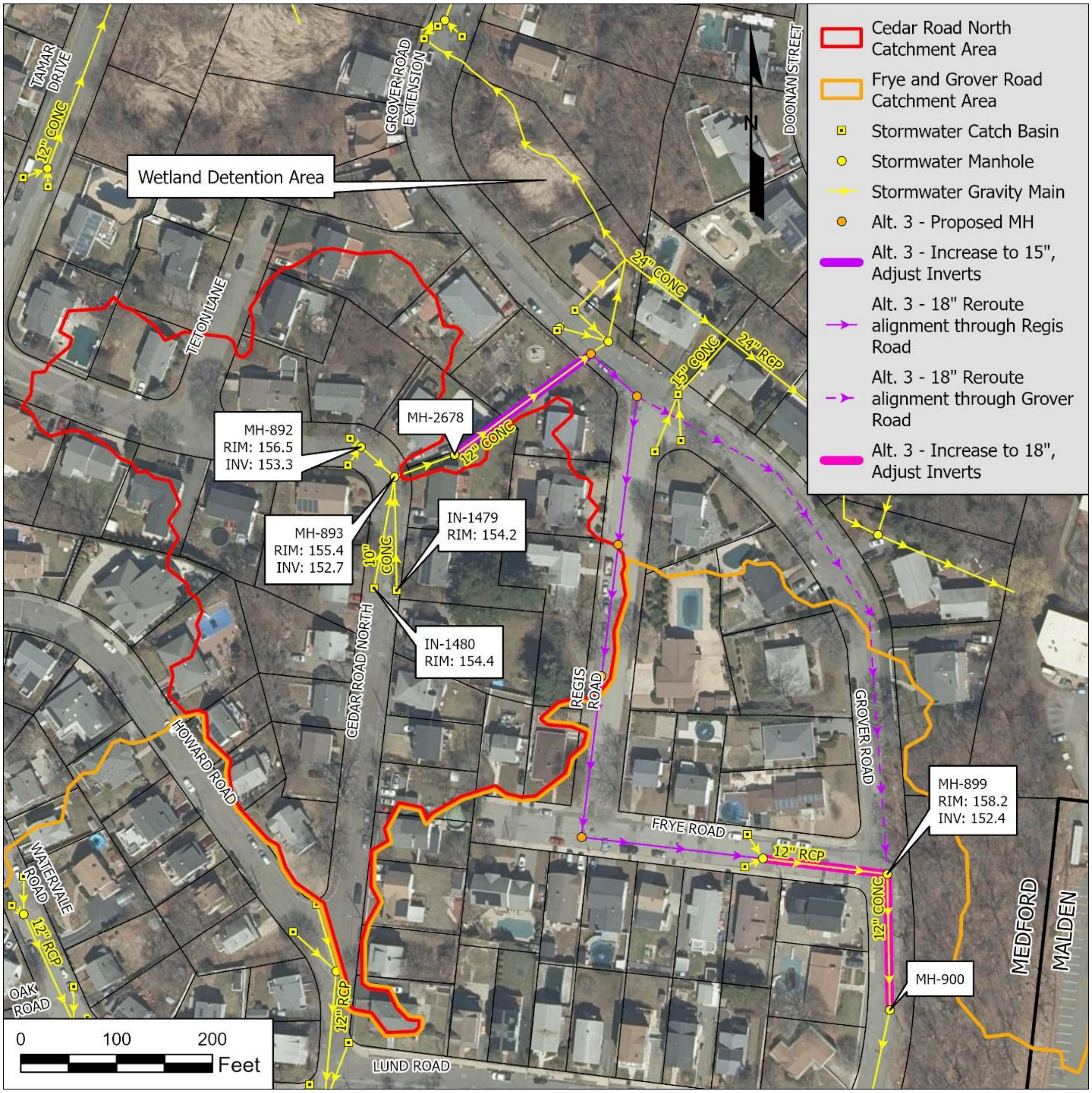

Figure 30: Cedar North Road Alternative 3

5.2.2.1 Alternative 1 - Reroute the two lower catch basins on Cedar Road North to the existing drainage system on Grover Road through the existing sewer easement and Frye Road, retrofit two manhole covers on Cedar North Road to be pressure-tight

The two lower catch basins on Cedar Road North have approximate rim elevations of 154-154.5. The two higher catch basins on Cedar Road North have approximate rim elevations of 157. Manholes MH-892 and MH-893 which connect the catch basins to the wetland detention area have rim elevations of approximately 156.5 and 155.4, respectively. Rerouting the two lower catch basins on Cedar North Road would raise the lowest rim elevation connected to the wetland detention area to 155.4 at MH-893. While this provides some additional flood mitigation for smaller storms, large storm events can still exceed the MH-893 rim elevation of 155.4 causing a similar extent of flooding in this area. To address this, the two manholes MH-892 and MH-893 could be retrofitted with pressure-tight manhole covers to prevent stormwater overflows at these manholes and further raise the lowest potential overflow elevation connected to the wetland detention area to 157 at the rim elevations of the higher catch basins. Combining rerouting of the two lower catch basins with 120 LF of 12-inch pipe and 820 LF of 15-inch pipe, with retrofitting of the two manholes with pressure-tight manhole covers, mostly eliminates flooding for the 10-year, 24-hour, 2070 scenario (Figure 31). This alternative eliminates flooding for the 10-year, 24-hour, 2030 storm scenario. Rerouting through the existing sewer easement reduces costs by reducing the required length and depth of pipe, paving and traffic management but has other constructability challenges associated with performing work through private developed.

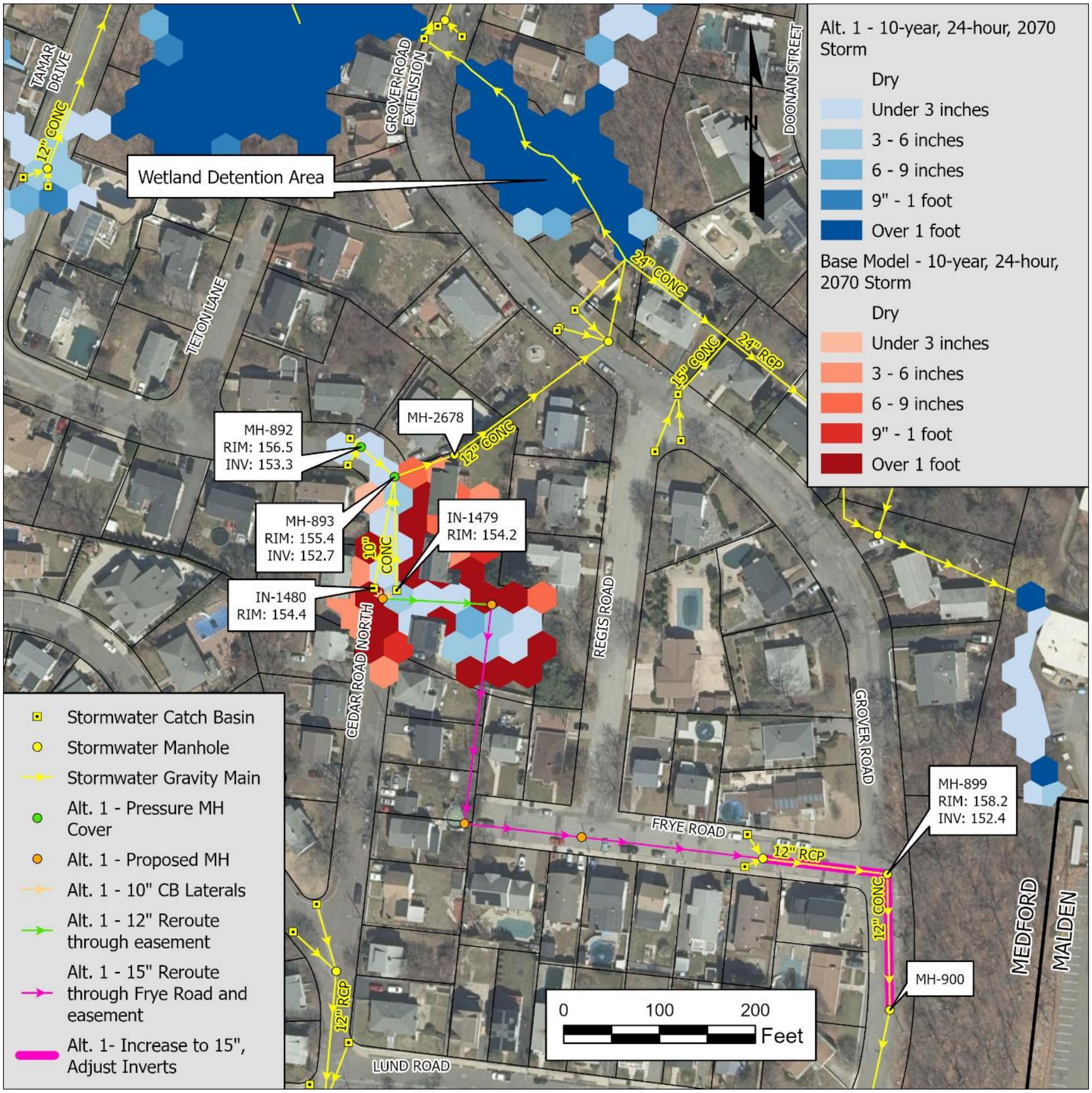

Figure 31: Cedar Road North Alternative 1 flood mitigation for 10-year, 24-hour, 2070 storm

Kleinfelder's preliminary opinion of probable cost for connection to the existing Frye Road drainage system via the existing easement is $532,000 for construction costs and $292,600 for engineering design, engineering services during construction and construction contingency for a total project cost of $824,600. The construction cost estimate includes the cost of construction staging and mobilization, 120 LF of 12-inch RCP drain pipe, 820 LF of 15-inch RCP drain pipe, 48-inch precast drain manholes, tree and stump removal, utility support and coordination, paving, rock excavation, and traffic management. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.2.2.2 Alternative 2 - Reroute all four catch basins on Cedar Road North to the existing drainage system on Grover Road through the existing sewer easement and Frye Road

The reroute alignment for this alternative could start from MH-893 or could start downstream of MH-2678 where the existing drain crosses a different portion of the existing sewer easement. The reroute alignment starting from MH-893 requires slightly more paving and traffic management but is preferrable in terms of minimizing pipe depths and was used to estimate cost. Rerouting through the existing sewer easement has the noted benefits and drawbacks described for Alternative 1. This alternative eliminates flooding during the 10-year, 24-hour, 2070 design storm with 250 LF of 15-inch pipe and 820 LF of 18-inch pipe to reroute flow from the catch basins (Figure 32). Figure 33 shows the simulated peak hydraulic grades along the reroute profile for the 10-year, 24-hour, 2070 design. The proposed drain pipes at the beginning of the reroute are shallow depth to minimize the overall pipe depths along the reroute and also to cross over the existing sewer.

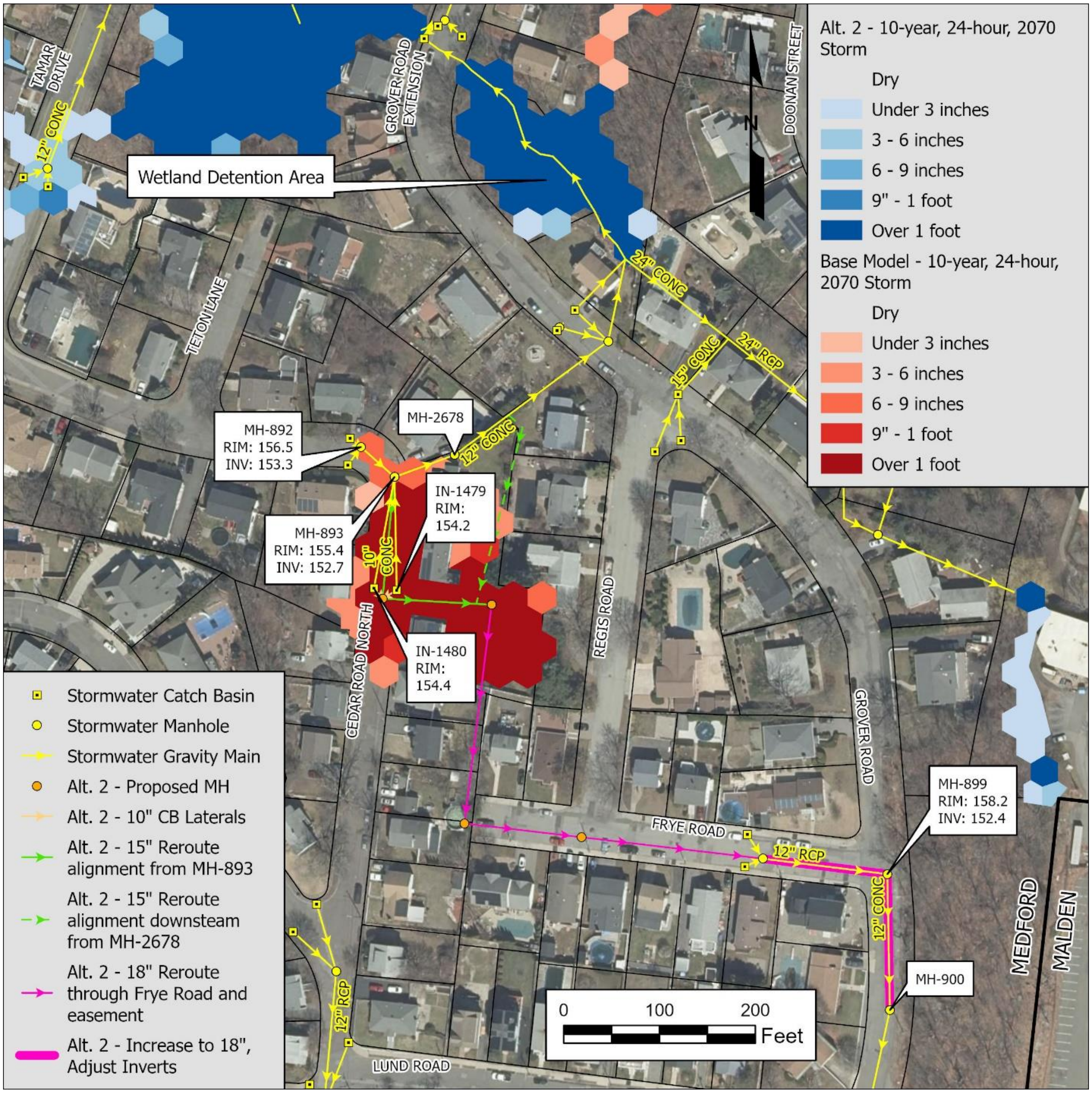

Figure 32: Cedar Road North Alternative 2 flood mitigation for 10-year, 24-hour, 2070 storm

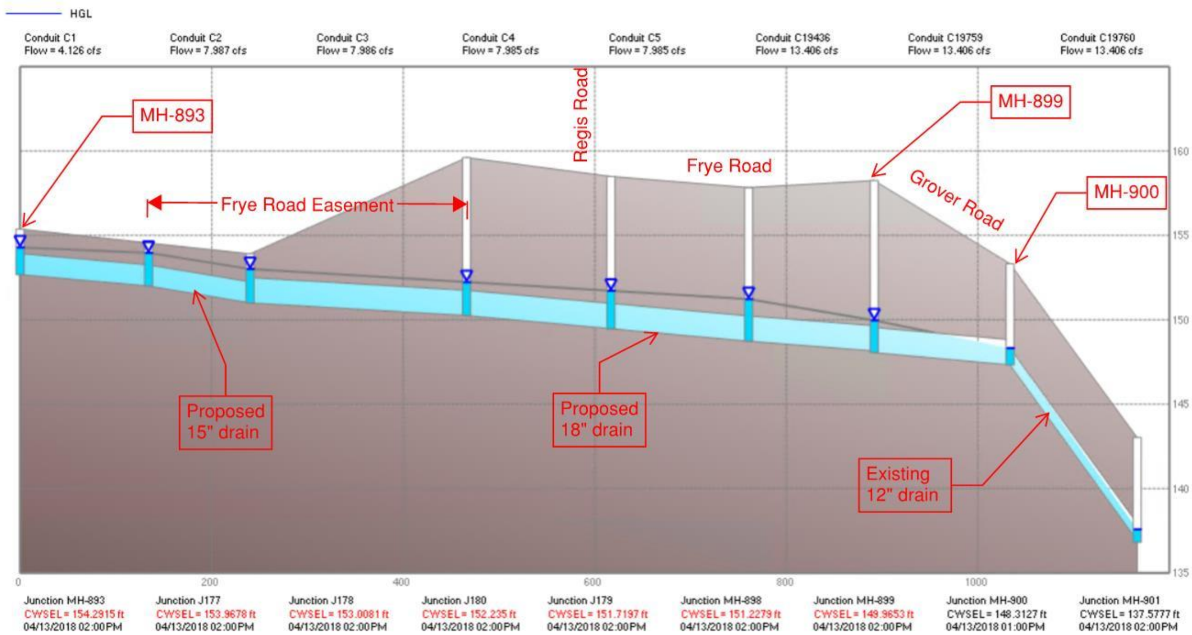

Figure 33: Simulated peak hydraulic grades along Cedar Road North reroute profile for 10-year, 24-hour, present day storm

Kleinfelder's preliminary opinion of probable cost for this alternative is $608,900 for construction costs and $334,900 for engineering design, engineering services during construction and construction contingency for a total project cost of $943,800. The construction cost estimate includes the cost of construction staging and mobilization, 250 LF of 15-inch RCP drain pipe, 820 LF of 18-inch RCP drain pipe, 48-inch precast drain manholes, tree and stump removal, utility support coordination, paving, rock excavation and traffic management. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.2.2.3 Alternative 3 - Reroute all four catch basins on Cedar Road North to the existing drainage system on Grover Road through Regis Road or Grover Road

The reroute alignment for this alternative starts just upstream of MH-897 where the invert elevation of the existing drain is approximately 150.6. The reroute alignment could follow Regis Road and Frye Road or could follow only Grover Road to the proposed downstream connection at MH-900. The Regis Road option requires slightly shallower pipe overall but also requires replacement of approximately 150 linear feet of existing drain and reconnection of two catch basins that is not required for the Grover Road only option. Both reroute alignments in this alternative require deeper pipe installation and more paving, utility coordination and traffic management compared to Alternatives 1 and 2. However, this alternative removes the constructability challenges associated with performing work through private developed properties. The Regis Road option was used to estimate the cost of this alternative. This alternative eliminates flooding during the 10-year, 24-hour, 2070 design storm with 280 LF of 15-inch pipe and 930 LF of 18-inch pipe to reroute flow from the catch basins (Figure 34).

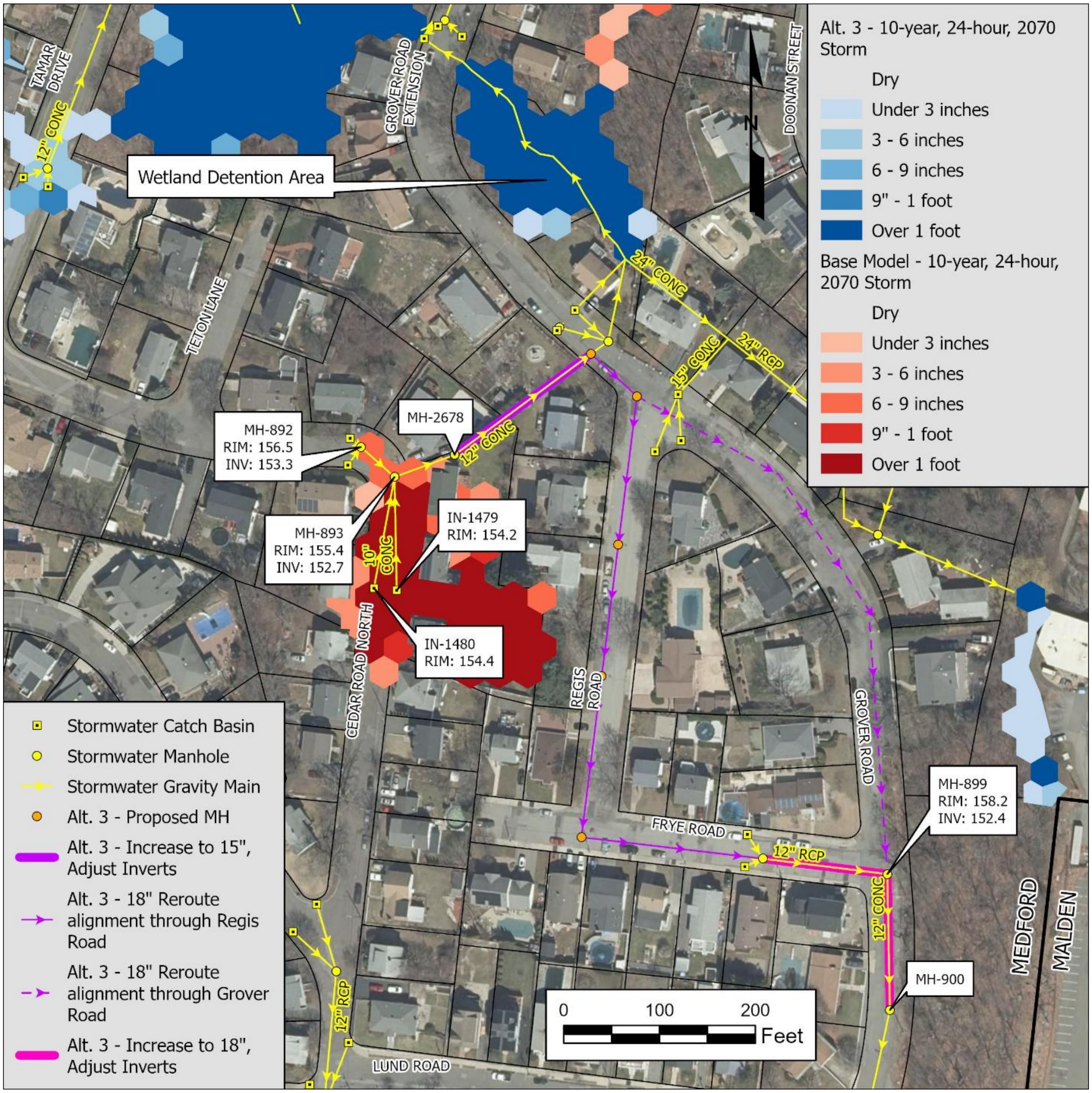

Figure 34: Cedar Road North Alternative 3 flood mitigation for 10-year, 24-hour, 2070 storm

Kleinfelder's preliminary opinion of probable cost for this alternative is $693,600 for construction costs and $381,500 for engineering design, engineering services during construction and construction contingency for a total project cost of $1,075,100. The construction cost estimate includes the cost of construction staging and mobilization, 280 LF of 15-inch RCP drain pipe, 930 LF of 18-inch RCP drain pipe, 48-inch precast drain manholes, utility support coordination, paving, rock excavation and traffic management. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.2.3 Cedar Road North Alternatives Assessment

Table 4: Cedar Road North Alternatives Assessment and Comparison

Alternative	Effectiveness (35%)	Cost (35%)	Constructability (15%)	GI (15%)	Score
Alt. 1 - Reroute two catch basins through easement and Frye Road	4	4	3	1	3.4
Alt. 2 - Reroute four catch basins through easement and Frye Road	5	3	3	1	3.4
Alt. 3 - Reroute four catch basins through Frye Road or Grover Road	5	2	3	1	3.05

5.2.4 Cedar Road North Recommendations

Kleinfelder assigned Alternatives 1 and 2 the same overall score. Alternative 1 eliminates flooding for the 10-year, 24-hour, 2030 storm event and mostly eliminates flooding for the 10-year, 24-hour, 2070 storm event. Alternative 2 eliminates flooding for the 10-year, 24-hour, 2070 storm event. Alternative 2 removes the hydraulic link to the wetland detention area as opposed to Alternative 1 which leaves the link in place resulting in some minor flooding in the 10-year, 24-hour, 2070 storm event. For this reason, Kleinfelder recommends Alternative 2 as a more robust, long term solution to the localized flooding. The construction cost for Alternative 1 is estimated to be slightly less than Alternative 2 mostly due to the slightly reduced lengths and diameters of pipe required. Kleinfelder recommends the City consider replacement of the existing catch basins along the recommended reroute alignment with leaching catch basins to increase infiltration in this area with favorable soils.

5.3 LINCOLN STREET

5.3.1 Lincoln Street Hydraulic Evaluation

Model simulations of the August 19, 2021 event show flooding impacts on Lincoln Street between Fairfield Street and Harvard Avenue particularly at 35/37 and 55 Lincoln Street. The driveways of the 35/37 and 55 Lincoln Street properties slope down from the roadway elevation to basement garages which have private infiltration drainage systems in front of the garages. These private infiltration systems were not explicitly modeled as the exact characteristics of the systems are unknown. These properties are impacted by stormwater overflows from the City's drainage catch basins in the roadway directly in front of the properties. The deeper modeled flood depths directly in front of these properties are a result of the 2D mesh surface in the model capturing the low garage driveway elevations. While these flood depths are mitigated somewhat by the private drainage systems, the depths highlight the low elevations at these properties and susceptibility to flooding.

Drainage along Lincoln Street consists of 12-inch pipes with shallow slopes that connect to a 15-inch drain in Fairfield Street which increases downstream to 18-inch at Arlington Street and then 24-inch in the vicinity of Mystic River Road before discharging to the Mystic River at an outfall. The Fairfield Street drain conveys stormwater flows for a relatively small upstream catchment area. Modeling analysis indicates that the shallow slopes of the 12-inch drain in Lincoln Street, the shallow slopes of the Fairfield Street drains, and a tailwater condition at the Mystic River outfall during larger storm events, contribute to stormwater overflows at the Lincoln Street catch basins (approximately elevation 7.0). Figures 35 and 36 show the simulated peak hydraulic grade profiles along Lincoln Street for the August 19, 2021 storm and along Fairfield Street during for the 10-year, 24-hour, present day storm.

Modeling analysis also indicates that the drain on Harvard Avenue has limited conveyance capacity. The drain on Harvard Avenue is 12-inch pipe which increases to 15-inch pipe in the vicinity of Mystic River Road before discharging to the Mystic River at an outfall. The catch basin and drain manhole rim elevations on Harvard Avenue (approximately elevation 10.0) are slightly higher than on Lincoln Street (approximately elevation 7.0-8.0). Model simulations of the August 19, 2021 and 10-year, 24-hour, present day storm show some minor stormwater overflows at the Harvard Avenue and Lincoln Street intersection resulting in overland flow in the street from the higher elevation at the intersection to the lower elevation of the catch basins in front of 55 Lincoln Street. This indicates that overflows from the Harvard Avenue drain could be contributing additional stormwater flow to the Lincoln Street drain and worsening flooding impacts on Lincoln Street. Kleinfelder recommends the City investigate this further to confirm if the modeled conditions match observed conditions during large storm events. If this is the case, the City could consider additional measures to mitigate flooding on Lincoln Street and Harvard Avenue such as increasing the pipe diameter of Harvard Avenue drain or replacing catch basins connected to the Harvard Avenue drain with infiltrating catch basins.

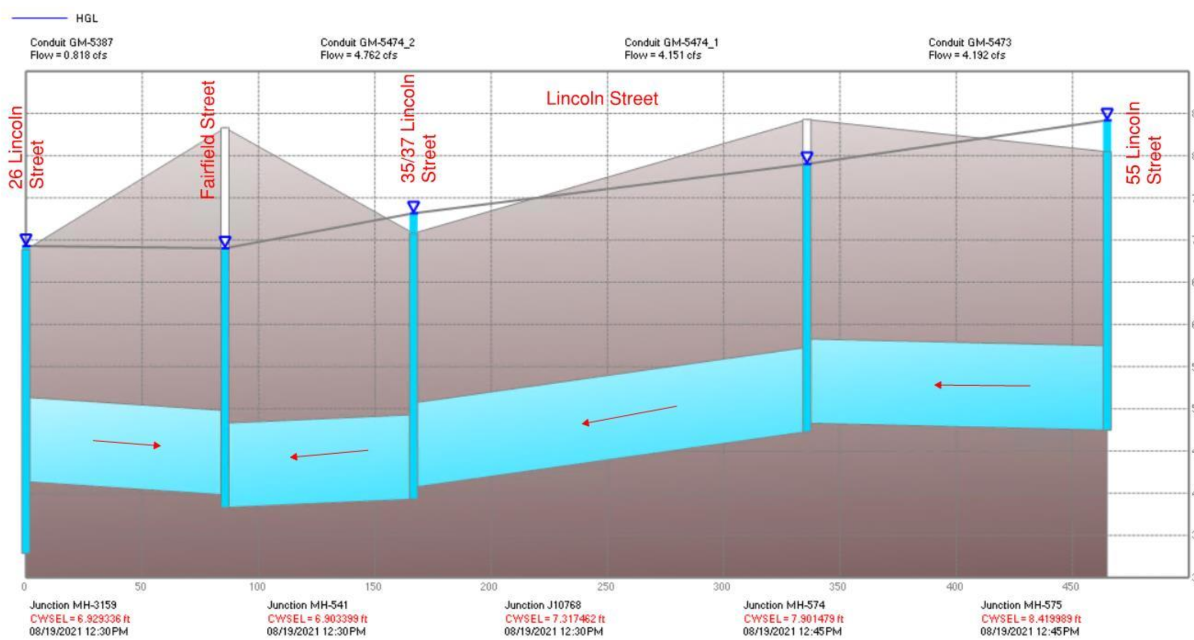

Figure 35: Simulated peak hydraulic grades along Lincoln Street for August 19, 2021 storm

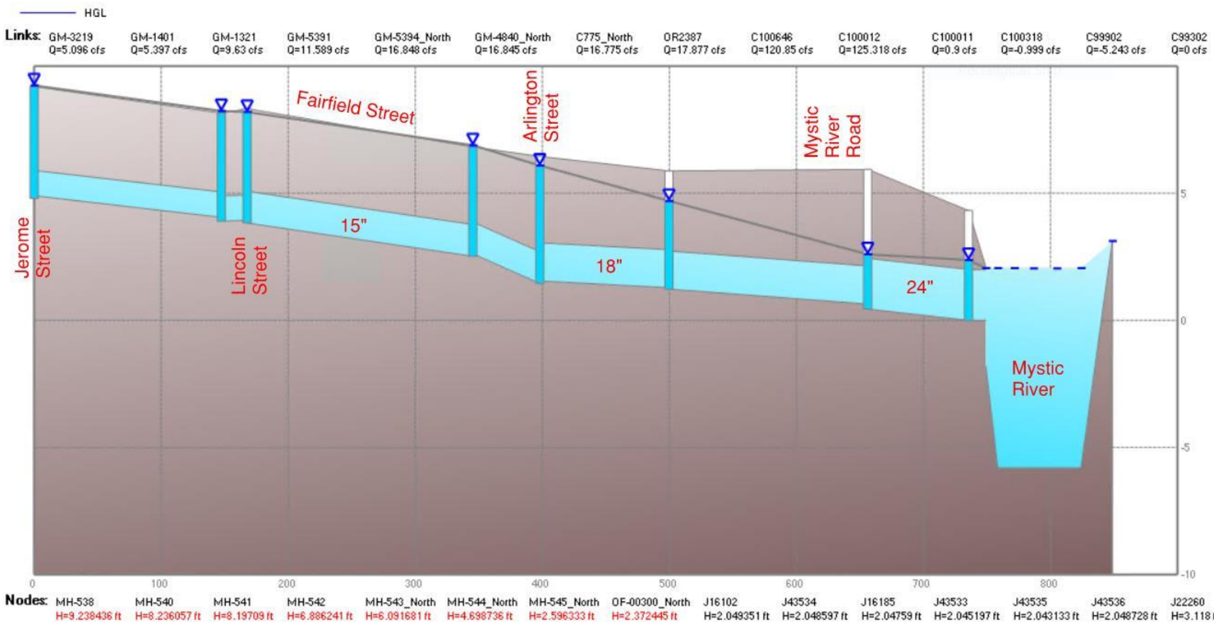

Figure 36: Simulated peak hydraulic grades along Fairfield Street for 10-year, 24-hour, present day storm

Kleinfelder modeled the performance of the existing drainage infrastructure for a 10-year, 24-hour storm, present day, design storm. Figure 37 shows the modeled extent and depth of flooding under this existing infrastructure scenario.

Figure 37: Lincoln Street existing infrastructure flooding for 10-year, 24-hour, present day storm

5.3.2 Lincoln Street Alternatives

Kleinfelder evaluated the following three alternatives to mitigate localized flooding at the Lincoln Street location:

- Alternative 1 - Increase pipe diameters of the Lincoln Street drain and Fairfield Street drain to Mystic River Road
- Alternative 2 - Increase pipe diameters of the Lincoln Street drain and Fairfield Street drain to Mystic River Road, and add green infrastructure on Lincoln Street
- Alternative 3 - Increase pipe diameters of the Lincoln Street drain and Fairfield Street drain to outfall

Figures 38-40 detail the evaluated alternatives.

Figure 38: Lincoln Street Alternative 1

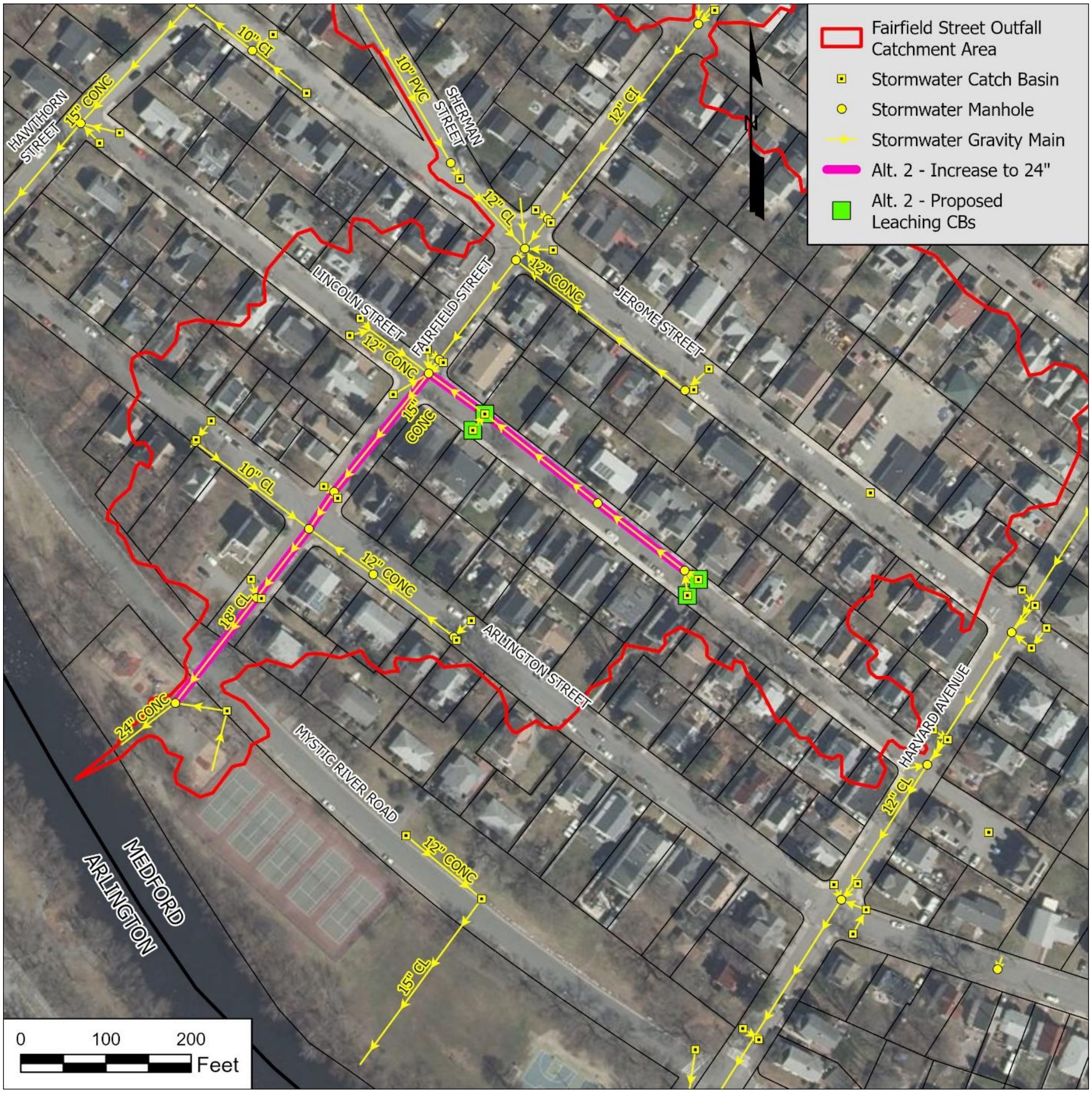

Figure 39: Lincoln Street Alternative 2

Figure 40: Lincoln Street Alternative 3

5.3.2.1 Alternative 1 - Increase pipe diameters of Lincoln Street drains and Fairfield Street drains to Mystic River Road

Alternative 1 involves increasing the pipe diameters of the Lincoln Street drain and Fairfield Street drain to Mystic River Road to increase the conveyance capacity of these drains. These portions of Lincoln Street and Fairfield Street contain other parallel utilities in the roadway which affects the cost and constructability of the alternative. This alternative does not require increasing the size of the outfall and the permitting associated with making modifications to an outfall. However, the alternative would still require DCR permitting for work in Mystic River Road. This alternative eliminates flooding in the vicinity of 35/37 Lincoln Street for the 10-year, 24-hour, present day design storm with 870 LF of 24-inch pipe (Figure 41). As noted in Section 5.3.1, the remaining modeled flooding on Lincoln Street is primarily the result of stormwater overflows at the Harvard Avenue and Lincoln Street intersection.

Figure 41: Lincoln Street Alternative 1 flood mitigation for 10-year, 24-hour, present day storm

Kleinfelder's preliminary opinion of probable cost for this alternative is $807,800 for construction costs and $444,300 for engineering design, engineering services during construction and construction contingency for a total project cost of $1,252,100. The construction cost estimate includes the cost of construction staging and mobilization, 870 LF of 24-inch RCP drain pipe, 48-inch precast concrete drain manholes, utility support and coordination, paving, rock excavation, and traffic management. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.3.2.2 Alternative 2 - Increase pipe diameters of the Lincoln Street drain and Fairfield Street drain to Mystic River Road, and replace catch basins on Lincoln Street with leaching catch basins

Alternative 2 involves the increase of pipe diameters described in Alternative 1 plus the replacement of catch basins along Lincoln Street with leaching catch basins to provide some additional flood mitigation and green infrastructure benefit by increasing infiltration. The soils in this area are classified as hydrologic soil group A and have high infiltration rates based on NRCS soil data. These soil conditions are favorable for installing leaching catch basins. Leaching catch basins are typically designed with a 4-foot deep sump below the lateral invert elevation to provide a small storage volume that must fill prior to flow leaving the catch basin through the lateral. Leaching catch basins were modeled as 4-foot diameter storage nodes with 4-foot deep sumps and infiltration parameters matching the infiltration parameters of the subcatchments in this area. This alternative eliminates flooding in the vicinity of 35/37 Lincoln Street for the 10-year, 24-hour, present day design storm with 870 LF of 24-inch pipe (Figure 42). The addition of leaching catch basins results in a slight decrease in the modeled peak flows within the Lincoln Street and Fairfield Street drains. As noted in Section 5.3.1, the remaining modeled flooding on Lincoln Street is primarily the result of stormwater overflows at the Harvard Avenue and Lincoln Street intersection.

Figure 42: Lincoln Street Alternative 2 flood mitigation for 10-year, 24-hour, present day storm

Kleinfelder's preliminary opinion of probable cost for this alternative is $851,800 for construction costs and $468,500 for engineering design, engineering services during construction and construction contingency for a total project cost of $1,320,300. The construction cost estimate includes the cost of construction staging and mobilization, 870 LF of 24-inch RCP, leaching catch basins, 48-inch precast concrete drain manholes, utility support and coordination, paving, rock excavation, and traffic management. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.3.2.3 Alternative 3 - Increase pipe diameters of the Lincoln Street drain and Fairfield Street drain to outfall

Alternative 1 involves increasing the pipe diameters of the Lincoln Street drain and Fairfield Street drain to Mystic River outfall to increase the conveyance capacity of these drains. These portions of Lincoln Street and Fairfield Street contain other parallel utilities in the roadway which affects the cost and constructability of the alternative. This alternative requires additional permitting associated with making modifications to an outfall in addition to DCR permitting for work in Mystic River Road. This alternative eliminates flooding in the vicinity of 35/37 Lincoln Street for the 10-year, 24-hour, 2030 design storm with 610 LF of 24-inch pipe and 340 LF of 30-inch pipe (Figure 43). As noted in Section 5.3.1, the remaining modeled flooding on Lincoln Street is primarily the result of stormwater overflows at the Harvard Avenue and Lincoln Street intersection.

Figure 43: Lincoln Street Alternative 3 flood mitigation for 10-year, 24-hour, 2030 storm

Kleinfelder's preliminary opinion of probable cost for this alternative is $992,100 for construction costs and $545,600 for engineering design, engineering services during construction and construction contingency for a total project cost of $1,537,700. The construction cost estimate includes the cost of construction staging and mobilization, 610 LF of 24-inch RCP, 340 LF of 30-inch RCP, 48-inch precast concrete drain manholes, utility support and coordination, paving, rock excavation, and traffic management. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.3.3 Lincoln Street Alternatives Assessment

Table 5: Lincoln Street Alternatives Assessment and Comparison

Alternative	Effectiveness (35%)	Cost (35%)	Constructability (15%)	GI (15%)	Score
Alt. 1 - Increase pipe diameters on Lincoln and Fairfield Streets	3	3	3	1	2.7
Alt. 2 - Increase pipe diameters on Lincoln and Fairfield Streets and install leaching catch basins	3	3	3	3	3
Alt. 3 - Increase pipe diameters on Lincoln and Fairfield Streets and increase outfall size	4	2	2	1	2.55

5.3.4 Lincoln Street Recommendations

Kleinfelder recommends Alternative 2 which consists of increasing the pipe diameters of the Lincoln Street drain and Fairfield Street drain to Mystic River Road and replacing catch basins along Lincoln Street with leaching catch basins. This alternative does not require increasing the size of the outfall and provides some green infrastructure benefit by increasing infiltration. This alternative eliminates flooding in the vicinity of 35/37 Lincoln Street for the 10-year, 24-hour, present day design storm. Modeling analysis indicates that overflows from the Harvard Avenue drain could be contributing additional stormwater flow to the Lincoln Street drain and worsening flooding impacts on Lincoln Street. Kleinfelder recommends the City investigate this further to confirm if the modeled conditions match observed conditions during large storm events.

5.4 BOWEN AND GOLDEN AVENUES

5.4.1 Bowen and Golden Avenues Hydraulic Evaluation

Bowen and Golden Avenues between Mystic Avenue and Willis Avenue is a local low point in elevation with a history of flooding during large storm events. Drainage on Bowen Avenue consists of four catch basins connected to a shallow sloped 12-inch pipe. Drainage along Golden Avenue consists of four catch basins connected to shallow sloped dual 8-inch pipes. Drainage along both Avenues connects to a 15-inch pipe on Willis Avenue, which connects to the 72-inch Two Penny Brook culvert pipe between Goldsmith Avenue and Whyte Street which discharges to the Mystic River. Modeling analysis indicates that the relative size and slope of the Willis Avenue catchment area, the shallow slopes of the Bowen and Golden Avenue drainage pipes, and the limited conveyance capacity of the 15-inch pipe in Willis Avenue result in elevated hydraulic grades causing flooding at this location. The flat topography along Bowen and Golden Avenues between Mystic and Willis Avenues results in temporary ponding of stormwater until hydraulic capacity in the drainage network is restored. Figures 44, 45, and 46 show the simulated peak hydraulic grade profiles along Bowen, Golden, and Willis Avenues respectively for the August 19, 2021 storm event. The slope of the Willis Avenue drain is limited by a crossing over the existing 8-inch sewer at Goldsmith Avenue.

The Willis Avenue catchment area consists of relatively high impervious cover which increases the amount of stormwater runoff generated during storms. The portions of Bowen, Golden and Wright Avenues between Main Street and Willis Avenue do not have any piped drainage and are sloped fairly steep from the higher ground elevation (approximately elevation 20-22) at Main Street to the lower elevation at Willis Avenue (approximately elevation 10). Stormwater runoff on these street lengths sheet flows to Willis Avenue where it can enter the drainage network through catch basins. The steep slopes in this portion of the Willis Avenue catchment area result in a shorter time of concentration and contribute to increased peak flows in the Willis Avenue drain.

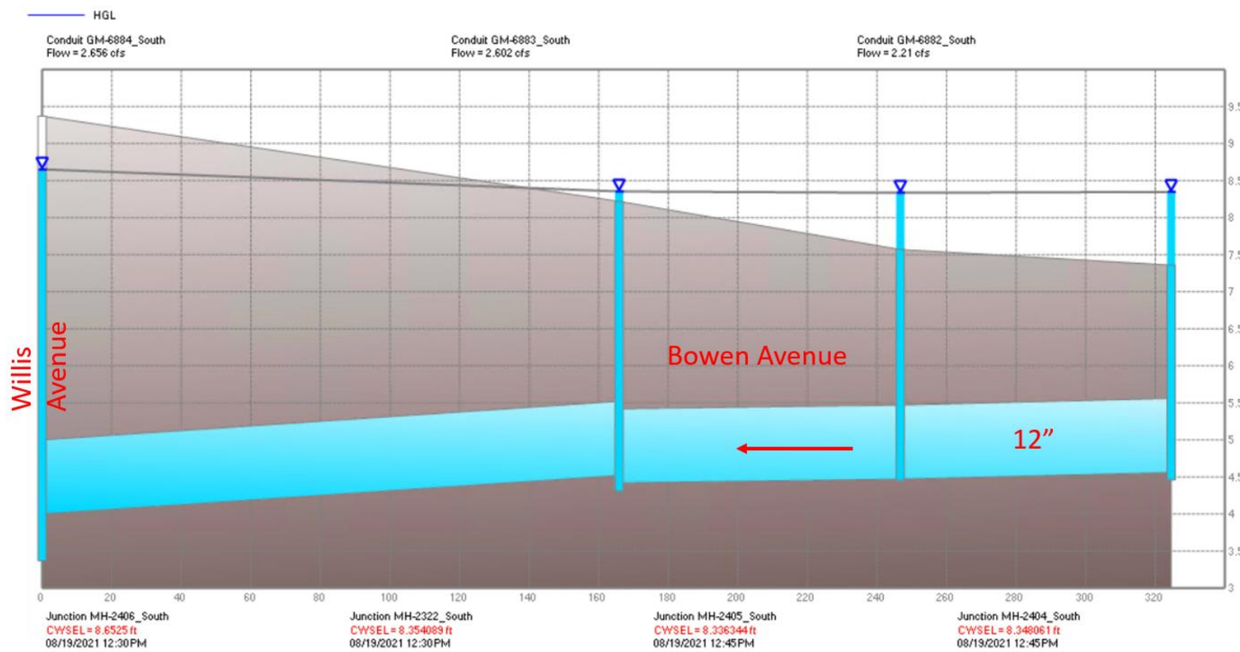

Figure 44: Simulated August 19th, 2021 Bowen Avenue pipes hydraulic conditions

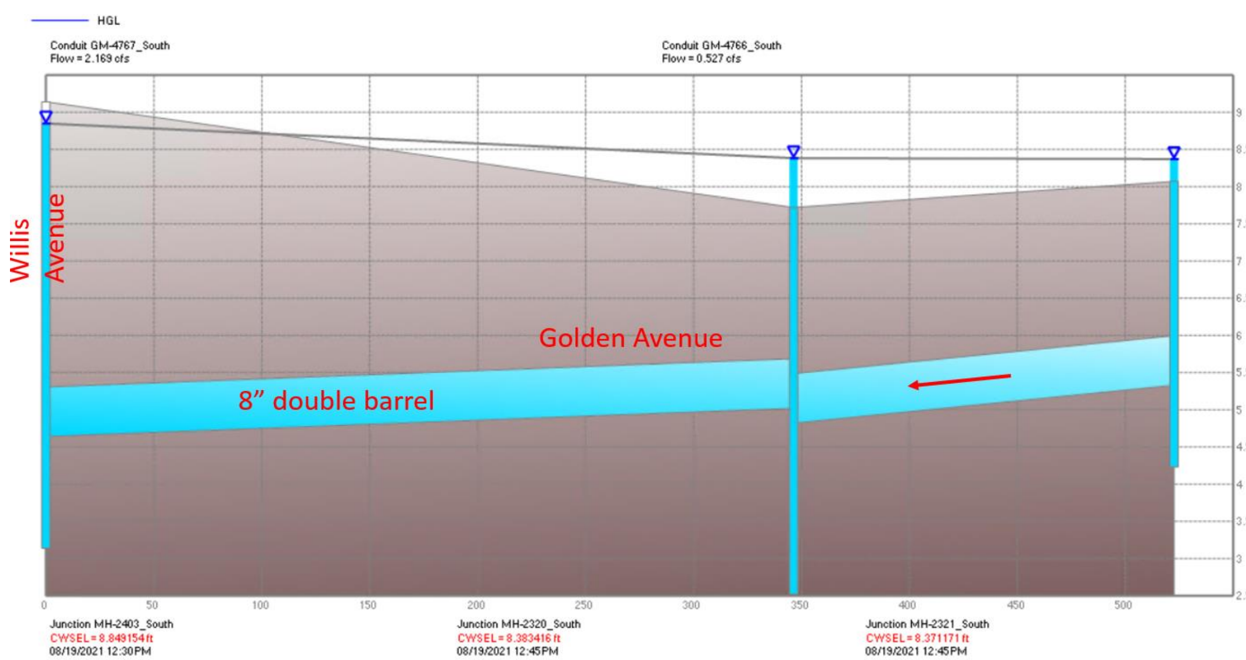

Figure 45: Simulated August 19th, 2021 Golden Avenue pipes hydraulic conditions

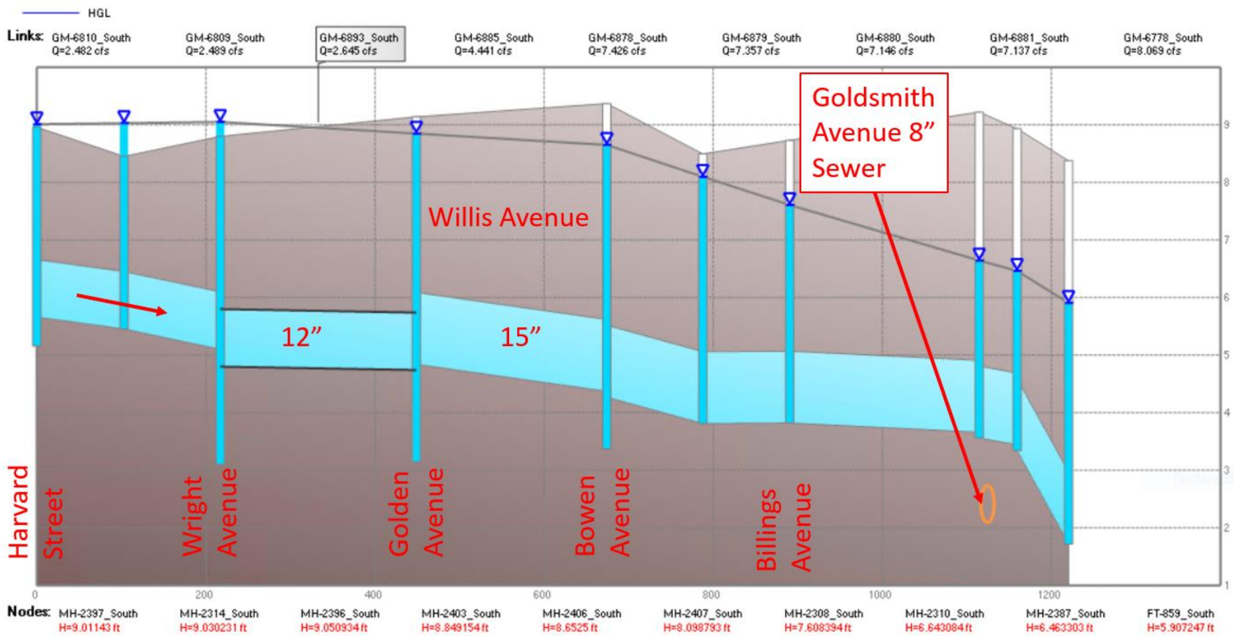

Figure 46: Simulated August 19th, 2021 Willis Avenue pipes hydraulic conditions

Kleinfelder modeled the performance of the existing drainage infrastructure for a 10-year, 24-hour storm, present day, design storm. Figure 47 shows the modeled extent and depth of flooding under this existing infrastructure scenario.

Figure 47: Bowen and Golden Avenues existing infrastructure flooding for 10-year, 24-hour, present day storm

5.4.2 Bowen and Golden Avenues Alternatives

Kleinfelder evaluated the following three alternatives to mitigate localized flooding at the Bowen and Golden Avenues location:

- Alternative 1 - Connect Bowen and Golden Avenue drains to Mystic Avenue drain
- Alternative 2 - Connect Bowen and Golden Avenue drains to Mystic Avenue drain and increase the pipe diameter for approximately 300 LF of Mystic Avenue drain
- Alternative 3 - Increase pipe diameter and adjust slope of the Willis Avenue drain

Figures 48-50 detail the evaluated alternatives. Kleinfelder evaluated each of these alternatives individually, however; the three alternatives are not mutually exclusive and multiple alternatives could be implemented in phases.

Figure 48: Bowen and Golden Avenues Alternative 1

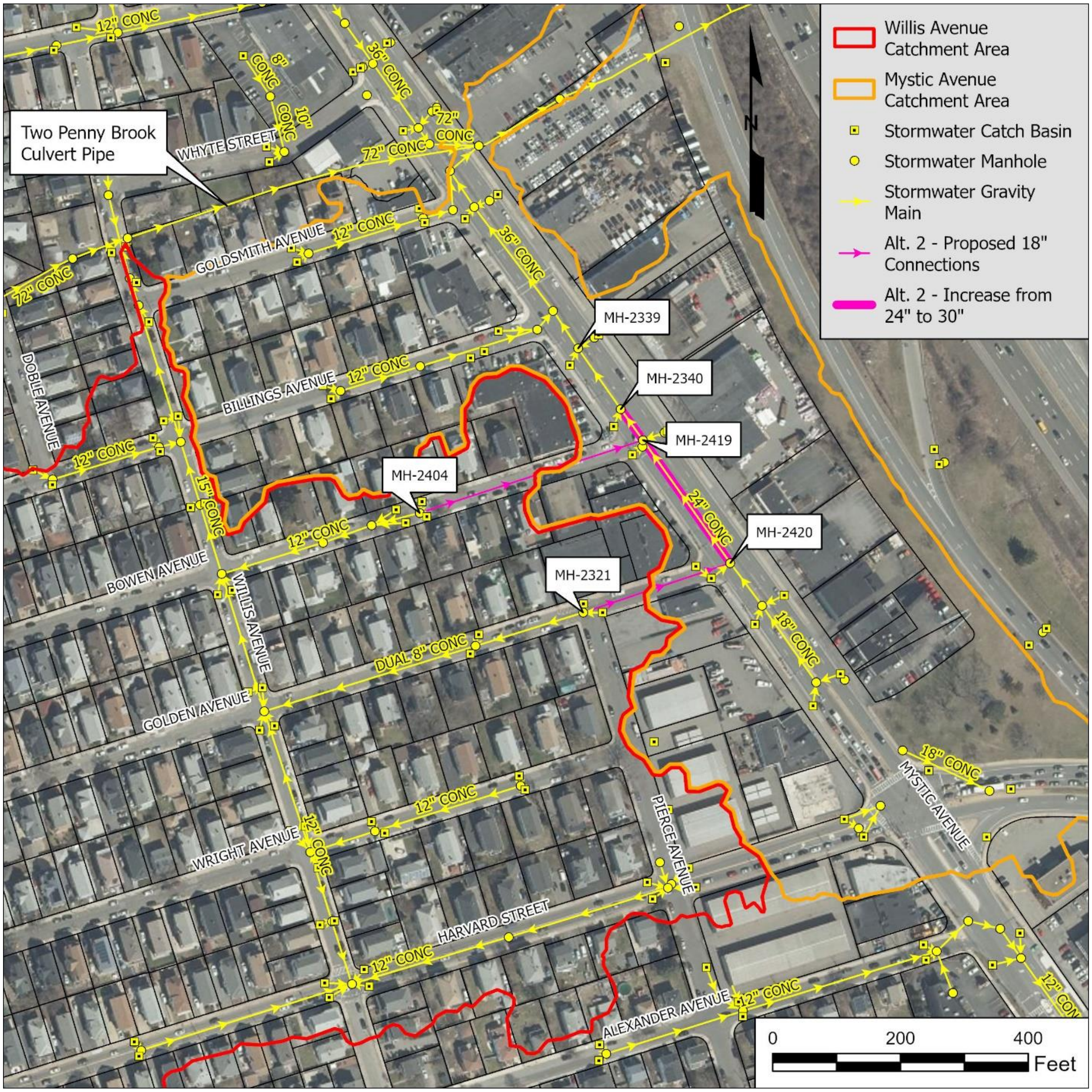

Figure 49: Bowen and Golden Avenues Alternative 2

Figure 50: Bowen and Golden Avenues Alternative 3

5.4.2.1 Alternative 1 - Connect the Bowen and Golden Avenue drains to the Mystic Avenue drain

Alternative 1 involves installing pipe connection between MH-2404 on Bowen Avenue and MH-2419 on Mystic Avenue and MH-2321 on Golden Avenue and MH-2420 on Mystic Avenue. The connections allow the existing drains on Bowen and Golden Avenue to remain in place and create a hydraulic link between the Willis Avenue and Mystic Avenue drains. The connections act as overflow outlets, allowing stormwater to be conveyed to Mystic Avenue as well as Willis Avenue when the hydraulic grade in the area is elevated (Figure 51). The Mystic Avenue drain has lower invert elevations than the Bowen, Golden and Willis Avenue drains which allows for the installation of pipe connections with moderate slopes capable of providing significant conveyance capacity. This alternative requires excavation in Mystic Avenue which is under MassDOT jurisdiction and requires an access permit. The proposed connections would have to cross the existing water main in Mystic Avenue. This alternative provides some moderate flood mitigation for the 10-year, 24-hour, present day design storm with 620 LF of 18-inch pipe to connect the Bowen and Golden Avenue drains to the Mystic Avenue drain (Figure 52).

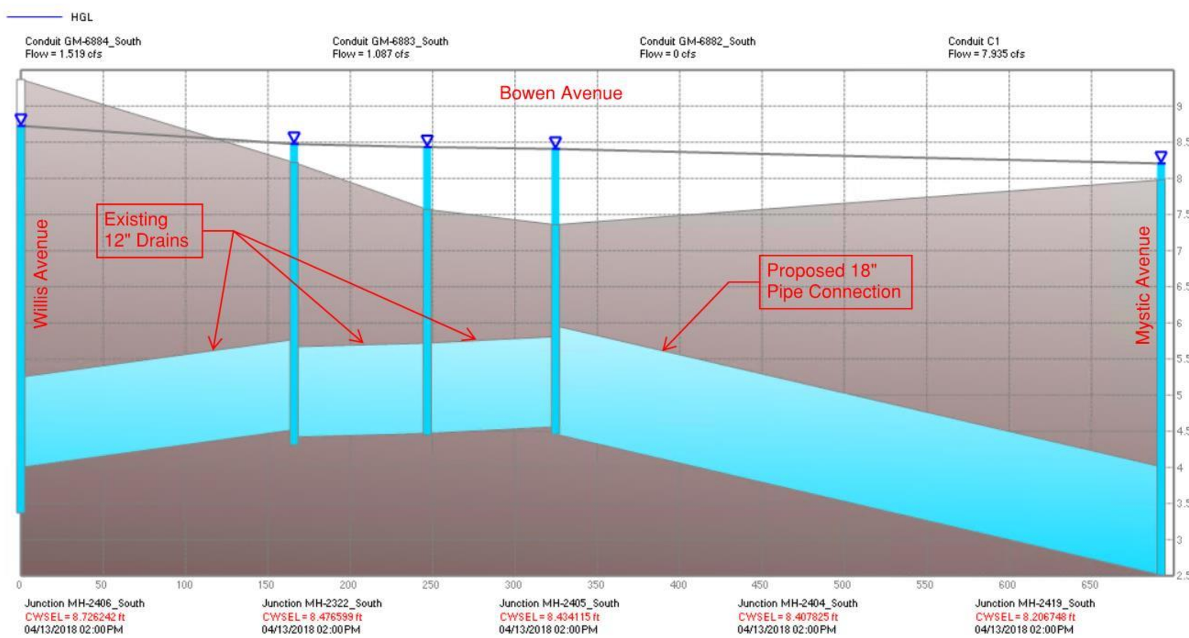

Figure 51: Simulated peak hydraulic grades along Bowen Avenue for Alternative 1 for 10-year, 24-hour, present day storm

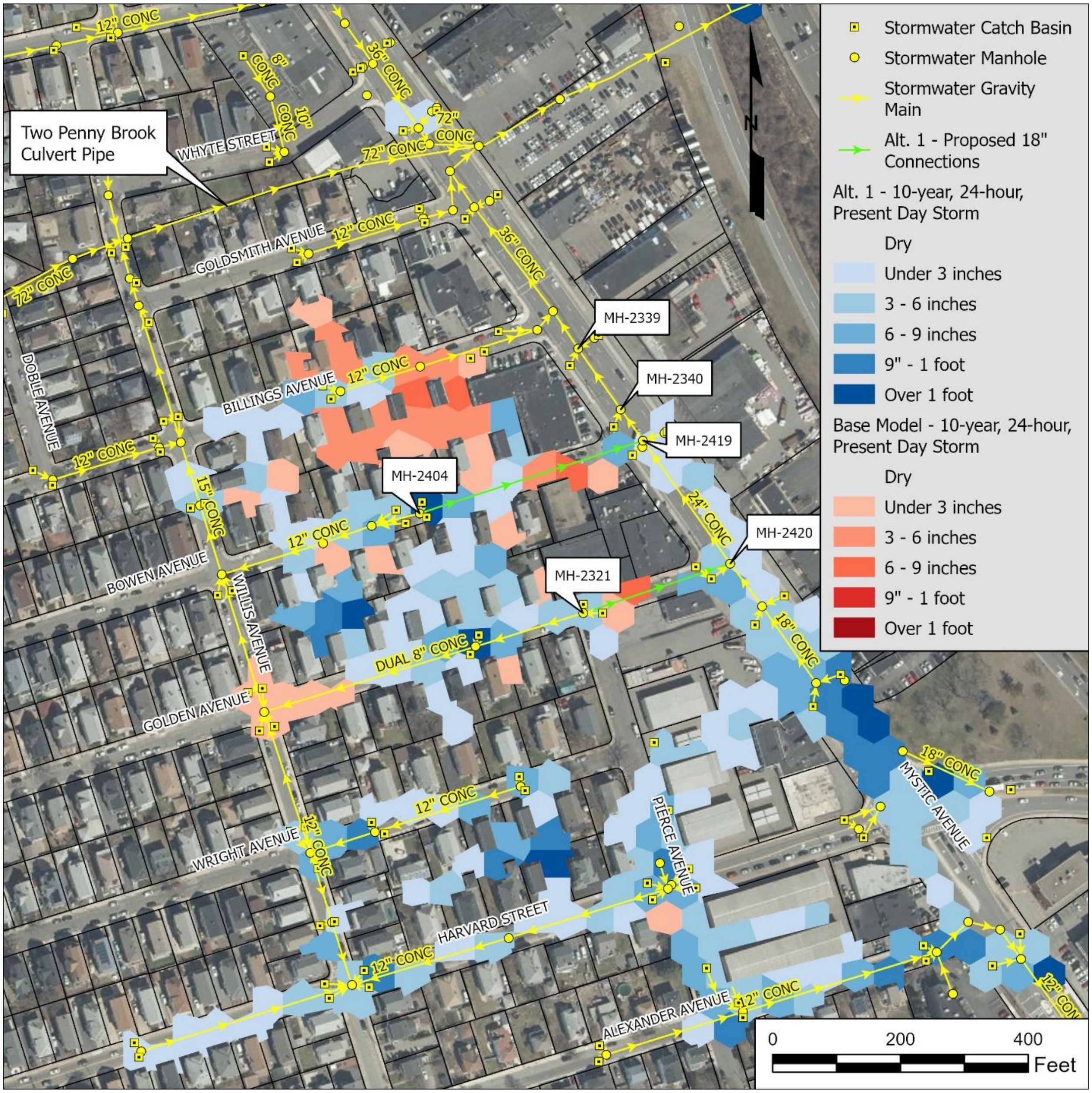

Figure 52: Bowen and Golden Avenues Alternative 1 flood mitigation for 10-year, 24-hour, present day storm

Kleinfelder's preliminary opinion of probable cost for this alternative is $508,500 for construction costs and $279,700 for engineering design, engineering services during construction and construction contingency for a total project cost of $788,200. The construction cost estimate includes the cost of construction staging and mobilization, 620 LF of 18-inch RCP drain pipe, 48-inch precast drain manholes, utility support and coordination, paving, rock excavation, and traffic management. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.4.2.2 Alternative 2 - Connect the Bowen and Golden Avenue drains to the Mystic Avenue drain and increase the pipe diameter for approximately 300 LF of Mystic Avenue drain

Alternative 2 involves the pipe connections to the Mystic Avenue drain described in Alternative 1 plus increasing the pipe diameter of the Mystic Avenue drain for approximately 300 LF. The existing Mystic Avenue trunk line increases from 24-inch to 36-inch somewhere between the intersection with Bowen Avenue (MH-2420) and MH-2339 near the intersection of Billings Avenue. The exact location of the existing increase in pipe diameter is unknown as diameter of these pipe lengths is not specified in the City's GIS. It is likely the that pipes in between these manholes are 24-inch, 30-inch, 36-inch or a combination of these pipes sizes. Field investigations of the Mystic Avenue drain were not completed as part of this project. Kleinfelder recommends additional field investigations of this drain in a future design phase. For the purposes of modeling existing conditions and evaluating this alternative, Kleinfelder assumed the existing drain increases from 24-inch to 36-inch at MH-2340 in between the portions of drain with known pipe diameters specified in the City's GIS. Increasing the pipe diameter of the Mystic Avenue drain provides additional conveyance capacity and flood mitigation but also increases construction costs with the additional pipe installation, paving, utility coordination and traffic management required. Mystic Avenue is a busy roadway under MassDOT jurisdiction and requires an access permit to perform work. This alternative provides some additional flood mitigation compared to Alternative 1 for the 10-year, 24-hour, present day design storm with 620 LF of 18-inch pipe and 300 LF of 30-inch pipe (Figure 53).

Kleinfelder
Bright People. Right Solutions.

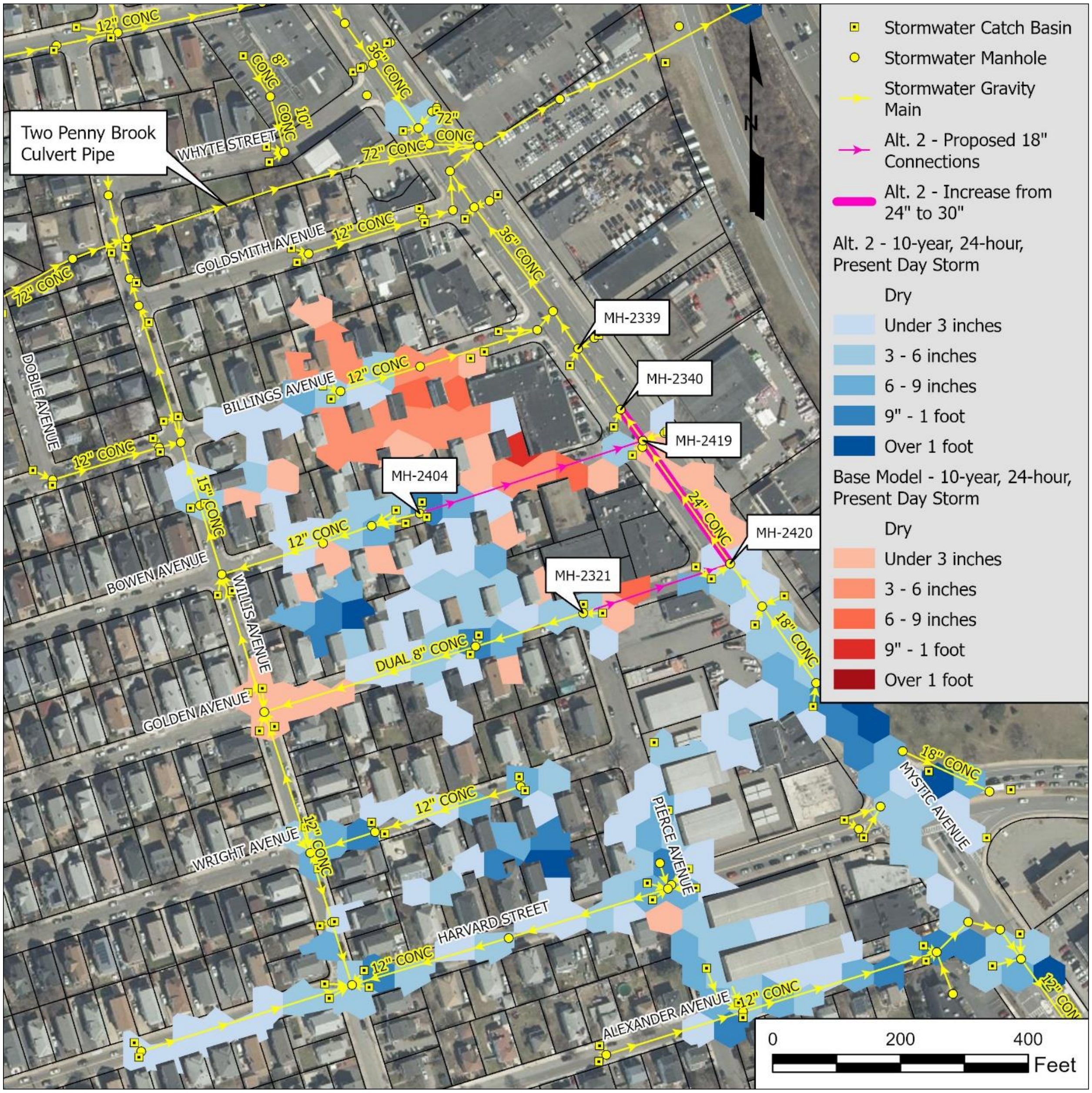

Figure 53: Bowen and Golden Avenues Alternative 2 flood mitigation for 10-year, 24-hour, present day storm

Kleinfelder's preliminary opinion of probable cost for this alternative is $863,600 for construction costs and $475,000 for engineering design, engineering services during construction and construction contingency for a total project cost of $1,338,600. The construction cost estimate includes the cost of construction staging and mobilization, 620 LF of 18-inch RCP, 300 LF of 30-inch RCP, 48-inch concrete drain manholes, utility support coordination, paving, rock excavation and traffic management. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.4.2.3 Alternative 3 - Increase pipe diameter and adjust slope of the Willis Avenue drain

Alternative 3 involves increasing the pipe diameter and adjusting the slope of the Willis Avenue drain from Bowen Avenue to the connection with the Two Penny Brook culvert pipe. As shown in Figure 46, the slopes of the existing Willis Avenue drain pipes are fairly shallow. This alternative involves adjusting the drain pipe slopes to maintain a more constant and steeper slope. The crossing of the drain and the existing 8-inch sewer at Goldsmith Avenue could potentially be modified or reconfigured to further optimize the slope of the drain but was not considered for this preliminary analysis. This alternative increases the conveyance capacity of the drainage network downstream of the localized flooding on Bowen and Golden Avenues. This portion of Willis Avenue is narrow with parking on both sides of the road and other parallel utilities in the roadway which affects the cost and constructability of the alternative. This alternative provides some moderate flood mitigation for the 10-year, 24-hour, present day design storm with 780 LF of 30-inch pipe (Figure 54).

Figure 54: Bowen and Golden Avenues Alternative 3 flood mitigation for 10-year, 24-hour, present day storm

Kleinfelder's preliminary opinion of probable cost for this alternative is $1,015,000 for construction costs and $558,300 for engineering design, engineering services during construction and construction contingency for a total project cost of $1,573,300. The construction cost estimate includes the cost of construction staging and mobilization, 780 LF of 30-inch RCP, 48-inch precast concrete drain manholes, utility support coordination, paving, rock excavation, and traffic management. Refer to Appendix E for the detailed preliminary opinion of probable cost.

5.4.3 Bowen and Golden Avenues Alternatives Assessment

Table 6: Bowen and Golden Avenues Alternatives Assessment and Comparison

Alternative	Effectiveness (35%)	Cost (35%)	Constructability (15%)	GI (15%)	Score
Alt. 1 - Connect to Mystic Avenue drain	2	4	3	1	2.7
Alt. 2 - Connect to Mystic Avenue drain and increase pipe diameter for 300 LF	2	3	2	1	2.2
Alt. 3 - Increase pipe diameters and adjust slope of Willis Avenue drain	2	2	2	1	1.85

5.4.4 Bowen and Golden Avenues Recommendations

Kleinfelder recommends Alternative 1 which consists of connecting the Bowen and Golden Avenue drains to the Mystic Avenue drain. This alternative provides moderate flood mitigation at a lower cost and required length of pipe compared to Alternatives 2 and 3. Alternative 1 limits the amount of excavation in Mystic Avenue to only work associated with the connection to the existing drain. Kleinfelder recommends further evaluation of the flood mitigation performance of Alternative 1 for short duration storms events. Similar to the Fern Road location, the three alternatives evaluated are not mutually exclusive. The increase of the Mystic Avenue or Willis Avenue drains evaluated as part of Alternatives 2 and 3 could be implemented at a later date to provide additional flood mitigation benefits.

6 SUMMARY & CONSIDERATIONS

The recommendations presented in this report provide the City with preliminary design solutions to address localized flooding in the identified locations. Implementation of the recommended design alternatives will require further analysis and field investigations including detailed survey, subsurface investigations, and investigations of the existing infrastructure. Kleinfelder recommends that further hydraulic modeling analysis be performed, as necessary, to further refine the recommended design alternatives and ensure that a detailed final design solution achieves the desired flood mitigation effectiveness. Kleinfelder recommends that the City consider evaluating the flood mitigation effectiveness of recommended alternatives for different storm frequencies, durations and/or distributions (for example, a 10-year, 2-hour storm) in a future design phase. The preliminary opinions of probable cost presented in this report provide the City with the information to make decisions regarding funding, prioritization and scheduling of future projects. Kleinfelder recommends that the City consider pursuing grant opportunities to fund design and/or implementation of the recommended flood mitigation solution.