City of Iowa Colony Master Drainage Plan

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Prepared For:

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Texas Water Development Board
City of Iowa Colony
Brazoria County
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List of Acronyms and Abbreviations

1D/2D	1-dimensional/2-dimensional
ACE	Annual Chance Event
COIC	City of Iowa Colony
BCA	Benefit-Cost Analysis
BCDCM	Brazoria County Drainage Criteria Manual
BCDD5	Brazoria County Drainage District No. 5
BDD4	Brazoria Drainage District No. 4
BDF	Basin Development Factor
BCR	Benefit-Cost Ratio
DEM	Digital Elevation Model
DCM	Drainage Criteria Manual
ETJ	extraterritorial jurisdiction
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
FIRM	Flood Insurance Rate Map
GIS	Geographic Information System
HEC	Hydrologic Engineering Center (U.S. Army Corps of Engineers)
HMS	Hydrologic Modeling System
LiDAR	Light Detection and Ranging
MDP	Master Drainage Plan
NAD	North American Datum
NAVD	North American Vertical Datum
NRCS	Natural Resources Conservation Service
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWI	National Wetlands Inventory
ORNL	Oak Ridge National Laboratory
RAS	River Analysis System
RFPG	Regional Flood Planning Group

StratMap	Strategic Mapping Program
SVI	Social Vulnerability Index
TCEQ	Texas Commission on Environmental Quality
THC	Texas Historical Commission
TIN	triangulated irregular network
TNRIS	Texas Natural Resources Information System
TPWD	Texas Parks and Wildlife Department
TxDOT	Texas Department of Transportation
U.S.	United States
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WSEL	water surface elevation

Executive summary

The area of interest for this study is the City of Iowa Colony (COIC) and the surrounding Extra-Territorial Jurisdiction (ETJ). COIC is located south of Houston in northern Brazoria County. In recent years, the city has experienced significant growth with the development of several master planned communities within the city limits and ETJ. The purpose of this report is to develop a Master Drainage Plan (MDP). This master drainage plan is a joint effort funded by City of Iowa Colony, the Texas Water Development Board (TWDB), Brazoria County, Brazoria Drainage District No. 4 (BDD4), and Brazoria County Drainage District No. 5 (BCDD5).

The study area encompasses approximately 27.8 square miles and includes the three (3) primary drainage channels that serve the stormwater runoff from the study area. These streams are the West Fork Chocolate Bayou, North Hayes Creek and South Hayes Creek which are all tributaries to Chocolate Bayou. These tributaries are presented in the Federal Emergency Management Agency's (FEMA) December 30, 2020, Flood Insurance Study (FIS) as detailed studied streams with identified flood hazard boundaries and base (100-year) flood elevations.

For the flood hazards identified in the 2020 FEMA FIS, both the North Hayes Creek and South Hayes Creek flood hazards were prepared using the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center's HEC-2 computer program based on steady state backwater calculations. Peak flows for the various storm events were determined using the regional regression equations presented in the 1977 U.S. Geological Survey Report 77-110 titled Technique for Estimating the Magnitude and Frequency of Floods in Texas. The West Fork Chocolate Bayou flood hazards were last updated in 2015 using the USACE's HEC-RAS (River Analysis System) and HEC-HMS (Hydrologic Modeling System) computer programs. The HEC-RAS simulation of flood profiles is based on steady state backwater calculations. The HEC-HMS simulation of stormwater runoff utilizes the rainfall data presented in the United States Weather Bureau's 1961 document titled Technical Paper 40 – Rainfall Frequency Atlas of the United States.

The goal of this project is to provide a better understanding of the existing flood hazards along the study streams using the most current rainfall data coupled with recently adopted regional drainage criteria and newer computer simulation methodology, and to identify drainage improvement projects that can be implemented to help reduce existing flood risks to properties within the study area. The intent of the hydrologic and hydraulic model simulations is not to revise the published FEMA-identified flood hazards but to assist in the efforts for achieving the overall project goal.

Hydrologic and hydraulic model simulations of the study area were prepared to determine the existing conditions flood hazards. Two alternative drainage improvement concepts were analyzed and compared to the existing conditions results to determine the benefits for reducing flood risks. The first alternative (Capital Improvement Project - CIP) includes the construction of nine (9) flood risk reduction ponds along the studied streams within six (6) general areas to provide additional floodplain storage volume capacity and peak flow attenuation during major storm events. The second alternative (Alt) includes channel widening to provide additional conveyance capacity and the construction of ten (10) ponds to mitigate for the improvements.

The assessment of the existing flood hazards and potential benefits resulting from the two alternative drainage improvement concepts were prepared considering the 24-hour, 0.2% (500-year), 1% (100-year), 2% (50-year), and 10% (10-year) annual chance storm events based on National Oceanic and Atmospheric Administration (NOAA) Atlas 14 rainfall depths. The USACE' HEC-HMS computer program is used to simulate stormwater runoff for the study area watershed. The USACE's HEC-RAS computer program (1-dimensional/2-dimensional unsteady flow approach) is used to simulate flood routing and conveyance of flood flows along the streams and throughout the overbanks within the study area. This report outlines the steps and procedures followed in preparing the drainage study and presents the results of the findings. Cost and benefits were quantified for each drainage alternative. A summary table comparing flood risks of the existing conditions and the two alternative drainage improvements referenced in this study is provided in **Table ES.1.**

Due to the more complex modeling approach, detailed terrain and updated rainfall data used in the study efforts, both the depth and extent of flood hazards along the streams are increased from those identified in the FEMA Flood Insurance Rate Maps (FIRM). This suggests that the number of existing structures located within the study area that are susceptible to flood risk is increased more than that previously anticipated from the FEMA FIRM flood hazards. Based on the FEMA FIRM flood hazard boundaries, approximately 12.2 square miles within the study area are considered to be inundated from a 100-year flood event. In comparison, approximately 16.3 square miles are considered to be inundated from a 100-year flood event resulting from the updated assessment of existing flood hazard conditions. Further, the assessment has resulted in the determination that the three main streams within the study area have a level of service to safely convey flood waters from less than a 10-year storm event.

Building upon the updated existing conditions flood hazards assessment, a CIP is identified. The CIP is made up of the construction of several flood risk reduction ponds along the three streams throughout the watershed. The locations of the ponds are chosen to avoid ongoing and planned areas of development within the study area. With the exception of one pond located in the upper reach of the West Fork Chocolate Bayou watershed, the remaining ponds are all located within the downstream reaches where there is minimal number of structures (i.e., mostly agricultural farmland). The ponds are proposed to help provide additional floodplain storage within the overall drainage system of the study area with the intent of reducing the flood risks throughout the watershed. A total of 3,671 acre-feet of storage volume across 9 ponds is anticipated to be added for the 100-year flood event. However, due to the limited ability to efficiently convey the flood waters to these ponds, the reduction on flood depths is minimal (no more than 0.12 foot).

An alternative plan was developed to determine if additional reduction in flood risks to the study area could be realized. This alternative incorporates channel modifications along the three streams within the study area to help provide additional level of service and improved flood carrying capacity. The plan also includes a total of 10 ponds including the 9 ponds from the CIP plan plus the expansion of an existing COIC detention pond. The total detention volume provided across 10 ponds is 4,363 acre-feet storage volume.

Modifications to existing stream crossing structures were not included within the alternative plan. The results of the analysis suggest that the channel modifications have the potential to provide significant flood risk reduction within the study area. However, the volume provided in the ponds is not sufficient to mitigate for the increases in flood hazards further downstream of the study area. The improved flood flow conveyance capacity of the streams has the potential to push more water into the receiving Chocolate Bayou stream, thus resulting in increases to flood depths along this stream. It is determined that additional storage volume of approximately 2,000 acre-feet is needed for the Alt plan to offset the impacts anticipated. Due to the lack of available right-of-way within the study area, this volume would need to be provided downstream, outside of the study area. It is recommended that a future partnership project with the drainage districts be formed to explore future opportunities for improving channel conveyance and adequately offsetting its impacts.

The CIP and Alt projects were evaluated based on cost and benefit. The CIP and Alt projects have a total cost of $110.98 million and $278.96 million respectively. The CIP project has a higher BCR and is easier to implement. In comparison to the Alt, the CIP plan also has less challenges as it relates to ROW acquisition, environmental constraints, and utility conflict. Additionally, the recurring costs associated with operation and maintenance were much higher for the Alt plan compared to the CIP.

On the basis of the findings documented in this report, it is recommended the CIP plan be considered for inclusion in the TWDB State Flood Plan. The COIC is located in Region 6 San Jacinto Regional Flood Planning Group. This report and supporting technical data has been submitted to San Jacinto RFPG for evaluation and suitability for inclusion in the regional flood plan. The potential funding strategies to implement the project include COIC internal funding, joint/cop-operative funding, impact fees and external funding sources at the state and federal level.

Table ES.1 Flood Risk Comparison Summary

ESTIMATED PROJECT BENEFITS	EXISTING CONDITIONS	CAPITAL IMPROVEMENT PLAN: PONDS ONLY	ALTERNATIVE: PONDS AND CHANNEL WIDENING
Area in 100yr (1% annual chance) Floodplain (sq.mi.)	16.16	15.83	14.34
Area in 500yr (0.2% annual chance) Floodplain (sq.mi.)	19.33	19.18	18.5
Estimated number of structures at 100yr flood risk	1111	1043	875
Residential structures at 100-year flood risk	1075	1007	840
Estimated Population at 100-year flood risk	657	630	566
Critical facilities at 100-year flood risk (#)	0	0	0
Number of low water crossings at flood risk (#) [1]	9	8	8
Estimated number of road closures (#)	N/A	N/A	N/A
Estimated length of roads at 100-year flood risk (Miles)	25.76	24.19	19.19
Estimated farm & ranch land at 100-year flood risk (acres)	8.62	8.21	7.02
Number of structures with reduced 100yr (1% annual chance) Flood risk	-	666	956
Number of structures removed from 100yr (1% annual chance) Flood risk	-	68	236
Number of structures removed from 500yr (0.2% annual chance) Flood risk	-	63	357
Residential structures removed from 100yr (1% annual chance) Flood risk	-	68	235
Estimated Population removed from 100yr (1% annual chance) Flood risk	-	27	91
Critical facilities removed from 100yr (1% annual chance) Flood risk (#)	-	0	0
Number of low water crossings removed from 100yr (1% annual chance) Flood risk (#)	-	1	1
Estimated reduction in road closure occurrences	-	N/A	N/A
Estimated length of roads removed from 100yr flood risk (Miles)	-	1.57	6.57
Estimated farm & ranch land removed from 100yr flood risk (acres)	-	0.41	1.6
Estimated reduction in fatalities (if available)	-	N/A	N/A
Estimated reduction in injuries (if available)	-	N/A	N/A

[1]Represents all stream crossings that are inundated during the 100-year event

1.0 Introduction

This project is identified as the City Of Iowa Colony Master Drainage Plan. The City of Iowa Colony and its ETJ are located within the Chocolate Bayou Watershed a sub-basin within the United States Geological Survey Hydrologic Unit Code 10 (USGS HUC-10) 1204020404 Mustang Bayou watershed.

1.1 Planning area general description

The study area encompasses three tributaries of Chocolate Bayou – West Fork Chocolate Bayou, North Hayes Creek and South Hayes Creek that fall within the jurisdictional limits of the BDD4 and BCDD5. The general study limits extend from the confluence with Chocolate Bayou in the East to FM 521 Road on the west side, and from the County Road 60 on the south to Texas State Highway 6 on the north (see **Exhibit 1**).

A majority of the study area is open pasture with mixed use single-family residential development. The topography of the area is relatively flat, with expansive floodplains that extend beyond the channels. The study area is bisected by a major transportation corridor identified as Texas State Highway 288. This roadway has a north-south alignment with crossings of all three drainage channels. Most of the properties located east of State Highway 288 are identified as being inundated during a 1% annual chance (100-year) flood event. There is floodplain identified for some properties west of State Highway 288, but not to the extent as it is in the eastern portion of the study area.

The city and its ETJ are currently experiencing substantial development. While current regulations are in place to ensure that these new development result in no adverse impact to the flood hazards along the receiving streams, there are no requirements for these developments to improve the existing flood hazards on adjacent properties. Further, these new developments have the potential to utilize land that may be better suited for the implementation of flood risk reduction features for the existing community.

1.2 Project purpose and objectives

The proposed project is identified as the 2022 City of Iowa Colony Master Drainage Plan. The plan is prepared through a collaborative effort between the City of Iowa Colony, Brazoria County, Brazoria Drainage District No. 4, and Brazoria County Drainage District No. 5 with 50% matching grant funds from the Texas Water Development Board. This report is prepared to document the analysis of existing drainage conditions and proposed improvements that help to reduce flooding within the study area (COIC and its ETJ).

The objectives of the project are to:

- Delineate drainage areas and generate Atlas 14 rainfall runoff hydrographs
- Develop Unsteady flow (i.e., flow values vary over time) HEC-RAS 1D/2D models to analyze existing flood risks
- Develop flood reduction goals and objectives based on the existing conditions analysis

- Identify two (2) alternatives that can be implemented for flood risk reduction
- Develop Unsteady flow HEC-RAS 1D/2D models to analyze benefits of the proposed alternatives
- Quantify cost and flood risk reduction benefits of each alternative
- Prepare a master plan report documenting technical methodologies, model results, and discussion of the findings of the study.

1.3 Scope of work

The focus of this study is to evaluate existing flood hazards along the three major streams that receive stormwater runoff from the COIC and its ETJ, and to analyze proposed projects to reduce flooding.

The baseline models created are based on 2018 LiDAR and supplemented with topographic survey for a majority of the stream crossings. The study does not include hydraulic modeling of the internal storm drainage network and creeks/channel system that convey flows to the three major streams within the study area.

The purpose of the improvement projects is to provide flood risk reduction benefits and are not intended to mitigate future development conditions. The development conditions identified are based on the existing development within the city in addition to major development projects which have been approved or are under construction at the time of the beginning of the study. Potential upgrades to the existing bridge and culvert crossings are outside the scope of this analysis and were not considered in this study effort. Determination of potential impacts of the project on Waters of the U.S. and/or jurisdictional wetlands is beyond the scope of work for this project.

The baseline models created for this study are not intended to be used to support any FEMA map revisions. However, the models developed for this MDP could be further refined and used to revise the FEMA FIRMS at a later date and under another contact.

1.4 Assumptions and constraints

The proposed project must ensure no adverse impacts to existing flood hazard conditions. The proposed project is intended to reduce flood risks throughout the COIC and its ETJ and is not intended to mitigate future development. The development conditions assumed are based on current development and developments that are in progress at the start of the study.

The study limits encompass the COIC and its ETJ - the downstream limit of the hydraulic model is located at the confluence with Chocolate Bayou. Backwater effects from Chocolate Bayou are not considered in this analysis. Rather, the assumed tailwater condition is based on normal depth with the energy grade line slope set equivalent to the channel slope.

2.0 Data collection and review

Data collected and reviewed for this project include the effective FEMA model data, drainage reports and models by other engineers, construction drawings for various development projects, Texas Natural Resources Information System (TNRIS) and topographic survey of existing stream crossings.

FEMA FIS:

The Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) provides useful information about the existing flood hazards within the study area resulting from flooding along the West Fork Chocolate Bayou, North Hayes Creek and South Hayes Creek. Information about the hydrologic and hydraulic models used to define the flood hazards are available from FEMA through their Technical Data Request service. Information provided within the models is assessed and compared to other data to verify the relevance for use in the MDP study effort. The existing FEMA flood hazards and watershed boundaries for each stream are shown in **Exhibit 2** and **Exhibit 3**, respectively.

Based on the assessment of the model data, it is determined that the hydrologic information is not useful. The hydrology for the North and South Hayes Creeks uses regional regression equations to determine the peak flows along the streams. Further, while the hydrology for West Fork Chocolate Bayou is updated using the USACE HEC-HMS simulation of runoff conditions, the hydrologic calculations for all three streams reference rainfall depths estimated from the U.S. Weather Bureau's Technical Paper No. 40 Rainfall Frequency Atlas of the United States. The rainfall depths for the respective storm events are less than those currently recommended for use by the National Weather Service's Hydrometeorological Design Studies Center (i.e., National Oceanic and Atmospheric Atlas 14 rainfall).

The hydraulic models of all three streams provide useful information with respect to existing cross section geometry and stream crossing structures. Channel cross section geometry from the FIS hydraulic models is compared to the sections prepared using the RASMapper feature of HEC-RAS. Further, the channel roughness values referenced in the FIS models are considered for use within the HEC-RAS 1D/2D model. The channel crossing structures were identified in the models and locations verified with existing aerial photography to confirm their existence. Only those structures determined to currently exist were included within the HEC-RAS 1D/2D model.

Drainage Impact Analysis for the Phase Three Development of Meridiana (December 2017):

This drainage report was prepared by EHRA Engineering to address the drainage impacts associated with the ongoing development of the Meridiana subdivision within the West Fork Chocolate Bayou watershed. Information referenced from this report include the design drawings for the Meridiana Parkway bridge crossing of the West Fork Chocolate Bayou.

Drainage Impact Analysis for Sharp-Scherer and Sharp-Dobson Tracts (November 2022):

This drainage report was prepared by LJA Engineering, Inc. to address the drainage impacts associated with the proposed development in the West Fork Chocolate Bayou watershed. Information referenced from this report is used to help delineate the sub-basin alignment within the watershed.

Survey Data for Stream Crossing Structures along North Hayes Creek and South Hayes Creek (June 2022):

Topographic survey data was obtained for ten (10) structures crossing North Hayes Creek and South Hayes Creek. This information was prepared to verify the structure sizes and details not available from other sources. This information is used to clarify the geometric features within the HEC-RAS model.

2.1 Public meeting and technical coordination

Throughout the project duration, a series of public meetings and steering committee meetings were held. These meetings were important to ensure that the stakeholders understand the goals and scope of the project study. All public and steering committee meetings were held at the City of Iowa Colony City Hall.

The first public meeting was held on February 23, 2022, to inform the public of the proposed study and to gather input regarding flooding issues in the areas. The second public meeting was held on June 1, 2022, to present the findings of the existing conditions evaluation and conceptual drainage improvements that could achieve the goals and objectives of the project. At each of the meetings, opening remarks were made by ADICO, LLC (representing the COIC) and a formal presentation was made by ADICO and Ward, Getz and Associates, PLLC to discuss the project. Exhibits were shown on the projector screen during the presentation.

Poster boards were also set up at the front of the room to facilitate Q&A after the presentation. The public meetings were not well attended by the general public and no input/ comments were received. The meetings were held in the evening at 6pm and notices were published on the City's website weeks in advance. **Appendix E** includes the copies of the public notices.

In addition to the public meetings, a series of Steering Committee meetings were held in 2022 (February 18, May 5, and May 24) with representatives from ADICO (COIC Engineer), BDD4 and BCDD5. During these meetings, results of existing conditions analysis was discussed and input/feedback on conceptual project alternatives was gathered to collaboratively identify the project features that should be included/excluded in the analysis.

2.2 Base mapping information

The primary source of terrain data used for this hydraulic study was developed from the Texas Natural Resources Information System (TNRIS) StratMap 2018 Upper Coast LiDAR data set (50 cm resolution) and supplemented with the TNRIS USGS 2019 Hurricane LiDAR data set (70 cm resolution). Both LiDAR data sets were surveyed by Fugro Geospatial, Inc. Multipoint files were projected and adjusted into Horizontal NAD83 State Plan projection and Vertical NAVD88 elevation using U.S. foot measurement. Both the hydrologic and hydraulic analysis for the study area were completed based upon this topographic data.

2.3 Survey

Limited field survey was performed to help verify existing stream crossing structures. Photos and field sketches of various structures were collected from various agencies to help verify the geometry of the structures simulated in the hydraulic model. The hydraulics section of this report describes the details of how the survey data has been incorporated into the study efforts.

2.4 Storm drainage system infrastructure assessment

The City of Iowa Colony is a small but growing community that includes a mix of residential communities and rural areas. The storm drainage system in each of the areas vary considerably. Stormwater from these systems discharge into drainage channel/creeks that bisect the community.

The typical storm drainage system within the subdivision generally consists of a combination of surface and subsurface drainage systems that are designed to collect and manage rainwater runoff from the community's streets, sidewalks, parking lots, and other impervious surfaces. This includes a network of underground storm sewer, stormwater detention basin and outfalls.

The drainage system for rural communities can vary depending on the specific characteristics of the community and the surrounding landscape. In general, however, the drainage system for rural communities is designed to manage rainwater runoff from the community's roads, agricultural land, and other impervious surfaces. These includes a network of ditches and culverts. These ditches are designed to collect and channel water away from the community's roads and other paved surfaces. The culverts are installed beneath roads and other crossings to allow water to flow beneath them.

Redevelopment of rural areas are required to mitigate from floodings. This may include storm sewer system, detention basin and detention improvements to offset post development runoff.

Field topographic survey was requested for eleven (11) structures within the boundaries of the West Fork, North Hayes, and South Hayes watersheds. These structures are identified with letters A through K. Due to right-of-entry issues, field data was not collected for Bridge crossing “E”, resulting in topographic information for a total of 10 structures. Four (4) structures located along North Hayes and six (5) structures along South Hayes. The information obtained includes cross sections at each of the bridge crossings, elevations of high chord and low chord along with size and number of piers. Surveyed bridge data and locations have been included in **Appendix G**.

3.0 Hydrologic modeling

For this study, the hydrologic methodology utilized is based on the guidance outlined in the May 2022 Brazoria County Drainage Criteria Manual (BCDCM). The study's simulation of hydrologic processes was conducted using the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) computer program (version 4.8) which is used to compute peak flows and generate runoff hydrographs applied in the Hydraulic Analysis.

3.1 Model development

The HEC-HMS model simulates stormwater runoff based on sub-basin parameters including drainage area, rainfall, soil infiltration losses, transformation of rainfall excess to runoff, and channel and overbank flood routing. Peak flows and storm runoff hydrographs were determined for the 10% (10-year), 2% (50-year), 1% (100-year) and 0.2% (500-year) annual chance rainfall events. The resulting storm water runoff hydrographs from each sub-basin are used as input within the hydraulic model simulation of the flood hazards for the study area.

The hydrology for the CIP simulation uses the same hydrology as that identified for the existing conditions. The proposed flood risk reduction ponds are assumed to be dry-bottom ponds that do not result in an increase in impervious cover and does not change the overall drainage characteristics of the sub-basins that encompass the ponds. This approach provides a direct determination of the benefits realized by adding storage to the overall drainage system within the study area.

3.2 Subbasin delineation

The sub-basins for the study area were delineated utilizing several sources for guidance. The final sub-basin boundary alignments were influenced by existing features such as recent aerial photographs of existing development, roadway and irrigation canal alignments, channel confluences, and topographic elevation contours. A combination of the TNRIS StratMap Upper Coast LiDAR 2018 and USGS Hurricane LiDAR 2019 were used to generate topographic elevation contours for the watershed. The resulting drainage area map of the sub-basins for existing and proposed conditions can be found in **Exhibits A-2** and **A-3** of **Appendix A** of this report.

3.3 Basin development factor (BDF)

The BDF is the measure of the level of improvements made to a basin's drainage system and thereby, the basin's conveyance and runoff routing efficiency. The BDF method is used to determine the time of concentration (TC) and storage coefficient (R) needed for Clark's Unit Hydrograph Method. The BDF method is composed of two main factors: 1) the main conveyance system (i.e., major drainage channels and principal tributaries) for the basin, and 2) the collector system for sub-areas of the basin. The BDF value ranges from 0 (representing basins with no improved conveyance systems) to 12 (representing areas with fully effective drainage systems). The BDF reflects improvements in the drainage system itself and does not directly account for impervious cover. The BDF value is based on the following parameters: basin area, length of channel flow, development type, and land use. The BDF Factor is determined using the following equation.

$$BDF = \frac{(I * 3) + (C * 6)}{N + I + C} + \frac{(OS * 1) + (R * 1.5) + (SS_{pre1992} * 3) + (SS_{post1992} * 6)}{U + OS + R + SS_{pre1992} + SS_{post1992}}$$

Where,

N = Length of natural channel (ft)

I = Length of improved channel (ft)

C = Length of concrete channel (ft)

U = Undeveloped area (ac)

OS = Open space graded to drain area (ac)

R = Developed area served by roadside ditch (ac)

$SS_{pre1992}$ = Pre-1992 developed area served by storm sewer (ac)

$SS_{post1992}$ = Post-1992 developed area served by storm sewer (ac)

Aerial imagery was used to define the boundaries for land use throughout the study area including undeveloped areas, open spaces graded to drain, developed areas served by roadside ditch, and areas developed before and after 1992 for each of the sub-basins. Refer to **Exhibit A-1** for the watershed land use. The factors determined for Existing, CIP, and Alternative conditions for each of the subbasins are listed in **Table A1** of the **Appendix A** section of this report.

3.4 Storm events

The hydrologic model for this study simulates the stormwater runoff in consideration of four (4) storm events. The storm event categories discussed within this report are in terms of percent Annual Chance Event (ACE) terminology. **Table 3.1** below relates this to the conventional annual recurrence interval nomenclature.

Table 3.1 Storm Event Nomenclature

Terminology	Percent Annual Chance Event
10-Year Storm	10% ACE
50-Year Storm	2% ACE
100-Year Storm	1% ACE
500-Year Storm	0.2% ACE

LiDAR data sets. The boundaries followed natural watershed ridge break lines where applicable and were influenced by specific points of interest along the stream such as at major roadway crossings and stream confluences (refer to **Exhibits A-2** and **A-3** located in **Appendix A** of this report). A total of twenty-six (26) sub-basins were identified for this study: fourteen (14) for the West Fork Chocolate Bayou watershed, six (6) for the North Hayes Creek watershed, and six (6) for the South Hayes Creek watershed.

3.6 Precipitation data

Precipitation data was obtained from the Brazoria County Drainage Criteria Manual dated May 10, 2022. The study area is located within the Region 1 rainfall area of the county. The total precipitation depths corresponding to the respective storm events reflect NOAA Atlas 14 rainfall values. **Table 3.2** provides a summary of the precipitation depths utilized in this study. For this study, the rainfall depths for the NOAA Atlas 14, 24-hour duration, 10-year (10% annual chance), 50-year (2% annual chance), 100-year (1% annual chance), and 500-year (0.2% annual chance) rainfall events were used as inputs in HEC-HMS to determine the peak flows for each of the sub-basin conditions.

Table 3.2: Total Precipitation Depths (Inches) for Brazoria County Region 1

RETURN PERIOD	5 MIN	15 MIN	1 HOUR	2 HOUR	3 HOUR	6 HOUR	12 HOUR	1 DAY
10-YEAR (10%)	0.86	1.73	3.33	4.32	4.97	6.15	7.43	8.83
50-YEAR (2%)	1.17	2.34	4.50	6.24	7.48	9.66	11.80	14.10
100-YEAR (1%)	1.31	2.61	5.05	7.23	8.84	11.6	14.30	17.00
500-YEAR (0.2%)	1.65	3.27	6.56	9.91	12.50	17.00	21.20	25.30

The rainfall hyetographs created in HEC-HMS are based on the Type III distribution (peak center of the storm at 67%) with an intensity-duration of 5 minutes. Additionally, the total storm area is input as 0.01 square miles to calculate runoff hydrographs based on BCDCM criteria.

3.7 Green and ampt loss method

This study uses the Green and Ampt loss method to calculate rainfall losses due to infiltration. This method was derived using a simplification of the comprehensive Richard's equation (1931) for unsteady water flow in soil. The parameters utilized in the methodology are:

- Initial Canopy Storage: the percentage of the canopy that is full of water at the beginning of the simulation.
- Max Canopy Storage: the maximum amount of water that can be stored in the canopy before fall-through to the surface begins (inches).
- Crop Coefficient: a ratio applied to the potential evapotranspiration when computing the amount of water to extract from the soil.

- Initial Content: the initial saturation of the soil at the beginning of the simulation (inches).
- Saturated Content: the maximum holding capacity of the soil (expressed as a volume ratio).
- Suction or Wetting Front Section: a function of the soil texture and is expressed in inches.
- Hydraulic Conductivity: the volume of water that will flow through a unit of soil in a given time (inches/hour).
- Impervious Cover: the percentage of the sub-basin which is impervious area (%).

The appropriate values have been established in the Brazoria County DCM and are referenced in **Table 3.3** below.

Table 3.3: Green and Ampt Loss Parameters in Brazoria County

INTIAL CANOPY STORAGE (%)	MAX CANOPY STORAGE (IN)	CROP COEFFICIENT	INITIAL CONTENT (IN)	SATURATED CONTENT	WETTING FRONT SUCTION (IN)	HYDRAULIC CONDUCTIVITY (IN/HR)
0	0.1	1	0.075	0.46	12.45	0.024

3.8 Clark's unit hydrograph method

The Clarks Unit Hydrograph Method is used to transform the excess runoff into the stormwater runoff hydrographs for each sub-basin. This method reflects two processes: 1) translation of excess runoff from its source to the outlet, and 2) attenuation of the excess rainfall due to surface storage within the drainage area. The translation and attenuation for a drainage basin, given its hydraulic conveyance characteristics, is reflected by the time of concentration (Tc) and storage coefficient (R) parameters.

The Basin Development Factor (BDF) method is used to determine the Tc and R values for each sub-basin. The BDF for a drainage area is a measure of the level of improvements made to a basin's drainage system and in turn, the basin's conveyance and runoff routing efficiency. The BDF is particularly helpful in identifying changes in the runoff response for a basin due to changes to the drainage conveyance characteristics.

When coupled with the BDF, TC and R reflect the runoff's response to drainage conveyance characteristics of the basin. The resulting TC and R values calculated for each sub-basin are presented in **Appendix A** of this report.

In general, Clark's Unit Hydrograph method is the most effective transform method for representing the ponding occurring within the subbasins of flat areas, such as Brazoria County. Clark's Unit Hydrograph method requires the time of concentration (TC) and a storage coefficient (R) for each subbasin to calculate the peak flow and create a hydrograph for each of

In general, Clark's Unit Hydrograph method is the most effective transform method for representing the ponding occurring within the subbasins of flat areas, such as Brazoria County. Clark's Unit Hydrograph method requires the time of concentration (TC) and a storage coefficient (R) for each subbasin to calculate the peak flow and create a hydrograph for each of the storm events. For the BDF method the TC and R are based on the BDF value, as well as, adjustment factors for slope, detention and ponding within a drainage area. The following set of equations are used to determine the final TC and R parameters for Clark's Unit Hydrograph Method.

$$T_r = 10^{[(-0.05228*BDF) + 0.4028\log_{10}(A) + 0.3926]}$$

$$TC_{BDF} = \left(T_r + \frac{\sqrt{A}}{2}\right)$$

$$R_{BDF} = 8.271e^{-0.1167*BDF} \text{ X } A^{0.3856}$$

$$TC = K_s * C_f * \left(T_r + \frac{\sqrt{A}}{2}\right)$$

$$R = K_s * C_f * RM_x * \left(8.271e^{-0.1167*BDF} * A^{0.3856}\right)$$

Where,

BDF = Basin Development Factor (0 to 12, dimensionless)

Ks = Slope factor (< 1)

Cf = Correction factor for detention (DR > 10)

Tr = Lag time (hr)

TCBDF = Time of concentration based on BDF (hr)

RBDF = Clark storage coefficient or residence time based on BDF (hr)

A = Watershed area to point of interest (sq. mi.)

DR = Detention rate for watershed or subwatershed (ac-ft/sq. mi.)

RMx = Ponding factor (x=return period) for DPP ≥ 20%

TC = Adjusted time of concentration (hr)

R = Adjusted Clark storage coefficient or residence time (hr)

Slope Adjustment Factor $\boldsymbol{K_s = -0.162 \ln(S * S_0) + 1.5232}$

Detention Adjustment Factor $\boldsymbol{Cf = 3*10-5*DR2-0.00095*DR+1}$

Ponding Adjustment Factor $\boldsymbol{RM_x = C_p * DPP^e}$

Where,

S = Channel slope measured along the entire watercourse (ft/mi)

So = Overland slope, avg. of multiple representative "perpendicular" slopes (ft/mi)

DR = Detention rate (ac-ft/sq. mi)

DPP = Percentage of the watershed affected by ponding (%)

Cp, e = Ponding Calibration Coefficients (**Table 3.4**)

Table 3.4: Ponding Adjustment Equation Coefficients per Return Period

Return Period (Years)	$\boldsymbol{C_p}$	$\boldsymbol{e}$
10-year	1.28	0.199
50-year	1.23	0.153
100-year	1.21	0.132
500-year	1.17	0.086

The information used to calculate the slope adjustment factor were determined for each sub-basin using the elevations provided from the 2018 and 2019 LiDAR terrain data sets. To estimate the detention volumes within each subbasin, existing detention ponds were identified with the use of current aerial imagery, and 2021 Brazoria County parcel data. For each pond, the detention rate (assumed to be 0.65 ac-ft/ac based on current regulations) was multiplied by the parcel area containing the detention pond to estimate the detention volume. The sum of the detention volume of the parcels located within each subbasin is used to estimate the overall detention rate for each subbasin to calculate the detention adjustment factor.

For the study area, ponding is assumed to occur in rice fields and other low-lying depressions. To quantify the ponding adjustment factor, the areas of ponding were identified and outlined to determine their area using aerial imagery. The ponding area and the empirical ponding calibration coefficients, which are unique for each storm event frequency, are used to determine the ponding adjustment factor applied to the storage coefficient for each subbasin and storm event.

3.10 Comparison of peak flows

The FEMA FIS provides a summary of the peak flows for the three streams considered in this MDP. However, a direct comparison of the FEMA flows to the MDP existing-conditions flows cannot be performed as these flows are based on different methodology for computing stormwater runoff for the watershed.

For an attempted comparison, the FEMA 1% ACE storm flows for the streams are compared to the MDP existing conditions 2% ACE storm flows. The 24-hour, 1% ACE total precipitation for pre-Atlas 14 rainfall is 13.5 inches. The Atlas 14 24-hour, 2% ACE total precipitation value is 14.1 inches. The total depth of precipitation is fairly close with a difference of 1.1 inches. **Table 3.5** provides a summary of the peak flow comparisons.

Table 3.5. Peak Flow (cfs) Comparisons

FEMA LOCATION	HEC-RAS STATION	GENERAL LOCATION	FEMA 1% ACE	MDP 2% ACE	DIFFERENCE
WEST FORK CHOCOLATE BAYOU					
CONFLUENCE WITH CHOCOLATE BAYOU	165	At Chocolate Bayou	3,734	2,923	-811
1,600 FT UPSTREAM OF CR 67	14440	Confluence with 101-05-00	3,131	3,355	224
1,000 FT UPSTREAM OF SH 288	32138	State Highway 288	2,418	2,753	335
1,300 FT UPSTREAM OF CR 81	39472	Confluence with 101-01-00	1,470	1,664	194
NORTH HAYES CREEK					
AT RIVER MILE 0	349	At Chocolate Bayou	1,238	1,585	347
AT RIVER MILE 1.09	6045	Confluence with Tributary	1,104	1,475	371
SOUTH HAYES CREEK					
AT RIVER MILE 1.36	7748	Confluence with Tributary	1,671	1,276	-395
AT RIVER MILE 3.43	18667	Iowa Colony Blvd	1,643	998	-645
AT RIVER MILE 3.99	21326		1,262	1,110	-152
AT RIVER MILE 5.19	27494	Confluence with Tributary	1,134	1,052	-82
AT RIVER MILE 6.03	32114	County Road 48	829	628	-201
AT RIVER MILE 7.46	37203	Upstream Limit of Detailed Study	622	300	-322

The peak flow for the existing conditions MDP is determined using the RASMapper feature in the HEC-RAS computer program. RASMapper has the ability to calculate the combined peak flow values determined across each 2D cell along a profile (i.e., cross section) alignment. Cross sections with an alignment across the floodplain were identified at locations approximating those identified in the FEMA FIS for each stream. As expected, there is a lot of variation between the peak flows. This can be attributed to the effects of the overbank storage as well as cross-basin flows leaving one watershed and contributing to the flows of another. This is clarified in **Figure 3.1** which reflects the extent of flooding within the study area and how the floodplains for all three streams are merged at various locations. Clarification of the existing flood hazards are also shown in **Exhibit 4** through **Exhibit 8**.

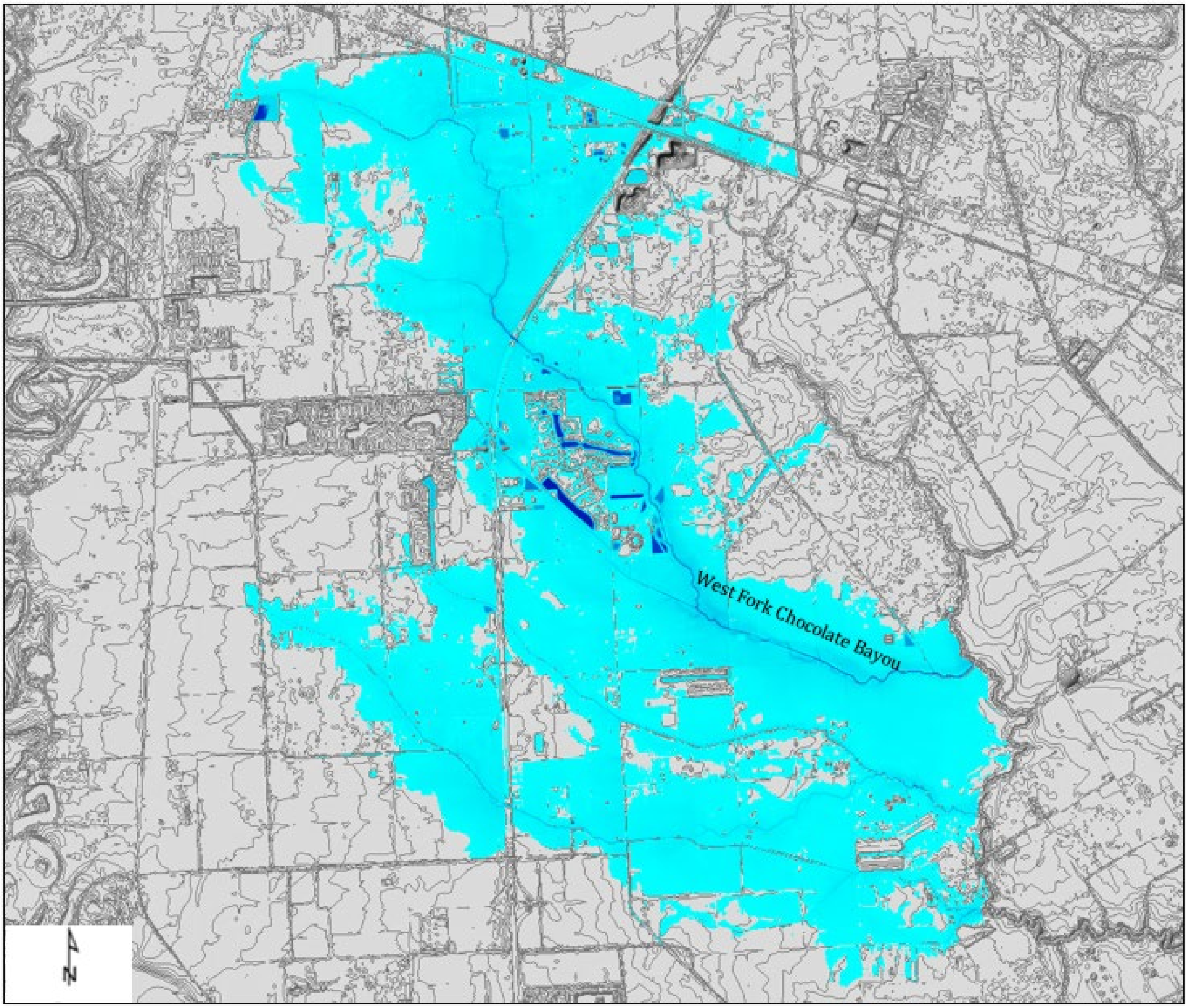

Figure 3.1 2% MDP Existing Conditions Inundation Map

3.11 HEC-HMS inputs and results

Tables A1, A2 and **A3** located in **Appendix A** contain the parameters used to calculate the BDF, Tc and R values for each sub-basin considered within the study area for the Existing, CIP and Alternative project conditions. Existing conditions of the study area and the boundaries delineated for subbasins are reflected in **Exhibit A-2** located in **Appendix A**. The location of the ponds assumed in CIP can be found in **Exhibit 14**. The ponds and channel improvements for the Alternative improvement project can be found in **Exhibit 23**.

For this study, the alternatives analyses do not consider future development, based on the assumption that future development will detain to mitigate any potential impacts to the streams. Therefore, most subbasin boundaries, HEC-HMS parameters and resulting hydrographs are assumed to remain the same from existing to the CIP plan. However, the BDF factors are updated for the Alt plan to reflect the channel improvements as shown on **Exhibit A-4**. The tables in **Appendix A** show the computed parameters for the loss and transform method**.**

4.0 Hydraulic modeling

A 1D/2D unsteady flow hydraulic model was used to determine the current flood hazard and quantify the benefits of two flood reduction alternatives for Iowa Colony and ETJ. The United States Army Corps of Engineers' hydraulic modeling software HEC-RAS (version 6.3.1) was used for the 1D/2D analysis of the study area. As recommended in the May 2022 Brazoria County Drainage Criteria Manual (BCDCM), the Harris County Flood Control District's document titled Two-Dimensional Modeling Guidelines (HCFCD, July 2018) is referenced for the 1D/2D hydraulic modeling procedures and approach for documenting results.

4.1 Model development

Models were created to determine the extent of flood hazards for the study area resulting from the 10-year, 50-year, 100-year and 500-year storm events for existing, CIP and alternative project conditions. The following section describes the detailed inputs, methodology, and results for the HEC-RAS 1D/2D model.

The 1D/2D modeling approach was chosen for the simulation of flood hazards due to the very flat terrain of the watershed and variable flow patterns anticipated along the overbank areas within the study area. The portion of the channels within the limits of the high banks is modeled using the 1-dimensional flow approach. This is considered acceptable since the flow path is generally known, following the alignment of the channel and contained within the high banks. The flow along the overbanks outside of the channel high banks is modeled using the 2-dimensional flow approach. Once the channel high bank is overtopped and/or breached, the water can go in many directions along the overbank.

4.2 Existing conditions

The terrain created to represent existing conditions was developed from the Texas Natural Resources Information System (TNRIS) StratMap 2018 Upper Coast LiDAR data set (50 cm resolution) and supplemented with the TNRIS USGS 2019 Hurricane LiDAR data set (70 cm resolution). Both LiDAR data sets were surveyed by Fugro Geospatial, Inc. Multipoint files were projected and adjusted into Horizontal NAD83 State Plan projection and Vertical NAVD88 elevation using U.S. foot measurement. Both the hydrologic and hydraulic analysis for the study area were completed based upon this topographic data. Additional modifications were included to the terrain to account for development built between 2018, when the LiDAR was taken, and present conditions. The modifications to the terrain were input by creating surfaces in AutoCAD Civil 3D based on approved and constructed plans and merged with the 2018 and 2019 LiDAR.

There are three tributaries to Chocolate Bayou modeled in HEC-RAS including West Fork of Chocolate Bayou, North Hayes Creek and South Hayes Creek. The cross-section locations and bridge information for West Fork of Chocolate Bayou are based on the models built and updated in the approved Drainage Impact Analysis for the Phase Three Development of Meridiana, Revised December 2017 for HEC-RAS. The cross-section locations and some bridges were based on the HEC-2 FEMA models for North Hayes Creek and South Hayes Creek. However, the elevations within the cross-section are determined using the existing

LiDAR. The cross-sections were trimmed to the respective channel high banks and a uniform manning's n-value (channel roughness) of 0.050 was assumed for the natural channels.

For the unsteady flow simulation, HEC-RAS converts the cross-section geometry into a set of curves defining relationships between hydraulic parameters and stage. To define the curve for each cross section, hydraulic tabulation (Htab) parameters are needed. For the channel HTab parameters, starting elevations was set to the minimum channel elevation and increments were set to 0.1 with 200 points to calculate the rating curves for each of the cross-sections. The HTab parameters at bridges and culverts use the HEC-RAS default number of points and curves. The head water maximum elevation at each crossing structure is set to be 1.0 foot above the bridge deck elevation.

For West Fork, the inputs for the bridges and culverts were based on the updated models for the Meridiana development. However, since there were no existing HEC-RAS models for South and North Hayes Creeks, the inputs for the bridges and culverts were based on the HEC-2 models of these streams available from Brazoria County. Modifications to many of the structures were made to account for adjustments to the alignment and bridge geometry, or removed entirely based on the inspecting aerial imagery and recent maintenance reports. Additional bridges and culverts were missing from the HEC-2 models and were added using the elevations and images provided via a 2022 topographic survey. However, some bridges or culverts were not analyzed due to lack of information. **Exhibit 10** shows the location of bridges and culverts along the three streams within the study area.

Lateral structures are used within the HEC-RAS model to connect the 1D cross-sections to the 2D mesh. These structures were identified with alignments following the high banks of the channel along the edge of the cross-sections. The lateral structures are simulated to have a width of 1-ft and a weir coefficient of 0.5 (assumed to represent the transfer between the 1D and 2D domain without any major change in elevation). The 2D mesh was then created by generally outlining the subbasin areas determined in the hydrologic analysis with a maximum mesh size of 400-ft x 400-ft.

Breaklines are used along the crest of high ground features within the 2D mesh to enforce cell faces along these features and correctly direct the movement of water through the 2D domain. Breaklines were drawn and enforced along major roads, elevated areas, non-studied waterways and ponds at the highest elevations. The mesh size of 2D cells adjacent to breaklines is held to a minimum of 100-ft by 100-ft and a maximum mesh size of 300-ft by 300-ft.

The 2D boundary condition lines were established as the final step of the existing geometry. One was placed roughly covering the northern, southern, and western boundary of the project area. Along the eastern boundary where the stream outfalls are located, three boundaries were placed adjacent to the stream outfalls. Boundary conditions were drawn just upstream of the most upstream cross section of each river and the appropriate flow hydrograph was used for those boundary conditions. The 1D/2D HEC-RAS geometry for existing conditions can be found in **Exhibit B-2** of the **Appendix B** section of this report.

4.3 Capital improvement plan

The proposed Capital Improvement Plan conditions include the addition of nine (9) regional flood risk reduction ponds along the three streams, see **Exhibit 14**. The CIP geometry was created by copying the existing-conditions geometry and modifying the terrain to represent the proposed ponds. Specifically, the 2D mesh was modified by removing the terrain data from within the boundaries of the proposed ponds. These areas are replaced with a storage features having stage-volume relationships. Along the border each pond, additional lateral structures were incorporated to provide a flow connection between the ponds and the 2-D mesh. No changes were made to the stormwater runoff hydrographs.

4.4 Alternative analysis

Alternative conditions include the ponds proposed in Capital Improvement Plan with additional channel modifications along the three main streams of the study area. The channel modifications are included to provide additional flood conveyance capacity. **Exhibit 23** provides a summary of the drainage concept for this alternative plan.

Therefore, in the geometry, cross-sections were widened to the accommodate the channelization. For West Fork, the ultimate right-of-way was assumed to be 175-feet with a bottom width of 60-ft, while in North and South Hayes the proposed right-of-way was assumed to be 150-ft, with a bottom width of about 35-ft. The bottom widths were assumed to begin 1-ft above the existing mimimum elevaiton of the channel to avoid triggering environmental permiting. **Figure 4.1** shows the typical cross-section changes from existing to the proposed channel improvements implemented in the Alternative Analysis.

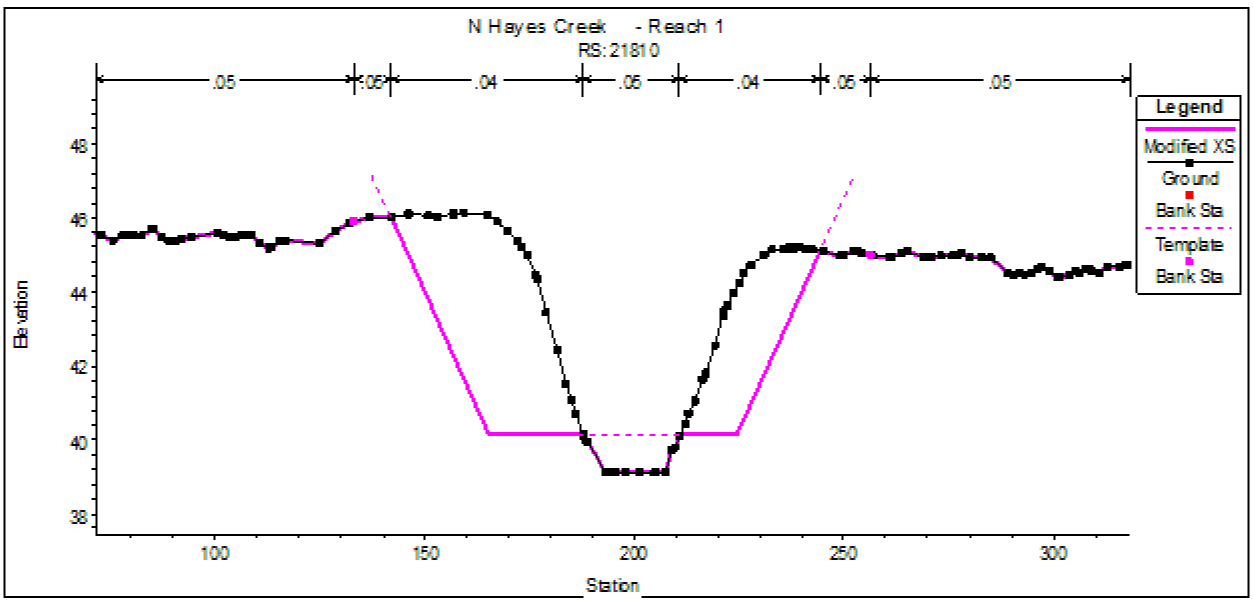

Figure 4.1: Typical Channel Improvement Cross-section

Adjustments were made the overbank weirs along the lateral structures and outfall pipes to reflect the extended cross-sections and widened channels. These channels were gradually reduced on the downstream end to allow for a smooth transition into the downstream unimproved condtions. The mannning's n value for the channelized areas were updated to 0.04.

4.5 Unsteady flow data and plans

A total of five (5) plans were created for each of the geometry files analyzed, a restart file (to create stable initial conditions) and each rainfall event analyzed (10-year, 50-year, 100-year, and 500-year). A restart plan was created with each of the model geometries and an Unsteady Flow File (RST) for each of the conditions, to stabilize the model in the beginning of the run time. **Appendix B** shows the model plan settings used to run the HEC-RAS models.

4.6 Manning's roughness coefficients

Manning's "n" values for the channel sections were assigned by visual inspection and assessment of available aerial imagery. Further, the existing available model data for the streams were reviewed to identify the values referenced.

Overbank "n" values within the 2D hydraulic meshes are associated with different land uses within the study area. Development of the land use dataset for association with overbank "n" values began with searching for existing land use datasets within the study area. The 2015 National Land Cover dataset (NLCD) covers the entire study area. The land cover classification was updated based on aerial imagery as needed to reflect recent development, see **Exhibit B-1**.

This analysis did not include calibration of n values. Rather, the 2D Manning's n values applied are based on the values included in *Table 3.3.1* of the *Harris County Flood Control District Two-Dimensional Modeling Guidelines*.

4.7 Cross sections

Model cross sections were closely based on the alignment of the effective cross sections where applicable and truncated since only the main channel is represented as 1-dimensional. New channel cross sections were created where needed. The overbank areas are modeled as 2dimensional cells using terrain data reflecting 2018 LiDAR elevations. For developments which occurred since 2018 or are currently in progress, the LiDAR is modified to reflect final grades depicted on construction drawings.

4.8 Boundary conditions

Normal depth based on the slope of the land was used for the downstream boundary condition for each of the streams for the 1D portion of the model. Sub-basin inflows were applied to the 1D portions of the model as lateral or uniform lateral inflows. Normal depth boundary conditions were applied to the 2D mesh boundaries where portions of the flow left the model system for neighboring watersheds beyond the limits of the study.

Lateral structures are used to provide a flow transition feature between the 1-dimensional cross-section elements of the model to the 2-dimensional grid mesh. The alignments for the lateral structures follow the high banks along each stream and represent the end of the 1-dimensional channel sections.

4.9 Hydraulic results comparison

Profiles of the studied streams were computed, and areas of maximum inundation determined using the RASMapper feature within the HEC-RAS program.

Comparison of FEMA vs. MDP Existing

A direct comparison of the hydraulic results of the existing-conditions MDP flood hazards to the FEMA flood hazards is not possible since both use different methodologies for the computation of peak flows as well as water surface profiles. The flood hazards identified in the FEMA FIS utilize steady flow backwater calculations whereas the MDP utilizes unsteady flow calculations. Since the 1D/2D models were not calibrated to gauged peak flows or water surface elevation data, an attempt is made to compare the results to the FEMA 1D models to provide some validation.

For an attempted comparison, the FEMA 1% ACE flood elevations for the streams are compared to the MDP existing conditions 2% ACE flood elevations. The 2% ACE flood elevations of the MDP are used for comparison since the flood flows are based on an Atlas 14 total precipitation depth that is close to the pre-Atlas 14 1% ACE total precipitation depths referenced in the FEMA FIS. **Tables 4.1** through **4.3** provide a summary of the water surface elevation comparisons for the three streams within the study area.

Table 4.1. Flood Profile Elevation (ft) Comparison (West Fork Chocolate Bayou)

FEET ABOVE CONFLUENCE WITH CHOCOLATE BAYOU	HEC-RAS STATION	GENERAL LOCATION	FEMA 1% ACE	MDP 2% ACE	DIFFERENCE
2,296	2449	Tributary Confluence	38.9	37.7	-1.2
5,350	4024		39.1	38.6	-0.5
8,145	8320	CR 63 (Future)	39.5	40.9	1.4
9,228	10945		39.9	42.4	2.5
13,112	13220	CR 67	42.4	44.1	1.7
17,689	17779	CR 64	44.9	46.2	1.3
19,848	19920		45.4	47.2	1.8
23,540	23306	Meridiana Pkwy	47.2	49.3	2.1
27,674	27070	D/S of North Canal	49.8	50.8	1.0
32,070	31011	D/S/ SH 288	51.7	52.7	1.0
35,420	33855	Tributary Confluence	53.0	54.6	1.6
38,370	37923	CR 81	53.9	55.2	1.3
40,330	39472	Tributary 101-01-00	54.3	55.5	1.2
44,440	43626	D/S CR 383	55.8	56.9	1.1
48,370	46928		57.3	57.3	0.0
50,985	50013		58.0	57.7	-0.3

Table 4.2. Flood Profile Elevation (ft) Comparison (North Hayes Creek)

FEET ABOVE CONFLUENCE WITH CHOCOLATE BAYOU	HEC-RAS STATION	GENERAL LOCATION	FEMA 1% ACE	MDP 2% ACE	DIFFERENCE
3,240	3689		37.2	35.9	-1.3
3,640	3997	Private Drive Crossing	37.2	36.1	-1.1
6,770	7159		38.7	37.5	-1.2
7,270	7607	Wooden Bridge Crossing	39.9	37.8	-2.1
10,600	11065		41.8	40.2	-1.6
13,400	13776	CR 67	43.4	41.8	-1.6
14,300	14581		44.0	42.3	-1.7
17,362	17725		44.8	43.9	-0.9
19,713	20159	CR 62	47.4	45.2	-2.2
22,410	22732	CR 63	48.2	46.3	-1.9
26,340	26405	SH 288	48.8	48.9	0.1
27,990	28169	CR 758 (future)	49.3	49.3	0.0
30,400	30742	CR 64	51.1	50.0	-1.1

Table 4.3. Flood Profile Elevation (ft) Comparison (South Hayes Creek)

FEET ABOVE CONFLUENCE WITH CHOCOLATE BAYOU	HEC-RAS STATION	GENERAL LOCATION	FEMA 1% ACE	MDP 2% ACE	DIFFERENCE
3,020	3380	CR 121	35.7	34.1	-1.6
6,270	6801	Tributary Confluence	37.8	37.2	-0.6
7,900	8443		38.4	38.4	0.0
9,870	10267		40.9	39.6	-1.3
11,650	12382	CR 67 (future)	42.1	41.2	-0.9
14,220	14384		43.3	42.2	-1.1
18,130	18667	CR 65	45.6	44.8	-0.8
20,880	20923		46.4	46.5	0.1
24,200	24358	SH 288	48.1	48.2	0.1
24,770	24663		48.5	48.7	0.2
28,720	29063		50.8	50.1	-0.7
30,320	30342	CR 62	51.6	50.9	-0.7
32,120	32190	CR 48	52.2	51.5	-0.7
34,810	34868	CR 382	53.6	52.7	-0.9
37,260	37203		54.6	53.4	-1.2

The comparison in the previous tables is based on the FEMA floodway data table for flood elevations without floodway and without consideration of backwater effect from Chocolate

Bayou. The results provide varying degrees of differences between computed water surface elevations for all the streams. A comparison of the extents of flooding between the two simulations is shown in **Figure 4.2**.

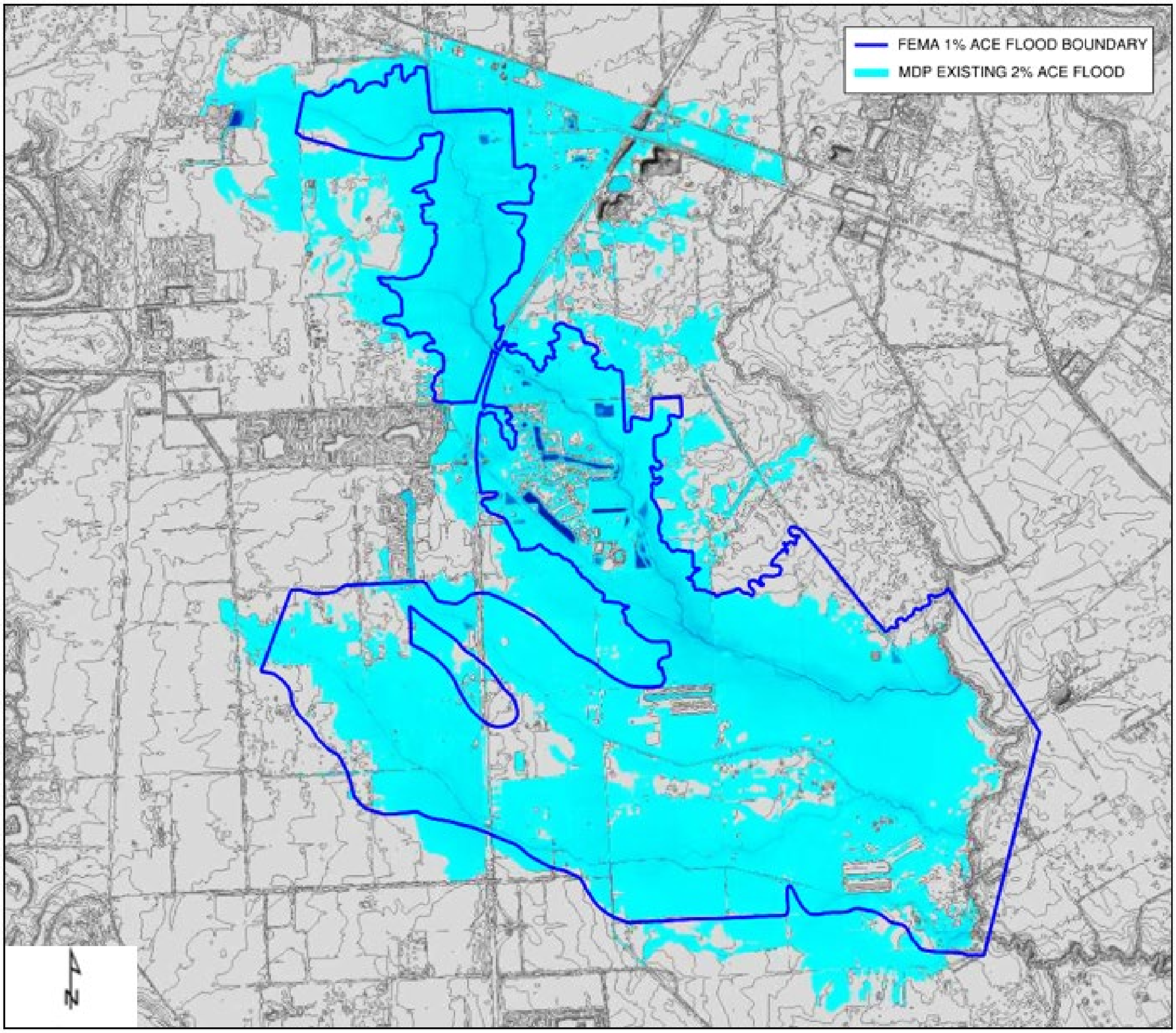

Figure 4.2: Flood Hazard Inundation Map Comparison

As expected, there is substantial variation in the limits of flood inundation. In the lower reach of the streams, the FEMA flood boundary includes the extent of inundation that is caused by backwater from Chocolate Bayou. In the upper reach of West Fork Chocolate Bayou, the MDP extent of flooding appears to exceed that of the FEMA floodplain. This correlates well with the increase in flood elevation referenced in **Table 4.1**. The MDP extent of flooding in the upper reaches of North Hayes Creek and South Hayes Creek appear to be less than that identified for the FEMA floodplain. This correlates well with the decrease in flood elevations referenced in **Tables 4.2** and **4.3**.

The flood depths across the three streams vary as shown in **Figure 4.3**. This figure reflects the interaction of the flows across the stream watersheds and how the depth of flooding is represented across the 2-dimensional terrain mesh.

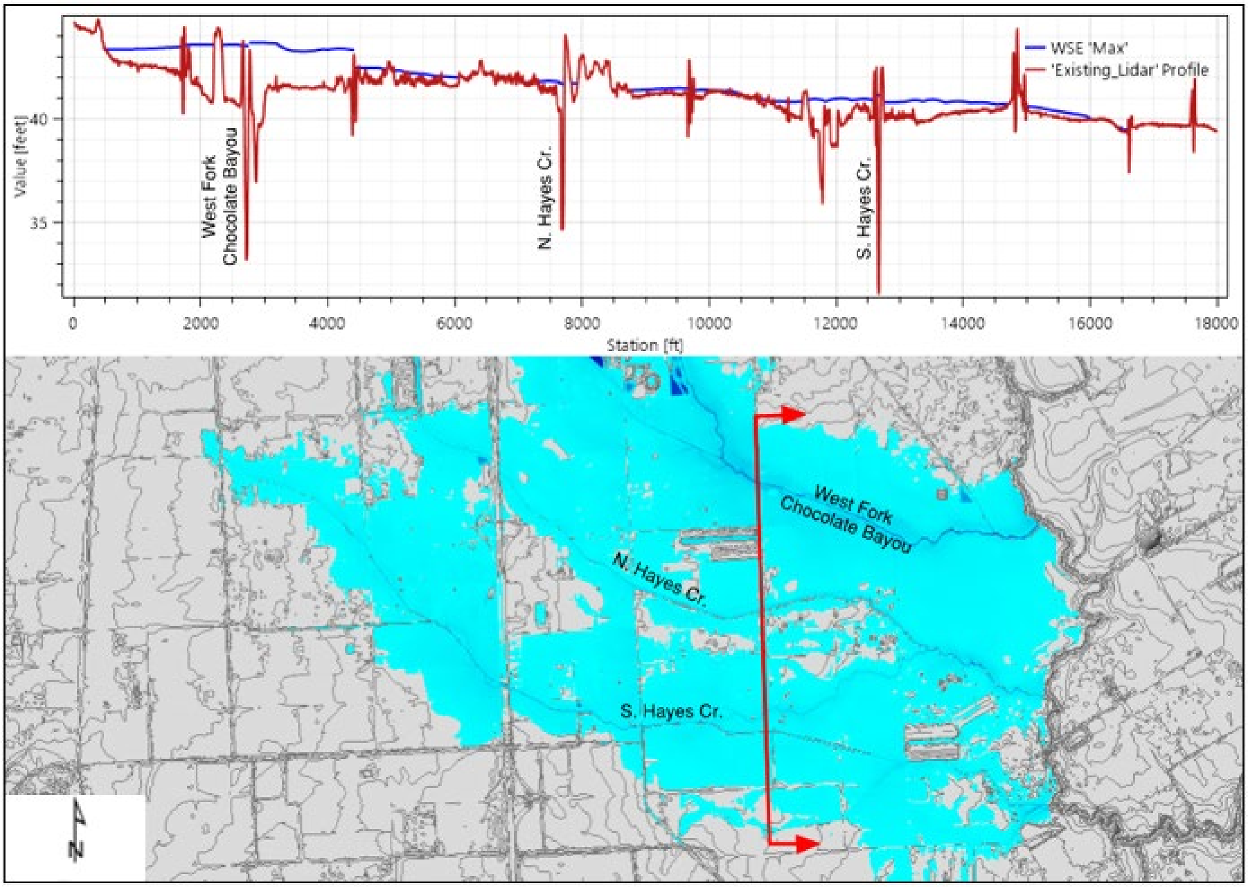

Figure 4.3. Typical Cross Section Across Study Area 0.2% ACE Floodplain

Based on the above, it is concluded that a direct comparison to the FEMA flood hazards is not possible. Rather, the results of the MDP modeling efforts reflect reasonable representations of the current flood hazards for the study area based on current regional drainage criteria, recently adopted precipitation, and updated terrain. This information is acceptable for assessing existing flood risks throughout the watershed and identifying the appropriate recommended master drainage plan features for the study area.

Comparison of Existing vs. CIP

A direct comparison of the hydraulic results of the existing-conditions MDP flood hazards to Capital Improvements Plan (CIP) flood hazards is made for the 1% ACE flood. A detailed comparison of the 1-dimensional results along the channel cross sections is presented in **Appendix B**. The change in the 1% ACE flood elevations within the 2-dimensional terrain mesh simulation is presented in **Exhibit 18**. The results suggest that there will be minimal reduction to the maximum water surface elevations within the study area. The following **Tables 4.4** through **4.6** provide an abbreviated summary of the maximum water surface elevation along the channel at specific locations for the 1% ACE flood. Additional description of the CIP flood reduction project is presented in **Section 7.1** of this report.

Table 4.4. 1% Annual Chance Flood Elevation (ft) – Existing vs CIP (West Fork Chocolate Bayou)

FEET ABOVE CONFLUENCE WITH CHOCOLATE BAYOU	HEC-RAS STATION	GENERAL LOCATION	EXIST	CIP	DIFFERENCE
2,296	2449	Tributary Confluence	37.89	37.84	-0.05
5,350	4024		38.85	38.78	-0.07
8,145	8320	CR 63 (Future)	41.20	41.09	-0.11
9,228	10945		42.65	42.57	-0.08
13,112	13220	CR 67	44.49	44.37	-0.12
17,689	17779	CR 64	46.52	46.41	-0.11
19,848	19920		47.48	47.40	-0.08
23,540	23306	Meridiana Pkwy	49.57	49.50	-0.07
27,674	27070	D/S of North Canal	51.00	50.92	-0.08
32,070	31011	D/S/ SH 288	52.99	52.90	-0.09
35,420	33855	Tributary Confluence	54.91	54.79	-0.12
38,370	37923	CR 81	55.43	55.33	-0.10
40,330	39472	Tributary 101-01-00	55.79	55.71	-0.08
44,440	43626	D/S CR 383	57.13	57.03	-0.10
48,370	46928		57.53	57.50	-0.03
50,985	50013		57.91	57.90	-0.01

Table 4.5. 1% Annual Chance Flood Elevation (ft) – Existing vs CIP (North Hayes Creek)

FEET ABOVE CONFLUENCE WITH CHOCOLATE BAYOU	HEC-RAS STATION	GENERAL LOCATION	EXIST	CIP	DIFFERENCE
3,240	3689		36.40	36.11	-0.29
3,640	3997	Private Drive Crossing	36.63	36.33	-0.30
6,770	7159		38.06	37.77	-0.29
7,270	7607	Wooden Bridge Crossing	38.36	38.10	-0.26
10,600	11065		40.84	40.58	-0.26
13,400	13776	CR 67	42.29	42.12	-0.17
14,300	14581		42.67	42.56	-0.11
17,362	17725		44.17	44.10	-0.07
19,713	20159	CR 62	45.52	45.54	0.02
22,410	22732	CR 63	46.57	46.26	-0.31
26,340	26405	SH 288	49.18	49.18	0.00
27,990	28169	CR 758 (future)	49.58	49.58	0.00
30,400	30742	CR 64	50.30	50.30	0.00

Table 4.6. 1% Annual Chance Flood Elevation (ft) – Existing vs CIP (South Hayes Creek)

FEET ABOVE CONFLUENCE WITH CHOCOLATE BAYOU	HEC-RAS STATION	GENERAL LOCATION	EXIST	CIP	DIFFERENCE
3,020	3380	CR 121	34.26	34.13	-0.13
6,270	6801	Tributary Confluence	37.43	37.33	-0.10
7,900	8443		38.57	38.51	-0.06
9,870	10267		39.73	39.67	-0.06
11,650	12382	CR 67 (future)	41.40	41.37	-0.03
14,220	14384		42.42	42.54	0.12
18,130	18667	CR 65	45.23	45.06	-0.17
20,880	20923		46.77	46.75	-0.02
24,200	24358	SH 288	48.72	48.72	0.00
24,770	24663		49.30	49.30	0.00
28,720	29063		50.32	50.32	0.00
30,320	30342	CR 62	51.09	51.09	0.00
32,120	32190	CR 48	51.66	51.66	0.00
34,810	34868	CR 382	52.95	52.95	0.00
37,260	37203		53.75	53.75	0.00

Comparison of Existing vs. Alt

A direct comparison of the hydraulic results of the existing-conditions MDP flood hazards to Alternative (Alt) flood hazards is made for the 1% ACE flood. A detailed comparison of the 1-dimensional results along the channel cross sections is presented in Appendix B. The change in the 1% ACE flood elevations within the 2-dimensional terrain mesh simulation is presented in Exhibit 27. The results suggest that there will be a significant reduction in the maximum water surface elevations in the upper reaches of the study area. However, the Alt plan also results in significant increases in flood elevation in the lower reaches of the study area. The following Tables 4.7 through 4.9 provide an abbreviated summary of the maximum water surface elevation along the channel at specific locations for the 1% ACE flood. Additional description of the CIP flood reduction project is presented in Section 7.2 of this report.

Table 4.7. 1% Annual Chance Flood Elevation (ft) – Existing vs Alt (West Fork Chocolate Bayou)

FEET ABOVE CONFLUENCE WITH CHOCOLATE BAYOU	HEC-RAS STATION	GENERAL LOCATION	EXIST	ALT	DIFFERENCE
2,296	2449	Tributary Confluence	37.89	38.15	0.26
5,350	4024		38.85	39.13	0.28
8,145	8320	CR 63 (Future)	41.20	41.53	0.33
9,228	10945		42.65	42.95	0.30
13,112	13220	CR 67	44.49	44.93	0.44
17,689	17779	CR 64	46.52	46.63	0.11
19,848	19920		47.48	47.10	-0.38
23,540	23306	Meridiana Pkwy	49.57	48.61	-0.96
27,674	27070	D/S of North Canal	51.00	50.60	-0.40
32,070	31011	D/S/ SH 288	52.99	52.69	-0.30
35,420	33855	Tributary Confluence	54.91	54.63	-0.28
38,370	37923	CR 81	55.43	55.21	-0.22
40,330	39472	Tributary 101-01-00	55.79	55.63	-0.16
44,440	43626	D/S CR 383	57.13	56.79	-0.34
48,370	46928		57.53	57.34	-0.19
50,985	50013		57.91	57.96	0.05

Table 4.8. 1% Annual Chance Flood Elevation (ft) – Existing vs Alt (North Hayes Creek)

FEET ABOVE CONFLUENCE WITH CHOCOLATE BAYOU	HEC-RAS STATION	GENERAL LOCATION	EXIST	ALT	DIFFERENCE
3,240	3689		36.40	36.66	0.26
3,640	3997	Private Drive Crossing	36.63	36.89	0.26
6,770	7159		38.06	38.33	0.27
7,270	7607	Wooden Bridge Crossing	38.36	38.63	0.27
10,600	11065		40.84	41.06	0.22
13,400	13776	CR 67	42.29	42.45	0.16
14,300	14581		42.67	42.73	0.06
17,362	17725		44.17	43.29	-0.88
19,713	20159	CR 62	45.52	44.58	-0.94
22,410	22732	CR 63	46.57	45.54	-1.03
26,340	26405	SH 288	49.18	47.81	-1.37
27,990	28169	CR 758 (future)	49.58	49.20	-0.38
30,400	30742	CR 64	50.30	50.28	-0.02

Table 4.9. 1% Annual Chance Flood Elevation (ft) – Existing vs Alt (South Hayes Creek)

FEET ABOVE CONFLUENCE WITH CHOCOLATE BAYOU	HEC-RAS STATION	GENERAL LOCATION	EXIST	ALT	DIFFERENCE
3,020	3380	CR 121	34.26	34.38	0.12
6,270	6801	Tributary Confluence	37.43	37.62	0.19
7,900	8443		38.57	38.66	0.09
9,870	10267		39.73	39.81	0.08
11,650	12382	CR 67 (future)	41.40	41.53	0.13
14,220	14384		42.42	42.46	0.04
18,130	18667	CR 65	45.23	44.39	-0.84
20,880	20923		46.77	45.98	-0.79
24,200	24358	SH 288	48.72	48.16	-0.56
24,770	24663		49.30	48.83	-0.47
28,720	29063		50.32	50.05	-0.27
30,320	30342	CR 62	51.09	50.77	-0.32
32,120	32190	CR 48	51.66	51.46	-0.20
34,810	34868	CR 382	52.95	52.81	-0.14
37,260	37203		53.75	53.74	-0.01

5.0 Existing conditions flood risk analyses

The resulting water surface elevations from the HEC-RAS 1D/2D modeling was used to identify the riverine flooding hazard for the study area. This effort resulted in maps for the 1% and 0.2% annual chance flood events. Using GIS analyses, flood exposure analyses were prepared to determine risk elements including, number of structures, length of roadway, population, and agricultural areas within the 1% and 0.2% annual chance flood hazard areas. The resulting level of service determined for the existing channel system is shown in **Exhibit 9**. **Exhibits 11** through **13** show the areas of existing inundation and the impacts to existing building, agricultural land, and roadways.

Additional GIS datasets used for the analyses included November 2021 structures dataset (manually updated to include structures constructed up to October 2022 based on satellite imagery), road centerlines from TxDOT, and 2018 LiDAR from TNRIS updated with estimated finished grading for development added since 2018. The November 2021 structures dataset from TWDB, which uses underlying TNRIS structures with duplicate structures removed and additional information including the Land use type (TNRIS), social vulnerability index (CDC), and estimated population for day and night (ORNL and TWDB), was used as a base layer, with additional structures added for development that has occurred up to October 2022. The finished floor elevation of the structure is assumed to be at natural ground based on 2018 LiDAR (Stratmap) taken at the centroid of the structure.

5.1 Existing conditions flood hazards

To quantify the benefits of the proposed drainage improvements, an existing conditions flood risk analysis was prepared. The results of the HEC-RAS 1D/2D analysis is used to delineate areas that would be inundated by the 100-year (1% annual chance) and 500-year (0.2%annual chance) storm events (see **Exhibit 4**).

The level-of-service for each channel segment and the overall pre-project condition was estimated by determining which storm event could be contained within the channel banks. **Exhibit 9** shows the existing conditions level-of-service for each channel segment. Overall, each of the channels failed to contain the 10-year flows for a majority of the stream and therefore the existing conditions are rated as less than a 10-year storm event capacity for the study area.

The depth of flooding at each structure for all storm events was determined by overlaying the water surface elevation and compared to the finished floor elevation assumed for the structure. The number of structures with an inundation depth determined to be at or above 1-inch were recorded, and separated by structure type. The estimated damages were also calculated using the depth-damage function assumed from the TWDB BCA Input Worksheet to calculate the total estimated damages per storm event as a baseline to determine benefits. The flooded structures are shown in **Exhibit 11**.

As part of this analysis, there are many additional benefits that may be quantified but are not easily attached to a direct monetary cost and are generally not included in the traditional BCR calculation. One of the additional benefits calculated in this study is the benefit to the population directly affected by the flood risk. The metrics used in this study to determine direct benefits relating to the population are analyzing the population directly affected at the time of the event and the community's ability to recover from the flood damages. The structure data provided by TWDB contained an estimate of the number of people residing in a structure during the day and at night. The social vulnerability index (SVI), an indicator of at-risk communities, was also attached to each of the structures in the data received from TWDB. The total number of people within all structures determined to have a flood depth greater than 1-inch were assumed to be affected. Additionally, the average SVI of all of the inundated structures for each of the storm events are compared to assess a community's ability to respond.

The study area has a significant portion of land dedicated to farming and ranching; therefore, an additional mitigation of flood risk is reducing inundated agricultural land, especially for extended periods of time. Therefore, an additional potential risk to inhabitants is quantified by calculating the amount of agricultural land inundated 6-inches of flood depth or greater in existing conditions for extreme flood events. **Exhibit 12** shows the agricultural land at risk for the extreme rainfall events in existing conditions.

Another concern when it comes to flood risk is limited accessibility by roadway. The length of inundated roadway is determined considering the maximum depth in the roadway for the extreme rainfall events in the study area to determine the impacts to the transportation and mobility. For this analysis, the roadway is assumed to be impassible when the flood depth reaches above 6-inches in the center line. The total length of road considered impassible for each of the extreme rainfall events was determined as a baseline to calculate project benefits and is shown in **Exhibit 13**. **Table 5.1** shows the existing flood risks calculated in this study.

Table 5.1. Existing Flood Risk

Flood Risk	Value
Area in 100-yr (1% annual chance) Floodplain (acres)	10,432.7
Area in 500-yr (0.2% annual chance) Floodplain (acres)	12,528.3
Estimated number of structures at 100-yr flood risk	1,087
Residential Structures at 100yr flood risk	670
Estimated Population at 100-yr flood risk	971
Critical Facilities at 100-year flood risk (#)	1
Number of low water crossings at flood risk (#)	20
Estimated number of road closures (#)	N/A
Estimated length of roads at 100-year flood risk (Miles)	23.8
Estimated farm & ranch land at 100-year flood risk (acres)	7,929.1
Pre-Project Level of Service	<10% ACE

6.0 Flood reduction goals and objectives

The results of the flood risk analyses suggested that 17.9% of all structures within the study area are at risk of flooding with depths varying from 1 inch to as a high as 48 inches. The results suggest that the three streams do not have sufficient conveyance capacity for the 10% annual chance storm event. Based on evaluation of the flood risks, goals and objectives were defined to guide the overall approach and recommendations of the drainage planning.

6.1 Flood reduction goals and objectives

The goal of this MDP is to reduce the risk of structural flooding in COIC and ETJ. Based on the results of the existing conditions analysis, the following flood reduction goals and objectives were established for the plan:

- Remove 20% of existing structures from the floodplain.
- Reduce Water Surface Elevation by 0.5 ft throughout the study area.

The above goals were established as a minimum for the study realizing that limitations for implementing the appropriate drainage features to achieve the goals exist. Specifically, the recommended flood risk reduction solutions must have no negative effect on neighboring areas.

7.0 Flood reduction alternative analyses

Two flood reduction alternatives were considered and analyzed as part of this study. The initial approach taken was to add regional offline pond along the streams to provide additional floodplain storage capacity during major storm events. The location and extent of the ponds were coordinated with the steering committee members, being careful to avoid placement of ponds that cross existing pipeline corridors or roadways. The results showed minimal reduction in water surface elevations and highlighted the need for conveyance improvements of the streams. The second alternative identified comprised of channel conveyance improvements and ponds as mitigation for the resulting flow increases associated with the channel improvements. The channel improvements identified are based on the capacity needed to help reduce the depth of flooding within the study area by 0.5 foot. These alternatives do not consider upgrades to the capacity of the existing stream crossings.

The alternatives are described below:

<u>Capital Improvement Plan (CIP):</u> Off-line flood risk reduction ponds

<u>Alternative (Alt):</u> Channel Improvements to help reduce flood depths by 0.5 foot and offline ponds as mitigation for the increase in peak flows

The alternatives are discussed in the sections below.

7.1 Capital improvement plan flood reduction project

The Capital Improvement Plan (CIP) focused on providing additional storage capacity to the existing system. The project identified consists of nine flood risk reduction ponds – 4 ponds along West Fork Chocolate Bayou, 3 ponds along North Hayes Creek and 2 ponds along South Hayes Creek, see **Figure 7.1** below. The pond locations are chosen based on available open space and through collaboration with the steering committee. **Exhibit 14** provides an overview of the capital improvements plan drainage features. **Exhibits 15** through **17** provide clarification of the areas of inundation during the storm events considered in the assessment.

With the construction of the CIP, the level of service for the three streams are improved. **Exhibit 19** provides clarification of the resulting level of service. The inundated structures, agricultural land and roadways are clarified in **Exhibits 20** through **22**.

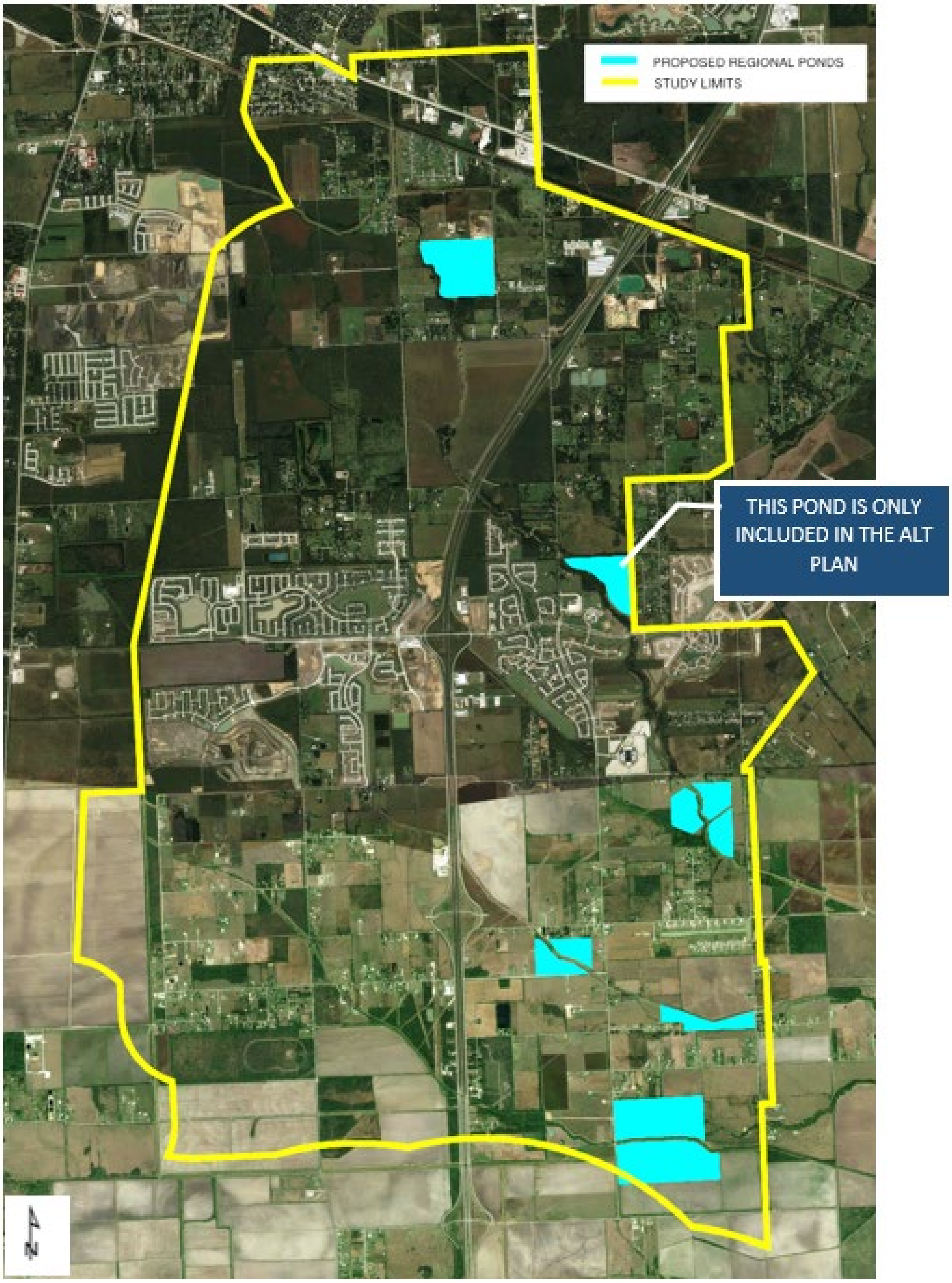

Figure 7.1 Proposed Regional Flood Risk Reduction Ponds

The flood risk reduction ponds were strategically placed along the streams at locations where they would provide the most efficient volume, help regulate flows, and reduce impacts and minimize possible conflicts with future developments.

The depth of the ponds is based on the assumption that the outfall pipe that will connect the ponds to the adjacent channels is 1-ft above the channel flowline. The ponds are assumed to be grass lined 4:1 side slopes with 30-ft maintenance berms at the top to provide sufficient maintenance access. A trapezoidal weir is placed along the channel to divert flows into each of the basins, and the appropriate size outfall pipe is identified for each.

Table 7.1. Flood Risk Reduction Pond Volume (1% ACE).

Stream	Basin Name	Maximum Storage Volume (ac-ft)
West Fork	WF1	527
West Fork	WF2	692
West Fork	WF3	218
West Fork	WF4	363
West Fork	WF5	199
N Hayes	NH1	103
N Hayes	NH2	124
N Hayes	NH3	159
S Hayes	SH1	967
S Hayes	SH2	1011

Subsequent impact studies will need to be prepared as part of the implementation of these flood risk reduction pond projects in the future to confirm the appropriate size of the weir and outfall pipe structures.

7.2 Alternative analysis flood reduction project

Based on the results of Capital Improvement Plan and feedback at the Steering Committee meetings, the decision was made that Alternative would focus on channel conveyance improvements plus ponds as mitigation of the increased flows. **Exhibit 23** shows a general schematic of the Alternative drainage features considered.

Based on the existing conditions analysis, the studied streams provide a low level of service (LOS), with out of bank flooding experienced during the 10% ACE flood event. The average channel depth for all streams in the study area is approximately 6.0 feet.

The intent of the Alt plan is to widen the channels to increase the level of service to meet the 100-year event. **Exhibit D-1** shows the ultimate channel right-of-way widths that were determined. Details concerning the determination of these widths is provided in **Appendix D**.

The U.S. Fish and Wildlife Service identifies the three studied streams as having riverine habitat with wetlands. This suggests that there is a likelihood that adjustments to these stream beds would have an environmental impact. In consideration of avoiding such impacts, channel benching is being proposed. The flowline of the channel remains the same, but the sides of the channel are flattened on either side this allows the flowline and streambed to remain undisturbed, acting similar to a pilot channel, while a more uniform trapezoidal channel is constructed above it. This will avoid or limit environmental impacts to the streambed habitats.

7.2.1 West Fork Chocolate Bayou

West Fork channel improvements stretch from Karsten Road (CR 383) to Manvel-Sandy Point Road (CR 67). With project channel widths ranging from 75 feet to 140 feet.

The ultimate ROW widths along West Fork Chocolate Bayou range from 240 feet to 590 feet.

The improvements include the following:

- Channel bottom width – varies from 34 feet to 84 feet.
- Channel depth – varies 6 feet to 9 feet.
- Mitigation Volume – provided in 5 ponds.

7.2.2 North Hayes Creek

North Hayes Creek channel improvements stretch from State Highway 288 to Manvel-Sandy Point Road (CR 67). With project channel widths ranging from 100 feet to 110 feet.

The ultimate ROW widths along North Hayes Creek range from 130 feet to 210 feet.

The improvements include the following:

- Channel bottom width – 60 feet.
- Channel depth – varies from 6 feet to 8 feet.
- Mitigation Volume – provided in 3 ponds.

7.2.3 South Hayes Creek

South Hayes Creek channel improvements stretch from State Highway 288 to Manvel-Sandy Point Road (CR 67). With project channel widths ranging from100 feet to 110 feet

The ultimate ROW widths along South Hayes Creek range from 140 feet to 250 feet.

The improvements include the following:

- Channel bottom width – 34 feet

- Channel depth – varies from 6 feet to 8 feet.
- Mitigation Volume – provided in 2 ponds.

All channel improvements will maintain a 4 to 1 side slope, and 30ft maintenance berms on both sides of the channel. A typical section for these improvements is shown in **Figure 7.2**.

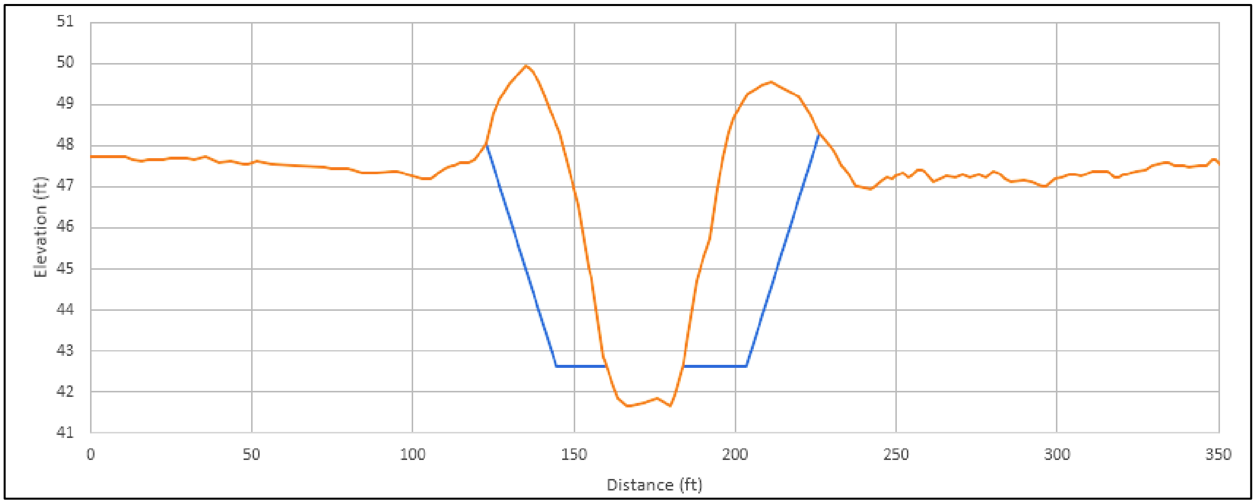

Figure 7.2 Typical Channel Improvements

Exhibits 24 through **26** provide clarification of the areas of inundation during the storm events considered in the assessment. With the construction of the Alt, the level of service for the three streams are improved. **Exhibit 28** provides clarification of the resulting level of service. The inundated structures, agricultural land and roadways are clarified in **Exhibits 29** through **31**.

7.3 Proposed improvements hydraulic model (HEC-RAS)

HEC-RAS (version 6.3.1) is used to route the storm water runoff through both the CIP and Alt drainage plan features. The terrain from the existing conditions analysis is modified to reflect the proposed improvements (i.e., flood risk reduction/mitigation ponds and channel widening). Lateral structures are added to reflect the diversion weirs and outfall pipe. The model results are used to determine the volumes and elevations in the ultimate ponds. The model layouts are shown in **Exhibit B-4**. The outfall of the HEC-RAS model uses normal depth as a tail water boundary condition.

7.4 Proposed hydrologic modeling

The CIP plan utilizes the same hydrologic models for existing conditions. For the Alt plan, the basin development factors were revised to account for the channel improvements. These changes primarily included changes in land use to account for the mitigation ponds, and minor area changes to sub basins along West Fork Chocolate Bayou where the ponds were placed on subbasin boundaries.

7.5 Project costs

To properly weigh alternative viability the cost associated with the improvements must be evaluated. For each alternative the costs were evaluated on the following factors, Pond ROW, Pond Excavation, Channel ROW, and Channel Excavation, with a 20% increase in the cost to account for contingencies. The costs shown in this section only reflect the construction costs and ROW acquisition costs. For total project costs including non-constriction, engineering design and development, maintenance, and other ancillary costs, please see **Appendix F.**

7.5.1 Mitigation Pond Cost

The mitigation pond cost reflects the excavation and haul off costs for the total volume excavated below existing natural ground in addition to the cost of the weir and outfall pipe.

7.5.2 Channel Improvement Cost

The channel improvement costs include site preparation, excavation, haul off and turf establishment.

7.5.3 ROW Acquisition Cost

The value for each parcel was based on the appraised value in HCAD multiplied by 3. Where the appraised value was not available, an estimate was made based on comparable properties nearby.

For full details see **Appendix C**. The following **Tables 7.2** through **7.4** provide a summary of the total costs for each alternative with respect to the stream.

Table 7.2. Project Cost for West Fork Chocolate Bayou

Scenario	Mitigation Pond Cost	Channel Improvement Cost	ROW Acquisition		25% Contingency	Total Cost
			Pond	Channel		
Capitals Improvements Plan	$13.9 M	n/a	$16.8 M	n/a	$7.7 M	**$38.4 M**
Alternative	$20.4 M	$5.7 M	$18.5 M	$8.8 M	$13.3 M	**$66.6 M**

Table 7.3. Project Cost for North Hayes Creek

Scenario	Mitigation Pond Cost	Channel Improvement Cost	ROW Acquisition		25% Contingency	Total Cost
			Pond	Channel		
Capitals Improvements Plan	$3.9 M	n/a	$8.4 M	n/a	$3.1 M	**$15.5 M**
Alternative	$3.9 M	$2.0 M	$8.4 M	$4.5 M	$4.7 M	**$23.6 M**

Table 7.4. Project Cost for South Hayes Creek

Scenario	Mitigation Pond Cost	Channel Improvement Cost	ROW Acquisition		25% Contingency	Total Cost
			Pond	Channel		
Capitals Improvements Plan	$20.6 M	n/a	$13.9 M	n/a	$8.6 M	**$43.1 M**
Alternative	$20.6 M	$1.4 M	$13.9 M	$9.3 M	$11.3 M	**$56.5 M**

In order to quantify the cost for the additional storage volume required for the Alt plan, an average $/acre-feet was determined from the CIP results which reflects a combination of the right-of-way acquisition and construction costs. The average cost per acre-ft was determined to be $ 37,415/ ac-ft.

Table 7.5. Summary of Total Construction Cost (including utility adjustments and contingency)

Scenario	Total Cost	Total Cost (including additional volume)
Capitals Improvements Plan	$96.9 M	n/a
Alternative	$146.6 M	$221.4 M

7.6 Project challenges

The results of the Capital Improvement Plan Flood reduction project highlighted the need for additional conveyance improvements as oppossed to additional storage capacity with the use of regional ponds.

As part of the Alternative analysis, channel improvements were determined based on the an increase in the level of service with the intent of reducing flood depths by 0.5 foot.There is a significant amount of volume stored and conveyed along the channel banks which provides natural attenuation of flows. The channel improvements convey flows more efficiently resulting in increased peak discharges which need to be mitigated with the use of ponds. The existing ponds identified within the study area do not provide enough volume to fully mitigate for the increase in peak flows that result downstream of the study area. Due to issues with available ROW, the additional remaining volume required to fully mitigate the LOS improvements will likley need to be provided downstream outside of the limits of this study area (i.eoutside of the COIC and ETJ. The resulting floodplain limits and flood depths for the Alt plan can found on **Exhibits 24** through **26**. A comparison of the water surface elevations for the Existing and Alt plan is provided on **Exhibit 27**.

While the results suggest an increase in level of service as shown on **Exhibit 28**, there is an increase in peak flows at the downstream end of the study area. A comparison of the 100-year runoff hydrographs for the two alternatives and the existing conditions flood hazards was prepared to identify the amount of additional storage volume needed to mitigate for the impacts. **Figure 7.3** shows the resulting hydrographs for the channels and overbank located with an alignment that approximates County Road 67. This is the location at the most downstream end of the proposed channel and pond improvements.

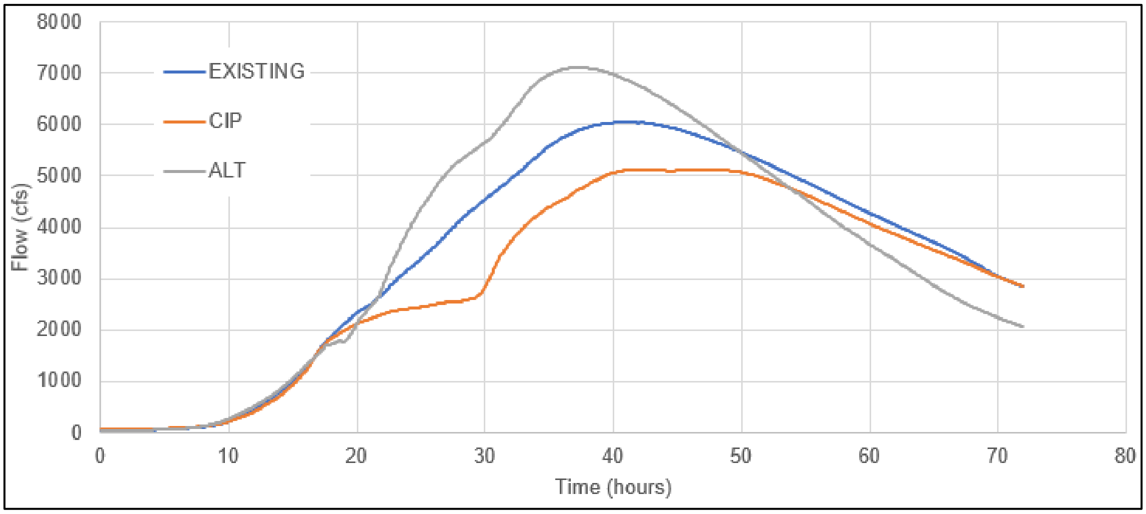

Figure 7.3 1% ACE Flow Profile at CR 67

As can be seen from **Figure 7.3**, the flow hydrograph is attenuated for Capital Improvement Plan. However, for Alternative, the flow hydrograph is increased above the existing conditions hydrograph.

The volume difference between the Alternative and existing conditions flow hydrograph was calculated. Based on this calculation, it is determined that approximately 2,000 acre-feet of additional storage volume is needed to provide full mitigation of the increases in peak storm water runoff resulting from the Alternative scenario. The inundated structures, agricultural land and roadways are shown on **Exhibits 29** through **31**.

7.7 Results and no adverse impact evaluation

The Texas Water Development Board (TWDB) rules defines "Negative Effect" as an increase in flood-related risks to life and property, either upstream or downstream of the proposed project. The guidance provided in Section 3.6.A of the TWDB's April 2021 Appendix C document titled Technical Guidelines for Regional Flood Planning is followed with respect to identifying the recommended regional flood plan.

The assessment of the regional flood plan effects on existing flood hazards utilizes a 1-dimensional/2-dimensional unsteady flow simulation of the streams and adjacent floodplain for the study area. Following the TWDB guidance, the maximum increase of 1-dimensional water surface elevations must be less than 0.05 foot measured along the hydraulic cross section. Further, the maximum increase of the 2-dimensional water surface elevations must be less than 0.35 foot measured at each computational cell. Inundation increases exceeding these limits must not extend beyond the public right-of-way, project property, or easement.

When comparing the CIP to Existing maximum water surface elevations, it is noticed that increases in water surface elevation in excess of 0.05 foot result within the channel reaches. However, these increases are contained within the channel section identified as public right-of-way and are located adjacent to proposed flood risk reduction ponds. Further, there are several questionable anomalies of water surface elevation differences within the areas outside of the channel where increases exceed 0.35 foot. These anomalies occur within areas represented by the 2-dimensional terrain mesh within the HEC-RAS simulation and mostly appear to be isolated at the west side of S.H. 288 near Shaw Road (see **Exhibit 18**). The closest plan feature to these areas is more than 0.75 mile to the west of S.H. 288. Additionally, there are areas with decreased water surface elevation surrounding each of these anomalies which suggest the issues with 2D computational mesh. These areas are not expected to experience increased water surface elevations as a result of the project.

While the Alt plan results in significant benefits in the upper reaches of the watershed, there plan suggests that there will be impacts downstream. The channel modifications will have the effect of reducing available natural storage along the streams, and the proposed ponds within the study area do not have the ability to provide sufficient volume to balance the volume losses. As referenced in Section 7.6, it is determined that approximately 2,000 acre-feet of mitigation volume will need to be created to effectively mitigate for the increases in peak discharges resulting from the Alt plan. Opportunity for providing this additional volume will need to be explored for areas outside the study area. A copy of TWDB No Negative Effect Determination Table has been included in Appendix F.

7.8 Cost and benefit

The proposed alternative drainage plans proposed will provide direct benefits throughout the study area. These benefits will extend to existing structures that will realize a reduced risk of flooding, as well as improvements to mobility during flood events. **Table 7.6** provides a summary of the benefits identified for each alternative. More detailed project benefits can be found in TWDB Exhibit C table format in **Appendix F**.

Table 7.6 Project Benefits Summary

ESTIMATED PROJECT BENEFITS	EXISTING	CAPITAL IMPROVEMENT PLAN: PONDS ONLY	ALTERNATIVE: PONDS AND CHANNEL WIDENING
Area in 100yr (1% annual chance) Floodplain (sq.mi.)	16.16	15.83	14.34
Area in 500yr (0.2% annual chance) Floodplain (sq.mi.)	19.33	19.18	18.5
Estimated number of structures at 100yr flood risk	1111	1043	875
Residential structures at 100-year flood risk	1075	1007	840
Estimated Population at 100-year flood risk	657	630	566
Critical facilities at 100-year flood risk (#)	0	0	0
Number of low water crossings at flood risk (#)[1]	9	8	8
Estimated number of road closures (#)	N/A	N/A	N/A
Estimated length of roads at 100-year flood risk (Miles)	25.76	24.19	19.19
Estimated farm & ranch land at 100-year flood risk (acres)	8.62	8.21	7.02
Number of structures with reduced 100yr (1% annual chance) Flood risk	-	666	956
Number of structures removed from 100yr (1% annual chance) Flood risk	-	68	236
Number of structures removed from 500yr (0.2% annual chance) Flood risk	-	63	357
Residential structures removed from 100yr (1% annual chance) Flood risk	-	68	235
Estimated Population removed from 100yr (1% annual chance) Flood risk	-	27	91
Critical facilities removed from 100yr (1% annual chance) Flood risk (#)	-	0	0
Number of low water crossings removed from 100yr (1% annual chance) Flood risk (#)	-	1	1
Estimated reduction in road closure occurrences	-	N/A	N/A
Estimated length of roads removed from 100yr flood risk (Miles)	-	1.57	6.57
Estimated farm & ranch land removed from 100yr flood risk (acres)	-	0.41	1.6
Estimated reduction in fatalities (if available)	-	N/A	N/A
Estimated reduction in injuries (if available)	-	N/A	N/A

[1] Represents all stream crossings that are inundated during the 100-year event

8.0 Benefit-Cost analysis

A benefit-cost analysis (BCA) was conducted for the CIP and Alt improvement projects to determine the value of the improvements relative to its cost. The result of the BCA is a benefit-cost-ratio (BCR) computed as the project benefits divided by its total cost over the expected life of the project. The BCR for each project is then compared to determine the most cost-effective option. The total project costs used in the BCA include non-construction costs (such as surveying, engineering design and permitting), construction costs, ROW acquisition costs and annual recurring costs such as operation and maintenance (O&M). These potential costs are estimated based on the items included in the TWDB Exhibit C cost template. For a detailed breakdown of costs, refer to **Appendix F**. The BCA method performed uses the assumptions from in the TWDB BCA Input Workbook for calculating structural damages due to riverine flooding provided by TWDB to calculate the expected project benefits over the lifetime of the project.

The expected benefits are achieved by calculating the expected damages for the baseline condition (in this case considered existing conditions) and subtracting the expected damages for the post-project condition for each of the storm event. The expected reduction of damages for each of the storm event is then multiplied by the probability of that event occurring over the life of the project to determine the expected monetary benefit for the project. In this analysis, the only benefits considered in the BCA are based on the expected damages to structures. Additional benefits quantified, but not included in the BCR, include quantifying agricultural land and length of roadway impacted for the extreme storm events. A description of the tools used, assumptions, inputs and steps for the BCA and additional benefits is provided below.

8.1 Assumptions and constraints

In addition to the benefits that could be monetized, some additional benefits of the project were quantified, but not included in the BCR since a direct monetary impact was not assumed. With this in mind, there are inevitably benefits that are not reflected in the traditional BCR calculated for the two projects analyzed.

The projects were analyzed on the basis of four storm events modeled in HEC-RAS 1D/2D for Iowa Colony. Although the extent of the models reaches further than the study area boundaries, the damages to structures and other impacts were only calculated within the study boundary area. Meaning, it is possible there are additional benefits from the project in question to areas outside of the study area that are not quantified and considered in the BCR for the project. There is potential for increasing the calculated BCR if these areas were considered in a future assessment.

The workbook provided by TWDB constrained the BCA analysis to three storm events. The ability to include more storm events would provide a more accurate representation of the project benefits. Additionally, for the study area there are limited number of structures that can be considered in the workbook for the residential and commercial areas and with over 1000 homes expected to be flooded in the 500-year storm event in the study area, the number of rows in the workbook were insufficient to represent these structures. Therefore, the workbook was not used directly to calculate the BCR. Instead, the core assumptions were used in the BCA analysis performed for these projects including: the residential structure and commercial structures depth-damage relationship (simplified from FEMA's BCA Toolkit 6.0), the project's expected lifetime (30-years), and considering project operation and maintenance costs annually.

8.2 BCA general considerations

Four storm events including the 10, 50, 100 and 500-year recurrence intervals are considered for the pre-project and post-project conditions. The costs and benefits compared in the BCA included direct flood damages expected over the project life, benefit derived from the project in terms of reduced flood damage, compared to the project costs (including capital costs and annual O&M costs over the project lifetime). The expected benefits are achieved by calculating the expected damages for the baseline condition (in this case considered existing conditions) and subtracting the expected damages for the post-project condition for each of the storm event. The expected reduction of damages for each of the storm event is then multiplied by the probability of that event occurring over the life of the project to determine the expected monetary benefit for the project. In this analysis, the only benefits considered in the BCA are based on the expected damages to structures. Additional benefits quantified, but not included in the BCR, include quantifying agricultural land and length of roadway impacted for the extreme storm events. A description of the tools used, assumptions, inputs and steps for the BCA and additional benefits is provided below. The summary of the BCR calculations are shown in **Table 8.1**.

Table 8.1 Benefit-Cost Ratio Calculations (Project Life 30-years)

Variable	CIP	Alt
Capitol Cost (Includes Design) ($)	$110.98 M	$278.96 M
Operation & Maintenance Costs ($/30 yrs)	$8.25 M	$18.83 M
Summary of Expected Benefits over the Project Lifetime		
Benefit to Residential Structures	$7.32 M	$19.77 M
Benefit to Commercial Structures	$0.99 M	$1.07 M
Benefit to Industrial Structures	$0.00	$10,868.15
Benefit to Agricultural Land	$0.00	$0.00
Total Expected Benefits ($/30 yrs)	$8.31 M	$20.84 M
BCR	0.07	0.07

The BCA for this planning study effort estimated damaged to structured based on LiDAR datasets and not on surveyed finish flood elevations. Furthermore, building foundation type was not taken into account so for communities such as mobile home parks or for foundation types with elevated floors, the assumptions are likely to overstate the damages. While a BCR of 1.0 is typically required, it is important to note that the study area includes large amounts of agricultural lands which have been removed from the floodplain, however the monetized benefits were not considered in the computation of the ratio. The ponds proposed also have the potential to be designed to be multi-purpose with amenities and recreational uses.

Since this is a planning level effort, the BCR allows for the comparison of the alternatives to determine the project most effective to be considered for more detailed study.

8.3 Project costs

The capital costs include the design and construction of the project (materials, labor, utility relocation and ROW acquisition). The operation and maintenance costs include the annual maintenance multiplied over 30-years to achieve the total cost of maintenance over the life of the project. For a detailed breakdown of costs for each of the projects, refer to **Appendix F**.

8.4 Expected benefits to damaged structures

A damage assessment was conducted to calculate flood damage in dollars ($) to structures, based on structure type and flood depth within the study area. The flood depth in each structure is determined by comparing the finish floor elevations to the water surface elevation for each of the storm events from the HEC-RAS analysis. A depth-damage curve is applied to determine the expected damage per flood depth based on the structure type. A sum of the total expected damages to the structures is calculated for each of the storm events. A summary of the number of structures and project damage estimated for the 100-year storm event, with the expected benefits for each of the projects in the 100-year event is shown in **Table 8.2**. The resulting expected damages and benefits calculated for all four storm events calculated can be found in **Appendix H**.

Table 8.2 Benefit to Structures Effected and Damage ($) for 100-year Storm Event

Structure Type	No. of Structures			Structural Damage		
	Existing	CIP	Alt	Existing	CIP	Alt
Commercial	35	35	34	$6,086,273	$5,918,050	$5,974,494
Industrial	1	1	1	$15,627	$15,627	$7,911
Residential	1075	1007	840	$66,334,774	$61,546,395	$46,868,239
Critical Infrastructure	0	0	0	$0	$0	$0
All Structures	1111	1043	875	$72,436,674	$67,480,071	$52,850,644
Benefits for All Structures	-	68	236	-	$4,956,603	$19,586,030

For residential damages, structure types are classified as “small”, “average” or “large” home to assess damages. The structure type for the study area is assumed to be “average” which uses 2,500 sq. ft per home for the damage curve. This was determined to be the most appropriate since the average residential home was determined to be 2,000 sq. ft.
For commercial and industrial structures, the damages can be assessed based on structure value or square footage. For this analysis, an average cost/ square footage is assumed for commercial, industrial, and critical facilities.

To calculate the total benefit based on damage of all structures over the life of each project, the calculated benefit for each of the storm events is combined with the probability of that event occurring over the lifetime of the project. The total benefit is the sum of all the possible benefits multiplied by their probability which is a method prescribed by FEMA. **Table 8.3** shows an example calculation to determine the benefit for CIP.

Table 8.3 Benefit for Overall Project Life (30-years) Calculation for the CIP

Recurrence Interval	Benefit ($) per Storm	Probability of Occurrence Over Project Life (%)	Benefit per Storm Over Project Life ($/30yrs)
500-year	$5,326,065	5.83%	$310,467
100-year	$4,956,603	26.03%	$1,290,202
50-year	$4,848,327	45.45%	$2,203,641
10-year	$4,703,070	95.76%	$4,503,702
		Total Benefit over Project Life	$8,308,011

8.5 Additional Benefits Quantification

Additional benefits were calculated outside of the traditional BCR calculation. Some of which compare the existing flood risk to the reduced risk directly to the population. The total number of people within all structures determined to have a flood depth greater than 1-inch were calculated for the post- project conditions. The number of people removed from risk and the increasing average SVI from existing to post-project conditions were considered to compare benefits for each of the projects. The benefit of increased roadway accessibility was quantified for the post-project conditions. The length of road intersecting the inundation boundary for maximum depths greater than 6-inches for the existing conditions is compared to the CIP and Alternative conditions to determine the miles of roadway removed in each of the extreme flood events (100-year and 500-year). Finally, the benefit to agriculture in the study area was quantified by comparing the amount of agricultural land inundated 6-inches of flood depth or greater from existing to post-project conditions for the extreme flood events. Change in flood risk for the level-of-service, flooded structures, agricultural land and roadways can be found in **Exhibits 19 – 22** for the CIP and **Exhibits 28-31** for the Alternative Improvement Plan.

Each of these benefits were calculated for the extreme flood event and scenario. The resulting summary tables comparing the existing to the post-project conditions for each storm event can be found in **Appendix H**.

9.0 Recommendations and next steps

Much of the study area is undeveloped and it is expected that development will be occurring in the southern part of the city for a while. The current alternatives have considered some of these larger projects that have already begun. Since future development will be required to detain for their improvements, this master drainage study should maintain relevance for some time. That being said, as the area changes and land use changes from rural to more urban environments it is important to note that there will be a time when the master drainage study will need to be reevaluated for those future conditions and to consider what will then be different limitations in acquiring ROW.

It is important to note that the solutions presented in this report only reflect conditions as they are now and likely to be in the near future. Future developments must be required to control their own stormwater outfalls to ensure the effectiveness of this project.

The analysis of the two potential alternative projects reflects the cumulative benefits of the regional ponds and/ or channel improvements in place. However, it is anticipated that ponds will be implemented across multiple projects with a detailed drainage study prepared for each stand-alone project to quantify its benefit and demonstrate no adverse impact.

When considering the funding of the project, it may be beneficial to isolate funding of improvements by separating improvements along each reach of stream as a separate program.

It is recommended that the CIP project be considered for inclusion in the TWDB State Flood Plan. This recommendation considers the BCA and ease of implementation. In comparison to the Alt project, the CIP project has less challenges for ROW acquisition, environmental constraints and utility conflict. The BCR for both the CIP and Alt plan is 0.07.

The proposed flood risk reduction ponds in the CIP project result in the placement of ponds in the upper, mid and lower reach areas of the COIC, providing benefits for both the densely developed areas to the north and the unimproved land to the south which has a high potential of being developed in the future.

CIP plan results in the removal of 68 structures from the 100-year floodplain. CIP plan also provides the greatest reduction in acreage of farm and ranch land inundation (263 acres), and reduction in miles of roadway inundated (1.57 miles).

Any projects downstream of the study area, particularly along West Fork Chocolate Bayou would also enhance the benefits of any regional improvements implemented within the COIC. Information regarding potential funding of the recommended CIP projects is discussed in the following section.

10.0 Funding strategy

Prior to the discussion of actual project costs, it must be noted that funding options, including full pass-through to developers, are possible along with various sources for direct project funding. The source that is potentially accessible for a particular project will depend upon the purpose of the project, the anticipated benefits of the project, estimated overall cost of the project, contributors, and the amount of participation by various contributors in providing project funding, and those who benefit from a particular project.

Provided that limitations on use of funds are consistent with the project of interest, potential strategies to use available funds include the following most effectively:

- Phasing of construction to spread funding needs over time
- Expanding internal funding options to use funds from sources under the control of the City of Iowa Colony
- Joint development of projects with other local and regional entities
- Joint development of projects with developers of the project
- Impact fees
- Establishing utility or special districts
- Accessing external funding to generate funds from non-City of Iowa Colony sources

These options are discussed in the following sections.

10.1 Project phasing and project decomposition

Large scale, expensive projects can be considered for phased construction, except if the project operation does not lend itself to phased development because of operational issues. Diversions, for example, will usually be excluded from possible phasing because of the impracticality of constructing a diversion in phases. Detention projects and channel improvements, on the other hand, are well suited to phased construction if funds are limited.

For projects to be phased the first phase should usually include ROW acquisition and environmental permitting since inability to obtain ROW or permits would render a project infeasible. For projects that could be phased, the project can be decomposed into sub-projects such that each phase is within feasible funding limits. Thus, e.g., channel improvement can be decomposed into individual reach sub-projects, with each sub-project reach composing a separate project to be built over time.

10.2 Developing additional internal funding

Internal funding is project funding provided by the City of Iowa Colony. This funding may be combined with money from other sources to generate the necessary money for a particular project. Internal funding may come from existing or new sources, the latter developed to supplement existing traditional sources.

Traditional sources of funding support the City of Iowa Colony general fund which can be utilized for a variety of purposes. Some traditional sources are following:

- General sales tax

- Property tax
- General license and permit fees,
- Fines and forfeitures
- Special district fees, such as industrial improvement district fees, collected from operators of industrial or commercial enterprises in specified areas in lieu of property taxes.
- Engineering/civil permits

Consideration can also be given to funds limited to specific purposes, such as the following:

- *Service Improvement Fees* (e.g., drainage improvement fees): These are fees that are collected for the specific purpose of generating revenue for funding of improvements for certain types of facilities (e.g., drainage systems). These fees are typically the same for each household and/or business and independent of any use levels. The authority to collect such fees can be established by ordinance.
- *Drainage District Fee Assignment*: These are funds collected by a drainage district for the purpose of management and operation of the drainage district system. These monies typically go directly and totally to the drainage district; however, overlap of drainage districts into the City of Iowa Colony could result in mutually beneficial use of drainage dollars.
- *Special Assessments*: These are fees charged to a particular set of individuals or business enterprises that are favorably impacted by a drainage project. Assessments can be either one-time charges or charges of short duration for the particular benefits received because of the project.
- *Department Transfers*: Funds from other operations in the City of Iowa Colony can be transferred to drainage projects if benefits to other operations can be identified.

10.3 Joint and cooperative funding of projects

By combining county funds with other public agency funds for specific projects, projects that would not be otherwise built can be built using fund leveraging. Partnering with TxDOT, HGAC, TPWD, or drainage districts is an option to use funds available through these agencies.

Using cooperative arrangements, external sources can be combined with City of Iowa Colony funds for projects which benefit both the county and partners in the project.

10.4 Coordination with Private Developers

Working in coordination with private developers is accomplished by having certain portions or features of a development funded by the City of Iowa Colony while the remaining portions are funded by private parties interested in implementing the project. When the public good can be demonstrated by such coordination, there is justification for city funds being used to construct certain portions of such private development. The development of regional detention systems is a prime example for this Study. The regional detention could serve many private parties as well as the public at large for reducing impacts for anticipated development, not just the current portion of the development. Another example is the acquisition of ROW for future development flow conveyance. Arrangements for City of Iowa Colony coordination with private developments are specific to the situation, but will commonly identify portions of a project, e.g., regional detention, which benefits many parties, including the population at large, as those features in which city support may be provided. Given the low capital requirement, this option is, quite-possibly, the best alternative for the City of Iowa Colony.

10.5 Impact fees

Impact fees are fees assessed property developers that are used to recover anticipated costs to be incurred in the future by a county or municipal entity because of the additional municipal services (including utility) that will arise because of the development. The impact fees can also be used to recover costs already incurred by the county or municipal in project development, such as might arise, for example, from coordination with private developers in the development of project. Impact fees are commonly assessed at the time of municipal permit application and based upon amount of area to be permitted. The essential features of impact fees are that they be established by ordinance and administered in an unbiased fashion.

10.6 Utility or special districts

Legally defined special entities with well-defined powers, i.e., state or county created districts, can be used to generate additional revenue through taxation of several types of projects.

Drainage districts or storm water utilities can be established by ordinance for the purpose of providing drainage and/or flood control services. Drainage districts typically have a broader range of responsibilities (e.g., provision of irrigation waters) than storm water utilities, which usually restrict their services to drainage or storm water drainage related issues. The district or utility is established with authority to levy various fees, commonly based upon a surrogate defining the amount of drainage service being provided (e.g., the amount of impervious area in a land parcel because the level of imperviousness affects the amount of runoff generated). Collected revenues are dedicated to provision of drainage and flood control in the service area of the district or utility.

10.7 External funding

External funding sources should always be investigated as part of a particular project. If investigation of funding sources is undertaken as part of preliminary engineering, the design of the project can be modified to meet requirements of funding sources so that funds from the funding source can be accessed.

Opportunities for funding different projects depend upon where the project is located, where the benefits of the project will be realized, whom the project will benefit, and the type of project. External funding sources for flood control projects can encompass flood control ponds and channel improvements to reduced flooding. Water quality and recreational components of a project expands the options for funding from additional sources with water quality responsibilities. External funding is typically accompanied by requirements for financial participation by the entity (often termed the “local sponsor”) seeking the external funding. The participation party may be a single entity, such the county, or a group of cooperating parties, such as the county, a drainage district, and a city. The following sections identify external drainage or flood control project funding sources.

10.8 External funding for drainage and flood control projects

The Some examples of funding sources potentially available for drainage improvement or flood control projects include:

FEMA Grants - these are grants usually administered by the Texas Water Development Board or Department of Emergency Management that are directed to prevention or response to floods.

Specific types of grants include:

- **Pre-Disaster Mitigation Grants (PDM):** This program provides grants and technical assistance to local communities for cost-effective hazard mitigation activities that complement a comprehensive hazard mitigation program to reduce injuries, loss of life, and damage and destruction of property.
- **Flood Mitigation Assistance Grant (FMA):** The FMA grant program provides federal funding to assist states and communities to fund cost effective measures to reduce or eliminate the long-term risk of flood damage to structures insurable under the National Flood Insurance Program (NFIP).
- **Repetitive Loss (RL) Grant Program:** This program provides grants for projects which can be shown by a benefit-cost analysis to reduce repetitive losses to residential structures

Texas Water Development Board Loans - The TWDB operates several loan programs for financing planning, design, construction, improvement or expansion of water and wastewater facilities. Wastewater facilities can be interpreted as to include systems that improve storm water quality. Loan programs though which such leverage might be achieved include the following:

- **Clean Water State Revolving Fund (CWSRF):** Using federal capitalization grants, the TWDB offers low interest loans through the Clean Water State Revolving Fund (CWSRF). CWSRF loans may be made to any political subdivision with the authority to own or operate a wastewater system to finance wastewater projects or to political subdivisions to finance nonpoint source pollution control or estuary management projects.
- **Texas Water Development Fund (DFund):** The TWDB offers through the DFund loans with interest rates at approximately 0.35 percent above the TWDB's cost of funds through the state general obligation bond-funded program. DFund loans are available for planning, design, and construction of various projects, including flood control project. Detention ponds built for flood mitigation and storm water quality improvement may qualify for loans under this program.
- **State Participation Program:** This program enables the TWDB to assume temporary ownership interest in a regional project when the local sponsors are unable to assume the debt for an optimally sized project.

Amenity Funding by Texas Department of Parks and Wildlife - Another external funding source to consider is the Texas Department of Parks and Wildlife (TDPW). Outdoor Recreation Grants are made available from the TDPW Account and the Land and Water Conservation Fund (LWCF) to local governments for the acquisition and/or development of outdoor recreation sites. These funds are available for acquisition and development of State and local park and recreation areas adjacent to storm water detention facilities. Of the various grant programs administered by the TPWD, the following have potential to provide money for detention pond amenity development:

- **Outdoor Recreation Grants**: This program provides matching grant funds to municipalities, counties, and other local units of government with a population less than 500,000 to acquire and develop parkland or renovate existing public recreation areas.
- **Indoor Recreation Facility Grants:** This program provides matching funds to. municipalities, counties, and other local units of government with a population less than 500,000 for constructing recreation centers, community centers, nature centers and other facilities (buildings). Such facilities might be included as part of the amenity features for some projects.
- **Regional Grants:** This grant program provides assistance to local governments with the acquisition and development of multi-jurisdictional public recreation areas in the metropolitan areas of the state. It allows cities, counties, water districts, and other units of local government to acquire and develop parkland for both active recreation and conservation opportunities.
- **Recreational Trail Grants:** TPWD also administers the National Recreational Trails Fund in Texas for the Federal Highway Administration (FHWA). This program receives its funding from a portion of federal gas taxes paid on fuel used in non-highway recreational vehicles.

10.9 State administered grant programs

Different agencies in the State participate in administering various grant and loan funds made available from federal sources.

Texas Coastal and Estuarine Land Conservation Program (TCELCP) - Texas General Land Office (GLO) administers the TCELCP program authorized by federal Public Law 107-00 for the purpose of protecting important coastal and estuarine areas that have significant conservation, recreation, ecological, historical, or aesthetic values, or that are threatened by conversion from their natural or recreational state to other uses [GLO, 2009]. Projects are prioritized for funding by the GLO and focus upon land acquisition for conservation purposes.

Texas Department of Rural Affairs - the Texas Department of Rural Affairs (TDRA) provides grants for a variety of rural development purposes. Among the grant programs, TDRA sponsors grants for disaster relief (such as hurricane recovery) and rural planning activities. Some of these grant programs could provide funding for drainage improvements and flood control projects:

- ***Disaster Relief and Urgent Need Fund***: Assistance available through this fund can be used for eligible relief activities in situations where the Governor of Texas has declared a state disaster or requested a federal disaster declaration.

- ***Small Towns Environmental Program:*** Funds in this program are used for water and sewer infrastructure improvements utilizing self-help methods such as local volunteer labor resources.
- ***Disaster Recovery:*** These are funds allocated to local and county entities for recovery from natural disasters, such as hurricanes, for areas designated by the Governor as a disaster area.
- ***Community Development Funds:*** These are funds available on a biennial basis for public facilities' development, including water and wastewater infrastructure, street and drainage improvements, housing activities, and some other limited purposes.

U.S. Army Corps of Engineers Project Monies - Executive Order No. 11888 (May 24, 1977) provides funds for floodplain management pursuant to the National Environmental Policy Act of 1969, the National Flood Insurance Act of 1968, and the Flood Disaster Protection Act of 1973. It directs the USACE to undertake projects to minimize the impacts of floods on human safety, health, and welfare, and to restore and preserve the natural and beneficial values served by floodplains by acquiring, managing, and disposing of Federal lands and facilities; providing Federally undertaken, financed, or assisted construction and improvements; and conducting Federal activities and programs affecting land-use.

USACE has joint participation programs in which local governments can financially participate. This participation is by a local sponsor, which might be the City of Iowa Colony. The USACE is usually responsible for the design and construction of the projects, but the local participant assumes responsibility for the subsequent operation and maintenance of the constructed facilitates. The following are of particular interest to the authorities of the USACE.

Multi-Purpose Detention Systems to Access Other Program Funds - while the primary purpose of the sub-regional detention ponds is provision of storage to mitigate increased runoff from land development, sub-regional detention ponds are also considered as opportunities for multi-use activities that provide community amenities and become a community asset. Inclusion of community amenities as part of a detention pond system may also increase the likelihood of obtaining external grant or loan monies for the pond development.

11.0 Conclusion

The work completed for this master drainage plan study resulted in the identification of two improvements projects that achieve the overall goal of flood risk reduction in the COIC.

The Capital Improvements Plan (CIP) described in Section 7.1 is recommended for consideration. The comprehensive plan provides benefit in reducing flood risk to the study area. The total cost of this plan is $111 million and removes 68 structures from the 1% annual chance event floodplain, 1.57 miles of roadway, and 263 acres of land.

The plan assumes that future developments will incorporate their own stormwater detention pond for the anticipated increase in stormwater runoff typically associated with these developments. This follows current criteria established by Brazoria County and the communities/agencies having jurisdiction within the study area. Should developments deviate from providing stormwater runoff detention, the plan would need to be modified to ensure that future flood risks are appropriately considered.

Hydrologic and hydraulic modeling was prepared for existing conditions and each project condition. Benefit-cost-analyses were prepared to determine the most cost-effective project. The study efforts identified two projects, CIP and Alt. The CIP project consists of 9 regional ponds located in the overbanks of West Fork Chocolate Bayou, North Hayes and South Hayes intended to provide flood risk reduction benefits. The results of the CIP analysis highlighted the need for conveyance capacity in the study area – this was used to inform the concept for the second project, identified as Alt. The Alt plan included both ponds and channel conveyance improvements to increase the channel level of service.

The existing conditions floodplain mapping developed in this study should be considered for adoption by Brazoria County and other regulatory agencies. The information can be used for future and current development in the West Fork Chocolate Bayou, North Hayes Creek and South Hayes Creek watersheds. The information from this study can be used to establish Base Flood Elevations along the respective streams, representing the best available information of flood hazards for the community.

It is the intent for the Study to be incorporated into the Texas Water Development Board (TWDB) State Flood Plan. Potential funding opportunities included in the plan includes the following:

1. Flood Infrastructure Fund (FIF): FIF provides funding for detention, drainage, and flood control projects.
2. State Flood Assessment Program (SFAP): SFAP provides funding for flood risk assessment and mapping projects.
3. Flood Protection Planning (FPP) program: FPP provides funding for flood protection planning projects.
4. Drinking Water State Revolving Fund (DWSRF): DWSRF provides low-interest loans for projects that improve drinking water quality. Eligible projects include flood protection projects that enhance the reliability and safety of water supply systems.

12.0 List of references

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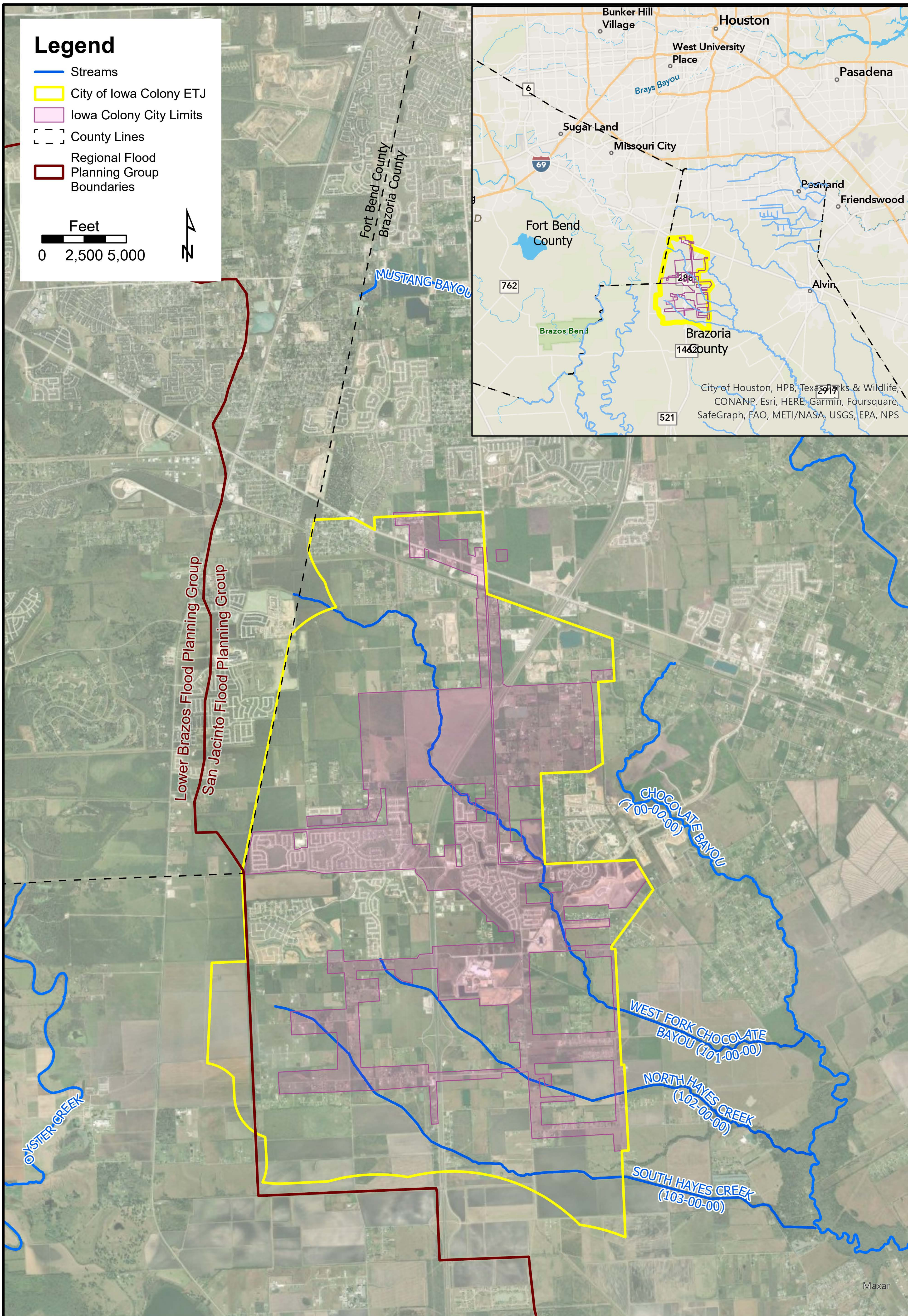
Exhibits



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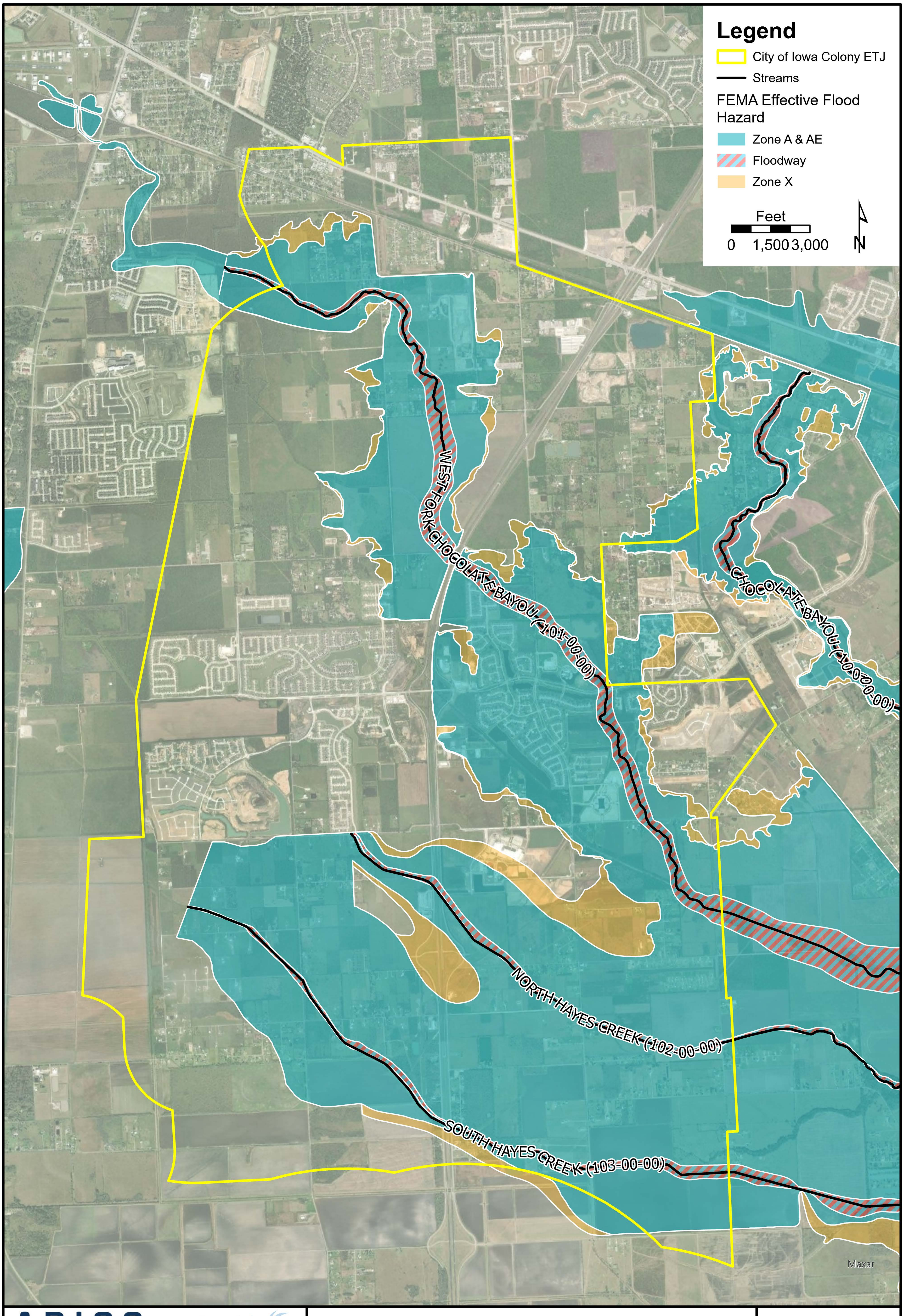
CITY OF IOWA COLONY

CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

PLANNING AREA

EXHIBIT 1

5/30/2023



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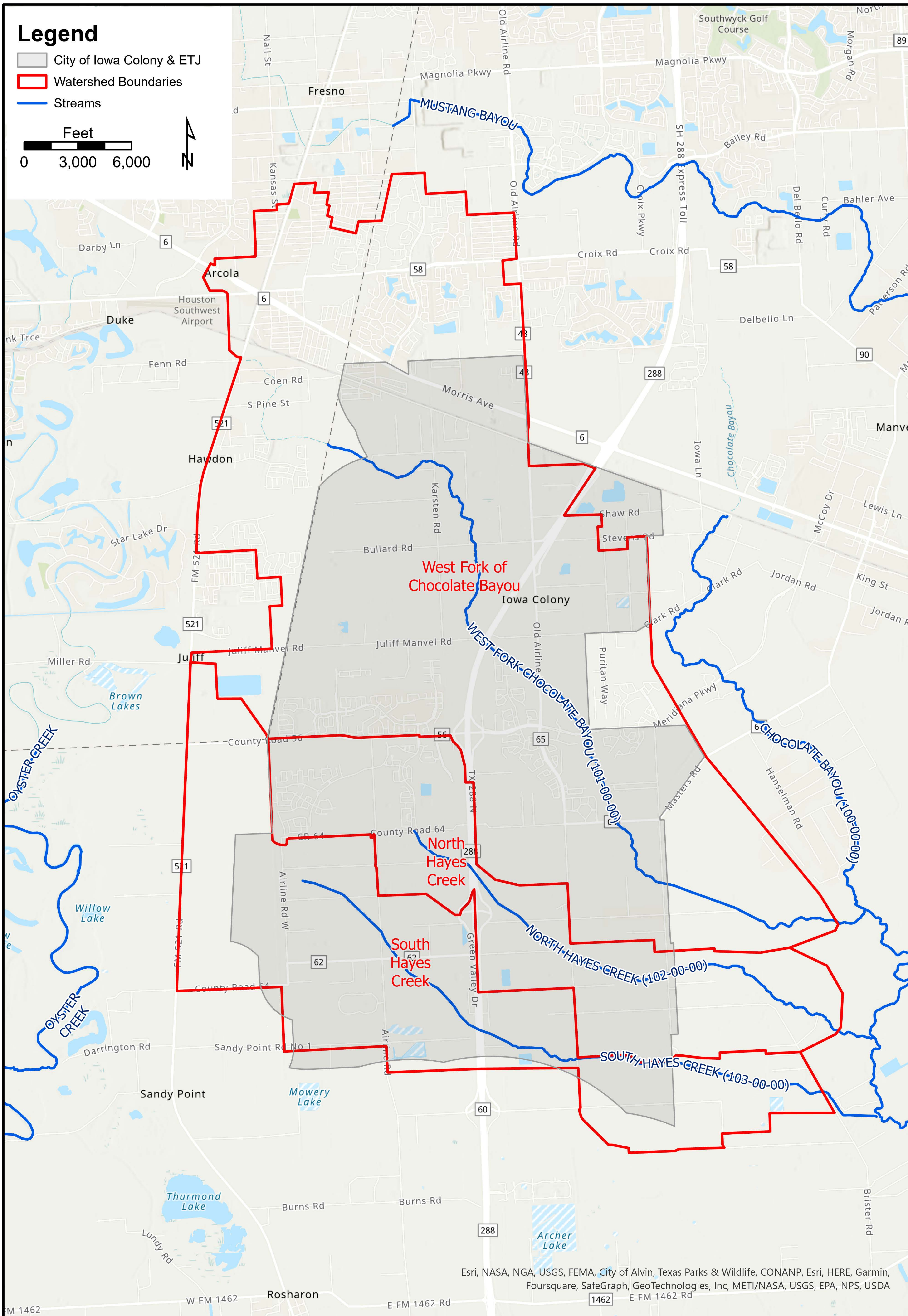
CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

FEMA FLOOD HAZARD MAP

EXHIBIT 2

5/30/2023



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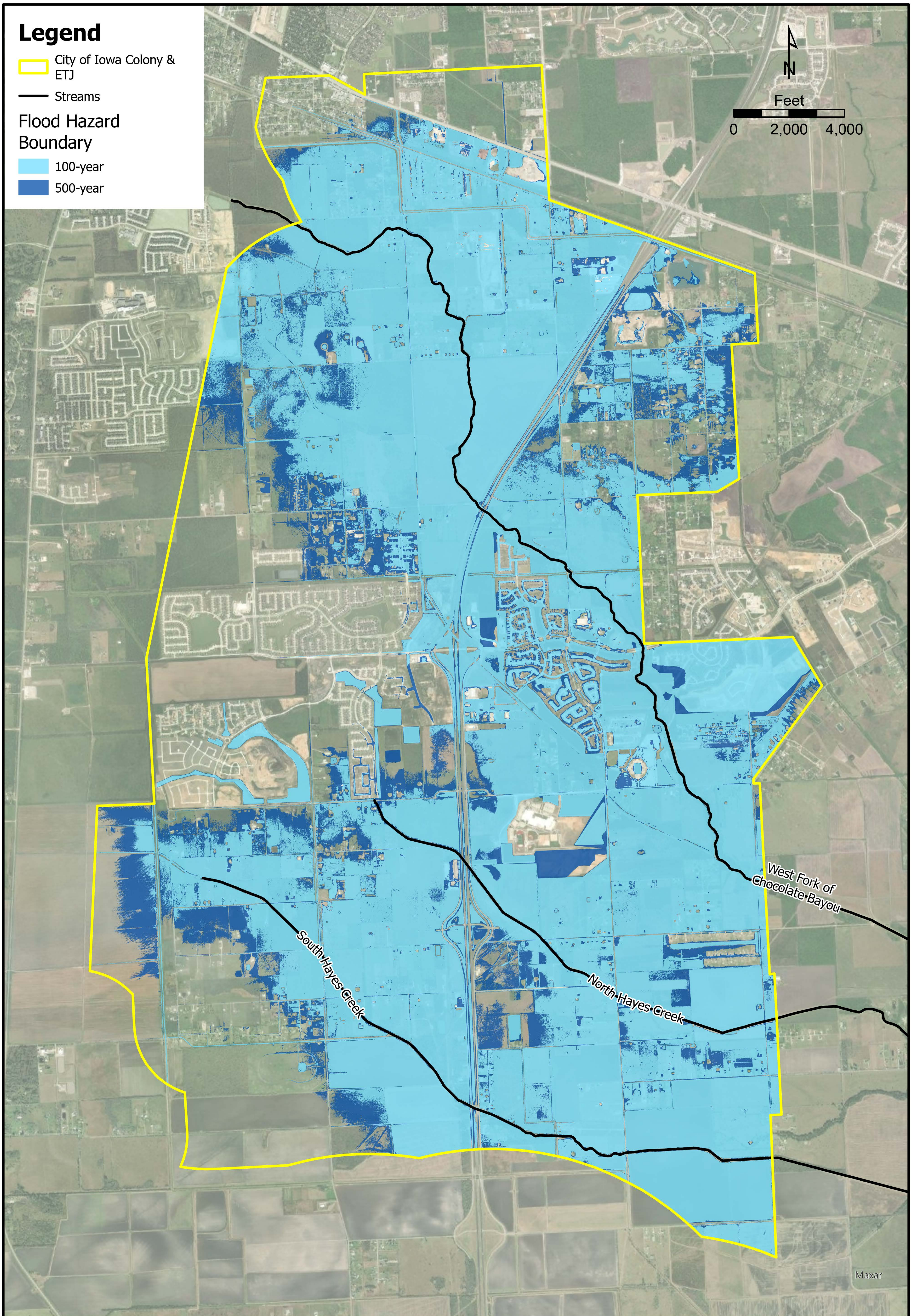
MASTER DRAINAGE PLAN

WATERSHED BOUNDARIES

EXHIBIT 3

5/30/2023



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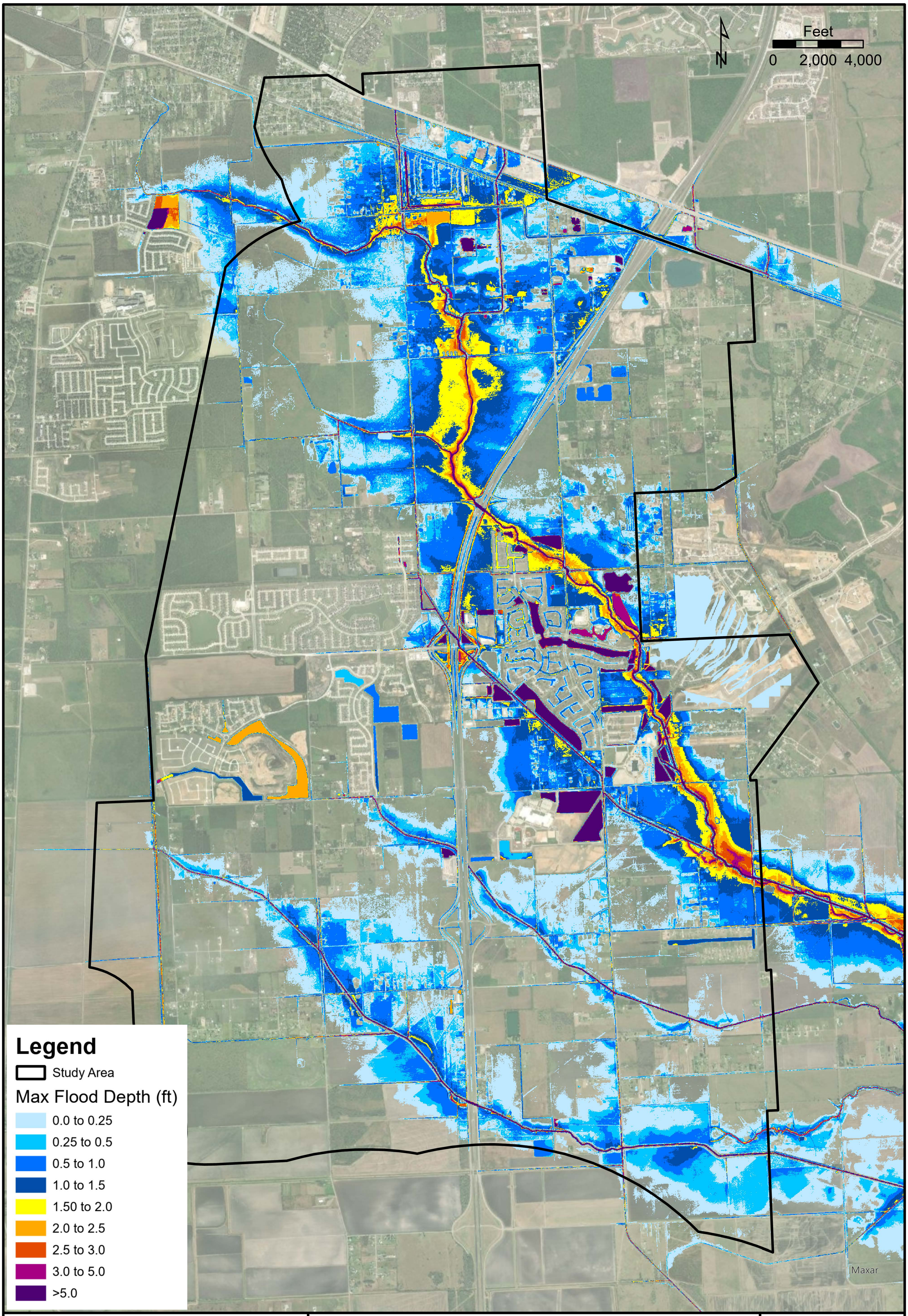
CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

FLOOD HAZARD MAP (EXISTING)

EXHIBIT 4

5/30/2023



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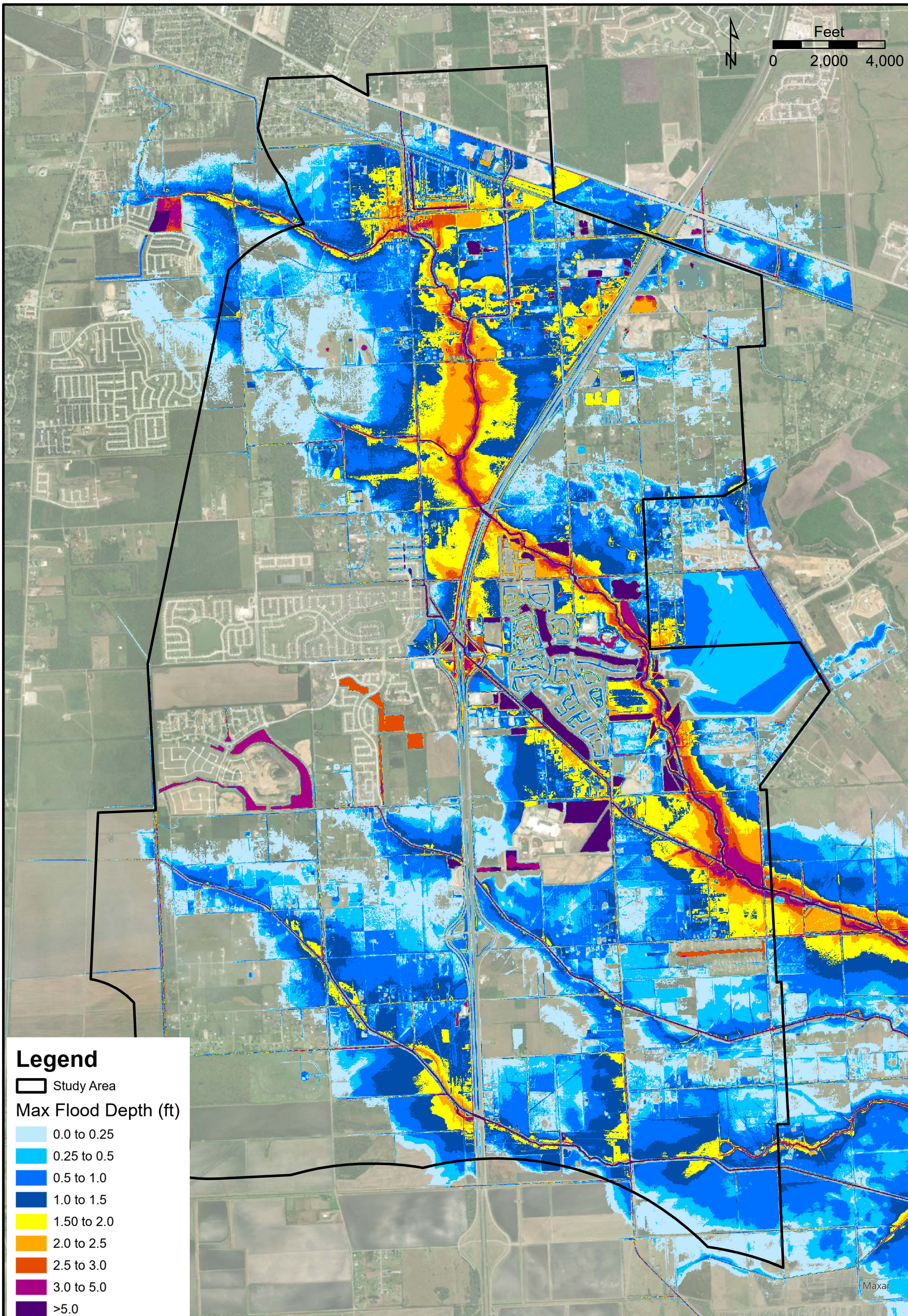
MASTER DRAINAGE PLAN

10-YEAR FLOOD HAZARD DEPTH (EXISTING)

EXHIBIT 5

5/30/2023



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MASTER DRAINAGE PLAN

50-YEAR FLOOD HAZARD DEPTH (EXISTING)

EXHIBIT 6

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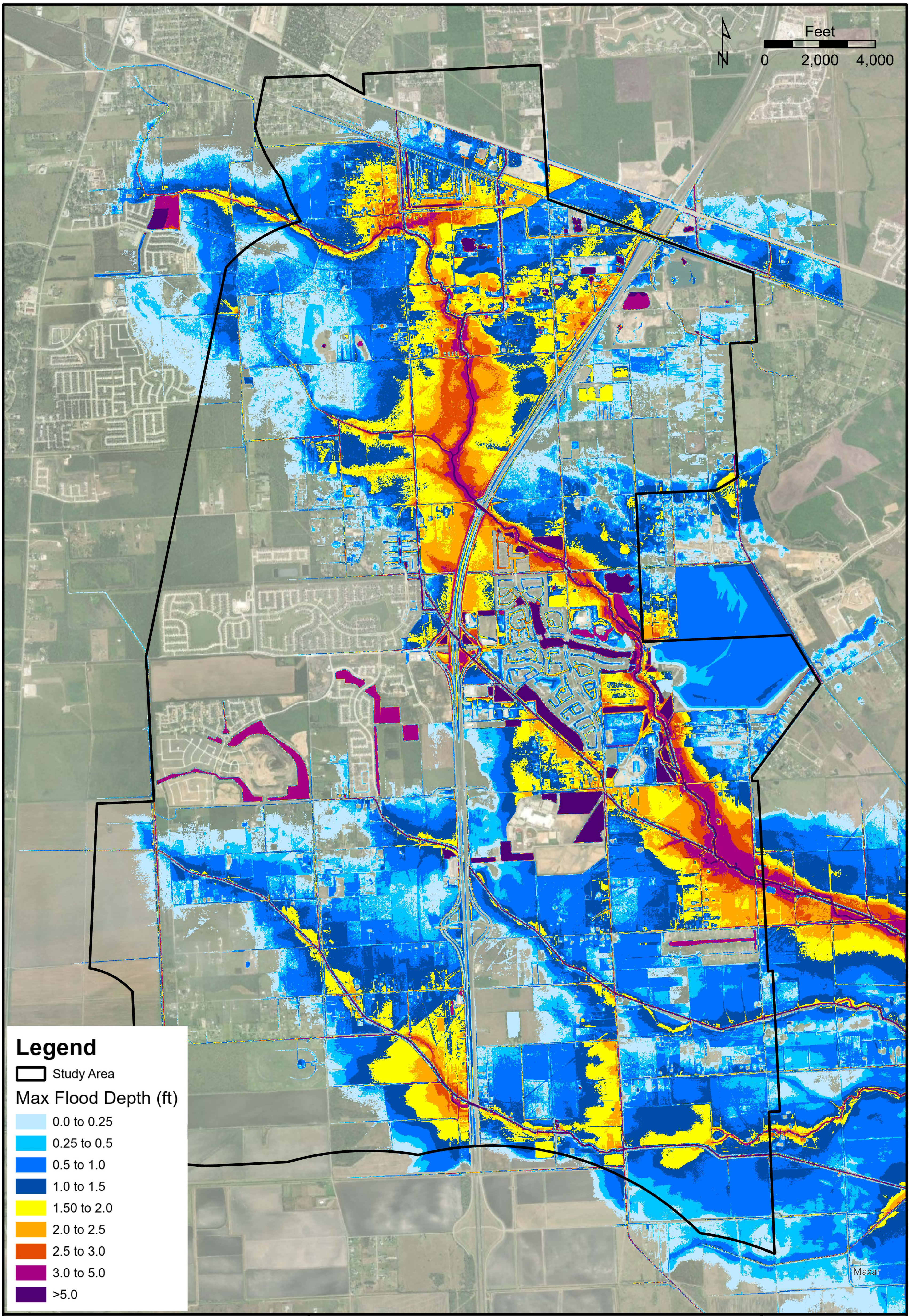

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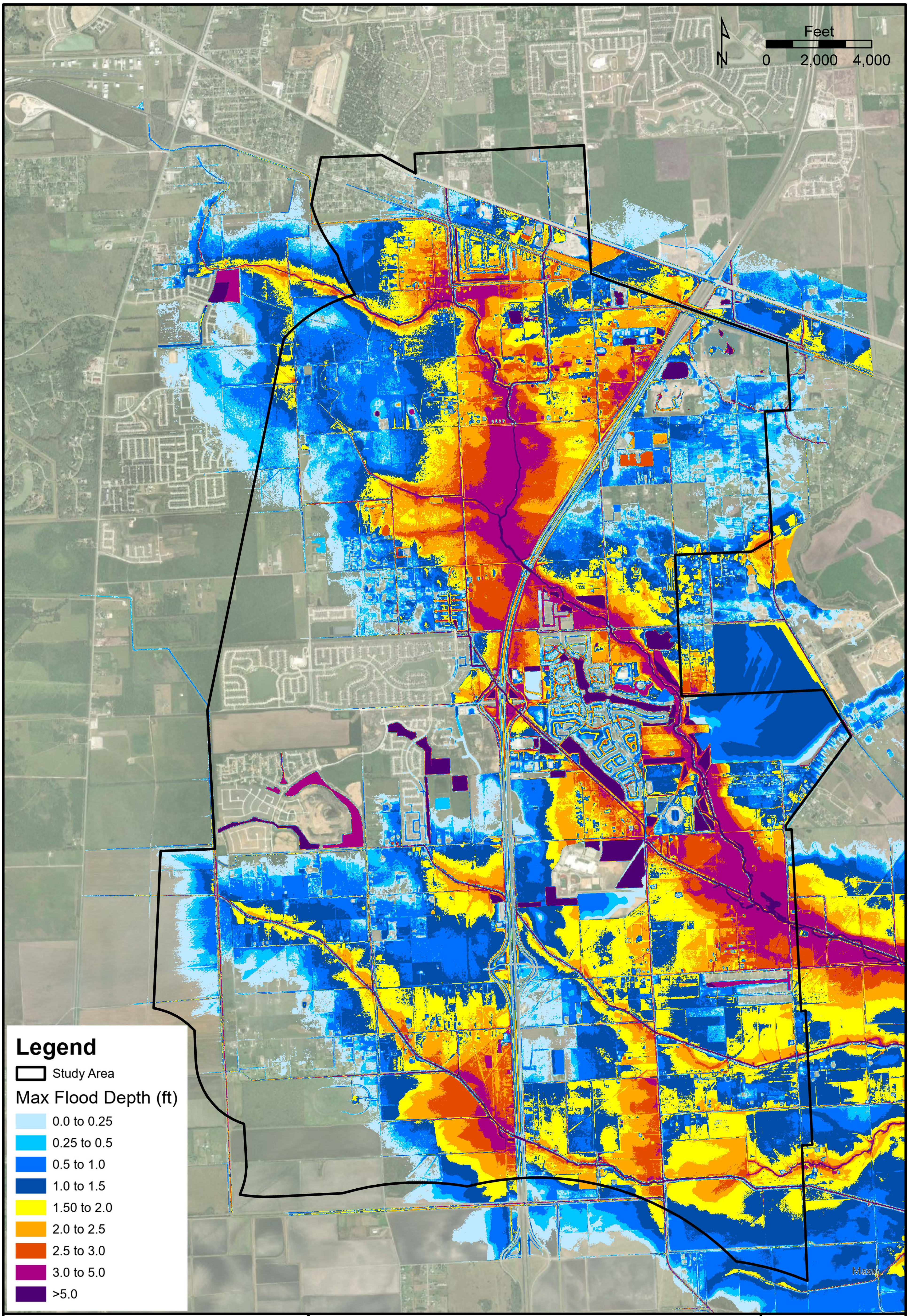
MASTER DRAINAGE PLAN

100-YEAR FLOOD HAZARD DEPTH (EXISTING)

EXHIBIT 7

5/30/2023



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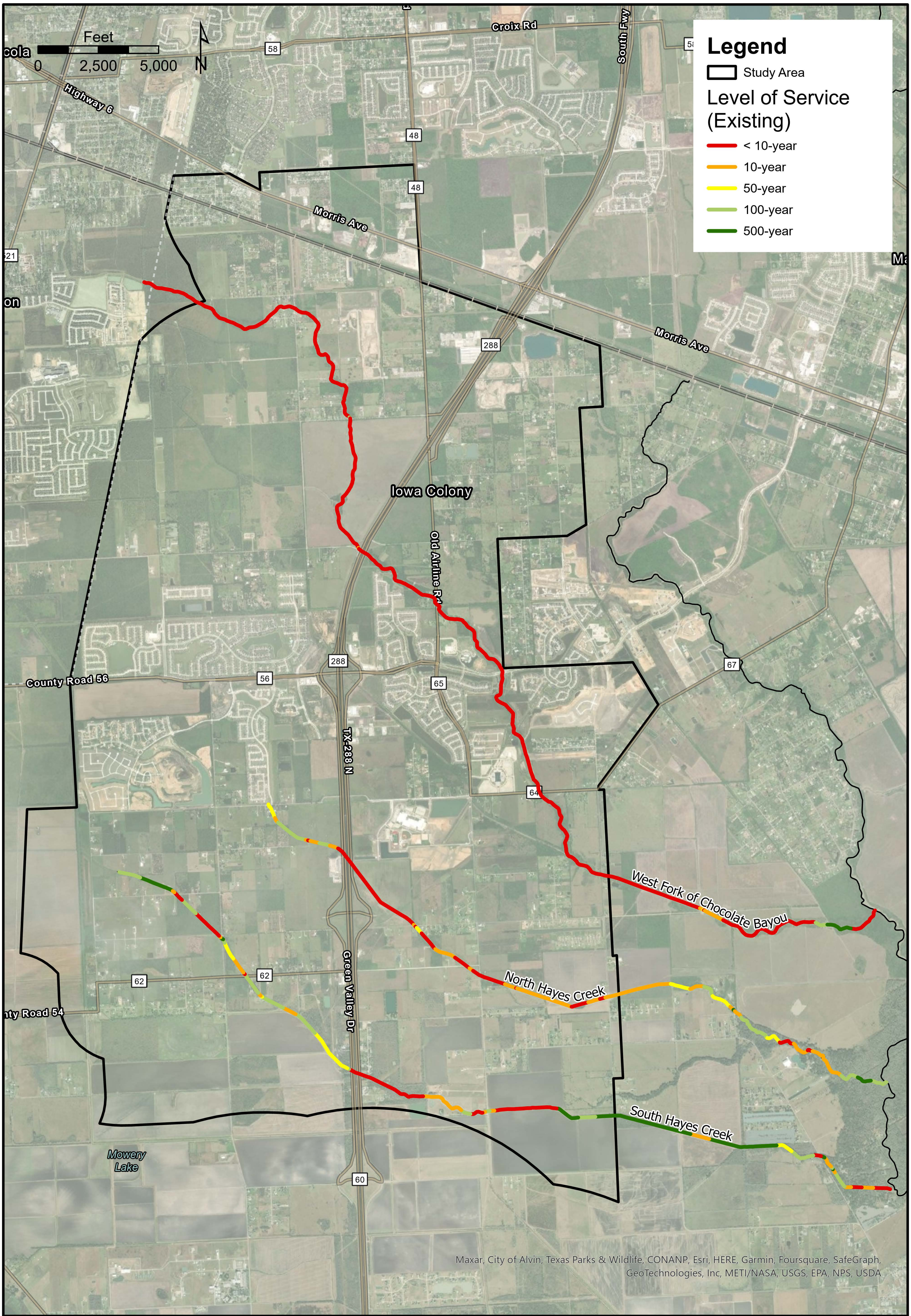
MASTER DRAINAGE PLAN

500-YEAR FLOOD HAZARD DEPTH (EXISTING)

EXHIBIT 8

5/30/2023



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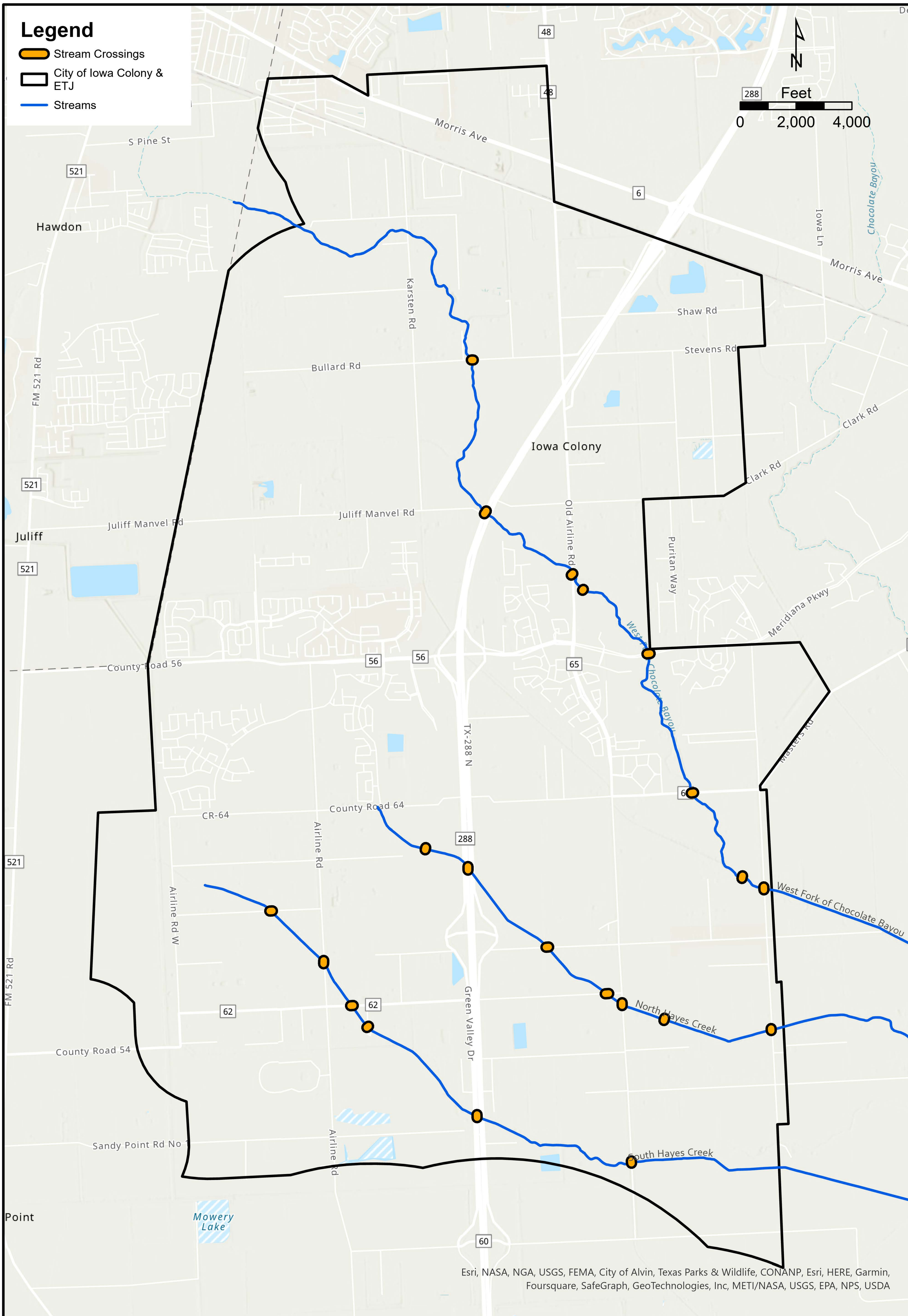
CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

LEVEL-OF-SERVICE (EXISTING)

EXHIBIT 9

5/30/2023



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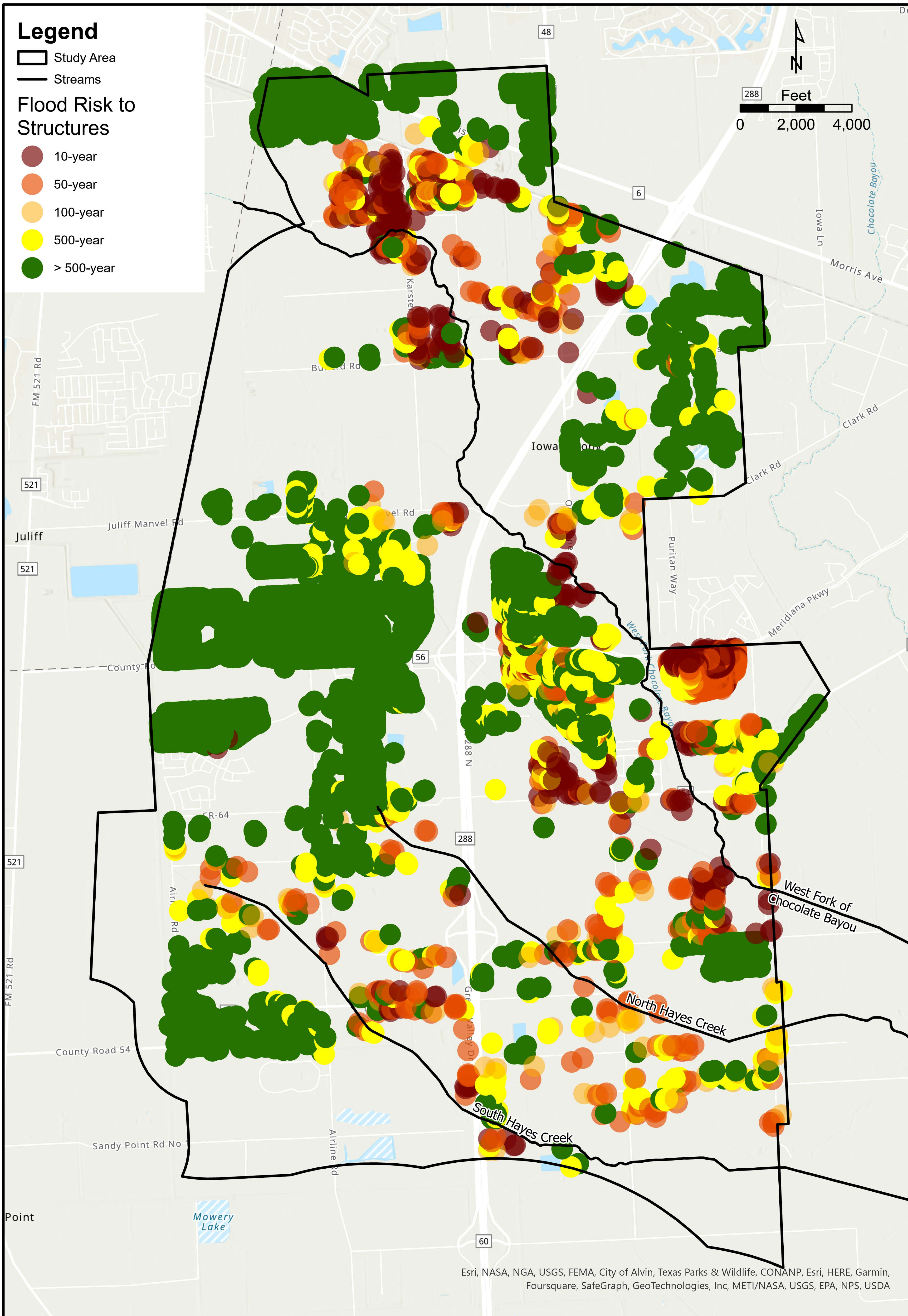
MASTER DRAINAGE PLAN

EXISTING INFRASTRUCTURE

EXHIBIT 10

5/30/2023



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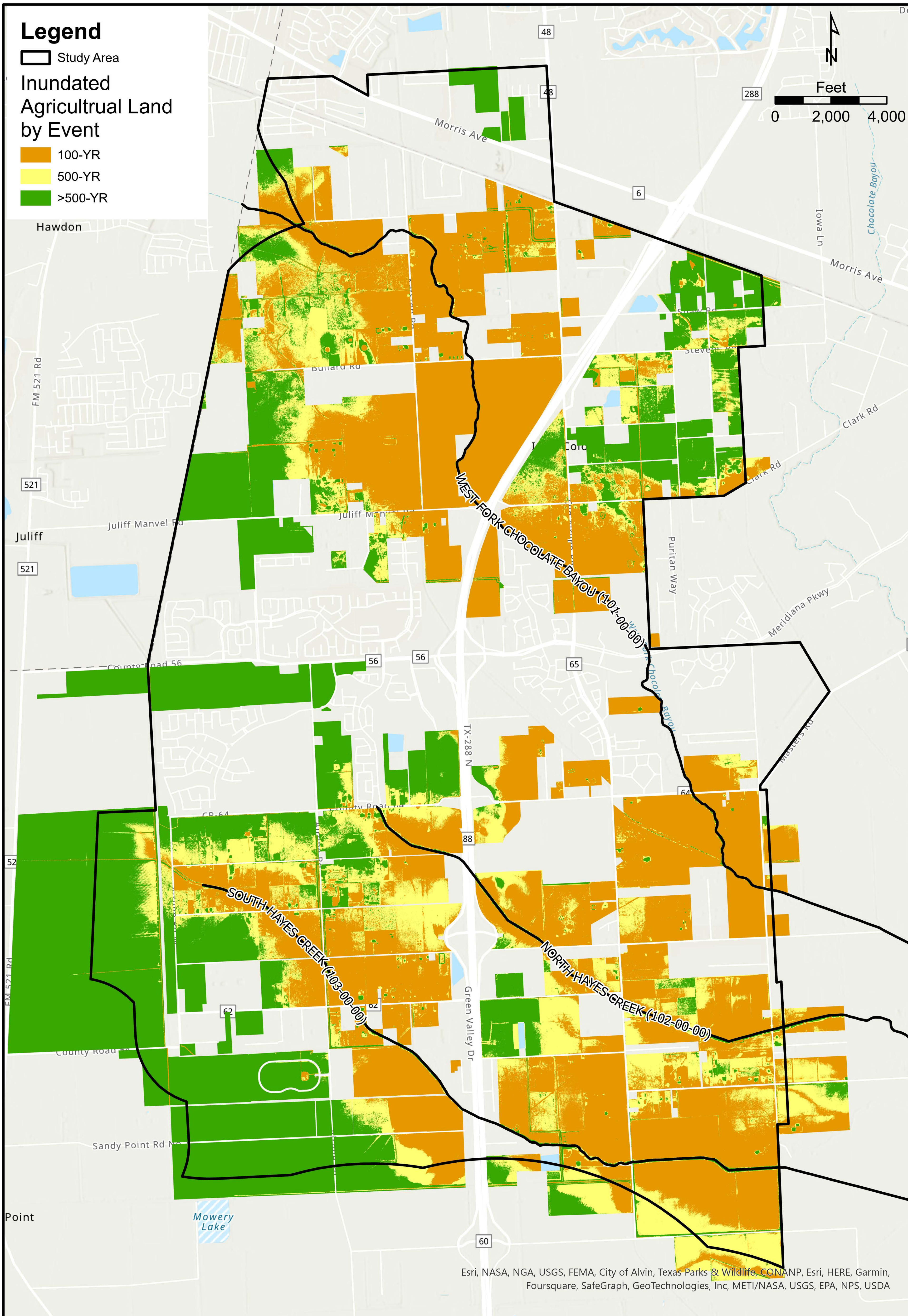
MASTER DRAINAGE PLAN

INUNDATED BUILDINGS FOR EXTREME RAINFALL EVENTS (EXISTING)

EXHIBIT 11

5/30/2023



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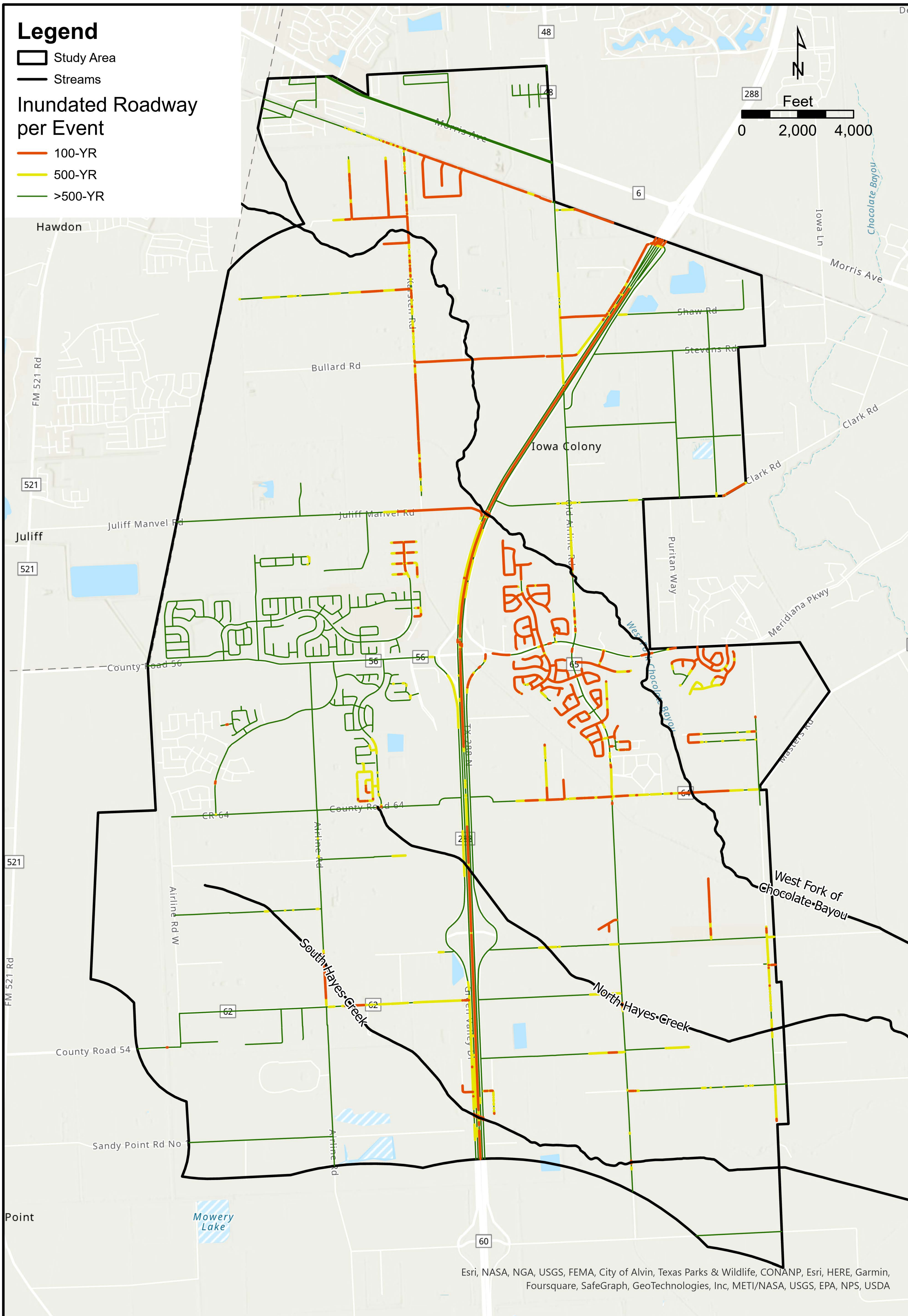
MASTER DRAINAGE PLAN

INUNDATED AGRICULTURAL LAND FOR EXTREME RAINFALL EVENTS (EXISTING)

EXHIBIT 12

5/30/2023



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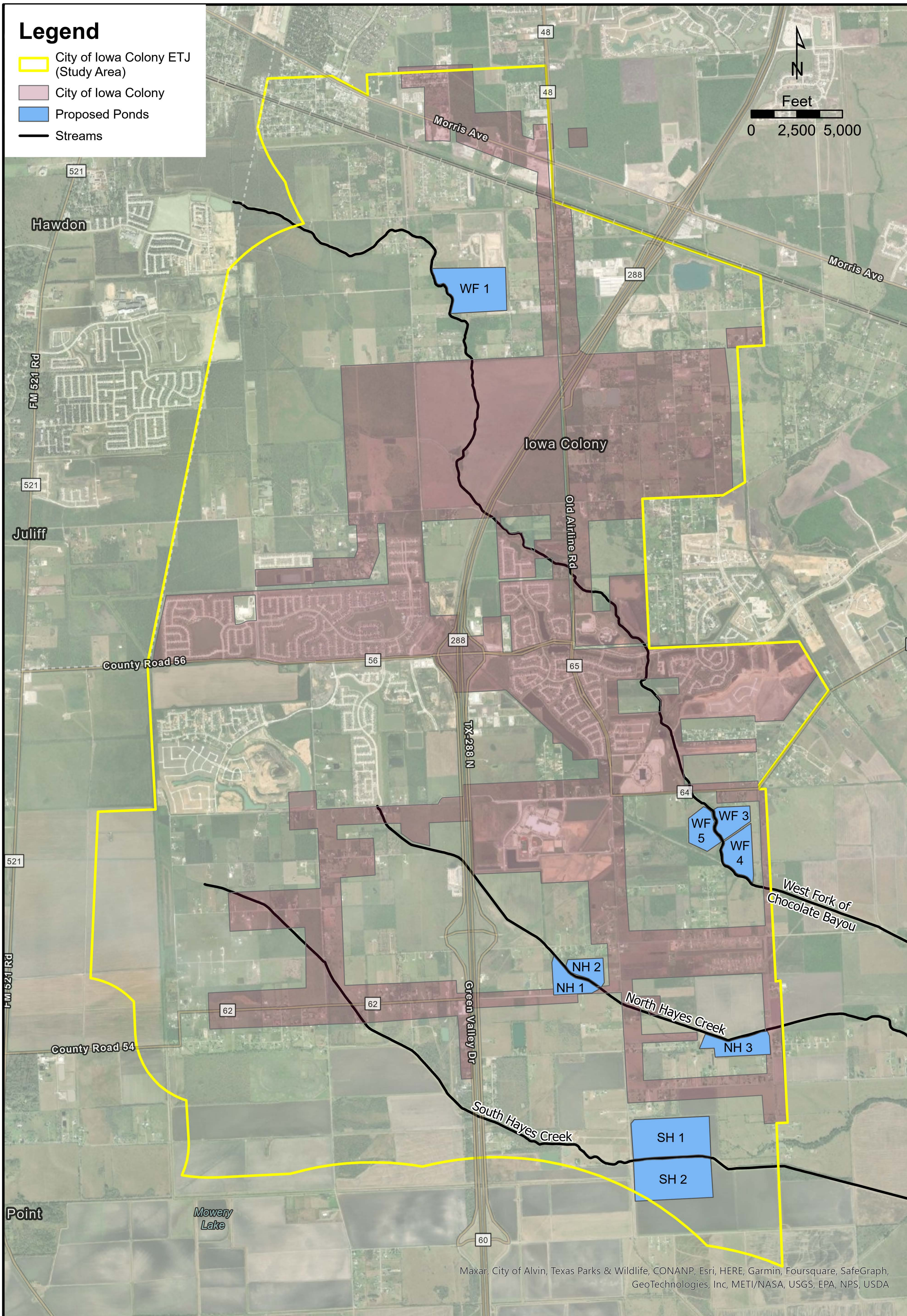
CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

INUNDATED ROADWAYS IN EXTREME RAINFALL EVENTS (EXISTING)

EXHIBIT 13

5/30/2023



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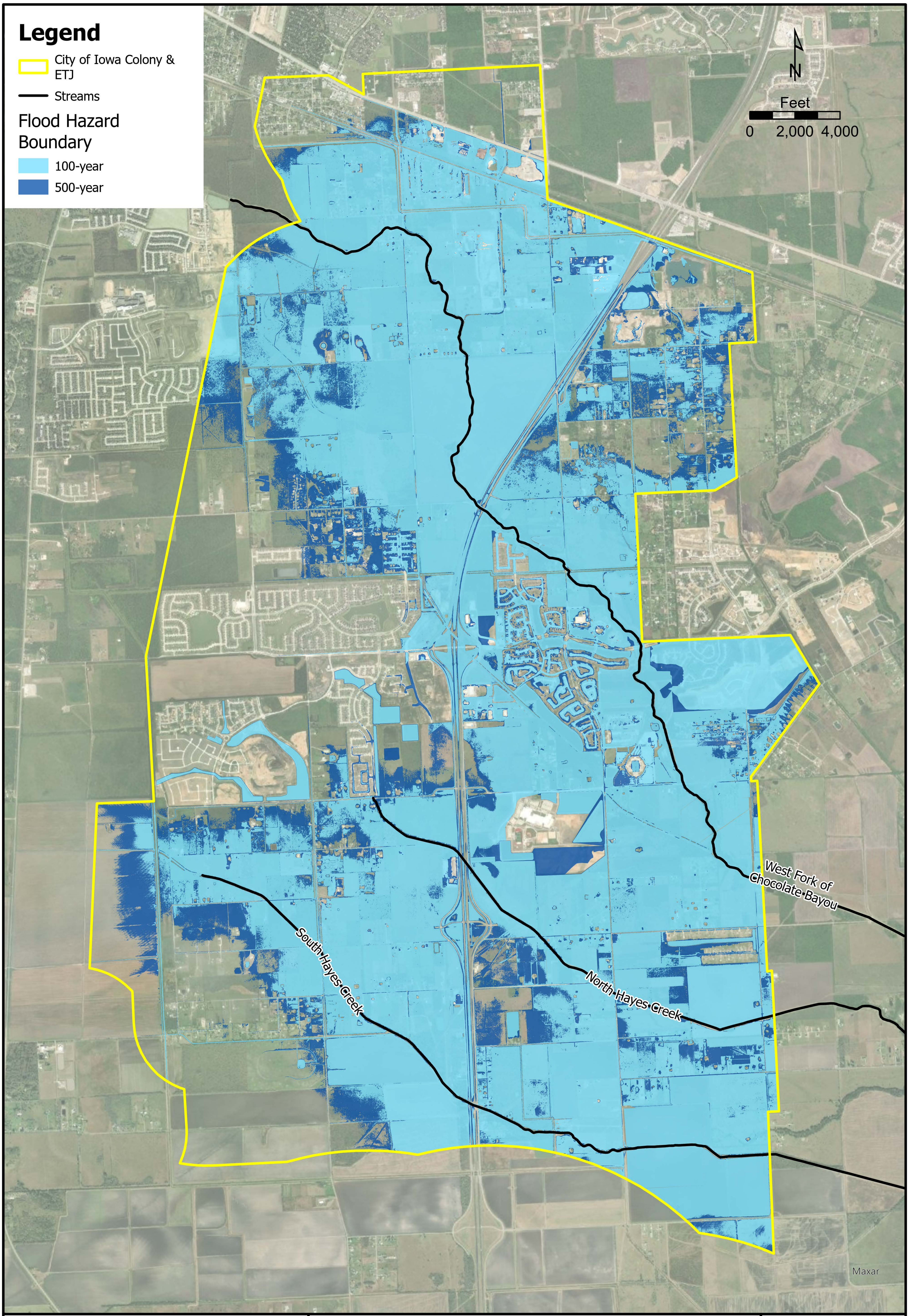
CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

CAPITAL IMPROVEMENTS PLAN (CIP) OVERVIEW

EXHIBIT 14

5/30/2023



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CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

FLOOD HAZARD MAP
CAPITAL IMPROVEMENTS PLAN (CIP)

EXHIBIT 15

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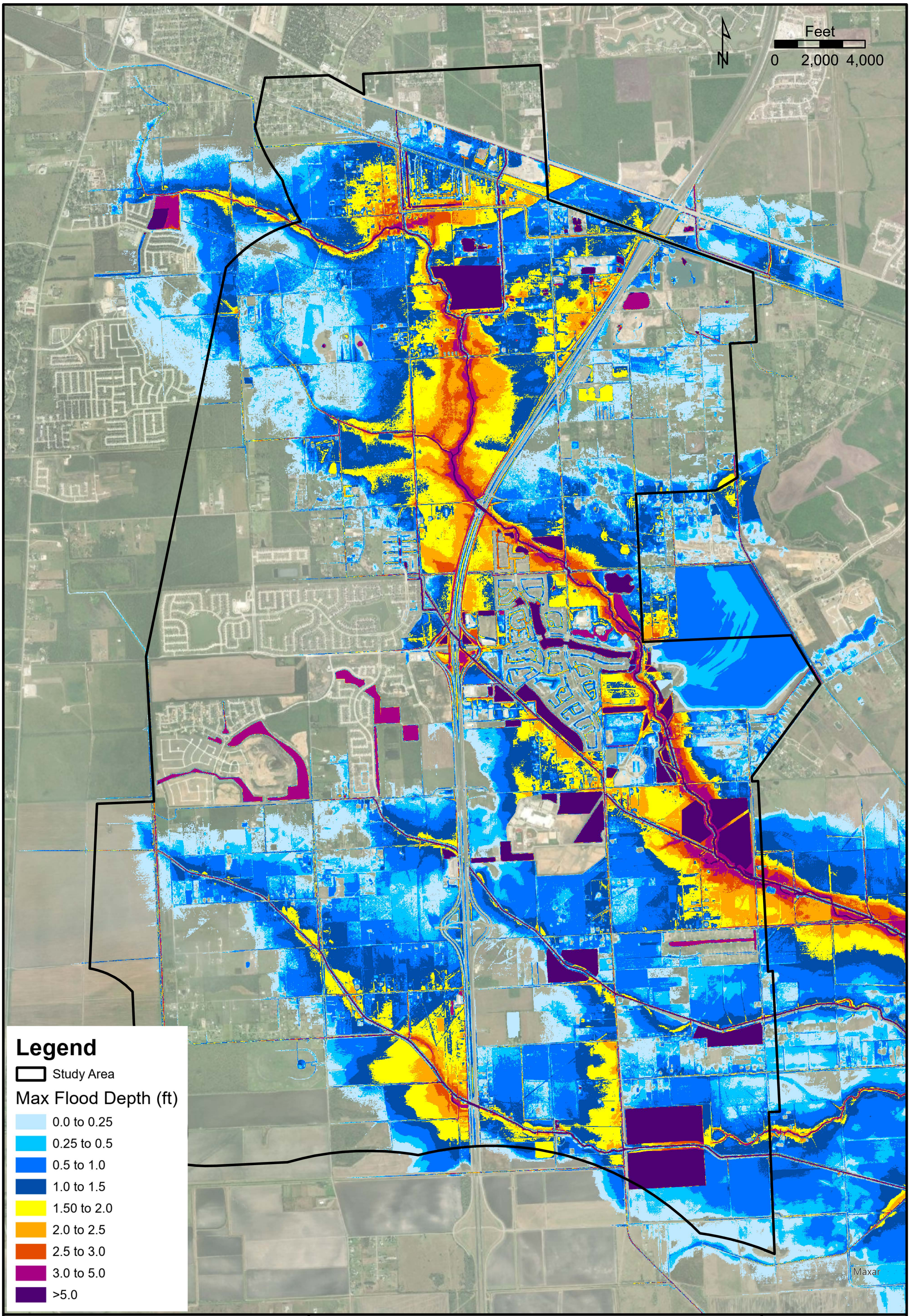

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MASTER DRAINAGE PLAN

100-YEAR FLOOD HAZARD DEPTH CAPITAL IMPROVEMENTS PLAN (CIP)

EXHIBIT 16

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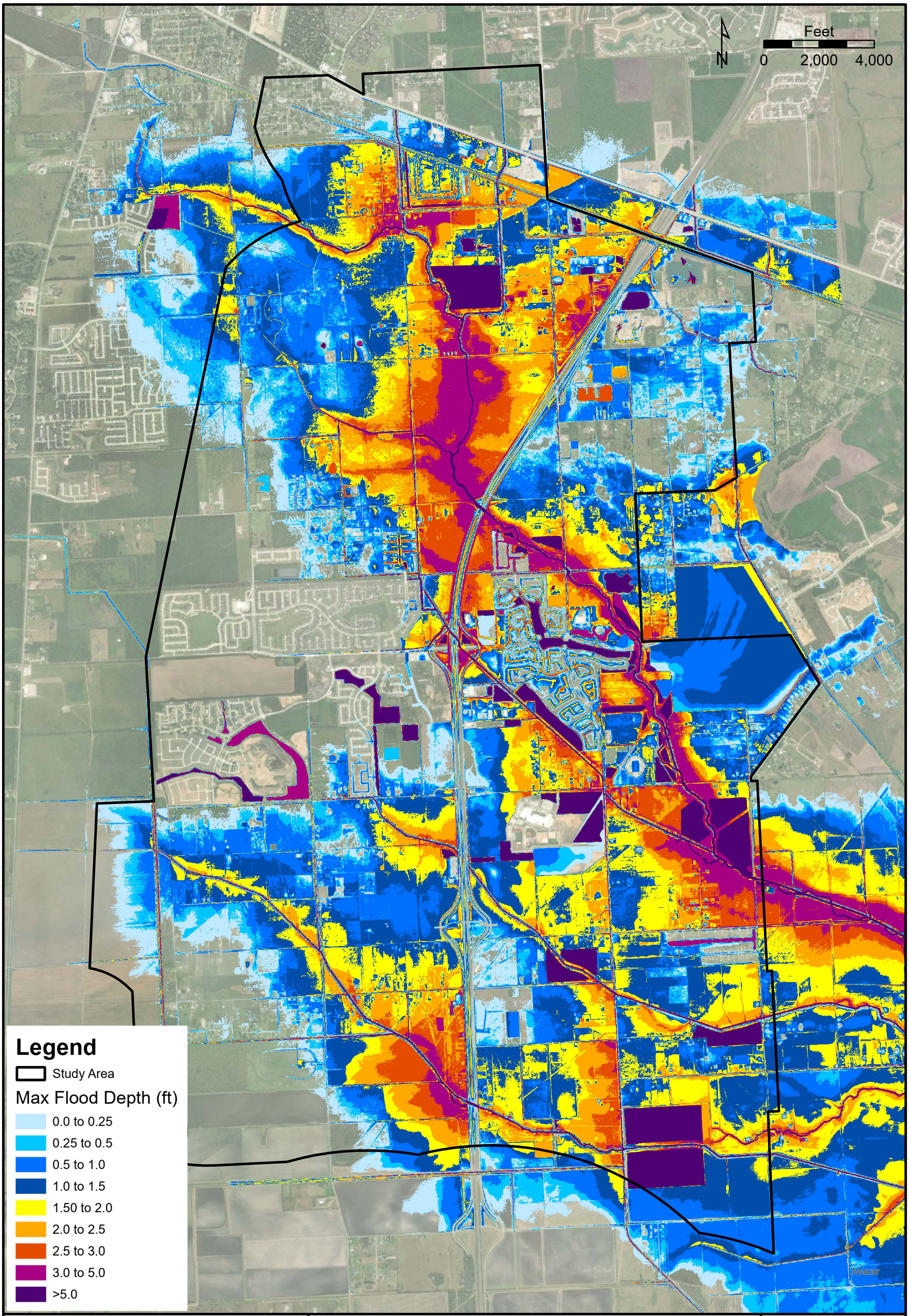

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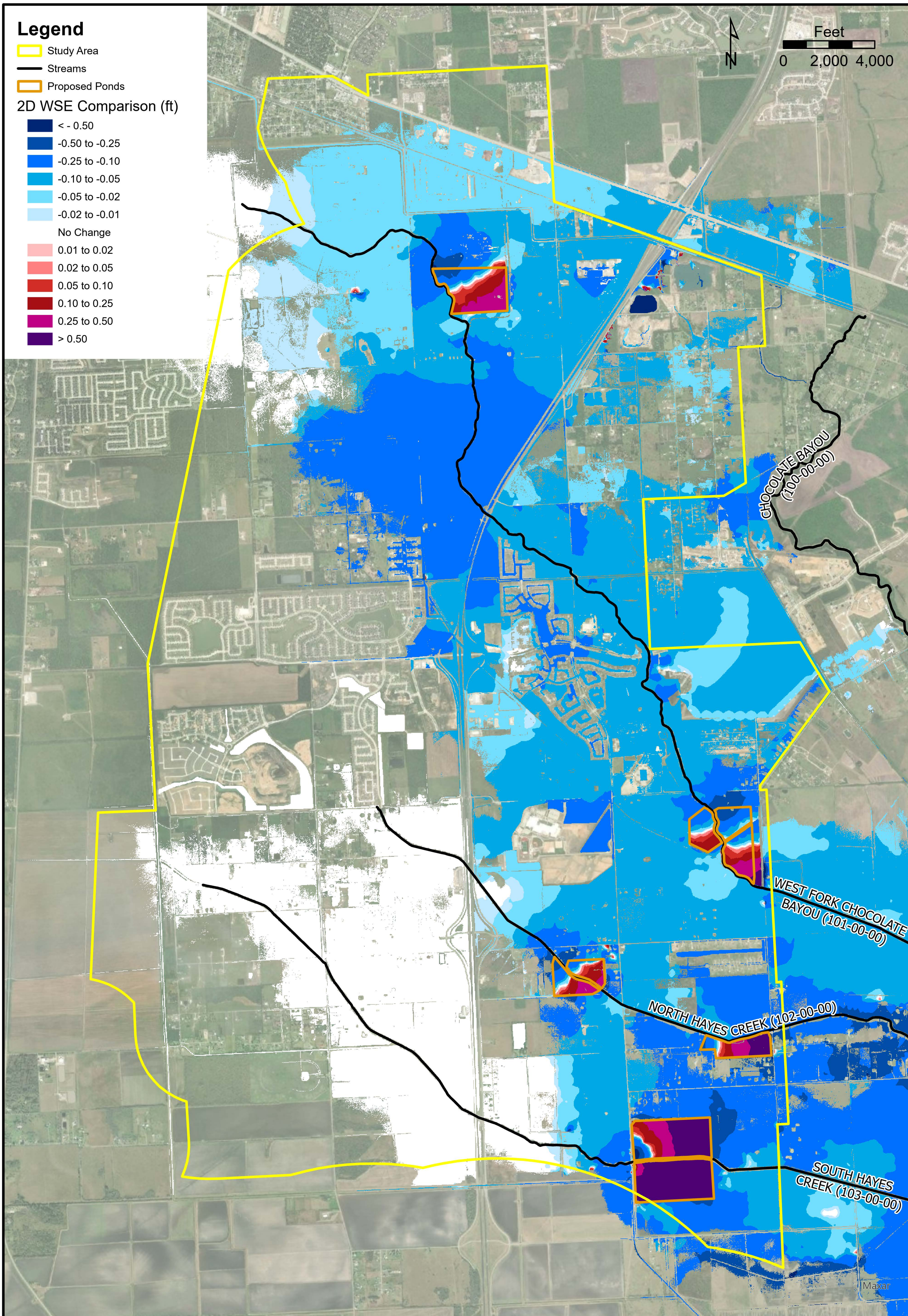
MASTER DRAINAGE PLAN

500-YEAR FLOOD HAZARD DEPTH CAPITAL IMPROVEMENTS PLAN (CIP)

EXHIBIT 17

5/30/2023



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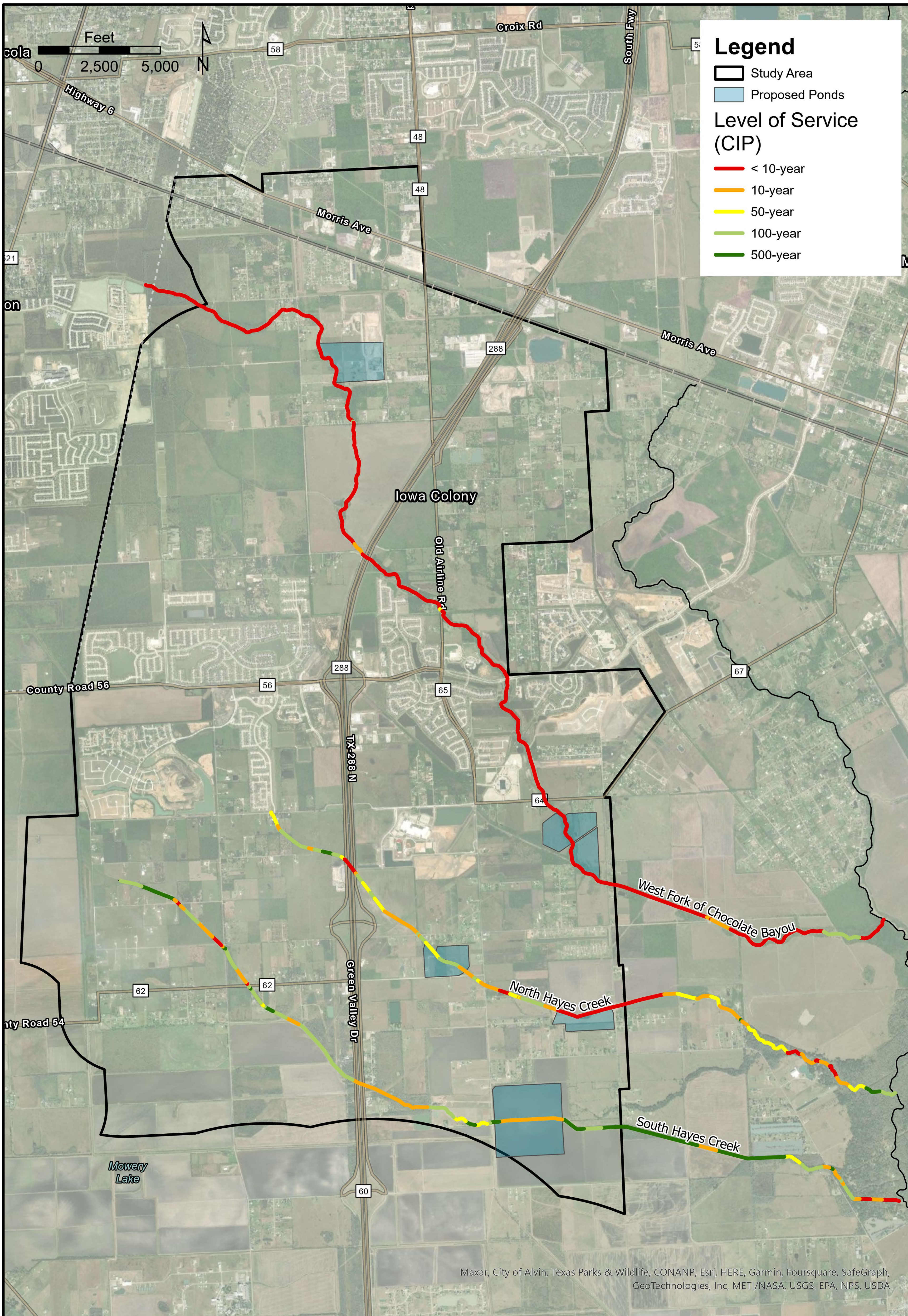
MASTER DRAINAGE PLAN

CHANGE IN WATER SURFACE ELEVATION (100-YEAR CIP VS EXISTING)

EXHIBIT 18

5/30/2023



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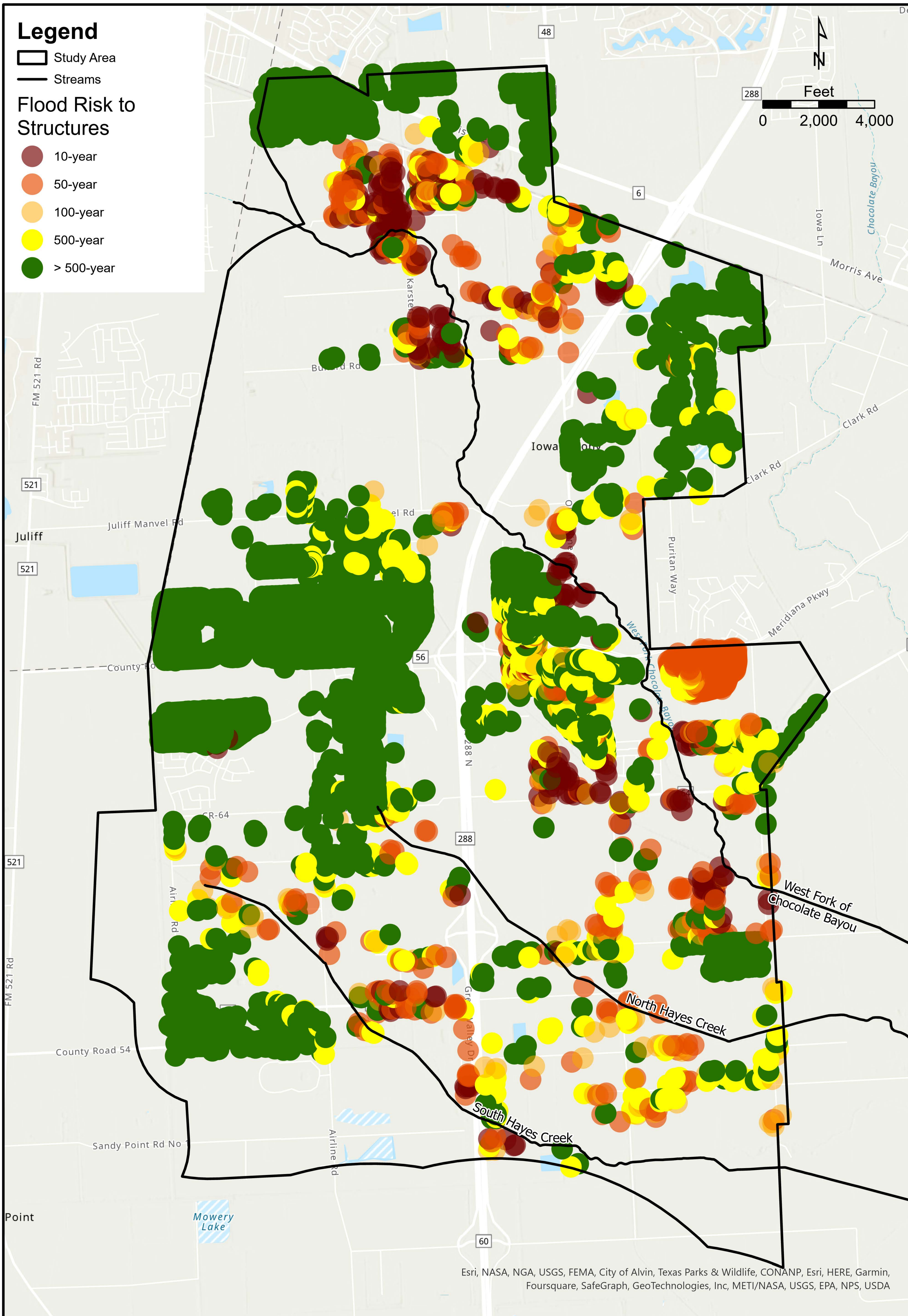
MASTER DRAINAGE PLAN

LEVEL-OF-SERVICE (CIP)

EXHIBIT 19

5/30/2023



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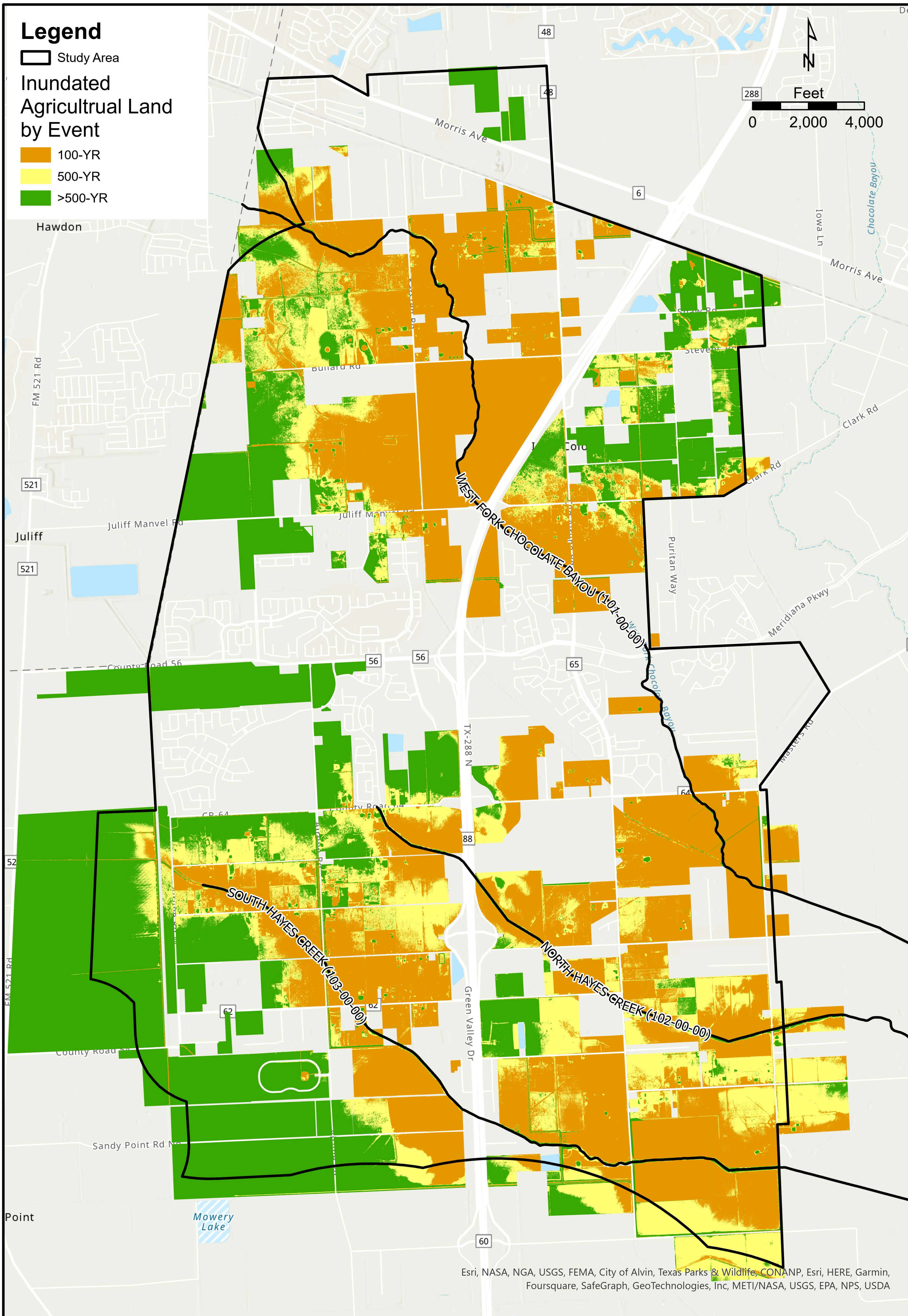
MASTER DRAINAGE PLAN

INUNDATED BUILDINGS FOR EXTREME RAINFALL EVENTS (CIP)

EXHIBIT 20

5/30/2023



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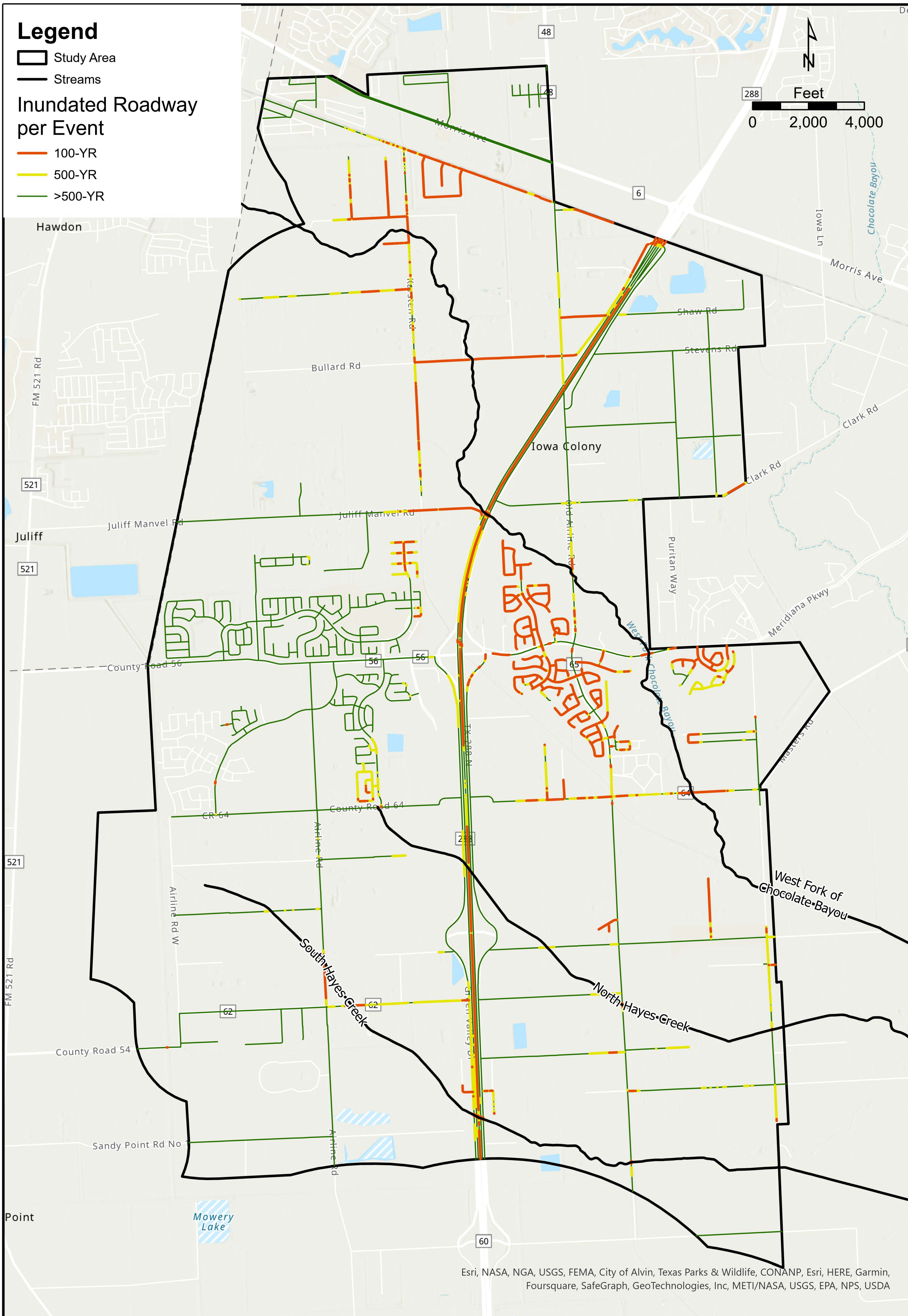
MASTER DRAINAGE PLAN

INUNDATED AGRICULTURAL LAND FOR EXTREME RAINFALL EVENTS (CIP)

EXHIBIT 21

5/30/2023



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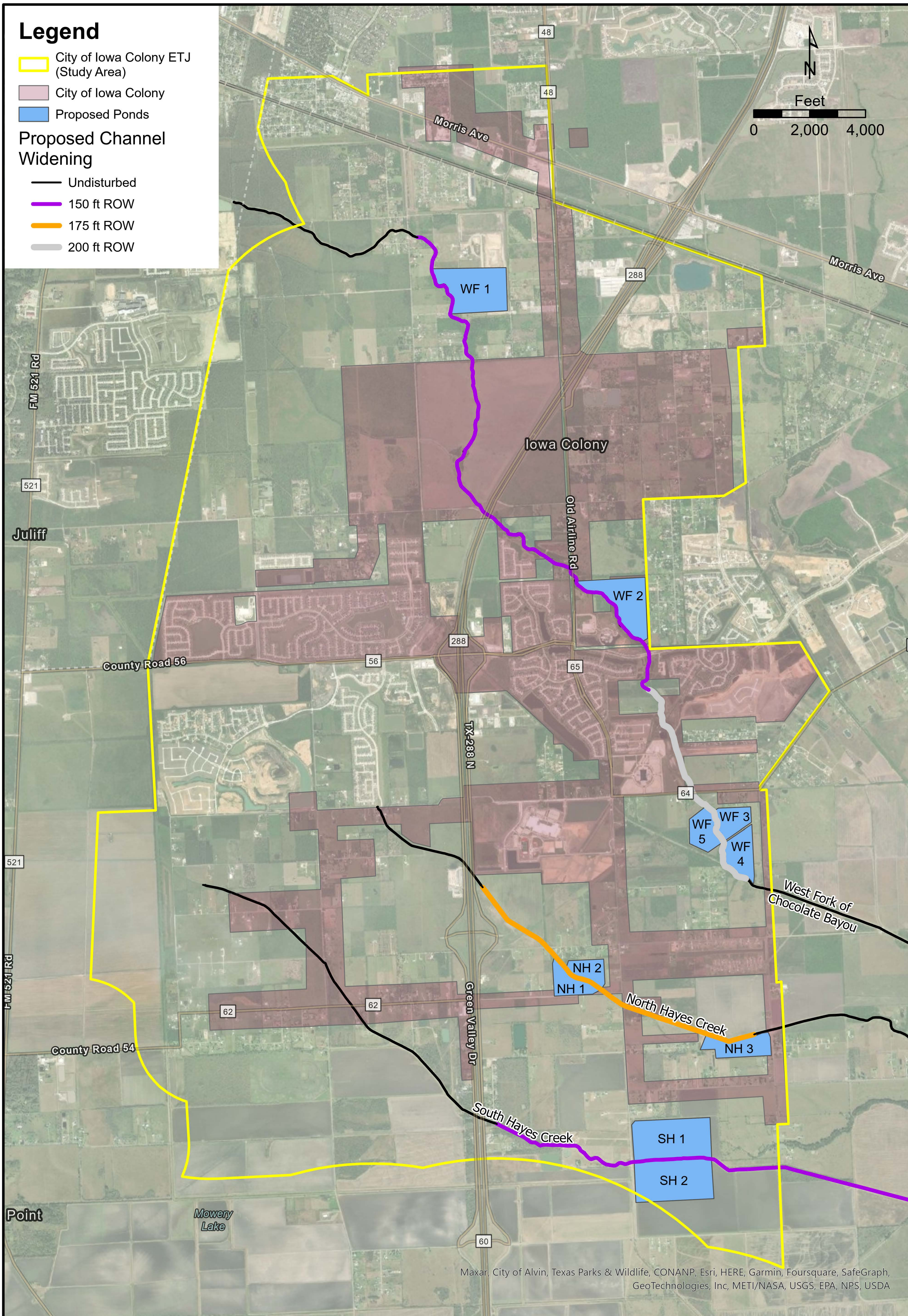
MASTER DRAINAGE PLAN

INUNDATED ROADWAYS IN EXTREME RAINFALL EVENTS (CIP)

EXHIBIT 22

5/30/2023



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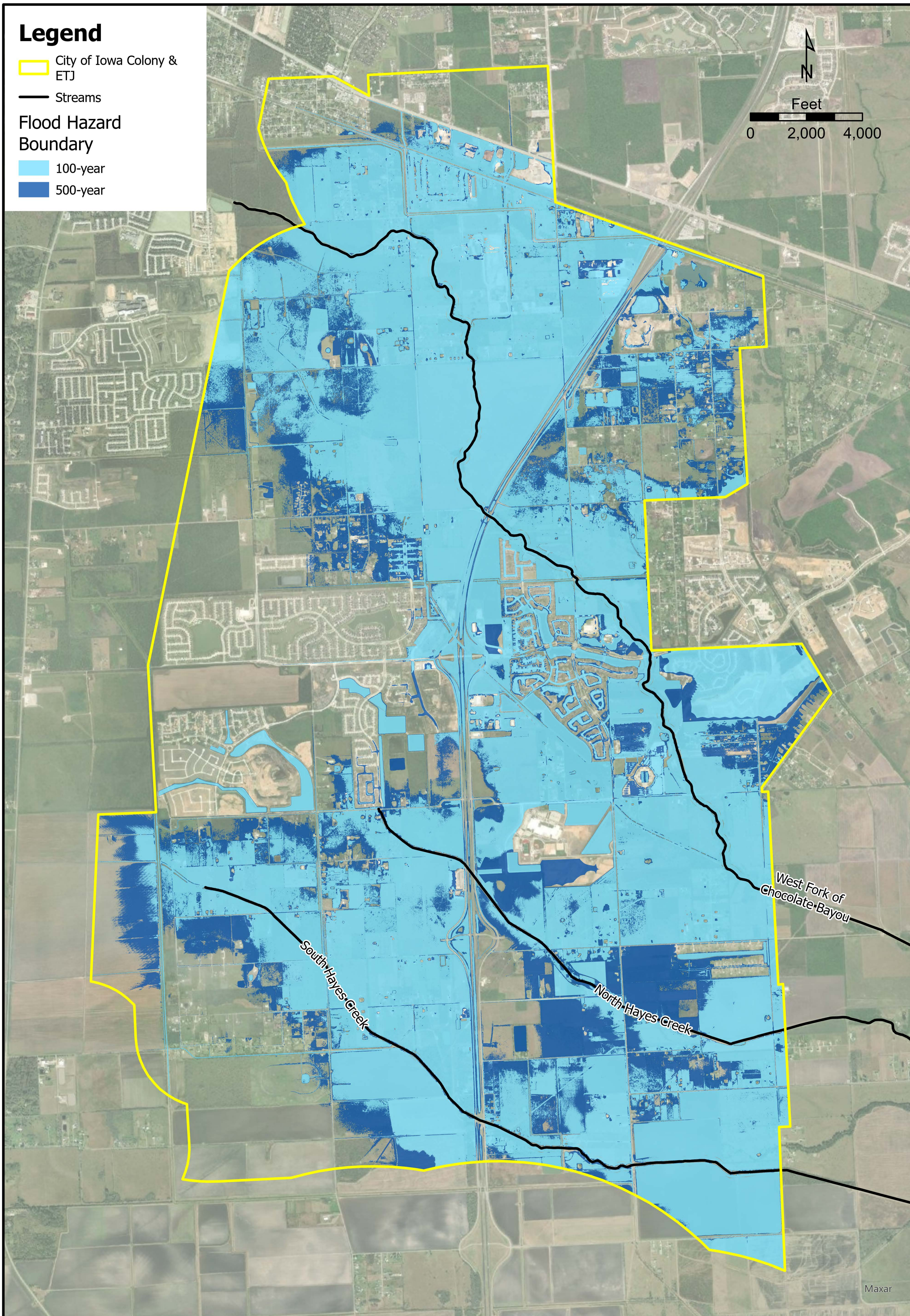
CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

ALTERNATIVE IMPROVEMENTS (ALT) OVERVIEW

EXHIBIT 23

5/30/2023



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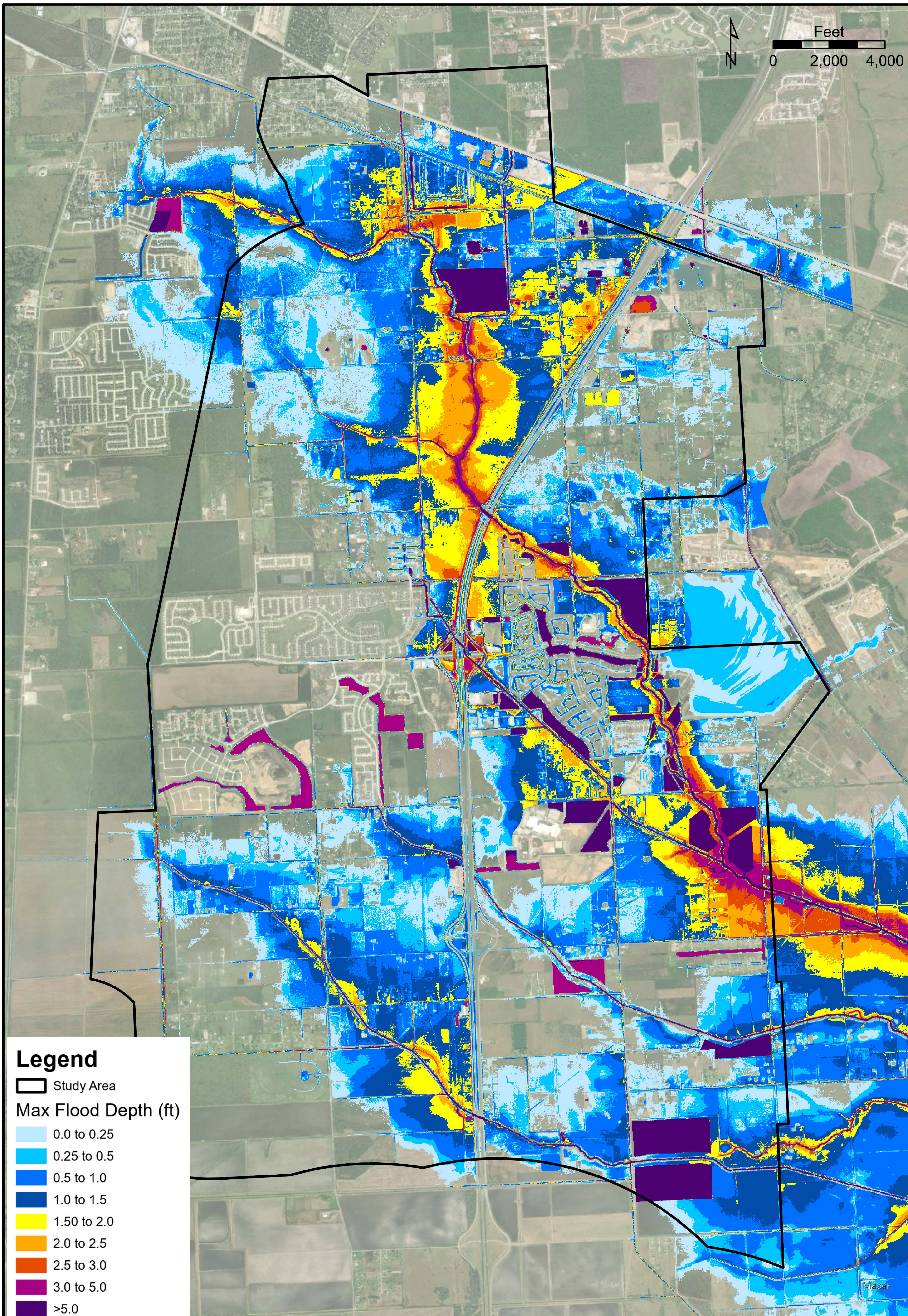
CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

FLOOD HAZARD MAP
ALTERNATIVE IMPROVEMENTS (ALT)

EXHIBIT 24

5/30/2023



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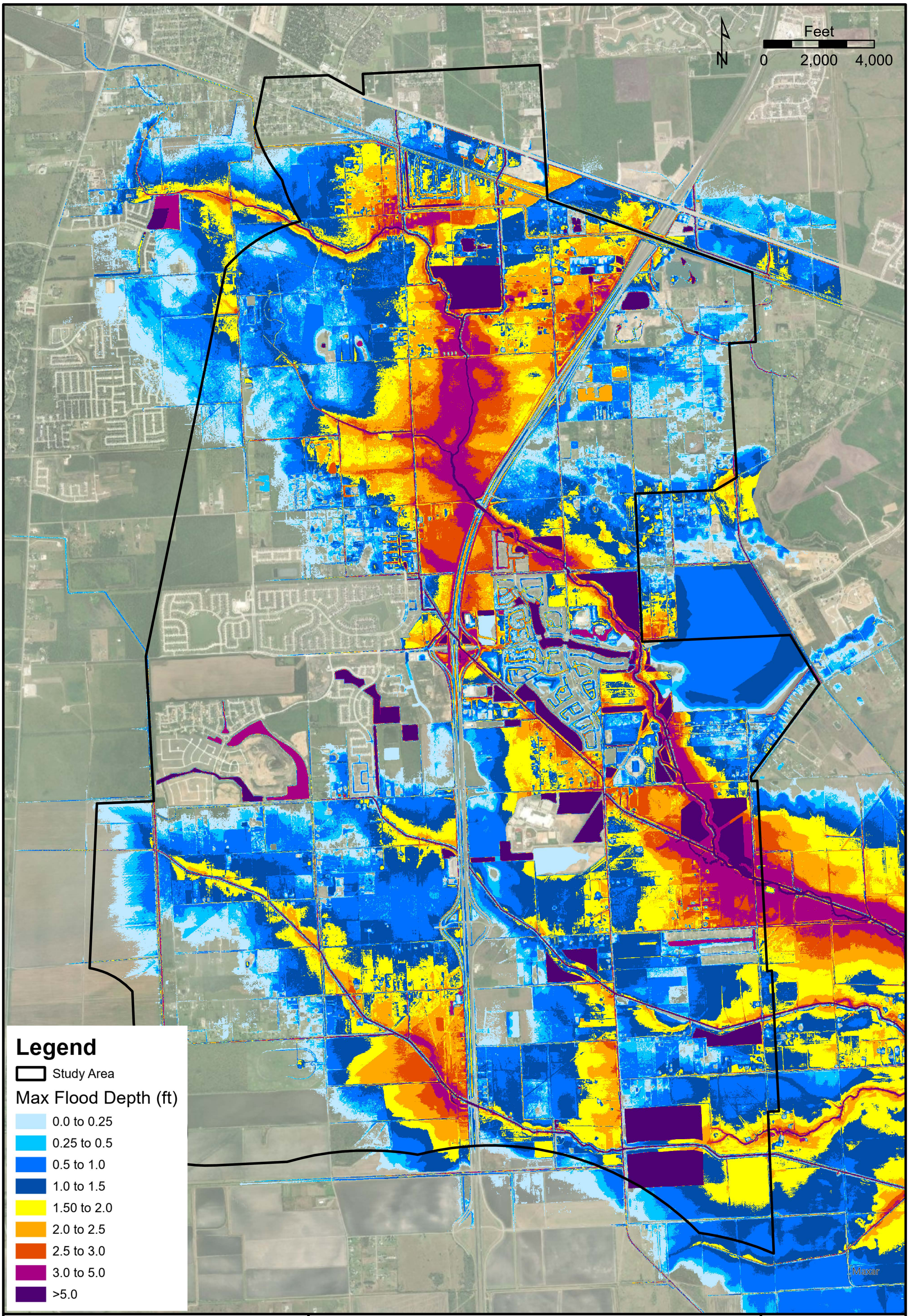
MASTER DRAINAGE PLAN

100-YEAR FLOOD HAZARD DEPTH
ALTERNATIVE IMPROVEMENTS (ALT)

EXHIBIT 25

5/30/2023

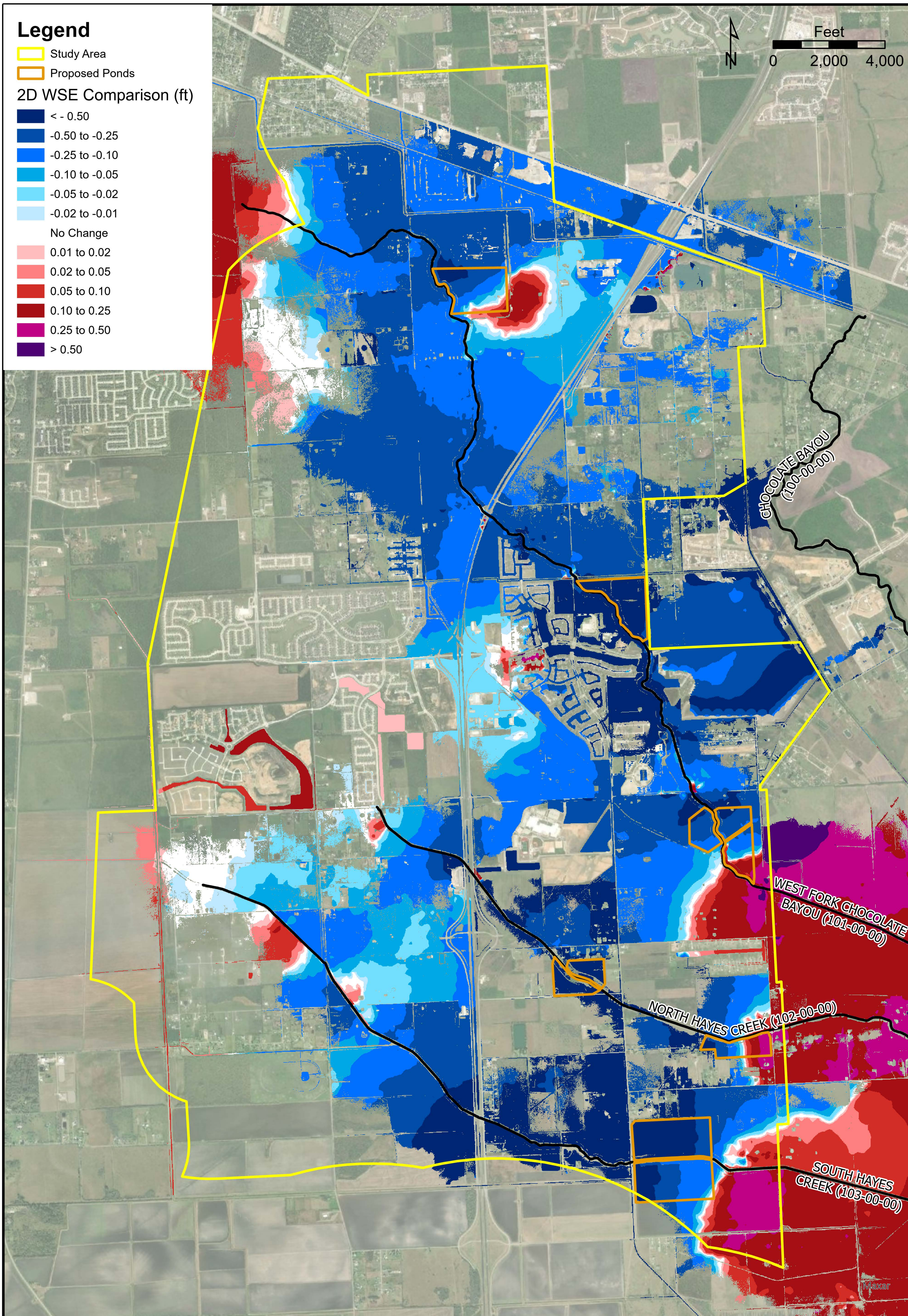


CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

500-YEAR FLOOD HAZARD DEPTH ALTERNATIVE IMPROVEMENTS (ALT)

EXHIBIT 26

5/30/2023



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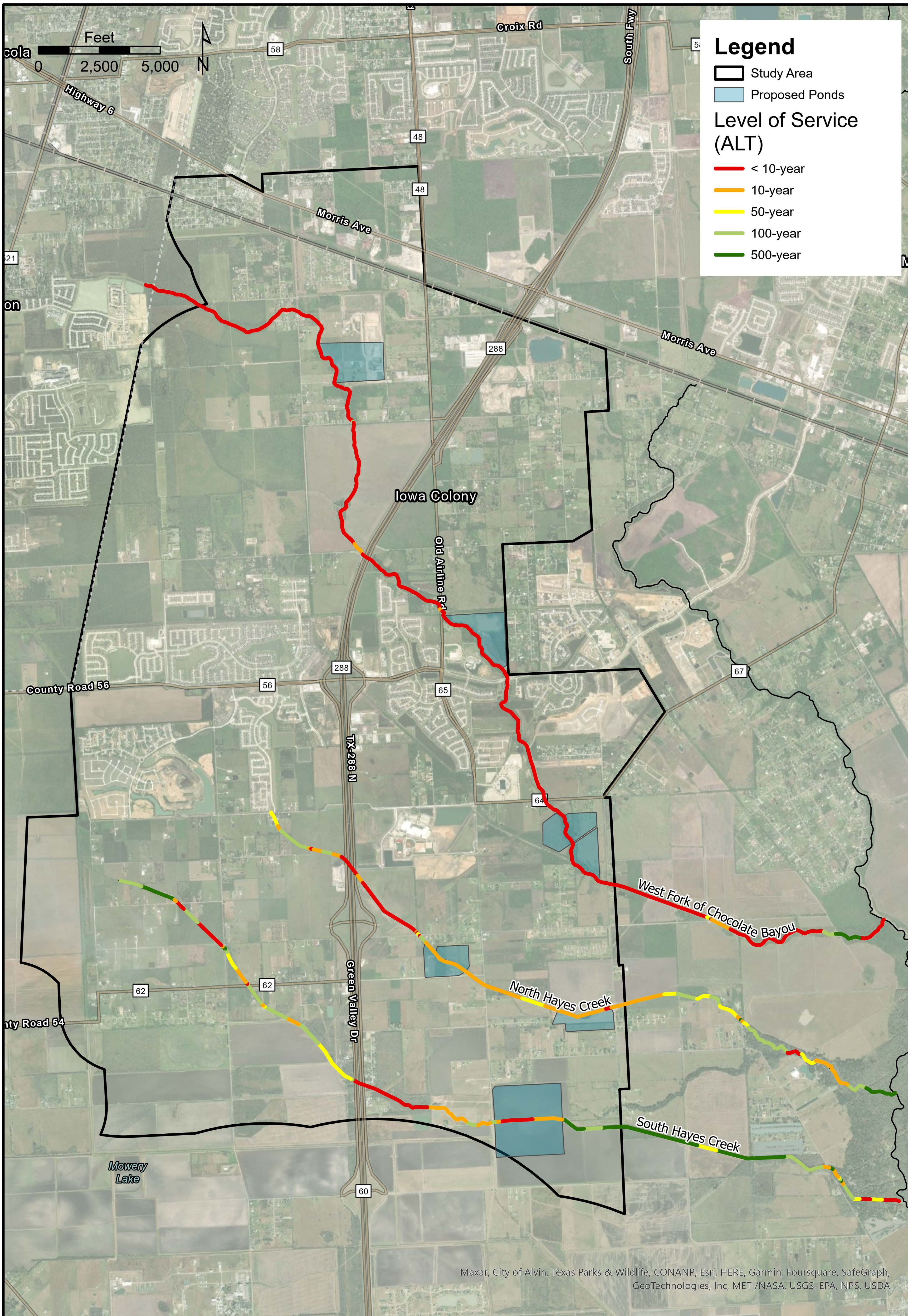
CITY OF IOWA COLONY

CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

CHANGE IN WATER SURFACE ELEVATION (100-YEAR ALT VS EXISTING)

EXHIBIT 27

5/30/2023



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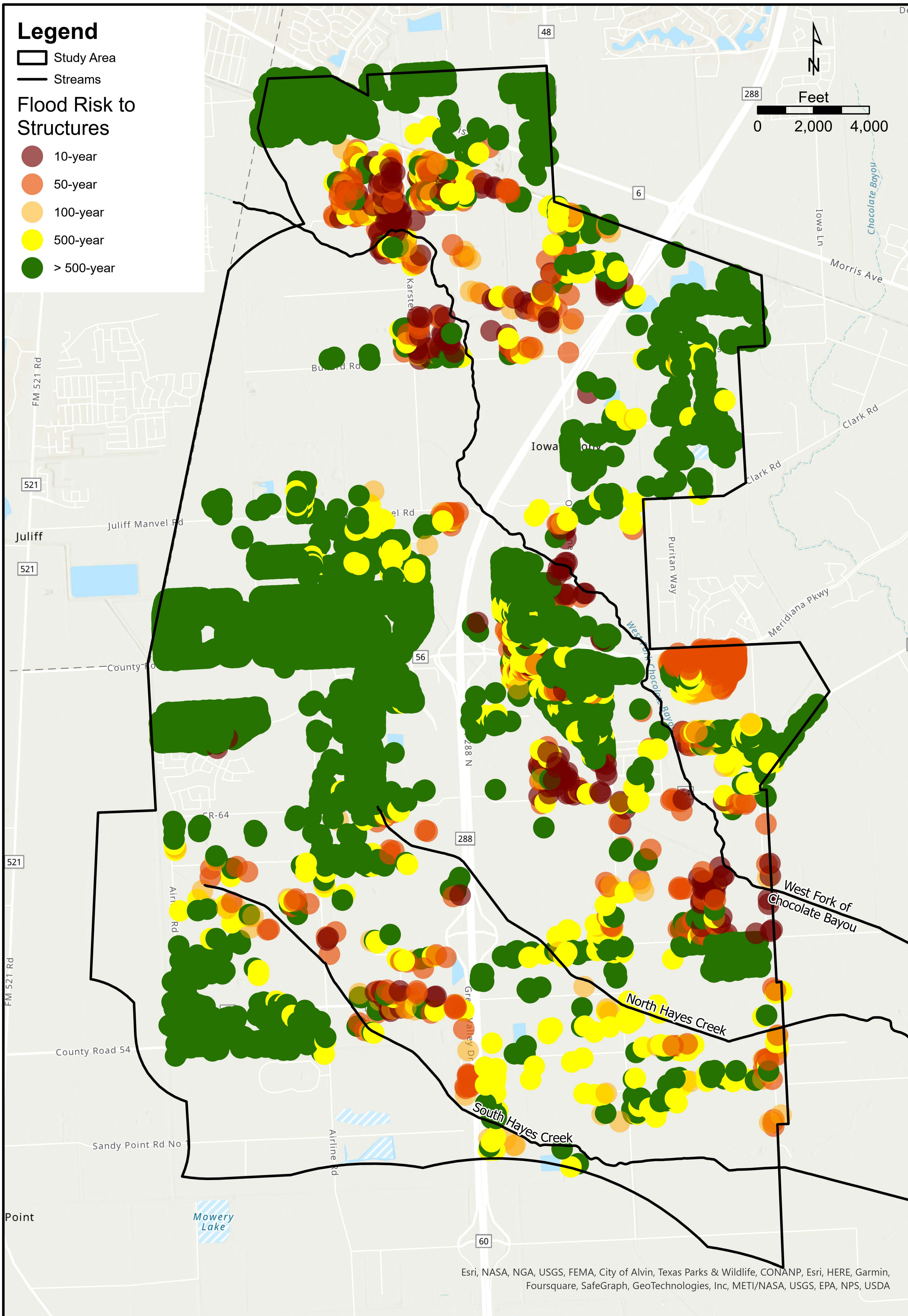
CITY OF IOWA COLONY

CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

LEVEL-OF-SERVICE (ALT)

EXHIBIT 28

5/30/2023



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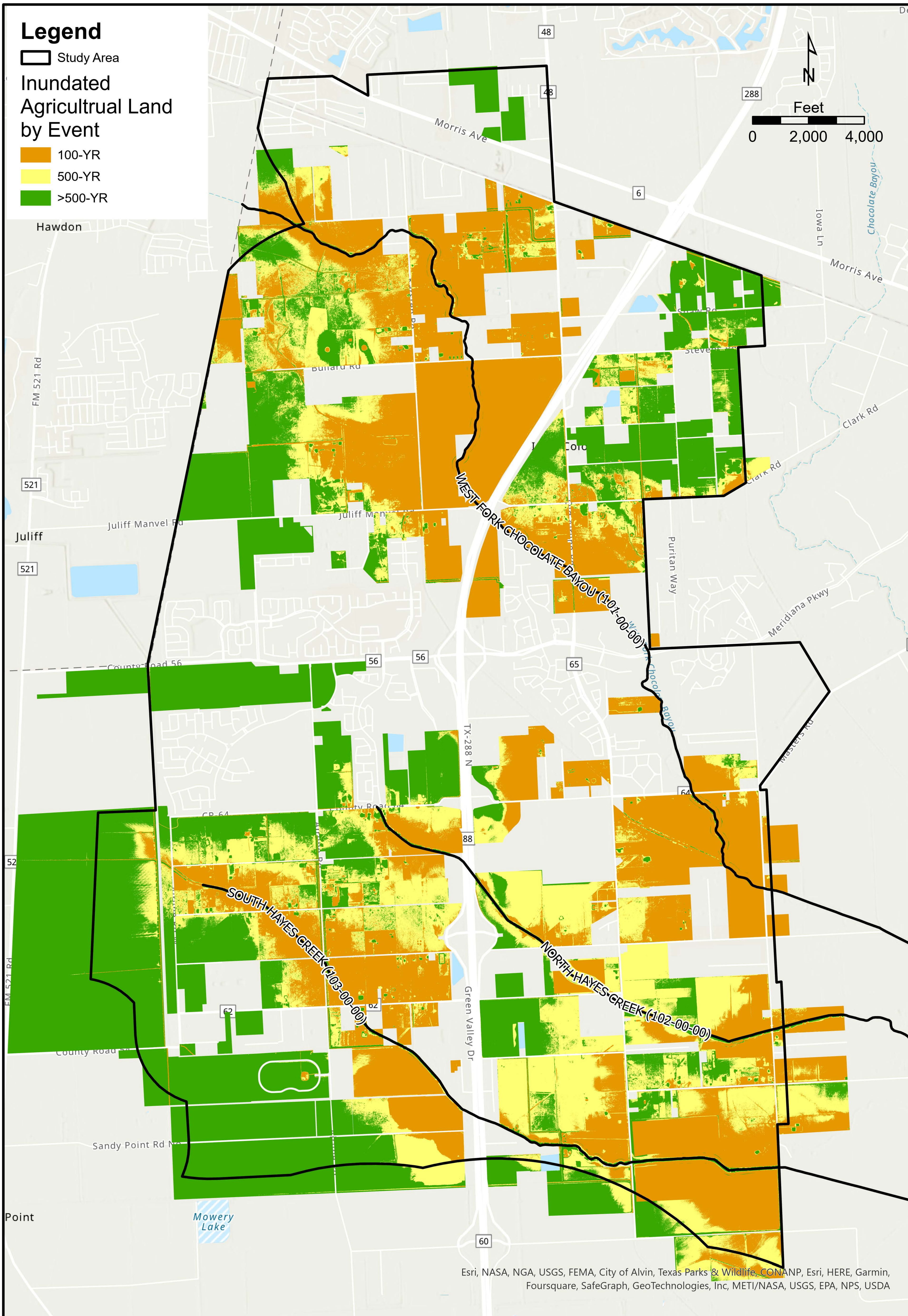
CITY OF IOWA COLONY

CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

INUNDATED BUILDINGS FOR EXTREME RAINFALL EVENTS (ALT)

EXHIBIT 29

5/30/2023



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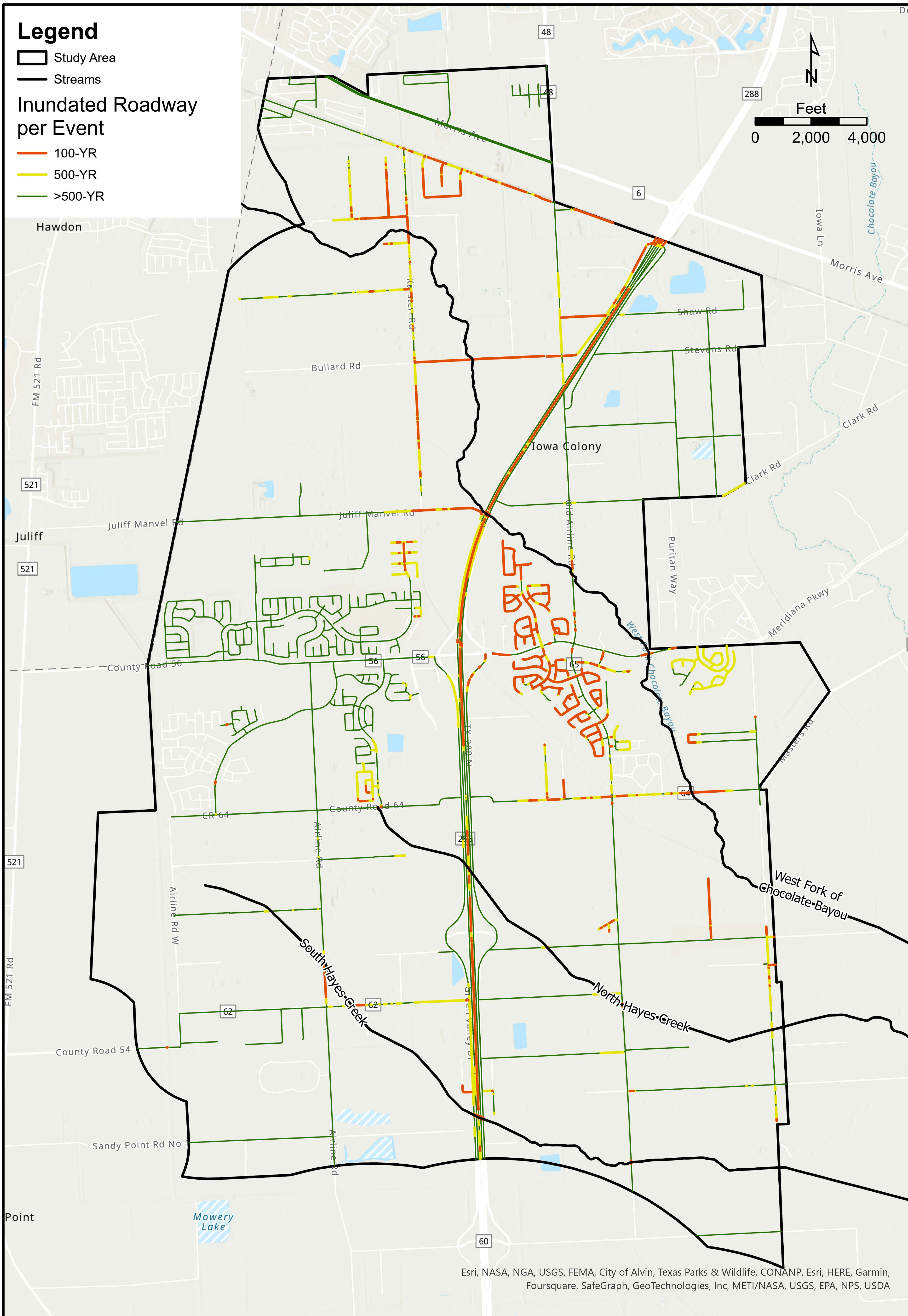
CITY OF IOWA COLONY

CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

INUNDATED AGRICULTURAL LAND FOR EXTREME RAINFALL EVENTS (ALT)

EXHIBIT 30

5/30/2023



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CITY OF IOWA COLONY

CITY OF IOWA COLONY
MASTER DRAINAGE PLAN

INUNDATED ROADWAYS IN EXTREME RAINFALL EVENTS (ALT)

EXHIBIT 31

5/30/2023

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